Economic evaluation manual

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More information

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This document is available on the Transport Agency's website at www.nzta.govt.nz

Document management plan

1) Purpose

This management plan outlines the updating procedures and contact points for the document.

2) Document information

Document name	Economic evaluation manual
Document number	0
Document availability	This document is located in electronic form on the NZ Transport Agency's website at www.nzta.govt.nz
Document owner	NZ Transport Agency, Planning & Investment
Document sponsor	Group Manager, Planning & Investment

3) Amendments and review strategy

All corrective action/improvement requests (CAIRs) suggesting changes will be acknowledged by the document owner.

	Comments	**Frequency**
Amendments (minor revisions)	Updates incorporated immediately they occur	As required
Review (major revisions)	Amendments fundamentally changing the content or structure of the document will be incorporated as soon as practicable. They may require coordinating with the review team timetable	At least annually
Notification	All users that have registered their interest by email to eem@nzta.govt.nz will be advised by email of amendments and updates	Immediately

4) Other information (at document owner's discretion)

There will be occasions, depending on the subject matter, when amendments will need to be worked through by the review team before the amendment is actioned. This may cause some variations to the above noted time frames.

Record of amendment

Amendment number	Description of change	Effective date	Updated by

Foreword

Investing in a wide range of activities that help to achieve land transport outcomes and deliver value for money is a significant part of the work of the NZ Transport Agency. We do this by using the resources available in the National Land Transport Fund.

The *Economic evaluation manual* provides procedures to help approved organisations evaluate the economic efficiency of their investment proposals in line with the Transport Agency's Assessment Framework.

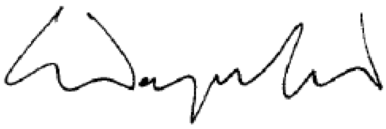
The *Economic evaluation manual's* procedures sit within the investment policy framework we set out in the Transport Agency's Knowledge Base. Users of the manual will need to be familiar with the Knowledge Base before they step into their economic efficiency calculations.

For this edition of the *Economic evaluation manual* we have revised the format along with some of our economic evaluation policies and procedures.

The manual is now a single electronic document (available in PDF), making it easier to use and to access the reference material needed to support economic efficiency calculations. It's also now a living document that we will continue to review and update. Please make sure you are on our register of users so we can contact you to let you know of any significant changes.

Please send any feedback you might have to the Transport Agency's *Economic evaluation manual* l team, at eem@nzta.govt.nz .

My thanks go to everyone who has helped review and update the *Economic evaluation manual*.



Geoff Dangerfield
Chief Executive

Contents

Concepts	Section 2 of this volume describes the basic concepts underlying the economic efficiency evaluation procedures for activities and packages of activities.
Simplified procedures	Section 3 contains simplified procedures lower capital cost activities These simplified procedures condense economic efficiency evaluation into a few worksheets.
Full procedures	Section 4 describes procedures and provides sample worksheets for full economic efficiency evaluation of land transport activities. The full procedures are to be used when either more detailed analysis is required than is provided in the simplified procedures, or the limits specified for the simplified procedures are exceeded.
Guidance on input values	Appendices A1 to A21 describe the methodology for valuing the various benefits and disbenefits considered in economic efficiency evaluation and provide standard unit values and other guidance on estimation of input values.
Blank worksheets	The NZ Transport Agency's website contains blank worksheets that can be copied and used for evaluations.

1.0 Introduction

1.1 Purpose

Purpose

The procedures in this manual are intended for:

- presenting economic evaluations in a consistent format
- presenting the costs and benefits, and their relative magnitude, of alternatives and options clearly and consistently
- ensuring that any assumptions are standardised across activities, as far as possible
- ensuring that the appropriate level of data collection and analysis will be undertaken for economic efficiency evaluations.

Assessing the monetised, non-monetised impacts, business benefits and equity impacts as an input to the effectiveness assessment factor of the allocation process.

Economic evaluation as a input into the funding allocation process

This manual provides the procedures to determine the economic efficiency of an activity. The economic efficiency is typically assessed by the benefit cost ratio is a core factor in the NZ Transport Agency funding allocation process, and a critical component of the business case approach as set out in the Planning and Investment Knowledge Base (PIKB) [www.pikb.co.nz].

Input to the NZ Transport Agency's allocation process

The numerical cost benefit analysis and guidance on assessment, quantification and reporting of non-monetised impacts covered by this manual is designed to be an input to the economic efficiency assessment factor used by the NZ Transport Agency in its funding allocation process.

1.2 Objectives and principles

What is the *Economic evaluation manual* (EEM)?

The EEM is the technical guidance and procedures for undertaking social cost-benefit analysis for transport investment. it allows users to determine the relative efficiency of options being considered.

It is a tool to assist practitioners to determine the economic efficiency factor of the NZ Transport Agency investment assessment framework. The EEM uses the outputs of many strategic planning and modelling tools, and the programme choices made through the business case approach.

The primary function of the EEM is to provide consistency, transparency and comparability between the economic efficiency of multiple activities. The manual should be used in conjunction with the activity development and assessment framework available in the PIKB for prioritisation of investment.

The EEM is not a tool for determining economic impact or for determining whether individual investments should be made.

The Planning and Investment Knowledge Base

The PIKB is the NZ Transport Agency repository for all policy and guidance associated with investment from the National Land Transport Programme (NLTP).

The PIKB is based on a series of processes, which guide users through the NLTP and RLTP development and investment approval of activities.

Users of the EEM should be familiar with the PIKB, including the business case approach to activity development, before stepping into economic efficiency calculation.

The Assessment Framework [PIKB link: PIKB (assessment-framework)] identifies the strategic fit, effectiveness and efficiency criteria of the multi-criteria analysis, and provides the relative thresholds for prioritising activities for investment.

Why do we use the EEM?

The EEM is used to provide transport evaluators with:

- common basis for assessment
- standardised values
- standardised procedures
- standardised worksheets
- relative magnitude of benefits and costs
- guidelines on appropriate data collection and analysis.

There is no perfect methodology to determine the economic efficiency of an activity or combination of activities; however this manual attempts to standardise techniques to ensure a single, stable comparison point between activities.

Users are able to propose alternative methodologies if they can demonstrate evidence of variations, account for any impact this may have on default factors already used, and sensitivity test appropriately. The outputs of the analysis must be wholly compatible with standard reporting.

If simplified procedures are used, these must be submitted using the provided simplified procedure templates and inputs. If an activity is above the threshold, or does not meet the assumptions for simplified procedures, full procedures should be used instead. The full procedures include a number of standard worksheets, and a set of approved procedures to derive the worksheet input values.

2.0 Concepts

2.1 Social cost benefit analysis

Social cost benefit analysis and financial analysis

Social cost benefit analysis (generally referred to as cost benefit analysis) goes beyond financial analysis, which only considers the financial merits of an investment. Social cost-benefit analysis considers the cost and benefits to the nation as a whole. This viewpoint is appropriate in the case of transport activities, which are undertaken on behalf of the nation and are publicly funded.

Social cost benefit analysis is a framework in which non-market benefits and costs such as safety improvements, environmental pollution and increased accessibility can be considered alongside commercial benefits and costs. The analysis involves determining the various benefits and costs associated with each alternative and option over a certain analysis period, to determine the relative economic efficiency of these alternatives and options. The results for the chosen alternative and option indicate the overall value of an investment from an economic efficiency viewpoint.

Financial analysis compares projected sales revenue to investment costs and operating expenses to evaluate the potential return on investment. Financial analysis does not consider the impact on society, environmental resources, or the economy.

Economic costs and shadow pricing

In many instances the market prices for goods and services do not equate to their economic values (also termed national resource costs). This difference may occur from transfer payments, such as taxes, duties and subsidies, or of market imperfections such as monopolistic pricing or other factors. When performing a cost benefit analysis it is necessary to substitute the market price of items with a value that takes account of these differences. This technique is termed shadow pricing.

The benefit values provided in this manual take account of the differences between market prices and national resource costs, and therefore do not require any adjustment.

All construction and maintenance cost estimates used in economic evaluations must exclude GST, so that they are national resource costs.

Need to consider alternatives and options

Early and full consideration must be given to alternatives and options (section 20(2)(e) of the LTMA 2003). Alternatives are different means of achieving the same objective as the proposal, either totally or partially replacing the proposal. For example, Transport Demand Management (TDM) programmes are generally alternatives to the provision of road capacity.

Options are variations on the proposal, including scale and scope of components.

All realistic options shall be evaluated to identify the optimal economic solution. Rigorous consideration of alternatives and options is also a key component of the NZ Transport Agency's investment process (as set out in the PIKB).

It is a common mistake for economic evaluations to concentrate on one preferred option. Narrowing the scope of the analyses too early can cause serious errors, such as:

- neglecting options that differ in type or scale, eg a road realignment that may eliminate a bridge renewal
- neglecting significant externalities, eg the impacts of change in traffic flow upon adjoining properties
- inconsistencies with wider strategic policies and plans, eg the impacts of improvements to a major urban arterial on downtown congestion.

Multi-modal studies

A multi modal study is a useful tool to address the LTMA requirement to consider alternatives and options. It will also help achieve an integrated “one network” approach to investment.

A multi-modal study is one that considers two or more transport modes. Usually a multi-modal study considers all relevant modes including walking, cycling, roads, buses, rail and any other public transport.

The aim of multi-modal studies is to investigate each mode of transport and to seek solutions to any current or predicted future problems. The output is a number of different strategic options aimed at addressing the problems within the study area. Further information on multi-modal studies and their use in NZ Transport Agency’s funding framework can be found in the PIKB at the following section: [PIKB (assessment-framework)].

Mutually exclusive alternatives and options

Mutually exclusive alternatives and options occur when acceptance of one alternative or option precludes the acceptance of others, eg when a new road is proposed and there is a choice between two different alignments. The choice of one alignment obviously precludes the choice of the other alignment and therefore the two options are mutually exclusive.

Mutually exclusive options shall be evaluated in accordance with the incremental cost benefit analysis procedure in Section 2.8.

Independent stages

Activity stages shall be treated as independent, individual activities if the different stages could be executed separately, and if their benefits are independent of other activities or stages.

Features to mitigate external impacts

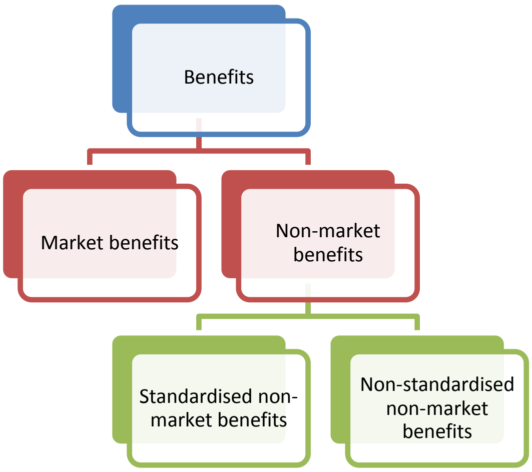
Where alternatives or options include features to mitigate or otherwise address external impacts or concerns and they significantly increase the cost, options with and without the features must be compared. This analysis shall be undertaken irrespective of whether the features are independent of the activity or mutually exclusive.

2.2 Benefits

Types of benefit

Three types of benefit (or disbenefit) are considered in economic evaluations of transport activities:

- Benefits with monetary values derived from the marketplace, eg, vehicle operating costs and the value of work travel time.
- Benefits that have been given a standard monetary value, eg the statistical value of human life, the value of non–work travel time, the comfort value gained from sealing unsealed roads, the frustration reduction benefit from passing opportunities and the carbon dioxide reduction benefit.
- Benefits that have not been given a standard monetary value, either because it is inappropriate or it has not been possible to establish a standard value, eg cultural, visual or ecological impact.



Benefits of transport activities may accrue to both transport users and other parties. Disbenefits, for example increases in vehicle operating costs, and are treated as negative benefits.

Assignment of benefit value

Market–based monetary values for the major land transport benefits are provided in this manual. Appendix A8 provides standard monetary values for several external impacts.

There are various techniques that allow economic values to be assigned to benefits, eg willingness to pay, avoidance or mitigation costs. Where benefits that do not have monetary values in this manual are likely to be significant, it may be desirable to undertake such an analysis.

Where no monetary value is available, the benefits should be described and where possible quantified, and also reported as an input into NZ Transport Agency's funding allocation process (refer to the PIKB).

Level of data collection and analysis

Generally, all activity benefits should be included in the economic evaluation. In some cases there are practical limits to the amount of time and energy that can or should be spent in gathering information and calculating total activity benefits. If a particular parameter is likely to contribute only a small amount of the total activity benefits, it is unwise to spend significant effort in obtaining this information and the use of the default values contained in Appendix A2 may be appropriate. Activities should be considered on a case–by–case basis to determine the appropriate level of data collection and analysis to apply.

Wider economic benefits

Wider economic benefits are impacts that can result from transport investment that have been used internationally to improve transport cost benefit analysis. They can be thought of as impacts that are additional to the conventional benefits to transport users. Great care is required to ensure that the estimates for wider economic benefits are truly additional to conventional benefits to avoid double counting.

The following wider economic benefits are applicable in the New Zealand context:

- Agglomeration where firms and workers cluster for some activities that are more efficient when spatially concentrated.
- Imperfect competition where a transport improvement causes output to increase in sectors where there are price cost margins.
- Increased labour supply where a reduction in commuting costs removes a barrier for new workers entering the workforce.

Further information on the calculation of wider economic benefits can be found in Appendix A10.2.

Benefits considered

The benefits used in economic efficiency evaluation of land transport activities are listed below showing the type of activity in which they are normally taken account of.

Benefit type	Road	Transport demand management	Transport services	Walking and cycling	Education promotion and marketing	Parking and land use	Private sector financing and road tolling
Travel time cost savings	✓	✓	✓	✓	✓		
Vehicle operating cost savings	✓	✓	✓	✓	✓		
Crash cost savings	✓	✓		✓	✓	✓	
Seal extension benefits	✓						
Driver frustration reduction benefits	✓						
Risk reduction benefits	✓	✓	✓		✓		✓
Vehicle emission reduction benefits	✓					✓	
Other external benefits	✓	✓	✓	✓	✓	✓	✓
Mode change benefits		✓	✓	✓	✓		
Walking and cycling health benefits		✓		✓			
Walking and cycling cost savings		✓		✓	✓		
Transport service user benefits			✓			✓	
Parking user cost savings		✓			✓	✓	
Journey time reliability benefits	✓	✓	✓	✓			
Wider economic benefits	✓		✓				
National strategic factors	✓	✓	✓		✓		

Combined benefit values	In some simplified procedures, benefit values consisting of combinations of primary benefits are used to simplify the calculations. Analysis which alters components of the simplified procedure should not be used as this will compromise the assumptions of the combined benefits.
National strategic factors	When evaluating activities it is expected that most, and in many cases all, of the benefits will relate to the monetised and non–monetised impacts described in this section and Section 2.3. However, despite the wide range of factors currently taken into account, there may also be certain national strategic factors that should be included in the analysis, particularly for large activities. National strategic factors are defined as national benefits that are valued by transport users or communities, but are not included elsewhere in the procedures in this manual. The factors for incorporating national strategic factors as benefits in the evaluation of an activity are where they: • will have a material impact on an activity's importance • comprise national economic benefits • have not already been counted in the core analysis • would likely be valued in a 'normal' market • the criteria for assessing national strategic factors and their valuation are discussed in more detail in Appendix A10. National strategic factors currently recognised by the NZ Transport Agency for road activities and transport services are described in Section 4.2. Other national strategic factor categories may be added to the list over time, particularly where it can be demonstrated that transport users are willing to pay for a benefit not included in the current procedures, as long as they can be shown to meet the criteria above. The NZ Transport Agency will consider other potential instances of national strategic factors on a case–by–case basis.
Business benefits	Benefits to businesses, such as increased revenue are economic transfers rather than national economic benefits and are therefore not included in the economic efficiency calculation. However, they may be quantified and reported as part of the funding allocation process where appropriate (refer to the PIKB). This is particularly relevant to transport demand management activities.
Double counting of benefits	The standard benefits listed in this manual generally constitute the total economic impact of improved levels of service, accessibility or safety. Certain external impacts of activities, such as increased land values, may arise because of the improved level of service and accessibility to nearby areas. These impacts shall be excluded from the evaluation because they represent a capitalisation of the direct benefits from reduced travel costs which have already been calculated, and including them would be double counting. For example, it would be double counting to claim increased land values as additional benefits if these benefits are merely a capitalisation of road-user benefits. In the case of a TDM activity, it would be double counting to include 'saved energy' benefits, vehicle operating costs savings and travel time savings in the same evaluation.

Disbenefits during implementation/ construction

Disbenefits considered in the economic evaluation during implementation should in most cases be restricted to travel time delays only, and do not need to include vehicle operating costs, crash cost, noise, dust, etc.

Where the activity/option results in minimal disruption (eg a tie in that does not require reduction in capacity during construction) there is no need to incorporate the disbenefits in the economic evaluation. Where the impact of disruption is material then the disbenefits of the activity/option shall be included in the evaluation.

The impact should be determined through sensitivity analysis, eg a preliminary estimate of the disbenefits to adjust the BCR. If the adjusted BCR remains within its funding efficiency profile level (ie low, medium, or high), then there is no need to undertake a detailed evaluation of the disbenefits, provided the difference between the BCRs is less than 10%. However, if the adjusted BCR falls to a lower profile level, which could impact the activity's priority or funding source, then a detailed evaluation of the disbenefits must be undertaken. If the adjusted BCR falls more than 10% then a detailed evaluation should be undertaken.

Seek guidance from the NZ Transport Agency if there is any doubt whether or not disbenefits should be taken into account for a particular activity.

Equity impacts

The consideration of equity impacts refers to analysis of how the benefits and costs of transport activities are distributed across population groups. The cost benefit analysis methods described in this manual do not directly deal with the distribution of benefits and costs on different sections of the public.

An analysis of the distribution of benefits and costs among different groups of people is not required for the economic efficiency evaluation of the activity. However, reporting of the distribution of benefits and costs, particularly where they relate to the needs of the transport-disadvantaged, is part of the funding allocation process.

For further guidance on equity impacts please refer to Appendix A15.

2.3 External impacts

Introduction

External impacts are benefits or disbenefits stemming from a activity that do not reside with the responsible government agencies, approved organisations or transport users. Because cost benefit analysis takes the national viewpoint, external impacts must also be considered.

Quantifying and valuing external impacts

Most of the potential external impacts are discussed in Appendix A8, which contains techniques for quantifying and, in some cases, valuing the impact. Benefits from sealing roads are addressed in simplified procedure SP4.

Where impacts are valued, they should be included as benefits or disbenefits in the economic efficiency evaluation. Non–monetised impacts should be quantified, where possible, and reported as part of any funding application.

For further guidance on external impacts please refer to Appendix A8.

2.4 Costs

Whole-of-life costs	The costs taken into account in an economic efficiency evaluation include all costs incurred in providing the transport infrastructure or service, and depend on the type of activity being evaluated. Costs are identified in the relevant sections of this manual for each of the different investment types. In all cases costs are whole-of-life costs and are to include all costs, including capital, operating and maintenance costs that are likely to be incurred at any time in the evaluation period.
Sunk costs	Where expenditure on an activity has already been incurred, it shall still be included in the evaluation if the item has a market value and this value can still be realised. Land is an example. Costs irrevocably committed which have no salvage or realisable value are termed sunk costs and shall not be included in the evaluation, eg investigation, research and design costs already incurred.
Funding gap	In the case of transport service activities, service provider costs can be compared with the predicted revenue or increase in revenue (where there is a pre-existing service), using a net present value (NPV) methodology to determine whether or not the activity is viable in a financial sense. The funding gap is the deficit in cash flow that needs to be funded by local and central government if the activity is to be financially viable from the service provider's point of view, based on the best estimate of service provider revenue and the service provider's desired rate of return. More guidance on how to determine the funding gap is given in Appendix A16.
Loans and interest payments	Capital costs shall be generally included in the analysis as cash flows according to the timing when the work is carried out, irrespective of any arrangements to finance the activity by way of loans. Interest payments on loans shall be excluded from the analysis. The exception to this is where NZ Transport Agency borrows to fund the NZ Transport Agency share of the activity, either by way of loans or participation in alternative funding arrangements eg Public Private Partnerships (PPP). In this case the costs to NZ Transport Agency are treated as cash flows from the National Land Transport Fund when actual payment is predicted to occur.

Cost	Road	Transport demand management	Transport services	Walking and cycling	Education promotion and marketing	Parking and land use	Private sector financing and road tolling
Construction cost	✓	✓	✓	✓	✓		
Maintenance costs	✓	✓	✓	✓	✓		
Operating cost	✓	✓	✓	✓	✓	✓	✓
Funding gap	✓	✓		✓	✓	✓	
Nett land cost	✓		✓	✓		✓	
Decommissioning / revocation costs	✓		✓				
Planning and design costs	✓	✓	✓	✓	✓	✓	✓
Finance costs							✓*

* Only to be considered when the finance costs (eg interest and service charges) are direct charges to the NZ Transport Agency and are funded from the National Land Transport Fund.

2.5 Present value and discounting

Introduction

The decision to invest in any form of asset requires comparing costs and benefits in different time periods and the trade-off between consumption opportunities now compared to consumption opportunities in the future. The judgement society makes about the value of an outcome today compared to an outcome tomorrow is called the time value of money. The time value of money means that society generally prefers benefits sooner than later so that the future is discounted relative to present. The discount rate allows the comparison different time periods by transforming future cost and benefits into present values.

The time value of money is treated in cost benefit analysis by discounting benefits and costs to present values to provide a common unit of measurement.

Benefits and costs may occur at various times over the duration of an activity and beyond.

Benefits and costs are discounted to take this timing into account using appropriate present–worth factors from Appendix A1.

Present value

The present value (PV) or present worth of a future benefit or cost is its discounted value at the present day. For a series of annual benefits or costs, the discounted values for each future year are summed to give the present values of the series.

Discount rate

The discount rate represents the rate at which society is willing to trade off present benefits and costs against future benefits and costs.

The discount rate, effective from 1 July 2013, shall be 6% per annum. This is the rate calculated by the NZ Transport Agency as being appropriate for transport investment and is subject to ongoing review.

Example

Society places a higher value on benefits that occur in the short term rather than far off in the future. For example, a higher value is given to a benefit of $1.00 available today than a benefit of $1.00 that is available in a year's time (after removing inflation effects). Applying a 6% discount rate, we can say that $1.00 in one year's time has a present value (PV) of $0.94.

Discount rate sensitivity test

While the base evaluation uses the standard 6% discount rate, sensitivity testing should be carried out at discount rates of 4% and 8%. In particular, sensitivity testing at the lower rate of 4% can be used for activities that have long term future benefits that cannot be adequately captured with the standard discount rate. Discounting at these other rates should be applied and reported as a standard sensitivity test for full procedures using the procedures in Appendix A1.

For the simplified procedures the time profile of costs and benefits allows a simple multiplier of 1.25 for 4% and 0.83 for 8% to be applied to the BCR calculated from a 6% discount rate to produce sensitivity test BCRs at the alternative discount rates.

Use of discount factors

The discount factors for various payment profiles contained in Appendix A1 can be used to calculate the PV of future costs and benefits. Appendix A1 also gives a detailed explanation of how the discount factors shall be applied.

Particular care shall be taken with amounts occurring in the first five years of the analysis period to allocate them to the correct time, as they will have a greater effect on the present values of costs and benefits than amounts occurring in later years. Refer to Appendix A1 for further detail.

Inflation and escalation

Inflation is defined as a general increase in prices and fall in the purchasing value of money. Escalation is defined in SM014 as an additional allowance to cover for increasing costs due to inflation throughout the activity life cycle. Thus inflation applies to the wider economy and escalation is specific to an activity.

Price inflation is a different concept from discounting. In general, all benefits and costs should be calculated in present-day (constant) dollars.

The discounting of future values reduces the significance of any differential future escalation that might be expected to occur between various categories of benefits and costs, and therefore no adjustment for inflation or escalation is required in the evaluation.

2.6 Time frame/period of analysis

Introduction

As the procedures outlined in this manual are time-dependent, it is important to set appropriate critical times and analysis periods. There are three critical times to be set up for the analysis process:

- Time zero – the date that all future cost and benefit streams are discounted to.
- Analysis period – the period, starting from time zero, for which all costs and benefits are included in the BCR calculations.
- Base date – the date used as a basis for determining the monetary unit values of costs and benefits.

Time zero

Time zero (the date all benefits and costs shall be discounted to) is 1 July of the financial year in which the activity is submitted for a commitment to funding. For example, if an activity included in the 2012–15 NLTP is submitted for funding in the 2013/14 year, time zero is 1 July 2013. All activity options shall use the same time zero for evaluation, irrespective of whether construction for all options would commence at that time.

In the case of activities being resubmitted in subsequent years, the evaluation shall be revised to the time zero appropriate to the year for which the activity is being submitted for a commitment to funding.

Analysis period

The time period used in economic evaluation shall be sufficient to cover all costs and benefits that are significant in present value terms. Evaluation periods specified in this manual are designed to capture at least 90% of the present value of future costs and benefits. For the 6% discount rate, the standard analysis period is 40 years.

The period of analysis may be less than the standard 40 years if it can be demonstrated that this is appropriate. In particular, the period of analysis should be no more than 10 years for TDM activities using promotion/education to change travel behaviour.

Base date for costs and benefits

The base date for dollar values of activity benefits and costs shall be 1 July of the financial year in which the evaluation is prepared. In the case of an activity being resubmitted in subsequent years, all dollar values of benefits and costs shall be adjusted to the same base date.

Factors for updating construction, maintenance and user benefits are given in Appendix A12. Where land costs are significant, the most recent possible estimate shall be used.

The base date for activity benefits and costs need not coincide with time zero. Generally, the base date for dollar values will be one year earlier than time zero.

2.7 Do-minimum

The do-minimum

Most forms of activity evaluation involve choices between different options or courses of action. In theory, every option should be compared with the option of doing nothing at all, ie the do-nothing.

For many transport activities, it is often not practical to do nothing. A certain minimum level of expenditure may be required to maintain a minimum level of service. This minimum level of expenditure is known as the do-minimum and shall be used as the basis for evaluation, rather than the do-nothing.

It is important not to overstate the scope of the do-minimum, ie it shall only include that work which is absolutely essential to preserve a minimum level of service. Note that this may not coincide with the current level of service or any particular desired level of service.

Particular caution is required if the cost of the do-minimum represents a significant proportion of, or exceeds the cost of the options being considered. In such cases, the do-minimum should be re–examined to see if it is being overstated.

Future costs in the do-minimum

In cases where the do-minimum involves a large future expenditure, the option of undertaking the activity now should be compared to the option of deferring the activity until this expenditure is due. Similarly, if the capital cost of the activity is expected to increase for some reason other than normal inflation, again the option of undertaking the activity now should be compared with the option of deferring construction and incurring the higher cost.

Benefit and cost differentials

The activity costs required for determining benefit cost ratios, including incremental benefit cost assessment (Section 2.8), and also first–year rate of return (Section 2.9) is the difference between the costs of the activity option and the costs of the do-minimum. The activity benefits are similarly the differences between the benefit values calculated for the activity option and those of the do-minimum.

It follows that where a particular benefit or cost is unchanged among all the activity options and the do-minimum, it does not require valuation or inclusion in the economic analysis. For completeness, it should be noted in any funding application that the benefit or cost is unchanged.

2.8 Benefit cost ratios

Introduction

The benefit cost ratio (BCR) of an activity is the present value (PV) of net benefits divided by the PV of net costs. An activity is regarded as economic or worthy of execution if the PV of its benefits is greater than the PV of its costs, ie an activity is economic if the BCR is greater than 1.0.

National benefit cost ratio

The NZ Transport Agency uses the national benefit cost ratio (BCR_N) as a measure of economic efficiency from a national perspective.

In its basic form, BCR_N is defined as:

$$BCR_N = \frac{\text{present values of national economic benefits}}{\text{present value of national economic costs}}$$

National economic benefits = net[1] direct and indirect benefits and disbenefits to all affected transport users plus all other monetised impacts

National economic costs = net[2] costs to the NZ Transport Agency and approved organisations (where there is no service provider or non-government contribution)

Or

net service provider costs plus net costs to the NZ Transport Agency and approved organisations (where there is a service provider).

The BCR_N applies equally to TDM activities, transport services and transport infrastructure activities. It indicates whether it is in the national interest to do the activity from an economic efficiency perspective.

Government benefit cost ratio

The NZ Transport Agency also uses a government benefit cost ratio (BCR_G), which indicates the monetised benefits obtained for the government expenditure (value for money from a central and local government perspective).

In its basic form, the BCR_G is defined as:

$$BCR_G = \frac{\text{present values of national economic benefits}}{\text{present value of government economic costs}}$$

National economic benefits = net direct and indirect benefits and disbenefits to all affected transport users plus all other monetised impacts.

[1] Net benefits are the difference between the benefits of the project option and the benefits of the do-minimum.
[2] Net costs are the difference between the cost of the project option and the cost of the do-minimum.

Government costs = net costs to the NZ Transport Agency and approved organisations.

Net cost to government

Where an external service provider is involved, the net costs to government include the 'funding gap' that is paid by local and central government to the service provider so that the service is financially viable to the service provider.

For freight services and high productivity motor vehicle (HPMV) activities the government costs also include the potential road user charges (RUC) foregone.

The BCR_G is equal to BCR_N where there is no service provider or non–government contribution. Public transport, freight transport and tolling activities usually involve a private operator providing a service and therefore require both BCR_N and BCR_G to be determined.

Third party contributions that specifically reduce the activity costs, including developer contributions can be deducted from the total of the activity costs to arrive at the net cost to government.

BCR rounding

The BCR shall be rounded to one decimal place if the ratio is below 10 and to whole numbers if the ratio is above 10. Any BCR calculated as less than 1.0 shall not be rounded.

Incremental cost benefit analysis

Where activity alternatives and options are mutually exclusive, incremental cost benefit analysis of the alternatives and options shall be used to identify the optimal economic solution.

The incremental BCR indicates whether the incremental cost of higher-cost alternatives and options is justified by the incremental benefits gained (all other factors being equal). Conversely, incremental analysis will identify whether a lower-cost alternative or option that realises proportionally more benefits is a more optimal solution.

Incremental BCR is defined as the incremental benefits per dollar of incremental cost.

$$\text{Incremental BCR} = \frac{\text{incremental benefits}}{\text{incremental costs}}$$

Further guidance on incremental cost benefit analysis is provided in Appendix A19.

2.9 First year rate of return

Introduction

First year rate of return (FYRR) is used to indicate the best start date for activities. The correct theoretical basis for determining the optimal start time would be to calculate the incremental BCR of starting an activity in year one compared to deferring the activity to year two or a later year. However, this is a relatively complex calculation. For most activities, FYRR provides an equivalent basis for determining the best start date. More information on developing activities for funding approval can be found in the guidance in the PIKB.

The FYRR provides guidance on the timing of an activity and is useful for sequencing mutually exclusive activities within a constrained budget. The FYRR should not be used to evaluate whether an activity should go ahead at all. That decision should be based on a full business case analysis, including comprehensive benefit cost analysis that spans the whole evaluation period. The merits of an activity that could exist for decades cannot be evaluated on the basis of what occurs in the first year of operation.

As a general rule, if the FYRR is less than the BCR divided by 15.4, then it potentially should be delayed. However it is important to take a network perspective when considering the timing of an activity within a programme of work. Calculating a profile of the FYRR of an investment, based on a number of assumed start dates, provides useful information on the optimal investment timing.

First year rate of return

For all activities, the FYRR shall be calculated for the preferred option.

FYRR, expressed as a percentage, is defined as the activity benefits in the first full year following completion of construction divided by the activity costs over the analysis period:

$$\text{FYRR} = \frac{\text{PV of the activity benefits in first full year following completion} \times 100}{\text{PV of the activity costs over the analysis period}}$$

2.10 Sensitivity and risk analysis

Introduction

The forecasting of future costs and benefits always involves some degree of uncertainty, and in some situations the resulting measures of economic efficiency (the BCR and FYRR) may be particularly sensitive to assumptions or predictions inherent in the analysis.

Two types of uncertainty may occur in a transport activity. Uncertainty about the:

- size or extent of inputs to an analysis, such as the variation in construction, maintenance or operating costs, future traffic volumes, particularly due to model results, growth rates and the assessment of diverted and induced traffic, travel speeds, road roughness or crash reductions
- timing and scale of unpredictable events, either from natural causes (such as earthquakes, flooding and landslips) or from human–made causes (such as accidental damage and injury from vehicle collisions).

Assessing the sensitivity of evaluations to critical assumptions or estimates shall be undertaken using either a sensitivity analysis or risk analysis, or both, as appropriate.

The uncertainty described here is not directly comparable to assessing the uncertainty as part of NZ Transport Agency's funding allocation process, which focuses on the confidence in the proposed activity (or package) delivering the desired outcomes.

Sensitivity analysis

Sensitivity analysis involves defining a range of potential values for an uncertain variable in evaluation and reviewing the variation in the evaluation as the variable changes within the range. This will highlight the sensitivity of the estimated final outcome to changes in input variables. Sensitivity analysis is an important tool for testing the veracity of the analysis and contributes to confidence at the decision making level.

Risk analysis

Risk analysis is a more detailed type of sensitivity analysis that involves describing the probability distributions of the input variables and those of the resulting estimates of benefits and costs. For a risk analysis to be possible, both the costs arising from each of the possible outcomes and their probability of occurrence have to be estimated.

Risk analysis can support development of ways of minimising, mitigating and managing uncertainties.

Methods for sensitivity and risk analyses

Guidance on completing a sensitivity analysis for proposed investments is given in Appendix A13 of this manual.

The general procedure for evaluating risk by an analysis of probabilities and expected values comprises the following steps:

1. Identify the uncertain elements in the activity and the chain of consequences for any unpredictable events.
2. Determine the benefits or disbenefits to transport users and the costs to the activity for each possible outcome.
3. Identify an annual probability of occurrence and the period of years over which this probability applies for each uncertain element.
4. Compute the expected values of benefits and costs for the uncertain elements in each year as the product of the costs and the annual probability of occurrence. Include these in the activity benefit and cost streams when discounting the cash flows.

A numerical simulation approach may be required in cases where the number and interaction of uncertain variables makes a deterministic approach inappropriate or impractical.

2.11 Packages

Introduction

The NZ Transport Agency seeks to encourage, where appropriate, approved organisations to develop packages of interrelated and complementary activities, either individually or in association with other approved organisations.

Packages are by definition multiple activities, which seek to progress an integrated approach to transport. Packages are intended to realise the synergy between complementary activities.

Packages may involve different activities, organisations and time periods. Packages should be:

- clearly related to specific transport issues and outcomes that emerge from a business case or other planning mechanism and aligned to land transport programmes and long–term council community plans
- optimised to make the most efficient and effective use of resources.

The extent to which particular packages, and where appropriate activities within such packages, are optimised to make the most efficient and effective use of resources, will be determined using the applicable evaluation procedures in this manual.

Types of packages

In general, packages will fall into one of the following three categories:

1. Packages for single agency with multiple activities;
   an example of such a package would be the development of integrated urban traffic control systems and complementary pedestrian and public transport priority measures.
2. Packages for multiple agencies with multiple activities;
   an example of such a package would be where a major state highway improvement is to be combined with traffic calming on local roads to improve the safety of the adjacent local road network. It is quite possible that when considered individually, neither activity represents an efficient use of resources. Travel time and capacity issues may reduce the benefits of the traffic calming when considered as an isolated activity. Similarly, main road traffic volumes may not be sufficient to warrant the highway upgrading as an isolated activity. However, the combined activity will benefit from the complementary nature of the two activities.
3. Packages for multiple agencies with a single activity;
   an example of such a package would be a proposal to seal a currently unsealed tourist route that passes through two local authorities. Such a proposal would be submitted as a package by the two approved organisations as a multiparty activity. There are benefits to existing traffic in sealing each section of the route. However, to realise all the potential benefits, the entire route needs to be sealed. Therefore, separate analyses shall be undertaken for each section of the route and of the route as a whole. In doing so, the evaluation should highlight the efficiencies of a package approach.

Refer to the PIKB: PIKB (development of packages/ programmes) for further information on developing a package of activities, or development of a programme of work through a business case.

Evaluation of packages

Section 4.8 describes the procedures for evaluating packages.

2.12 Transport models

Validation of transport models

When transportation models are used to generate demand forecasts and assign traffic to transportation networks, documentation should be provided to demonstrate the models have been correctly specified and produce realistic results. The documentation is listed in the series of checklists in FP Worksheet 8.3 and these should be completed for each analysis time period.

The aspects of the models covered by the validation checks are as follows:

- Activity model specification – including model type and parameters, data sources, trip matrices, assignment methodology and forecasting checks.
- A base-year assignment validation – comprising checks on link and screen–line flows, intersection flows, journey times and assignment convergence.
- Strategic demand model checks – incorporating validation of the models and techniques used to produce trip matrices.

Model reviewers may also use these checklists to confirm that appropriate documentation has been provided for review purposes.

Checks on output from traffic models

All activity benefits calculated using a traffic or transportation model shall be checked to show the results are reasonable. The checks shall be done and reported at two levels – coarse checks and detailed checks.

Coarse checks

The objective of these is to check if the travel time benefits calculated are of the right order of magnitude. More information on the required coarse model checks is contained in FP Worksheet 8.1.

Detailed checks

The objective of these is to ensure the travel times on individual road sections, through critical intersections and for selected journeys through the network, are reasonable. This analysis shall be undertaken for the first year of benefits and for a future year, and for both peak and off–peak periods if appropriate (FP Worksheets 8.2).

Evaluating congested networks and induced traffic effects

Guidelines are provided in Appendix A11 for modelling situations where very high levels of congestion are anticipated over the economic life of the scheme. Professional judgement should be used to determine the appropriate procedures to adopt. In cases where there are excessive or unrealistic levels of congestion in the do-minimum network, a number of techniques may be used to generate a realistic and stable representation of the do-minimum context. These commonly involve upgrading the capacity of the do-minimum network or using some form of growth constraint on the trip matrix, such as matrix capping.

The matrix derived from this process remains the same in both the do-minimum and activity option, and is then used in the standard fixed trip matrix (FTM) evaluation procedure. Appendix A11 provides details of growth constraint techniques.

In some situations, significant levels of congestion may be expected in the activity option across important parts of the network (spatially) affecting a substantial proportion of the activity life (temporally). The resulting induced travel may affect benefits as well as the choice of the activity option. The evaluation should incorporate an analysis of induced traffic effects and Appendix A11 contains procedures for evaluating these effects.

3.0 Simplified procedures

3.1 Selecting the procedure

Introduction

The simplified procedures are designed for the appraisal of low cost and low risk activities. This section contains simplified procedures for the following types of activities:

- SP1 Road renewals
- SP2 Structural bridge renewals
- SP3 General road improvements
- SP4 Seal extensions
- SP5 Isolated intersection improvements
- SP6 High productivity motor vehicle (HPMV) route improvements
- SP8 Freight transport services
- SP9 New public transport services
- SP10 Existing public transport services
- SP11 Walking and cycling facilities
- SP12 Travel behaviour change
- SP13 Road safety promotion

The criteria and thresholds for low cost and low risk are described at the beginning of each section.

Full procedures must be used if these criteria are not met.

The provided templates must be used when using these simplified procedures. The completed templates should be attached in Transport Investment Online. The templates are standardised to allow automated uploading and data extraction.

Application

Each simplified procedure is a stand-alone procedure. They are designed to be applied directly to each option being considered. Input values may be obtained from either:

1. the default figures provided
2. activity specific data collected
3. the information in the appendices.

Analysis which alters components of the simplified procedure should not be used as this will compromise the assumptions on which the procedure is based. Full procedures should be used instead.

Selecting the appropriate procedure

If the activity is …	Use
A road renewal, namely: • pavement rehabilitation (work category 214) • drainage renewals (work category 213) • seal widening (work category 231) • preventive maintenance (work category 241) Geometric improvements are excluded. Where the undiscounted cost ≤ \$5,000,000.	**SP1**
A structural bridge replacement or renewal (work category 322), where one of the following: • undiscounted cost is ≤ \$5,000,000 and the AADT ≥ 50 vpd • undiscounted cost is ≤ \$1,000,000, the AADT ≤ 50 vpd and a low cost option is not suitable • undiscounted cost of providing a suitable low cost option ≥ \$50,000 cheaper than providing a replacement bridge and the AADT ≤ 50 vpd. A decision chart is provided in SP2 to assist selection of the appropriate procedure.	**SP2**
A general road improvement, where the undiscounted cost ≤ \$5,000,000. Work categories 321, 323, 324 331 or 332 may apply here.	**SP3**
A seal extension (work category 325). Where the undiscounted cost ≤ \$5,000,000.	**SP4**
An isolated intersection improvement where the undiscounted cost ≤ \$5,000,000. Work categories 321, 323 or 324 may apply here.	**SP5**
A roading infrastructure improvement(s) specifically required to establish high productivity motor vehicle routes and where the undiscounted cost ≤ \$5,000,000. Work categories 215, 322 or 324 may apply here.	**SP6**
A freight transport service, where the undiscounted funding gap ≤ \$5,000,000 over three years. No specific work category is assigned for this work.	**SP8**
A new public transport service (work category 511, 512 or 515), where the undiscounted funding gap ≤ \$5,000,000 over the first three years of operation. Work categories 511, 512 or 515 may apply here.	**SP9**
An improvement to an existing public transport service (work category 511, 512 or 515), where the undiscounted funding gap ≤ \$5,000,000 over the first three years of operation. Work categories 511, 512 or 515 may apply here.	**SP10**

A walking or cycling facility (work category 451 or 452) where the undiscounted cost ≤ $5,000,000. Work categories 451 or 452 may apply here.	**SP11**
A travel behaviour change activity where the undiscounted implementation cost ≤ $5,000,000 over three years. No specific work category is assigned for this work.	**SP12**
A road safety promotion activity (work category 432) where the undiscounted implementation cost ≤ $5,000,000 over three years.	**SP13**

3.2 Supporting information

Standard input values

The following tables represent standard input values for use with the simplified procedures.

Tables

Table	Description
3.1	Single payment present worth factors for 6% discount rate
3.3	Discount factors for different growth rates for years 1 to 40 inclusive
3.3	Discount factors for different growth rates for years 2 to 40 inclusive
3.4	Crash cost discount factor for different traffic growth rates and speed limits for years 2 to 40 inclusive
3.5	Base vehicle operating costs (CB) including CO_2 – in cents/km (July 2008)
3.6	Roughness costs (CR) in cents/km (July 2008)
3.7	Travel time cost for standard traffic mixes for all periods combined - in dollars / hour (July 2008)
3.8	Rural mid-block equation coefficients (b_0) for heavy vehicle classes
3.9	Crash costs ($/reported injury crash - 2006)

Table 3.1: Single payment present worth factors for 6% discount rate

Year	SPPWF	Year	SPPWF	Year	SPPWF
1	0.94	16	0.39	31	0.16
2	0.89	17	0.37	32	0.15
3	0.84	18	0.35	33	0.15
4	0.79	19	0.33	34	0.14
5	0.75	20	0.31	35	0.13
6	0.70	21	0.29	36	0.12
7	0.67	22	0.28	37	0.12
8	0.63	23	0.26	38	0.11
9	0.59	24	0.25	39	0.10
10	0.56	25	0.23	40	0.10
11	0.53	26	0.22	41	0.09
12	0.50	27	0.21	42	0.09
13	0.47	28	0.28	43	0.08
14	0.44	29	0.18	44	0.08
15	0.42	30	0.17	45	0.07

Table 3.2 Discount factors (DF) for different growth rates for years 1 to 40 inclusive

Growth rate	0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%
Discount factor	15.49	16.49	17.48	18.48	19.48	20.47	21.47	22.46	23.46

Table 3.3 Discount factors (DF) for different growth rates for years 2 to 40 inclusive

Growth rate	0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%
Discount factor	14.52	15.52	16.51	17.50	18.50	19.49	20.48	21.48	22.47

Table 3.4 Crash cost discount factor for different traffic growth rates and speed limits for years 2 to 40 inclusive

Traffic growth rate	0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%
50 and 60km/h	8.56	9.56	10.55	11.54	12.54	13.53	14.52	15.52	16.51
≥ 70km/h	12.54	13.53	14.52	15.52	16.51	17.50	18.50	19.49	20.48

Table 3.5 Base vehicle operating costs (CB) including CO_2 – in cents/km (July 2008)

% gradient	Mean vehicle speed (over length of route)				
	0–30km/h	31–50km/h	51–70km/h	71–90km/h	91–105km/h
0	43.8	33.4	32.2	33.9	36.5
1 to 3	44.5	34.0	32.8	34.5	37.1
4 to 6	47.2	36.9	35.8	37.5	40.2
7 to 9	51.2	41.7	40.9	42.8	45.6
10 to 12	56.0	47.7	47.5	49.8	52.9

Table 3.6 Roughness costs (CR) in cents/km (July 2008)

Unsealed road roughness before sealing can be assumed to be 6.5 IRI (170 NAASRA counts) and 2.5 IRI (66 NAASRA counts) after sealing. If values higher than 6.5 IRI (or 170 NAASRA) for initial roughness of unsealed roads are used these need to be substantiated.

IRI m/km	NAASRA counts/ km	CR cents/km urban	CR cents/km rural
2.5	66	0.0	0.0
3.0	79	0.3	0.3
3.5	92	0.8	1.1
4.0	106	1.6	2.9
4.5	119	2.8	5.3
5.0	132	4.2	7.9
5.5	145	5.8	10.6

IRI m/km	NAASRA counts/ km	CR cents/km urban	CR cents/km rural
6.0	158	7.6	13.2
6.5	172	9.4	15.8
7.0	185	11.3	18.4
7.5	198	13.3	21.0
8.0	211	15.2	22.1
8.5	224	17.1	23.1
9.0	238	19.0	24.0

Table 3.7: Travel time cost for standard traffic mixes for all periods combined ($/hr - 2008)

Road type	Description	Travel time cost
Urban arterial	Arterial and collector roads within urban areas carrying traffic volumes greater than 7000 motorised vehicles/day.	19.36
Urban other	Urban roads other than urban arterial.	19.31
Rural strategic	Arterial and collector roads connecting main centres of population and carrying traffic of over 2500 motorised vehicles/day.	27.67
Rural other	Rural roads other than rural strategic.	27.04

Table 3.8 Rural mid-block equation coefficients (b_0) for heavy vehicle classes

Annual average daily traffic (AADT)	Coefficients b_0 by terrain type[1]		
	Level terrain (0 to 3%)	Rolling terrain (3 to 6%)	Mountainous terrain (>6%)
≤4,000	19	40	50
>4,000	19	19	41

[1]The terrain type can be selected by route gradient. The gradient ranges shown should generally be maintained throughout the mid-blocks. Sections of the road that are less steep can occur in rolling or mountainous sections for short lengths. Provided that the lower gradient length is followed by another rolling or mountainous gradient, then the entire section can be classified as rolling or mountainous.

Table 3.9 Crash costs ($/reported injury crash - 2006)

Speed limit and location	Crash cost
100km/h near rural	700,000
100km/h remote rural[2]	1,030,000

[2]100km/h remote rural roads are defined as carrying less than 1,000 vehicles/day and being more than 20mm from a town of 3,000 population or more.

Caveat on using table data

Where the values in tables 3.8 and 3.9 above do not accurately represent local conditions, provide additional information showing the values that have been used and whether these have been calibrated to local conditions.

3.3 Procedures

SP1 Road renewals

Introduction

These procedures (SP1) provide a simplified method of appraising the economic efficiency of work to be funded under work categories[3] within the Renewals activity class, for example pavement rehabilitation and preventive maintenance. The procedures are applicable to activities with an undiscounted capital cost of less than or equal to $5 million.

To be considered eligible for funding under these work categories, the activity must be shown to be the long term, least cost option for the road controlling authority, and must not include geometric improvements. (This requirement is not intended to prevent investment in work that will *coincidentally* give benefit to road users. For example seal widening will usually provide some safety benefits to road users but if the investment is justified on the grounds that it is the most cost effective way to maintain a road shoulder it shall be funded under the seal widening work category).

Under these procedures the present value (PV) cost of the option is determined and compared with the existing maintenance strategy. An existing maintenance strategy commonly includes pavement maintenance work such as dig-outs, reseals, and/or other localised repairs needed to 'hold' the condition of an asset.

The procedure uses a 6% discount rate and 40 year evaluation period. The procedures assume that activities will be completed within the first year and will be in service by the start of year two. Where costs are common to both the existing maintenance strategy and the option(s), they are not included in the analysis. All costs are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP1 Road renewals

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of existing maintenance strategy
3	Cost of option

[3] NZ Transport Agency's Planning and Investment Knowledge Base, activity classes.

SP2 Structural bridge renewals

Introduction

These procedures (SP2) provide a simplified method for appraising the economic efficiency of replacing a bridge for structural reasons. The benefits analysis focuses on the change in heavy commercial vehicle (HCV) users' costs as a result of the activity. Guidance on the application of these procedures is found in the decision chart on the following page.

If road improvements are being considered in conjunction with the bridge renewal, then the improvements are to be evaluated separately (using SP3, if applicable), when it is confirmed that bridge renewal is the preferred option.

The procedure for analysing structural bridge renewals is somewhat different to other activities, in that all options are identified and costed at the outset, including:

- cost of replacement bridge
- average daily traffic
- viability and cost of a concrete ford
- the HCV users of the bridge
- existence of an alternative route, its length and any necessary upgrade costs
- the cost to repair the bridge to a posted limit of 10 tonnes
- revocation costs
- demolition/ deconstruction costs.

Once this has been done, the decision chart on the following page can be used to determine the appropriate course of action and analysis procedure.

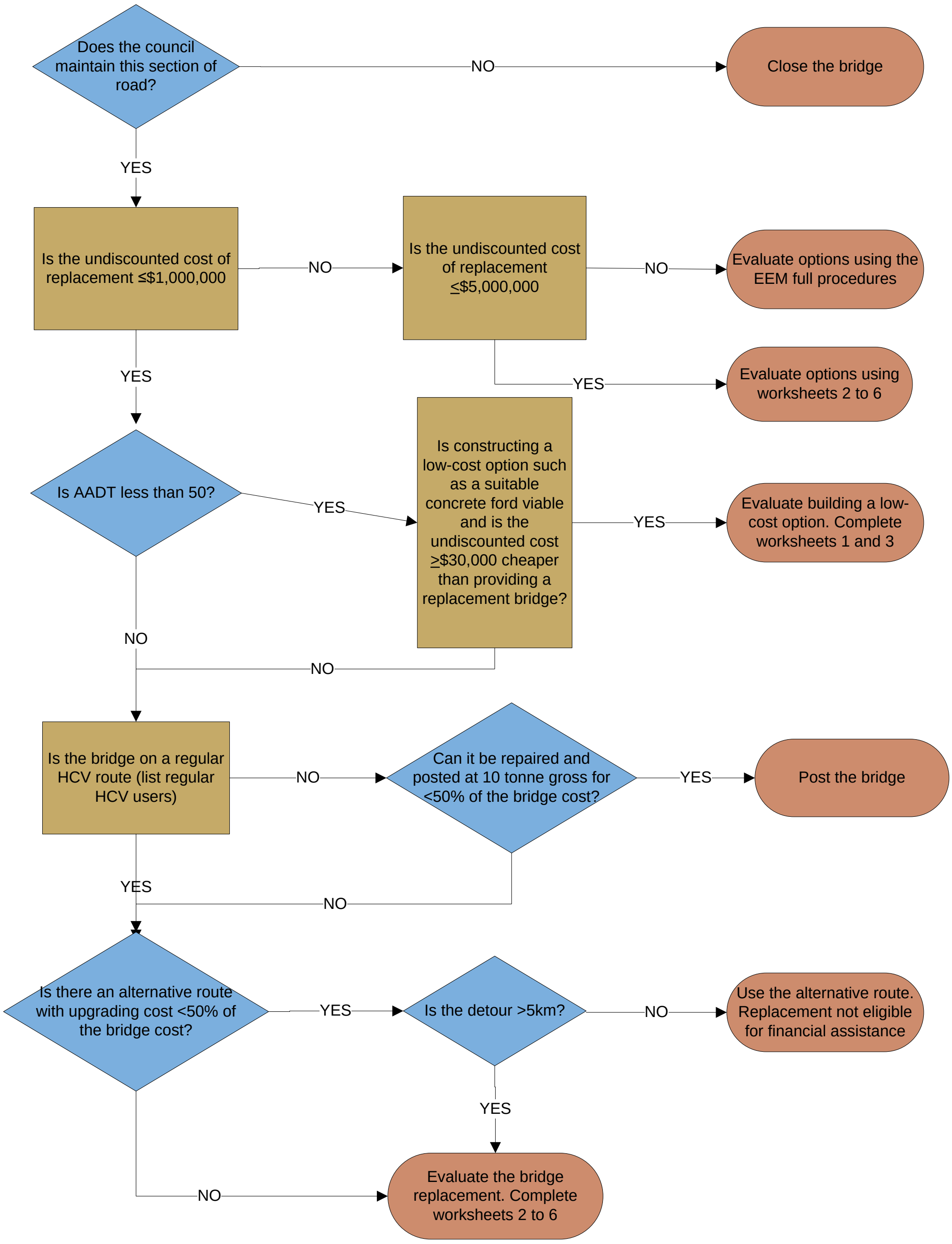
The procedure uses a 6% discount rate and 40 year evaluation period. The procedure assumes that activities will be completed within the first year and will be in service by the start of year two. Where costs are common to all the options, they are not included in the analysis. All costs are to be exclusive of GST.

Total bridge failure

This procedure does not allow for the possibility of total bridge failure. If this is a real possibility when certain options are chosen, then account should be taken of the extra costs this would impose on road users multiplied by the probability of failure occurring. The calculation of these probabilities should be undertaken by the same engineers who make the decisions regarding posting the bridge.

Decision chart for bridge replacements on low volume roads

Decision chart for bridge replacement



Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP2 Structural bridge renewals

This template includes:

Worksheet	Description
1	Building a ford on a low volume road
2	Evaluation summary for bridge renewal
3	Costs of the option(s)
4	HCV user costs when there is an alternative route
5	HCV user costs when there is no alternative route
6	BCR and incremental analysis

Supporting information

The following table provides default values for use within this simplified procedure:

Table SP2.1 Freight cost factors

% Class I	HCVI	HCVII
100	1.00	1.00
90	1.18	1.22
80	1.44	1.57
70	1.85	2.22
60	2.60	3.67
50	4.33	11.00

SP3 General road improvements

Introduction

These procedures (SP3) provide a simplified method of appraising the economic efficiency of general road improvements, including: road reconstruction, new roads and structures. They specifically exclude seal extension work (SP4), bridge renewals (SP2) and renewals (SP1). The method is for the evaluation of activities that have an undiscounted capital cost less than or equal to $5 million.

The procedures are designed to consider one option at a time. All suitable options for the proposed works should be considered in order to select the optimal solution. In most situations this will involve incremental analysis of the benefits and costs of the different options analysed. A description of all options considered should be described in worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included.

It is necessary to determine the expected future traffic growth rate for the activity. This can be done either by analysing the traffic count data (for at least the last five years and preferably for the last 10 years) or by using a default rate of zero percent.

The procedure uses a 6% discount rate and 40 year evaluation period. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to the do-minimum and the options, they are not included in the analysis. All costs are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP3 General road improvements

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of do-minimum
3	Cost of the option(s)
4	Travel time cost savings
5	Vehicle operating cost savings
6	Crash cost savings
7	BCR and incremental analysis

SP4 Seal extensions

Introduction

These procedures (SP4) provide a simplified method of appraising the economic efficiency of proposed seal extension works. The method is for the evaluation of activities that have an undiscounted capital cost less than or equal to $5 million.

The procedures are designed to consider one option at a time. All suitable options for the proposed works should be considered in order to select the optimal solution. In most situations this will involve incremental analysis of the benefits and costs of the different options analysed. A description of all options considered should be provided in worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included.

It is necessary to determine the traffic growth rate for the activity. This can be done either by analysing the traffic count data (for at least the last five years and preferably for the last 10 years) or by using a default rate of zero percent.

The procedure uses a 6% discount rate and a 40 year evaluation period. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to both the do-minimum and the options, they are not included in the analysis. All costs are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP4 Seal extensions

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of the do-minimum
3	Cost of the option
4	Travel time cost savings and seal extension benefits
5	Vehicle operating cost savings
6	Crash cost savings
7	BCR and incremental analysis sheet

Supporting Information

The following table provides default values for use within this simplified procedure:

Table SP4.1 Increase in mean speed for seal extension works

Unsealed section mean speed of light vehicles	Sealed section increase in mean speed (km/h) for increase in carriageway width (m)		
	No increase (seal as is)	Increase of 1 metre	Increase of 2 metres
> 60km/h	0	5	10
45 to 60km/h	5	10	20
35 to 45km/h	10	15	25
< 35km/h	15	20	30

SP5 Isolated intersection improvements

Introduction

These procedures (SP5) provide a simplified method of appraising the economic efficiency of isolated intersection improvements and are intended for activities that have an undiscounted capital cost up to $5 million.

Crash analysis involving an isolated intersection is only to be undertaken where the site has a crash history of:

- four or more non–injury crashes
- one injury and three or more non–injury crashes, or
- two or more injury crashes.

The most recent five calendar year crash history for the site should be used. Detailed crash listings, collision diagrams, a description of common factors in the crashes and a diagnosis of the site factors contributing to the problem should be submitted with the evaluation.

An intersection that does not meet the above criteria may still have a crash analysis carried out using predictive crash models. In such a case, SP5 does not apply and full procedures must be used.

The procedures are designed to consider one option at a time. All suitable options for the proposed works should be considered in order to select the optimal solution. In most situations this will involve incremental analysis of the benefits and costs of the different options. A description of all options considered should be provided in worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included.

It is necessary to determine the traffic growth rate for the activity. This can be done by analysing traffic count data (for at least the last five years and preferably for the last 10 years) or by using a default rate of 0%.

The procedure uses a 6% discount rate and a 40 year evaluation period. The procedure assumes that funded activities will be completed in the first year and will be in service by the start of year two. Where costs are common to both the do-minimum and the option under consideration, they are not included in the analysis. All costs are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP5 Isolated intersection improvements

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of the do-minimum
3	Cost of the option
4	Travel time cost savings
5	Vehicle operating cost savings
6	Crash cost savings
7	BCR and incremental analysis sheet

Supporting Information

The following table provides default values for use within this simplified procedure:

Table SP5.1 Multiplication factors for items with an estimated life of less than 40 years

Construction item	Multiplying factor (MF)
Traffic signs	2.5
Delineation (eg edge market posts, raised pavement markers, sight railing and chevrons)	3.7
Spray plastic	5.7
Road markings	15.5

SP6 High productivity motor vehicle (HPMV) route improvements

Introduction

These procedures (SP6) provide a simplified method of appraising the economic efficiency of high productivity motor vehicle routes. The procedures are applicable to activities with an undiscounted capital cost of less than or equal to $5 million.

They assume that:

1. the activity includes benefits from reduced vehicle operating costs and crash savings derived from reduced heavy vehicle trips
2. the route from which heavy vehicles are removed is primarily rural, with a minimal number of intersections.

If the route includes a significant proportion of travel in urban areas, the evaluator should instead use the crash cost savings procedures described in the transport services full procedures, Section 4.4.

The simplified procedure is designed to consider one option at a time. All suitable options for the proposed works should be considered in order to find the optimal solution. In some cases (eg where pavements are weak), it may be necessary to compare the freight transport option with a road reconstruction option for the affected road network. If there is more than one option, incremental analysis of the benefits and costs of the different options analysed should be used. A description of all options considered should be described in worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included.

Only additional costs required to allow passage of HPMVs on identified routes are included within this simplified procedure. Where an HPMV activity will bring forward or increase planned maintenance or bridge work these associated costs are redistributed accordingly within the cost tables.

The procedure uses a 6% discount rate and 40 year evaluation period. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to the do-minimum and the options, they are not included in the analysis. All costs are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP6 High productivity motor vehicle (HPMV) route improvements

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of options
3	HPMV VOC, CO_2 and travel time benefits
4	HPMV crash cost savings
5	BCR and incremental analysis

SP8 Freight transport services

Introduction

These procedures (SP8) provide a simplified method of appraising the economic efficiency of rail and sea freight transport services, with or without capital expenditure. The method is for the evaluation of activities that have an undiscounted funding gap that is less than or equal to $5 million over a three year period.

They assume that:

- there are costs to users which are additional to, and offset the difference between, road and rail or sea freight rates
- the primary benefits are road maintenance, renewal and improvement cost savings (net of road user charges), and road traffic reduction benefits (mainly CO_2 and crash cost savings) from the removal of freight from the road network
- the route from which heavy vehicles are removed is primarily rural, with a minimal number of intersections. If the road freight traffic spends a significant time traversing urban areas, the evaluator should instead use the procedures described in the transport services full procedures, Section 4.4, to evaluate road traffic reduction benefits and crash cost savings
- other benefits (positive or negative) are not significant. Allowance can be made for additional benefits if they are found to be significant.

Full procedures should be used in cases where these assumptions are not appropriate.

The procedures are designed to consider one option at a time. All suitable options should be considered in order to select the optimal solution. In some cases (eg where pavements are weak), it may be necessary to compare the freight transport option with a road reconstruction option for the affected road network. If there is more than one option, incremental analysis of the costs and benefits should be used.

A description of all options considered should be described in SP8- Worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included.

The procedures use a 6% discount rate, an evaluation period of up to 40 years, and a 12% service provider rate of return. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to the do-minimum and the options, they are not included in the analysis. All costs and revenues are to be exclusive of GST.

SP8-Worksheet 8 provides a feasibility evaluation using costs that are internalised to the service provider plus a composite value for non-internalised costs for road freight transport and for sea or rail transport. This may be used for activities without specific crash or congestion issues on the affected roads.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP8 Freight transport services

This template includes:

Worksheet	Description
1	Evaluation summary
2	Service provider costs
3	Funding gap analysis
4	Freight service user benefit
5	Net cost savings to government
6	Road traffic reduction benefits
7	BCR and incremental analysis
8	Feasibility evaluation

Supporting information

The following tables provide default values for use within this simplified procedure:

- SP8.1 Heavy vehicle types and EDA equivalents
- SP8.2 Cost of EDA by road type
- SP8.3 Economic costs of road freight transport

Caveat on using the table data

Where the values in tables 1 and 2 above do not accurately represent local conditions, provide additional information that shows what values have been used and whether these have been calibrated to local conditions.

Table SP8.1: Heavy vehicle types and EDA equivalents

Vehicle type	EDA		
	Laden trip	Unladen	Return trip
HCVIIa – up to 18 tonnes payload, six wheel truck, three axle trailer	1.38	0.2	1.58
HCVIIb – over 18 and up to 23 tonnes payload, eight wheel truck, two axle trailer	1.94	0.2	2.14
HCVIIc – over 23 and up to 28 tonnes payload, (forestry)	3.3	0.5	3.8

If the HCV traffic moves freight from its origin (freight source) to destination (distribution point) and returns empty to the origin, then use the return trip EDA. If the HCV traffic carries a load on its return trip and the freight transport activity will also carry the return load, then double the laden trip value.

Note: The evaluator will need to assess the appropriate RUC for the vehicles in question.

Table SP8.2: Cost of EDA by road type ($/EDA km - 2008)

Road type	EDA cost
Local road, designed pavement (LD)	0.70
Local road, undesigned pavement (LU)*	0.70–1.16
State highway (SH)	0.41

* Local road undesigned pavement refers to roads that were previously unsealed and were sealed by simply adding more aggregate and then a seal coat. The value of the $/EDA/km for local road undesigned requires judgement on the part of the local authority and evaluator to assess the EDA value.

Table SP8.3: Economic cost of road freight transport ($/tonne km – 2008)

	State highway	Local road (hilly terrain)
Total economic cost	$0.22	$0.32

SP9 New public transport services

Introduction

These procedures (SP9) provide a simplified method of appraising the economic efficiency of new public transport services and associated capital infrastructure. The method is for the evaluation of activities that have an undiscounted funding gap that is less than or equal to $5 million over the first three year period of operation.

They assume that:

- the new service will serve a geographical area that is not currently served by public transport
- services will be provided in the peak period, so that commuters change modes from private vehicles to public transport. A peak public transport service is one that passengers can board during the morning and evening commuter peak periods defined in Appendix A2.4
- benefits accrue to public transport and road users. Road user benefits result from road traffic reduction, and include travel time savings (including congestion reduction), vehicle operating cost savings, crash cost savings, and environmental benefits (including CO_2 reduction). The road traffic reduction benefit values assume that the road corridor has at least one point that operates at less than 80% capacity during the peak period
- other benefits (positive or negative) are not significant. Allowance can be made for additional benefits if they are found to be significant
- most traffic removed from the road network will be light vehicles and will not generate road maintenance, renewal or improvement cost savings.

Full procedures should be used in cases where these assumptions are not appropriate.

The procedures are designed to consider one option at a time. All suitable options should be considered in order to select the optimal solution. In most situations this will involve incremental analysis of the benefits and costs of the different options analysed.

A description of all options considered should be described in SP9-Worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included. Incremental analysis of the costs and benefits should be used where there is more than one option.

The procedures use a 6% discount rate, an evaluation period of up to 40 years, and a 12% service provider rate of return. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to the do-minimum and the options, they are not included in the analysis. They assume that activities will be completed within the first year and will be in service by the start of year two. All costs and revenues are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP9 New public transport services

This template includes:

Worksheet	Description
1	Evaluation summary
2	Service provider costs
3	Funding gap analysis
4	Public transport user benefits
5	Road traffic reduction benefits
6	BCR and incremental analysis

Supporting Information

The following table provides default values for use within this simplified procedure:

Table SP9.1: Diversion rates and road traffic reduction benefit values for major urban corridors

Urban area	Diversion rate (vehicle/km removed from road per new public transport passenger km)	Road traffic reduction benefit ($/vehicle/km per year removed from road – 2008)
Auckland	0.725 (72.5%)	$1.56
Wellington	0.777 (77.7%)	$1.00
Christchurch/other	0.675 (67.5%)	$0.34

SP10 Existing public transport services

Introduction

These procedures (SP10) provide a simplified method of appraising the economic efficiency of improvements to existing public transport services through service and/or capital infrastructure enhancements. The method is for the evaluation of activities that have an undiscounted funding gap that is less than or equal to $5 million over the first three year period of operation.

They assume that:

- service enhancements will be provided in the peak period, so that commuters change modes from private vehicles to public transport. A peak public transport service is one that passengers can board during the morning and evening commuter peak periods defined in Appendix A2.4
- benefits accrue to new and existing public transport users and to road users. Public transport user benefits include reliability, vehicle and infrastructure benefits. Road user benefits result from road traffic reduction, and include travel time savings (including congestion reduction), vehicle operating cost savings, crash cost savings, and environmental benefits (including CO_2 reduction). The road traffic reduction benefit values assume that the road corridor has at least one point that operates at less than 80% capacity during the peak period
- other benefits (positive or negative) are not significant. Allowance can be made for additional benefits if they are found to be significant
- most traffic removed from the road network will be light vehicles and will not generate road maintenance, renewal or improvement cost savings
- the activity will not generate a drop off in existing passengers (eg as a result of a fare rise)
- each trip on the improved service is an ‘average’ length for the urban centre. The benefit may therefore be overestimated where trips are shorter than the average and underestimated where trips longer than the average. Consider whether this is likely to be significant.

Full procedures should be used in cases where these assumptions are not appropriate.

The procedures are designed to consider one option at a time. All suitable options should be considered in order to select the optimal solution. In most situations this will involve incremental analysis of the benefits and costs of the different options analysed.

A description of all options considered should be described in worksheet 1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option needs to be included.

The procedures use a 6% discount rate, an evaluation period of up to 40 years, and a 12% service provider rate of return. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to the do-minimum and the options, they are not included in the analysis. All costs and revenues are exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP10 Existing public transport services

This template includes:

Worksheet	Description
1	Evaluation summary
2	Service provider costs
3	Funding gap analysis
4	Net benefits
5	BCR and incremental analysis

Supporting information

The following tables provide default values for use within the simplified procedure:

- SP10.1 Benefits of additional passengers
- SP10.2 Equivalent minutes to late ratios

Table SP10.1: Benefits ($/additional passenger boarding - 2008)

Urban area	Mode	Average trip length (km)	Road traffic reduction benefits		Public transport user benefits	
			Peak	Off peak	Peak	Off peak
Auckland	All	7.70	12.61	0.86	10.89	7.26
	Rail	16.50	17.27	1.65	16.75	11.17
	Bus/ferry	6.60	11.73	0.76	10.16	6.77
Wellington	All	12.14	13.25	1.25	13.85	9.23
	Rail	22.76	17.70	1.99	20.91	13.94
	Bus/ferry	6.97	11.97	0.89	10.41	6.94
Christchurch	All	8.05	2.71	1.24	11.13	7.42
Other	All	7.86	2.06	1.00	11.00	7.33

Caveat on using the above data

The above values are based on public transport trips of average length for each urban area or mode. Where the values in table SP10.1 above do not accurately represent local conditions, you should provide additional information that shows what values have been used and whether these have been calibrated to local conditions.

Table SP10.2: Equivalent minutes to late ratios

Valuation		
Departure	In vehicle travel	Combined
5.0	2.8	3.9

SP11 Walking and cycling facilities

Introduction

These procedures (SP11) provide a simplified method of appraising the economic efficiency of walking and cycling facility improvements. Activities may be stand-alone interventions, or a component of a wider transport solution. The method is for the evaluation of activities that have an undiscounted capital cost that is less than or equal to $5 million.

The procedures assume that the activity does not include signalised crossings over roads.

In cases where the above criteria are not appropriate, the full procedures should be used.

The simplified procedure is designed to consider one option at a time. All suitable options for the proposed works should be considered in order to select the optimal solution. In most situations this will involve incremental analysis of the benefits and costs of the different options analysed. In particular, where a separate dedicated cycleway is proposed the alternative option of providing wider sealed shoulders or cycle lanes on the carriageway must be considered.

A description of all options considered should be described in SP11-Worksheet 1 and included in the incremental analysis; for walking and cycling facilities, the worksheets for all the options must be submitted together with a summary of the incremental analysis.

To use the worksheets, it is necessary to determine both the current numbers, and growth rate of cycle/pedestrian traffic for the activity. These must be based on local counts and realistic projections. For cyclists these can be obtained using SP11-Worksheet 7.

The simplified procedure may be used as part of a multi-modal evaluation also covering travel behaviour change (TBhC) activities and infrastructure and public transport service improvements. The procedure uses a 6% discount rate and 40 year evaluation period. The procedure assumes that activities will be completed in the first year and will be in service by the start of year two. Where costs are common to the do-minimum and the options, they are not included in the analysis. All costs are to be exclusive of GST.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP11 Walking and cycling facilities

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of the do-minimum
3	Costs of the option
4	Travel time cost savings
5	Benefits for walking and cycling facilities
6	Crash cost savings
7	Cycle demand
8	BCR and incremental analysis

Supporting information

The following table provides default values for use within this simplified procedure:

Table SP11.1: Benefit factors for different types of cycle facilities

Type of cycle facility	Relative Attractiveness (RA}
On-street with parking, no marked cycle lane	1.0
On-street with parking, marked cycle lane	1.8
On-street without parking, marked cycle lane	1.9
Off-street cycle path	2.0

SP12 Travel behaviour change

Introduction

These procedures (SP12) provide a simplified method of appraising the economic efficiency of travel behaviour change (TBhC) activities. The method is for the evaluation of activities that have an undiscounted implementation cost that is less than or equal to $5 million over a three year period.

TBhC activities generally employ education, information and marketing based approaches to achieve voluntary changes in the travel behaviour of individuals.

This procedure may be used to evaluate the following types of TBhC proposal:

- community-based, eg travel awareness campaigns, rideshare
- household-based, eg personalised marketing, 'living neighbourhoods'
- school travel (school travel plans)
- workplace based (workplace travel plans)
- substitutes for travel, eg teleworking.

The procedure does not cover the following types of activity even though they may be included within the definition of TBhC in some countries:

- Demand management for special events. This is considered to be the responsibility of the sponsoring organisation and local authorities.
- Mobility management centres (European model). A one-stop-shop designed to promote and inform the public about environmentally friendly and safe transport options, selling public transport tickets and renting cycles and for individuals seeking advice on their travel options, such as public transport, carpooling, car sharing clubs. Essentially, such a centre is a means for delivering components of TBhC programmes rather than a TBhC programme in itself.
- Freight management, logistics or any other possible action to change the travel behaviour of commercial vehicle operators or fleets.

A multi-modal evaluation is required for a programme of measures involving TBhC activities if the cost of supporting infrastructure components (such as walk/cycle paths or minor road improvements) or public transport components is a significant proportion of the overall activity cost. Choice of procedure should be carefully considered if the supporting infrastructure is over one million dollars.

These procedures assume that:

1. associated improvement costs or the three year funding gap for public transport service improvements are a small proportion of the overall cost
2. a 6% discount rate and 10 year analysis period are used
3. activities adopted will be completed in the first year and will be in service by the end of year one
4. all costs are exclusive of GST.

In cases where the above assumptions are not appropriate, the full procedures should be used.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP12 Travel behaviour change

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of the option(s)
3	Benefits
4	BCR per head

SP13 Road safety promotion

Introduction

These procedures (SP13) provide a simplified method of appraising the economic efficiency of road safety promotion. The method is for the evaluation of activities that have an undiscounted implementation cost less than or equal to $5 million over a three year period.

Road Safety promotion generally employs education, information and marketing based approaches to achieve voluntary changes in the safety outcomes of individuals. This may include education, advertising, awareness raising and public information to users of the transport network.

A multimodal evaluation should be used for a programme of measures involving road safety promotion if the cost of supporting infrastructure components (such as walk/cycle paths or minor road improvements) or public transport components are significant, and critical to achieve the benefits.

These procedures assume that:

1. associated improvement costs or the three year funding gap for public transport improvements are a small proportion of the overall cost.
2. a 6% discount rate and 10 year analysis period are used
3. activities adopted will be completed in the first year and will be in service by the end of year one
4. all costs are exclusive of GST.

In cases where the above assumptions are not appropriate, the full procedures should be used.

Procedure

The procedure template, including guidance for completing the simplified procedure is provided below.

If you have any problems with the procedure template contact eem@nzta.govt.nz

SP13 Road safety promotion

This template includes:

Worksheet	Description
1	Evaluation summary
2	Cost of the option(s)
3	Social cost
4	Benefits
5	BCR per head

4.0 Full procedures

4.1 Application of full procedures

Relationship to activity type requirements and simplified procedures

Full procedures are to be used to appraise economic efficiency when the assumptions contained in the simplified procedures, including limits specified for the simplified procedures are exceeded.

The full procedures may be used for all types of land transport activities with appropriate adaptation. The benefits and costs considered in the evaluation should be adjusted or added to as appropriate to the activity type.

Worksheets

The full procedures contain a series of worksheets to guide the calculation and encourage consistency of presentation. These worksheets are used as far as is practical when preparing evaluations. Non-standard worksheets may be submitted with evaluation reports provided the necessary information can be readily obtained from such worksheets and is referenced on the activity checklist.

The worksheets provided in this manual are designed to allow some flexibility in methods of calculation since no two activity evaluations are exactly the same.

All activity evaluation reports shall contain an executive summary which is made up of Full Procedures (FP) Worksheets 1 to 7 inclusive. FP Worksheets 8to 18 are provided to assist with the calculations reported in FP Worksheets 1 to 7.

Much of the information required for FP Worksheets 1 to 7 contributes to other components of the Transport Agency's funding allocation process. The expectation is that the data entered on these worksheets can be transferred to the Transport Investment Online system (TIO) and vice versa as appropriate.

Blank worksheets

A complete set of blank worksheets is available in MSWord format on our website.

4.2 Evaluation of roading activities

4.2.1 Overview

Introduction

This chapter describes the specific procedures to be used to evaluate the economic efficiency of road activities.

In this chapter

Section	Topic
4.2.1	Overview
4.2.2	Stages of analysis
4.2.3	Method of evaluation
4.2.4	Costs of road activities
4.2.5	Benefits of road activities
4.2.6	References

4.2.2 Stages of analysis

Introduction

The following table outlines the stages of analysis in the economic efficiency evaluation. It is envisaged that a programme business case [PIKB link: PIKB (programme business case)] will have been completed before commencing evaluation of economic efficiency and applying the standard set of full procedures as set out below for evaluation of roading activities. The do-minimum and any other options must be assessed at every stage.

Stages

Stage	Description	See
1	Describe the do-minimum, alternatives and options and consider packaging activities to maximise outcomes.	Section 2.1, 2.7 and 2.11 FP Worksheet 1
2	Assemble basic information on route, traffic, demand estimates, patronage and statistical data as appropriate.	Section 4.2 FP Worksheets 10
3	Undertake transport model checks as required.	FP Worksheets 8
4	Calculate travel times for the do-minimum and options where appropriate.	Appendices A3, A4 and A11 FP Worksheets 11
5	Quantify and calculate the appropriate monetised activity benefits and disbenefits for the do-minimum and options, including: • travel time, including disbenefits during construction • vehicle operating cost • crash costs • vehicle passing options • monetised external impacts • vehicle emissions • national strategic factors • other external benefits.	Section 4.2.5 FP Worksheets 12-18
6	Describe and quantify where possible any significant non-monetised external impacts.	Section 4.2.5 Appendix A8 FP Worksheets 16
7	Describe and quantify any national strategic factors relevant to the activity and if possible determine the monetary value(s).	Appendix A10 FP Worksheet 18
8	Estimate the appropriate activity costs, including: • investigation and design • property • construction, including preconstruction and supervision • maintenance, renewal and operating • risk management	Section 4.2.4 FP Worksheets 2

	• mitigation of external impacts.	
9	Summarise the benefits and costs of the do-minimum and activity options, including their: • type • timing • estimated value • year in which estimate was made • growth rate over activity evaluation period.	FP Worksheet 2
10	Where appropriate, describe and evaluate the benefits and costs of mitigation measures.	Section 4.2.4 FP Worksheet 16.2
11	Discount the benefits, disbenefits and costs for the do-minimum and activity options over the period of analysis and sum them to obtain the present value (PV) of net national economic benefits and costs. Apply update factors as necessary.	FP Worksheet 9 Appendix A1 Appendix A12
12	Calculate the national benefit cost ratio, BCR_N and if appropriate, the government benefit cost ratio, BCR_G.	Section 2.8 FP Worksheet 3
13	Where there is more than one mutually exclusive option, use incremental analysis to select the preferred option.	Section 2.8 Appendix A19 FP Worksheet 4
14	Calculate the first year rate of return for the preferred activity option.	Section 2.9 FP Worksheet 5
15	Conduct a sensitivity analysis on the uncertain elements of the preferred activity option.	Section 2.10 FP Worksheet 6
16	Where the activity costs are greater than $5 million or there are other unpredictable events that may affect the activity, undertake a risk analysis.	Sections 2.10 and 4.10 Appendix A13 FP Worksheet 19
17	Complete the activity evaluation checklist to verify completeness of information, accuracy of calculations and validity of assumptions.	FP Worksheet 7
18	Complete the activity evaluation summary, including the activity details, location, do-minimum, alternatives and options, timing, PV of costs for the do-minimum, PV of net costs and net benefits for the preferred option, BCR and FYRR.	FP Worksheet 1

4.2.3 Method of evaluation

The do-minimum

Introduction

Generally, the do-minimum for road activities shall only include work that is absolutely essential to preserve a minimum level of service. However, in some cases, as described below, the do-minimum may need to be specified differently.

It is important that the do-minimum is fully described in the evaluation.

Low volume roads

For some activities on low volume roads, the existing level of maintenance expenditure may not be the do-minimum. In such cases, particularly where the existing level of maintenance expenditure is high, the maintenance expenditure shall be justified as an option along with other improvement options, and the do-minimum shall only be the work necessary to keep the road open.

Bridges serving little traffic

Similarly, if a bridge serves little traffic and is expensive to replace, a replacement option should not automatically be taken as the do-minimum, particularly if alternative routes are available to traffic presently using the bridge. In this case the do-minimum may be to not replace the existing bridge and to have no bridge. If it is unacceptable to have no bridge at all, then another possible do-minimum could be rehabilitating the existing bridge.

Pavement rehabilitation

The do-minimum generally should not include pavement rehabilitation to an improved standard. The only exception is when the present value of the cost of the activity and its future maintenance is less than the present value of continued maintenance of the existing situation.

For example, on steep unsealed roads, which need frequent grading, to remove corrugations the continued maintenance of the unsealed road can be more costly than sealing the road. In such a situation it is possible that sealing the road may be the do-minimum, so long as it is the lowest-cost option available (eg there is not a realignment option available that is even cheaper).

Road and traffic data

Road sections, intersections and time periods

For purposes of economic evaluation, a road activity needs to be divided into sections with similar geometric and traffic flow characteristics and with similar costs of construction and maintenance. In some cases it may be necessary to separately consider individual traffic movements at intersections. In other cases, vehicle operating costs may differ by direction of travel, for example on continuous sections of grade, and in these cases it will be necessary to consider each direction as a separate section.

For the do-minimum and for each activity option, the road should be divided into:

- road sections over which the terrain, road width, road roughness, speed limit and traffic volume are essentially constant, and/or intersections.

For minor activities and for pre-selection studies, all time periods can be considered together. For significant capital activities, it will be necessary to consider traffic variation with time of day and weekday versus weekend and holiday periods. The year or day must be divided into appropriate time periods (refer to Appendix A2.4).

Data for road sections

For each road section and intersection, the following data is collected as required:

- route data including length, average gradient and roughness
- traffic data for each time period
- crash data.

Activity location and layout

Information provided must include:

- a location/route map
- a map showing linked activities and/or strategic routes
- a layout plan of the activity.

As is appropriate to the particular activity, the layout plan shall show:

- section end points by name, physical features, including the start and end points of the activity
- intersections approaches and traffic movements
- identifying numbers for each road section, intersection approach and traffic movement
- road section lengths, average gradient and surface type
- speeds, if road sections are determined by speed changes
- locations of traffic survey points
- traffic volumes of intersection movements.

If crash savings are claimed for the activity a separate diagram showing crash sites in collision diagram format shall be attached to the report.

Traffic data (Appendix A2

Traffic data required for road activities includes:

- traffic composition
- vehicle occupancy and travel purpose
- traffic volumes

- travel times and speeds.

Appendix A2 provides default values for traffic composition, vehicle occupancy and travel purpose. Guidance is given on estimating traffic volumes and traffic growth, and measuring travel times and speeds. Where the traffic growth is likely to vary from the calculated normal traffic growth, future traffic volumes shall be predicted by taking account of:

- normal traffic growth
- diverted traffic
- intermittent traffic
- suppressed traffic
- induced or generated traffic (Appendix A11).

For activities with congested conditions it may be necessary to consider growth suppression or variable matrix techniques (see Appendix A11).

Irrespective of their capital cost, the effect of activities on traffic flows in the surrounding network should also be assessed. For example, a traffic management scheme having a small capital cost may have significant effects on traffic flows.

Estimation of travel time (Appendix A3)

Appendix A3 sets out procedures for determining travel times for various road and intersection types.

Crash data requirements

Crash records kept in the NZ Transport Agency crash analysis system (CAS) shall be used for determining the historic crash numbers at the site and typical crash rates. Other crash records, such as those kept by the ambulance or fire service, may be considered if crash analysis system records are incomplete.

If crash savings are claimed for the activity, a separate diagram showing crash sites in collision diagram format shall be attached to the report.

Period of analysis

Period of analysis	The analysis period for road activities shall start at time zero and finish 40 years (unless otherwise agreed with the NZ Transport Agency) from the year in which significant benefit or cost commences. Where several options are being evaluated, the analysis period for all options shall be determined by the option with the earliest benefit or cost. The start of construction/implementation shall be the earliest feasible date, irrespective of expectations of funding.

4.2.4 Cost of road activities

Introduction

For road activities, costs are those incurred by approved organisations and comprise:

- planning, investigation and design fees
- costs of property required for the activity
- construction costs, including preconstruction and supervision
- maintenance and renewal costs, including repair and reinstatement
- operating costs
- risk management costs
- external impact mitigation costs
- provisional costs
- government financing costs
- contingencies.

Planning, investigation and design costs

The costs of engineering investigation and design, and the costs of environmental and planning procedures, shall be included unless they have already been incurred, in which case they are sunk costs (and are not included in the evaluation).

Capital, maintenance and operating costs

Activity capital costs comprise property acquisition and construction costs, including preconstruction and supervision costs.

Costs for the maintenance and renewal of an asset shall be included as part of the activity costs where these occur in the analysis period.

Depreciation of capital assets is fully accounted for by the inclusion of maintenance and renewal costs so that no separate allowance shall be made for depreciation. To do otherwise would be double counting.

Operational costs (ie those routine or periodic costs not associated with the maintenance or renewal of an asset) shall be included as part of the activity costs where these occur in the analysis period.

Property costs

Where land has to be acquired for road development, its resource cost shall be assumed to equate to its market value for activity evaluation purposes. Similarly, land available for sale due to obsolescence of an existing road shall be included as a cost saving.

Where land required for an activity is already owned by the road controlling authority, its market value at the base date shall be included in the analysis. Land shall not be treated as a 'sunk cost', as the option of alternative use nearly always exists.

Market value shall be assessed on the basis that the land is available indefinitely for other use. Small isolated or irregularly shaped lots of land are often difficult to develop. If amalgamation with adjacent property is impracticable, the resource cost of the land is its amenity value only. If amalgamation is possible, the market value of the main property, with and without the addition of the small lot, shall be assessed. The difference is the resource value of the lot, which in some cases may be considerably more than the achievable sale price.

Risk management costs

Where there is a quantifiable risk of disruption to traffic, damage to vehicles, the roadway or structures, or injuries to road users from natural or human-made events, and the activity reduces or eliminates the impacts compared with the do-minimum, then the appropriate risk-management costs must be included in the activity evaluation.

The costs of mitigation, repair and reinstatement shall be included for each year of the analysis period over which they occur, both in the do-minimum and the activity options. These costs and benefits shall be included either as expected values or as a probability distribution, depending on the size and nature of the activity as discussed in Appendix A13.

External impact mitigation costs

Where a design feature to avoid, remedy or mitigate adverse external impacts is included in an activity and the feature significantly increases the activity cost, it shall be treated in the following way. If the feature is:

- required by the consenting authority in order to conform with the Resource Management Act or other legislation, then the cost of the feature shall be treated as an integral part of the activity cost
- not required by the consenting authority in order to conform with the Resource Management Act or other legislation, then the feature shall be described and evaluated in terms of benefits and costs, and the results reported in FP Worksheet 16.2.

Where several features are to be included or there are several ways of mitigating an adverse impact, they should be evaluated separately in FP Worksheet 16.2.

The cost of the preferred mitigation feature should be included in the activity cost calculations.

Provisional costs

Provisional costs shall be included for those costs that are expected to be incurred, but are not quantified at the time of preparing the estimate. For example, it may be known that street lighting is required but detailed costing for the lighting is yet to be undertaken.

Contingencies

Contingency allowances shall be included in the activity costs to allow for possible cost increases and the uncertainty of cost estimates. These allowances shall be based on the phase of development of the activity and the level of accuracy of the estimate and that phase. The following table of default contingency allowances provides guidance.

This information is to be used when the analyst does not have better information based on road controlling authority experience:

Phase	Earthworks component	Other works
Project feasibility report	30%	20%
Scheme assessment	25%	15%
Design and contract estimate	20%	10%
Contract	10%	5%

Residual value

The residual value of the investment at the end of 40 years has a very small effect on the evaluation when discounted at 6% and shall generally be omitted. Where two options have widely differing service lives, this shall be noted in the activity summary sheet.

4.2.5 Benefits of road activities

Introduction

Typical benefits for a road activity are the reduction in road-user costs and the reduction in external impacts compared with the do-minimum. Road user benefits considered include:

- travel time cost savings (including those gained from reduced traffic congestion and improved trip reliability)
- vehicle operating cost (VOC) savings
- crash cost savings
- comfort and productivity benefits from sealing an unsealed road
- driver frustration reduction benefits from passing options
- benefits from reducing or eliminating the risks of damage
- carbon dioxide reduction benefits
- other external benefits
- national strategic factors.

Travel time cost savings (Appendix A4)

Travel time savings are a function of travel times and traffic volumes and vary by travel purpose and mode, vehicle occupancy, traffic composition and congestion.

Appendix A4 provides unit values for vehicle occupant, vehicle and freight time costs, along with values for travel in congested conditions and procedures for estimating the costs of improved trip reliability. Unit travel time values are given for standard traffic compositions on urban arterial, urban other, rural strategic and rural other roads by time period.

New trips generated or induced as a result of travel time savings for existing traffic (see Appendix 11) shall be assessed at half the benefits from travel time saving per vehicle for existing traffic. This assumes that the benefits to new trips will be uniformly distributed between zero and the max.

Reduced traffic congestion (Appendix A4)

Road users value improvements in traffic congestion over and above the benefits gained from travel time saving. The benefits from reduced traffic congestion apply to both work and non-work travel time, and are calculated using the procedures in Appendix A4.

The change in congestion calculated using the procedures in Appendix A4, may also help demonstrate how a particular activity contributes to the wider objectives considered under the NZ Transport Agency funding allocation process.

Improved trip reliability (Appendix A4)

Journey times tend to vary throughout the day, particularly between peak and off-peak periods, and between weekdays and weekends. This type of variation is well known to regular drivers and is taken into account in calculating the travel time values (including congestion values).

Trip reliability is a different type of variability, which is much less predictable to the driver. (For example, drivers that make a particular journey at the same time every day, and some days it takes as little as 20 minutes, and on other days as much as 40 minutes.) Hence, when drivers plan their trips, they have to consider not just the expected travel time but also its variability. Where an activity improves trip reliability, the benefits apply to both work and non-work trips, and can be calculated using the procedures in Appendix A4.

The change in trip reliability calculated using Appendix A4 may also help demonstrate how a particular activity contributes to the wider objectives considered under the NZ Transport Agency funding allocation process.

In addition to the normal day-to-day variation in travel times, there can be occasional large delays resulting from major incidents (eg crashes or breakdowns). Assessing this type of variability is best handled separately from normal day-to-day variability and is outside the scope of the procedures contained in Appendix A4.

Vehicle operating cost savings (Appendix A5)

Vehicle operating cost (VOC) savings for road sections are functions of the length of the section, traffic volume and composition on the section, and vary by road roughness condition, gradient and vehicle speed. Unit values for VOC are given in Appendix A5. The values are made up of the following components:

- basic running costs of the vehicle, such as fuel, and repairs and maintenance
- additional running costs due to the road surface
- additional running costs due to any significant speed fluctuations from the cruise speed
- additional running costs due to traffic congestion
- additional fuel costs due to being stopped, such as queuing at traffic signals.

Crash cost savings (Appendix A6)

Crash cost savings are a function of predicted numbers of crashes and unit crash costs. Unit crash costs vary by crash type and severity, and vehicle speed, while predicted crash numbers need to take account of the road environment, under-reporting and the exposure to the risk of having a crash.

Based on historical data of crashes at the site and other information (including typical crash rates) the following methods can be used for estimating future crash numbers and costs:

- Crash-by-crash analysis, when there are limited modifications to an existing site and a high number of crashes (ie five or more injury crashes at the site, or three or more injury crashes per kilometre).
- Crash rate analysis, when a new facility is being provided or an existing site is being modified to such an extent that the historic crash record can no longer be used as the basis for prediction.
- Weighted crash procedure, when there are limited numbers of crashes and information is used from both of the above procedures, drawing on both site history and predictive model information.

Formulae for determining typical crash rates are given in Appendix A6. Unit values of crash costs are provided in Appendix A6 for each crash type by movement category, speed limit, severity and vehicle involvement.

Driver frustration reduction benefits (Appendix A7)

Vehicle passing options may be provided through the construction of dedicated passing lanes, climbing lanes, slow vehicle bays, and improved alignments.

Providing passing options releases vehicles from platoons of slower moving vehicles, allowing them to travel along the road at their desired speed until they are once again constrained by platoons. Typically, the evaluation of passing options has been undertaken by micro-simulation programmes, which use various vehicle performance models together with terrain data to establish, in detail, the speeds of vehicles at each location along the road. These assessments can be excessively complex, particularly given the general magnitude of such activities.

An alternative method is based on multiple simulations and the Unified Passing Model described in Appendix A7. This method can be used to identify the most appropriate strategy for providing improved vehicle passing options over a route, and assess the benefits of individual vehicle passing options within those strategies.

Other external benefits (Appendix A8)	Where an indicative monetary value has been established in Appendix A8, the external impact should be quantified, and the total benefit calculated using FP Worksheet 16.1. Benefits and disbenefits that do not have monetary values shall be described and, where appropriate, quantified in their natural units. This information is taken into account in the funding allocation process. It is assumed that the benefit of improved consumer travel options is included in the various willingness to pay values used in transport service.
Seal extension benefits (SP 4)	Road user comfort benefits and productivity gains from sealing an unsealed road should also be taken into account. Simplified Procedure SP4 provides information on productivity gains. A value of 10 cents per vehicle per kilometre can be used for road user comfort, which takes account of the other benefits associated with avoiding unsealed roads.
Risk reduction benefits (Appendix 13)	Where there is a quantifiable risk of disruption to traffic, damage to vehicles, the roadway or structures, or injuries to road users from natural or human-made events, and the activity reduces or eliminates the impacts compared with the do-minimum, then the benefits of the reduced or eliminated impacts must be included in the activity evaluation. The benefits of risk reduction shall be included for each year of the analysis period over which they occur, both in the do-minimum and the activity options. These benefits shall be included either as expected values or as a probability distribution, depending on the size and nature of the activity as discussed in Appendix A13.
Vehicle emission impacts (Appendix A9)	Benefits to the environment and public health result from the reduction of vehicle emissions. Appendix A9 provides procedures for the estimation of vehicle emissions. Carbon dioxide has been given a standard value of $40 per tonne and therefore any reduction in carbon dioxide emissions is included in the calculation of the BCR. The reduction of particulate emissions has also been assigned a monetary value and is included in the calculation of the BCR.
National strategic factors (Appendix A10)	The NZ Transport Agency recognises the following as national strategic factors for road activities and transport services (particularly large activities): • agglomeration • benefits of increased labour supply • effects of imperfect competition • providing for security of access on busy inter-regional routes • providing for investment option values – including building-in extra capacity or flexibility today to enable easier future expansion. The criteria for assessing national strategic factors and the valuation of the above factors are discussed in more detail in Appendix A10.

4.3 Evaluation of transport demand management

4.3.1 Overview

Introduction

This section describes the specific procedures to be used to evaluate the economic efficiency of transport demand management (TDM) activities, which may involve infrastructure, education, promotion and marketing, policing, work/study place policies, new transport services or service improvements, pricing and financial incentives, parking management, and land use design/management.

Most TDM programmes include a combination of positive and negative incentives. However, there are cumulative and synergetic impacts, so it is important to evaluate a TDM programme as a package, rather than each activity or strategy individually.

In this chapter

Section	Topic
4.3.1	Overview
4.3.2	Stages of evaluation
4.3.3	Method of evaluation
4.3.4	Cost of transport demand management activities
4.3.5	Benefits of transport demand management activities
4.3.6	References

4.3.2 Stages of analysis

Introduction

The following table outlines the stages of analysis in the economic efficiency evaluation. It is envisaged that a programme business case [PIKB link: PIKB (programme business case)] will have been completed before commencing evaluation of economic efficiency and applying the standard set of full procedures as set out below for evaluation of transport demand management. The do-minimum and any other options must be assessed at every stage.

Stages

Stage	Description	See
1	Complete the activity description, including the TDM package, the do-minimum, and the alternatives and options considered.	Section 4.3
2	Assess travel impacts: • target population • uptake • demand estimates and modal share.	Section 4.9, Appendix A20
3	If there is service provider, determine service provider costs, service provider revenue, and the funding gap.	Appendices A16, A17
4	Quantify the net costs to government.	Section 2.4
5	Quantify all national economic benefits and disbenefits that have monetary values.	Section 2.2
6	Describe, and quantify where possible, any significant non-monetised impacts.	Section 2.3
7	List any national strategic factors relevant to the preferred option. If possible determine the monetary value(s) of any national strategic factors.	Section 2.2
8	Describe business benefits, equity impacts (particularly those relating to transport disadvantaged) and any other significant effects not covered in stages 7 and 8.	Section 3.3
9	Discount the service provider costs and funding gap (stage 4) and net costs to government (stage 5) over the period of analysis to obtain the present value (PV) of these costs.	Section 2.5
10	Discount all monetised benefits (stage 6 plus stage 8 if monetised) over the period of analysis and sum them to obtain the PV of net national economic benefits.	Section 2.5
11	Where options being evaluated are mutually exclusive, use incremental analysis to select the preferred option.	Appendix A19
12	Determine the national benefit cost ratio (BCR_N) and the government benefit cost ratio (BCR_G).	Section 2.8
13	Perform sensitivity tests on the preferred option.	Section 2.10
14	If the PV of the net government costs is greater than one million dollars, undertake a detailed risk analysis.	Appendix A13

4.3.3 Method of evaluation

Consumer surplus-based evaluation

All TDM programmes have the objective of changing travel or transport behaviour. Therefore, TDM evaluation needs to use values that are perceived by users, rather than just the national resource costs that are discussed in Section 2.1. This requires a consumer surplus based evaluation, which is a method of measuring the value that consumers place on a change in the price or quality of the goods they consume (in this case travel is considered a ‘good’).

The basic technique for evaluating consumer impacts of price changes is to use the incremental cost to consumers who don’t change their travel, plus half the change in price times the number of trips that increase or decrease. This is known as the ‘rule of half’, which represents the midpoint between the old price and the new price.

For example, if a $1 highway toll increase causes annual vehicle trips to decline from three million to two million, the reduction in consumer surplus (the total net cost to consumers) is $2.5 million ($1 x two million for existing trips, plus $1 x one million x ½ for vehicle trips foregone). Similarly, if a 50c per trip public transport fare reduction results in an increase from 10 million to 12 million annual public transport trips, this can be considered to provide $5.5 million in consumer surplus benefits (50c x 10 million for existing trips, plus 50c x two million x ½ for added trips).

The rule of half assumes that a new user who was just discouraged from using a service before the service change (or implementation of a new service) will receive the full benefit of the service change or introduction and a user who is just marginal after the service change will receive nearly zero benefits. Hence, on average, new users receive half the unit benefits.

Consumer surplus impacts of transport changes that do not involve pricing can be evaluated using market surveys and other techniques that reveal consumer perceived costs, known as willingness to pay (WTP).

For purposes of economic evaluation, corrections are often required to the perceived benefit values derived from WTP surveys because some values (eg private vehicle operating costs and parking costs) tend to be misperceived.

TDM packages

Sections 4.8.2 and 4.8.3 provide guidance on packages that include TDM components.

Incremental analysis

The incremental cost benefit analysis process for evaluation of alternatives and options for TDM activities is the same as the incremental BCR process described in Section 2.8.

All effects (positive and negative) for which monetary values have been estimated should be included in the total benefits of the options when undertaking incremental cost benefit analysis.

Scale and scope of TDM options

TDM activities, like most economic programmes, will eventually have diminishing marginal benefit. There is an optimal level of implementation, beyond which incremental costs exceed incremental benefits. TDM programmes need to track these incremental impacts and limit such programmes.

For example, ridesharing programmes may be extremely cost effective when properly implemented, but once the potential rideshare market is satisfied there will be little additional benefit from simply expanding a rideshare programme, eg by sending out more promotional material. Instead, further expansion may require implementation of additional TDM strategies, such as commuter financial incentives, to expand the size of the market.

Similarly, cycling improvements can be cost effective where there is latent demand for this mode, but that does not mean that it is unnecessary to carefully evaluate investments in cycle paths to insure that they are cost effective. There may be better ways to support cycling, such as education and encouragement programmes.

Sensitivity analysis

Possible significant factors to TDM evaluations that should be considered for sensitivity testing include:

- demand estimates (refer to Section 4.9)
- funding gap (refer to Appendix 16)
- major contributors to benefits
- commencement of the proposal.

Major contributors to benefits

Major contributors to benefits critical to the outcome of the evaluation are likely to include:

- road traffic volumes, particularly model results, growth rates and the assessment of generated traffic
- transport service patronage or facility users
- maximum user charges estimated from consumer surveys.

For each significant factor the following shall be listed:

- the assumptions and estimates on which the evaluation has been based
- an upper and lower bound of the range of the estimate
- the resultant BCR at the upper and lower bound of each estimate.

4.3.4 Cost of transport demand management programmes

Introduction

Costs of TDM activities are the costs to government (the NZ Transport Agency and local government) and the service provider costs and revenue (where a service provider is involved). Service provider costs and revenue are addressed in Section 4.4.

Note: Increases in costs to consumers are defined as disbenefits in this manual. Costs of a TDM activity depend on whether additional system capacity is required, such as additional road space, parking space, or additional public transport vehicles or infrastructure. This often depends on whether the additional trips occur during peak periods (when there is no additional capacity) or off-peak periods (when additional capacity is available).

Activity costs

Activity costs include the costs of:

- investigation and design
- implementation/construction (including property and supervision)
- promotion and education
- maintenance
- operating
- monitoring.

The estimated costs for investigation and design should be identified separately from those for implementation. Cost estimates for initial indicative evaluations for TDM activity development funding can be obtained from past experience or judgement. The implementation cost estimate will be refined and the evaluation reconfirmed based on the completed plan before implementation funding is approved.

The cost of annual expenditure required to maintain the benefits of the TDM package over the evaluation period following completion of the activity should be estimated based on local experience and knowledge.

Activity operating cost is the cost of operating the new (or improved) facility or service. This is the cost to government plus the net cost to the service provider (service provider cost minus service provider revenue).

The cost of monitoring a TDM activity is not included in the cost benefit evaluation of an activity, except where an initial survey is an integral part of the activity and then it should be costed as such.

The marginal cost of carpooling is nearly zero if a vehicle has an extra seat that would otherwise travel empty (there is a small increase in fuel consumption and emissions). The incremental cost increases if the rideshare vehicle must drive out of its way to pick up riders, or if a larger vehicle (eg a van) is purchased just to carry passengers.

Similarly, if a public transport system has excess capacity, transfers from driving to public transport may have minimal incremental cost. If peak travel results in increased operating costs (including extra vehicles), then the net cost to government of this must be assessed.

Note:

- The impact on mode choice of any increase in fare resulting from purchase of extra vehicles must also be evaluated.

	• If increased patronage results in uncomfortably crowded vehicles, then this disbenefit should be included in the evaluation.
Road capital, maintenance and operating cost savings	Reduced vehicle travel can reduce the need to add roadway capacity, reduce some roadway operations, maintenance and renewal costs, and reduce some traffic service costs, such as policing and emergency response. Shifts from vehicle to bus transport may increase some road maintenance costs (heavy vehicles tend to cause high levels of road wear).
Parking cost savings to government	Reduced vehicle travel may result in a reduction in the demand for parking facilities. The parking cost savings of park and ride is the difference in cost between a parking space at the worksite and at the urban fringe. The parking cost saving to government is the net cost to government. This is the service provider costs minus service provider revenue. Usually this cost will be zero unless government is providing subsidised parking. The timing of any parking cost saving must be carefully assessed. Reductions in vehicle trips may provide little parking cost savings in the short-run if there is abundant parking supply. However, over the long term, the excess parking spaces or their land can be used for other purposes

4.3.5 Benefits of transport demand programmes

Introduction

Evaluation of TDM activities considers not only direct impacts but also additional costs and benefits to participants and society that may influence transport choice. All impacts should be considered, regardless of where they occur. Impacts within a particular area or analysis period may be highlighted, but costs and benefits that occur outside the jurisdiction should not be ignored. For example, a community's TDM programme may alleviate traffic congestion and parking demand in adjacent areas. These additional benefits should be mentioned even if they are not the primary consideration in decision making, since such benefits may justify support from other levels of government.

Benefits

Benefits to be considered in the economic efficiency evaluation of TDM activities are:

- vehicle operating cost (VOC) savings
- travel time cost savings
- trip reliability
- generated traffic
- spillover effects
- walking and cycling costs
- crash cost savings
- health benefits
- transport service user benefits
- parking user cost savings
- other user benefits
- carbon dioxide reduction
- other monetised and non-monetised environmental impacts
- community liveability improvements
- increased consumer travel options
- adjustment for public transport fares
- disbenefits during implementation/construction
- land use benefits
- national strategic factors

Business benefits

Benefits to businesses, that are not direct travel time or vehicle operating benefits, are economic transfers rather than national economic benefits and are therefore not included in the economic efficiency calculation. However, they can be an important factor in assembling a strategic case for a TDM programme and obtaining funding for workplace based programme and they should, therefore, be quantified where appropriate and reported as part of the overall evaluation (separately from the economic efficiency calculation).

Travel Impacts

TDM programmes affect travel behaviour in various ways, including changes in trip scheduling, route, mode, destination, and frequency, plus traffic speed, mode choice and land use patterns. Different types of travel changes provide different types of impacts, eg a shift from driving to non-motorised travel has significantly different impacts than a shift to public transport.

In order to evaluate the benefits associated with a TDM activity, it is necessary to estimate the likely impact that the activity will have on travel behaviour including changes in mode share. Methods for estimating the demand for a service or facility and modal share are provided in Section 4.9 Appendix A17.

A well-managed and properly supported TDM programme can affect a significant portion of total travel. Comprehensive TDM programmes can achieve cost-effective reductions in private vehicle travel compared with no TDM efforts, although most programmes have only small effects because they focus on particular types of trips (such as commuting), cover a limited geographic scope, or are limited to strategies that can be implemented by a particular government agency.

A well-managed commute trip reduction programme can reduce vehicle trips to a particular worksite if implemented within a regional TDM strategy that includes components such as road tolling, major public transport improvements and walking and cycling promotion and facilities improvement. Other types of trips can also be reduced using appropriate TDM strategies. Land use management strategies such as access management, smart growth and location efficient planning can reduce per capita vehicle travel in a specific area.

4.3.6 References

References

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4.4 Evaluation of transport services

4.4.1 Overview

Introduction

This section describes the specific procedures to be used to evaluate the economic efficiency of public transport and freight services.

In this chapter

Section	Topic
4.4.1	Overview
4.4.2	Stages in analysis
4.4.3	Method of evaluation
4.4.4	Costs of transport services
4.4.5	Benefits of transport services
4.4.6	References

4.4.2 Stages in analysis

Introduction

The following table outlines the stages of analysis in the economic efficiency evaluation. It is envisaged that a programme business case [PIKB link: PIKB (programme business case)] will have been completed before commencing evaluation of economic efficiency and applying the standard set of full procedures as set out below for evaluation of transport services. The do-minimum and any other options must be assessed at every stage.

Stages

Stage	Description	See
1	Complete the activity description including a description of the do-minimum, alternatives and options.	Sections 2.1, 2.7
2	Forecast the demand. **Note:** The demand estimate is used for calculating fare charges, revenue, user benefits for new and existing transport service users, and road traffic reduction benefits. Care should be taken to ensure assumptions are compatible with economic evaluation requirements.	Section 4.9
3	Determine service provider cost, service provider revenue and the funding gap.	Section 4.4.4, Appendix A16
4	Calculate the annual net cost to government, incorporating: • the funding assistance • the local and central government road construction cost savings • for freight services only, the road maintenance and renewal cost savings and RUC foregone.	Section 4.4.4
5	Calculate the annual transport service user benefits for existing (where there is a pre-existing service) and new transport services.	Section 4.4.5
6	Calculate the road traffic reduction benefits on an annual basis, including disbenefits during implementation/construction.	Section 4.4.5
7	Calculate other national economic benefits and disbenefits that have monetary values.	Section 2.2
8	Describe, and quantify where possible, any significant non-monetised effects.	Section 2.3
9	List any national strategic factors relevant to the preferred option. If possible determine the monetary value(s) of any national strategic factors.	Section 2.2
10	Describe equity impacts (particularly those relating to transport disadvantaged) and any other significant effects not covered in stages five to nine.	Appendix A15

11	Discount the annual service provider cost, service provider revenue, funding assistance, road construction cost savings, and (for freight services only) the road maintenance and renewal cost savings and RUC foregone over the period of analysis to obtain the present value (PV) of these costs.	Appendix A1
12	Discount the annual monetised benefits (stages five to seven) over the period of analysis and sum them to obtain the PV of national economic benefits.	Appendix A1
13	Where options being evaluated are mutually exclusive, use incremental analysis to select the preferred option.	Appendix A19
14	Determine the national benefit cost ratio (BCR_N) and the government benefit cost ratio (BCR_G).	Section 2.8
15	Perform sensitivity tests on the preferred option.	Section 2.10

4.4.3 Method of evaluation

Consumer surplus basis

Consumer surplus methodology is used to monetise the transport service user benefits of changes in price as well as non-price impacts (such as public transport journey time, reliability, frequency, and comfort).

For reduced journey time, improved frequency of services and interchange reductions, transport service user time savings are based on the standard values of vehicle occupant time (VOT) given in Appendix A4. For this purpose, waiting time is valued at two times the value of VOT. The values in Appendix A4 that are applicable to most transport service users are those for non-work travel purposes (including commuting to and from work).

For other types of non-price transport service impacts (such as improvements to trip quality, comfort) transport service user benefits are based on an equivalent change in fare that would be required to produce the same user response to that produced by the change in service quality. This consumer surplus based benefit, which assumes the demand curves are linear, is the same as that which would be derived if the full demand curves for a transport service were available.

Package involving transport services

If transport services are part of a wider package, then a multi-modal evaluation is necessary. This may involve evaluating road infrastructure components and/or the public transport components using the relevant procedures in sections 4.8.2 and 4.8.3, and aggregating the results. The procedure for evaluating the timing of package components should be used for packages that include significant transport service improvements.

Do-minimum definition

The do-minimum for evaluation of transport services is usually considered as a continuation of the present transport networks, service levels and the existing road network in the study area.

The do-minimum must include any costs and resulting demand implications of committed road or transport service improvements. All committed investment plans that relate to the do-minimum during the analysis period must be taken into account. Maintenance, renewal/replacement schedules and any planned transport service changes must also be included. Improvements are committed if they have been evaluated in accordance with the NZ Transport Agency's evaluation procedures and have been approved for funding.

Any investment plans that are not committed must be included in the evaluation as options.

Any changes to the road system that are committed must be included in the do-minimum.

Scope of do-minimum

It is extremely important to:

- not overstate the scope of the do-minimum
- only include, as part of the do-minimum, work that will preserve a minimum acceptable level of service. In some cases, particularly with respect to the road network, the do-minimum service level may be less than the existing level of service.

Costs and benefits

Detailed methodology for calculating costs and benefits of transport services are set out in Section 4.4.4 and 4.4.5 respectively, and in the associated appendices. Appendix A16 deals with funding gap analysis, which is a specific consideration for transport service appraisals.

Length of analysis period may be shorter	The period of analysis for freight or public transport services with or without infrastructure must take account of the potential for change in the service. An analysis period of up to 40 years is normally appropriate. The period of analysis for infrastructure activities is usually 40 years from the start of construction. An assumption is made that if the service changes within the evaluation period, then the changes will ensure that the system is at least as efficient as before the changes. Individual circumstances may modify this assumption, eg a freight service based on a non-renewable resource with a finite life.
Cost benefit analysis	Unlike the vast majority of road infrastructure activities, passenger and freight transport activities will usually involve a private operator providing a service and receiving revenue directly from users. In this situation, it is necessary to calculate both the BCR_N and BCR_G as described in Section 2.8.
Application to public transport services	Often, changes to existing public transport services are limited to additional peak period services that remove commuters from private vehicles. In such cases the cost of the service should only include the capital costs and the maintenance and operating costs of providing the additional peak period public transport services where there are road traffic reduction benefits. There may be cases where a new or improved public transport activity includes an off-peak component. The off-peak component should be evaluated and reported along with an explanation clarifying the reasons for its inclusion and any assumptions in the evaluation. A peak public transport service is one that passengers can board during the morning and evening commuter peak periods defined in Appendix A2.4.
Possible significant factors	Inputs to transport service activity evaluations that should be considered for sensitivity testing include: • demand estimates (refer to Section 4.9) • funding gap (refer to Appendix A16) • major contributors to benefits • commencement of the proposal.
Major contributors to benefits	Road traffic reduction benefits critical to the outcome of the evaluation may include: • traffic volumes, particularly model results, growth rates and the assessment of diverted and generated traffic and transport service users • travel speeds • crash reduction. For each significant factor the following shall be listed: • the assumptions and estimates on which the evaluation has been based • an upper and lower bound of the range of the estimate • the resultant BCR at the upper and lower bound of each estimate.
Benefit cost ratio of delaying proposal	For the preferred activity option, calculate revised BCRs of delaying the activity for various periods.
Incremental analysis	The results of incremental analysis shall be sensitivity tested using an incremental BCR 1.0 higher than the target incremental BCR.

Results of sensitivity tests

The results of the sensitivity tests, along with explanation of any assumptions or choice of test, shall be reported in a format similar to FP Worksheet 6.

4.4.4 Costs of transport services

Introduction

The costs to government of a transport service incorporate:

- funding assistance from government
- road maintenance, renewal and construction cost savings
- road user charges (RUC) foregone (for freight transport only)
- construction costs, including property, for any additional infrastructure required
- maintenance costs not already included in service contracts.

Road maintenance, renewal and construction cost savings

Some transport service proposals will provide a cost saving to government if:

- future planned road construction costs are avoided (freight and passenger services)
- the implementation of the activity results in a reduction to road maintenance and renewal expenditure when traffic is removed from the road (freight services only).

Government cost savings have the effect of reducing the denominator of the BCR, potentially making a transport service more attractive.

The proposed transport service and any other options are assessed to determine any planned road construction savings and, in the case of freight services, any road maintenance and renewal savings that will be made as compared to the do-minimum roading option.

Care must be taken when claiming a cost saving from future road construction avoided. The year or years in which the road construction would likely be funded must be assessed.

Note: Normally road construction cost savings should only be claimed if there is significant road traffic reduction benefits associated with the transport service proposal.

Road maintenance, renewal and improvement cost savings associated with implementation of a freight service are calculated by estimating the total annual amount of freight traffic, measured in terms of equivalent design axles (EDA), removed from the road network. The simplified procedure for freight services provides indicative EDA and $/EDA/km values. However, local values are to be used for activities where the default values provided in these simplified procedures do not represent local conditions. Also, if the amount of the freight traffic removed from the road network varies from year to year, separate calculations are required for each year.

Road user charges foregone

In New Zealand, RUC are levied against all diesel-engine vehicles, and vehicles over 3.5 tonnes.

For the purposes of this manual, it is assumed that all vehicles used in freight services will be paying road user charges.

Note: For public transport services it is not necessary to calculate the loss of RUC.

In the case of a freight service, lost RUC are subtracted from the road maintenance, renewal and construction cost savings to derive the net savings to government.

For freight-based services, it is assumed that heavy commercial vehicles will be removed from the road. Thus, the loss of RUC as a result of the introduction of a freight transport service will be based on the weighted average road user charge for the type of vehicle that is removed.

The funding gap, calculated in Appendix A16, indicates the funding assistance desired by the service provider from a commercial point of view.

The manner in which the funding assistance is actually provided is a matter of negotiation between the funder and the service provider taking into account the funder's funding policy. The actual cash flow of funding assistance, discounted using the appropriate economic present worth factor, is used in the economic evaluation.

Whether the service provider's desired funding assistance is justified from the government (public policy) point of view is indicated by the calculated government benefit cost ratio (BCR_G).

If BCR_G is >1.0, then consideration for funding assistance is justified by the monetised benefits and cost savings achieved by the improved or new transport service.

Determine the reduction in RUC revenue as a result of the introduction of a freight service using the following procedure:

Step	Action
1	From the demand estimate information generated in Section 4.9, list the following for each travel time period: • existing number of road trips by the vehicle type affected by the transport service proposal • the predicted new level of road trips by the vehicle type affected by the transport service proposal. **Note:** The travel time period used will depend on the particular freight service being proposed but in most cases will probably be an annual figure.
2	Determine the change in road trips by subtracting the existing number of road trips from the predicted new level of road trips.
3	Using the data from step 1 and consulting with the industry(ies) affected by the proposed freight service, determine the average licensed weight of the vehicle type(s) removed.
4	Using the RUC tables published by the NZ Transport Agency, establish the RUC (in $/1000km) for the licence weights of the vehicles removed.
5	Determine the length (km) of the road(s) affected by the proposed transport service.
6	Calculate the total number of kilometres of travelling saved: (change in road trips per annum) × (km per trip) Divide this by 1000 to find the annual thousands of kilometres saved.
7	Multiply the road user charge ($/1000km) by the annual thousands of kilometres saved to derive the total RUC revenue lost.

4.4.5 Benefits of transport services

Benefits	Benefits included in the economic efficiency evaluation of transport service activities are: • transport service user benefits • road traffic reduction benefits (vehicle operating cost (VOC) savings, travel time cost savings, CO_2 reduction and crash cost savings) • disbenefits during implementation/construction • other monetised and non-monetised impacts • national strategic factors. Travel time delays, and disruption during implementation/construction are considered as negative benefits
Treatment of financial transfers	The economic efficiency evaluation of transport services should concentrate on transport benefits. Any downstream benefits that are financial transfers, such as the impact on business and retail profitability, and property prices (other than where the change in property price is used as a proxy to value an impact) must not be included in the economic efficiency calculation.
Business benefits	It is not normally necessary, or relevant, to try to identify business benefits for transport service activities. Benefits to businesses are economic transfers rather than national economic benefits and are therefore not included in economic efficiency calculations.
Equity impacts	Equity impacts of transport service activities should be quantified wherever possible and reported as part of the evaluation (separately from the economic efficiency calculation). Refer to Appendix A18
Reporting of benefits and costs	The PVs of costs and benefits for transport services proposals for each option under consideration should be presented using FP Worksheet 21.

Funding gap analysis of transport services

Introduction

In the case of transport service activities, service provider costs can be compared with the predicted revenue or increase in revenue (where there is a pre-existing service), using a net present value (NPV) methodology to determine whether or not the activity is viable in a financial sense. The methodology for funding gap analysis is outlined in Appendix A16

Transport service user benefits

Introduction

Transport service users and potential users may be affected by the following factors:

- user charge levels (eg public transport fares and freight rates)
- travel time (eg service frequency, total trip time, interchange time)
- quality of service (eg reliability, comfort, damage)
- additional user costs (eg re-handling, inventory costs).

The purpose of this section is to calculate the net transport service user benefits and disbenefits of a transport service proposal, where there is a change in the user charge, the trip time, the quality of service or other user costs.

Transport service user definitions

For the purpose of this analysis, transport service users are both people being moved, and people who are paying for freight to be moved.

Users of a new transport service include those who have transferred from other modes and those who are completely new users (generated trips).

Inter-relationship of user benefits

The calculation of net benefits for users of a new transport service can be based on the difference between the proposed and the maximum user charge (at which no one would use the service). The result is then divided in half, based on the rule of half. This approach is most applicable to a new public transport service.

Calculate net user benefits for users of a new transport service using the procedure in Section 4.9 to determine the projected number of new service users.

$$\text{Net user benefits} = (P_{max} - P_{new}) \times Q_{new} \times ½$$

Where:

P_{new} = proposed user charge.

P_{max} = maximum user charge.

Q_{new} = projected number of new service users or volume of freight.

User benefits for existing transport service

The quantitative analysis of net transport service user benefits for a change in service is conducted by separating the transport service users into two categories:

- existing users
- new users.

Where an existing service is being improved, existing users receive the full benefit of the improvement, while new users are considered to receive one half of the existing user’s benefit. See Section 4.3.3 for further explanation.

Where existing transport service users may be adversely affected by disruptions during construction and/or the change in demand for the service, these disbenefits should be taken into account in the analysis.

Net transport service user benefits must be calculated for each option where there is a change to user charge levels, travel time, the quality of service or other user costs.

Benefits to new transport service users should be calculated using the rule of half.

The transport service user benefits are the change from the do-minimum. For a new rail or sea freight service the do-minimum is transport of the freight by road.

User benefits for existing public transport service

Transport service user benefits for an existing public transport service may include, but are not limited to:

- improved reliability
- reduced fare/price (a resource cost adjustment)
- reduced journey time
- improvements in service frequency
- reduction in interchange time
- improvements in quality (ie comfort)
- improvements in infrastructure and vehicle features.

Further detail on calculation of transport service user benefits is contained in Appendix 19.

Freight transport user benefits

Transport service user benefits (or disbenefits) for freight could result from differences in:

- user charge (freight rate)
- travel time for the freight
- service quality
- other user costs.

The last three points are particularly applicable for goods that are perishable or fragile, or where time and reliability of delivery are important.

If the freight service user is indifferent to modes, ie the user is satisfied that all modes will deliver the product in the same condition in the same time and with the same reliability, there will be no user benefits for transport service activities involving freight movement.

More usually, a freight transport service user will find that, for rail and sea transport, while the user charge may be lower than for road transport, travel time may be greater, service quality may be less, and there may be other user costs such as rehandling and inventory.

User benefits for freight should also take into account flexibility in options for frequency of transport and choice of service providers. In some cases, users transferring freight from road to a rail or sea transport service mode will experience reduced flexibility in the timing and route of services compared with using a road option. Any such reduced flexibility for the transport service user must be included as a disbenefit in evaluations.

Road traffic reduction benefits

Introduction

Road traffic reduction benefits resulting from transport service activities may include:

- travel time cost savings
- VOC savings
- CO_2 reduction benefits
- crash cost savings (see Appendix A6).

Nature of road traffic reduction benefits

Road traffic reduction benefits may be positive or negative.

In the presence of traffic congestion, the removal of some traffic will generally provide positive benefits to remaining road users. Some activities, however, may achieve their improved transport service level by reducing the available road capacity for other road users. The level of traffic congestion to remaining users may then be increased, creating a negative benefit.

Also traffic congestion may be increased where a proposed transport service increases the number of public transport vehicles on roads shared with other traffic.

The effect of increased transport output on overall traffic congestion will depend on:

- the change in the number of public transport vehicles per hour per period
- their size and performance characteristics
- the reduction in the number of trips
- the do-minimum composition of road traffic flow.

Extent of analysis

Analysis must be undertaken for the transport service activity and each option, compared against the do-minimum.

Level of detail

The level of detail required for this analysis is determined by the size of the proposal. For large scale activities, it is considered important that the travel time benefits and VOC savings are modelled to a reasonable degree of accuracy.

The information contained in this chapter will assist with the determination of the level of detail required.

Time periods

With respect to transport services, road traffic reduction benefits shall generally be limited to peak periods. The evaluator shall specify, and justify, the peak period times.

In some cases, for instance with most freight transport services, it may be appropriate to also consider off-peak period road traffic reduction benefits

Variation of effects

It may be necessary to establish the benefits for different activity years, if the do-minimum road option is characterised by increasing traffic congestion. Benefits or disbenefits may be estimated at five or 10 year intervals. Intermediate years may then be interpolated.

Methods for assessing travel time benefits

There are three basic approaches to assessing travel time benefits of transport service activities on road users and other modes:

- Speed flow relationship.
- Modelling using procedures for evaluating road activities (Appendices A3 and A11). Appendix A11 will assist in determining the appropriate modelling to undertake and Appendix A3 outlines the methods for calculating travel time saving

benefits.

- Output using a validated transport model (worksheet FP3.11 explains the validation process).

The choice of method depends on the magnitude of the corresponding road impact and the nature of the road(s) or road network affected by the introduction of the transport service.

If an accurate estimate of the benefits of reduced road traffic is wanted, then the procedures in Appendices A3 and A11 or output from a transport model should be used.

Definitions

The capacity of a road is the maximum flow rate at which vehicles can reasonably be expected to traverse a point under prevailing conditions.

A bottleneck is the point on a road section with the lowest capacity.

Choosing a method for travel time analysis

The following conditions identify when to use basic speed flow relationships for assessing road traffic impacts, and when to use more detailed methods:

- If the case to be assessed consists of mainly arterial routes and flow rates are less than 85% of capacity (see note below) then use basic speed flow relationships.
- If the case to be assessed consists of a variety of road types or a complex road network and a variety of intersections, and bottlenecks with flows that are near to or over capacity then use the detailed procedures in Appendices A3 and A11 or output from a validated transport model.

Note: If traffic flows are very near to or over capacity, during some period of the day, then it is advisable to use either the procedures in Appendices A3 and A11 or the output from a validated transport model. This is because a small reduction in traffic flow could result in a significant reduction in queuing, which would be ignored if basic speed flow relationships were used. Choosing a method for travel time analysis

Valuing travel time cost savings

Once the change in travel time has been determined using one of the above methods, the value of the travel time cost savings is calculated using the appropriate values given in Appendix A4. The increment for traffic congestion (denoted as CRV) may be added to the base values for vehicle occupant time (table A4.1 of Appendix A4) when the ‘ruling’ intersection or bottleneck of the corridor affected by the proposed transport service operates at least 80% capacity during the peak one hour period.

Note: Any increase in travel time cost is counted as a travel time disbenefit (negative benefit) and subtracted from the numerator of the benefit cost ratio (BCR).

Flow relationships

Step	Action
1	Obtain a speed flow relationship: • if a proven speed flow elasticity function exists, for the route to be analysed then use that function • if no speed flow elasticity function exists, for the route to be analysed then use flow detectors, capable of measuring speeds, to measure average speeds and traffic flows at low, medium and high levels of flow (note that the high levels of traffic flow should still be below the road capacity) and interpolate between the observed speed flow values as necessary.

2	From the demand estimates prepared in chapter 4, list the following information for both the peak and non-peak periods, as appropriate: • existing number of road trips • projected number of road trips following the implementation of the transport service proposal.
3	For the peak period, subtract the forecasted number of road trips from the existing number of road trips to determine the change in total peak period road trips.
4	Estimate the average existing traffic speed over the peak period. If this information is not already available, the evaluator may have to measure average speeds on the road(s) being evaluated. Generally accepted methods for measuring average speed include: • using loop detectors on the road • using a radar gun • using a test vehicle to travel the length of road(s) • during the appropriate time period(s).
5	Use the speed flow elasticity function from step one to determine the average traffic speed for the forecasted flow level at peak after the transport service is implemented. Subtract the current average traffic speed from the estimated average traffic speed to determine the change in average traffic speed.
6	Use the change in speed calculated in step five to determine the change in travel time over the route being analysed.
7	Multiply the change in travel time by the appropriate composite value-of-travel-time value from table A4.3 in Appendix A4 to determine the monetised value of the travel time cost savings per road trip.
8	Multiply the travel time cost savings value (step seven) by the number of remaining road users to determine the total benefit.
9	Repeat steps three to eight for the off-peak period(s) if appropriate.

Note: Steps six to eight may also be used in calculating the value of travel time cost savings when the change in travel time has been estimated using the procedures contained in Appendices A3 and A11 or with output from a validated transport model.

Vehicle operating cost savings

In congested urban areas, removing road traffic will smooth flows and tend to reduce energy consumption and, to a lesser extent, the wear and tear on vehicles (tyres, clutch, brake blocks, etc). Outside urban areas, where average speeds exceed 70km/h, reducing speeds may reduce vehicle operating costs (VOC) to a greater extent.

For purposes of estimating road traffic reduction benefits, VOC savings may be estimated as being equal to 14% of the value of travel time benefits for the same trips.

CO_2 reduction benefits

CO_2 reduction benefits may be estimated as four percent of the VOC savings.

Crash cost savings from transport service proposals

Introduction

A proposed transport service activity may reduce crashes by moving passengers or freight to safer modes of transport, such as buses and rail. While this may be an outcome of a transport service proposal, it is seldom the primary objective.

Crash occurrence (and crash cost) is affected by:

- trip diversion
- changes in travel demand
- a reduction in the number of potential conflicts between different modes.

Nature of crash benefits

Trip diversion from road to rail or bus will generally provide positive benefits to users that change mode. The crash risk (likelihood of having a crash) and crash costs of remaining users will be similar.

A reduction in the number of potential conflicts between modes will generally lead to positive benefits, by reducing the number of conflicts and in many cases the crash severity. Crashes between bus/rail and private motor vehicles tend to be more severe than those between two private motor vehicles.

Crash evaluation procedures

Proposed transport services should use the crash rate analysis method described in Appendix A6.4. Crash rate analysis makes use of predictions of the reported injury crash rate from areas that are similar to the proposed transport service location.

For a transport service proposal such as a rail service, crash rates for both road and rail must be used to predict the number of crashes and the subsequent costs. Roads should also be separated into urban and rural sections. FP Worksheet14.7 and Appendix A6.5 can be used for analysing urban and rural road routes respectively.

Crash rates and prediction models

Crash prediction models and crash rate equations are not provided for rail, buses or coastal shipping. Crash prediction models and crash rate equations from other sources are permitted, as long as the robustness of these other sources can be demonstrated.

Urban transport services – crash rates

The crash prediction models in Appendix A6.5 can be used to calculate crash rates for urban roads. The models predict crashes between major intersections (or on links). An adjustment factor of two may be used to estimate the total number or reported injury crashes on both the links and at intersections for urban roads with intersections when the frequency of intersections along a road and the volume of crossing traffic is fairly typical. This is based on an assumption that approximately 50% of crashes occur at intersections.

On some urban roads, particularly in the middle of towns and cities, intersections are often closely spaced and this factor is not valid. When either of these two factors is atypical, then the evaluation should use the intersection prediction models in Appendix A6.5 to calculate crash rates at the intersections. If the proportion of the trip on atypical roads is short then this issue can be ignored. A validated transportation model can be used to assist in more complex situations

Rural freight transport services – crash rates

For freight transport service proposal, where the road network affected by the activity is primarily rural in location, crash rate equations for heavy vehicles only are used to estimate the reduction in freight related crashes. This is a subset of the crashes given by the equation in Table A6.14 in Appendix A6.5.

Each freight route should be broken down by traffic volume and terrain type. The terrain type can be selected by analysing the route gradient data. The gradient bands for each terrain type should generally be maintained throughout each section. Sections of road that are less steep can occur in rolling or mountainous sections for short lengths. This is allowed provided that the lower gradient length is followed by another rolling or mountainous gradient. The appropriate crash rate is then used for each section.

Procedure for crash rate analysis

For each mode that will be affected by the transport service proposal, calculate the crash cost savings as follows:

Step	Action
1	If the activity to be assessed consists of predominately radial then arterial, collector and local routes, with a standard density of intersections, and motorways, or rural roads then use this procedure (for each option). If the activity to be assessed consists of a complex road network or arterial routes with very high or low density of intersections then use output from a validated transport model in conjunction with crash prediction models.
2	Where the transport service proposal affects urban road(s): • Using FP Worksheet 14.7, record for each mid-block road type (and land use) the length, average annual daily traffic current (AADT), and the predicted AADT after implementation of the transport service proposal. Where there is more than one length of any given mid-block road type and the AADT varies, an average of the AADT values can be used (alternative add rows to the bottom of FP Worksheet 14.7). • Using the coefficients (b_0 and b_1) provided, calculate the do-minimum crash rate (A_{dm}) for each mid-block road (link) type using the current AADT: $A = b_0 \times Q_T^{b1} \times L$ • Calculate the crash rate (A_{opt}) for each of the options, using the above crash rate equation and the AADT after implementation. • Intersection adjustment for collector and arterial road links only. Multiply the crash rates (A_{dm} and A_{opt}) for the appropriate road links by two to derive the adjusted crash rates.
3	Where the transport service affects rural road(s): • Using FP Worksheet 14.8, record for each section of road the length, AADT, terrain type and the daily number of heavy commercial vehicles that currently use the route and the daily number of heavy vehicle trips that will use the route following implementation of the transport service proposal. • Calculate the HCV exposure (in 100 million vehicle km per year) for both the do-minimum and each option using the current and option number of truck trips. • Multiply the HCV exposure by the appropriate coefficient (b_0) to determine the do-minimum and option reported injury crashes per year (A_{dm} and A_{opt}).

4	For other modes (ie existing transport services): • Develop or obtain crash rates for other modes (ie rail and buses). The crash rate will be based on a factor, such as the total number of passengers, annual tonnage, or similar. The factor selected will depend on the information available about crashes for the mode under consideration. • Calculate the change in the factor being used based on the projected demand for trips on other modes after implementing the transport service (from Section 4.9). • Calculate the do-minimum and option number of crashes resulting from the transport service for each 'other' mode for the current value of the factor (eg change in number of kilometres travelled, change in number of passengers, etc) and the increased value of the factor.
5	• Multiply the do-minimum and option number of crashes for urban and rural roads and 'other' modes by the appropriate standard crash costs - 'all other sites' costs in table A6.22 in Appendix A6.9. • Calculate the crash cost savings for each option affected by the implementation of the transport service by subtracting the option crash costs from the do-minimum crash costs for rural and urban roads and on other modes. • Sum the crash cost savings (or cost increases) on urban and rural roads and on 'other' modes. • Enter the total crash cost savings for each option into the reporting table.

Disbeneftis during implementation/construction

Introduction

Disruption costs to existing users of transport services during the implementation of a new or improved transport service shall be included in the evaluation as a disbenefit (negative benefit).

Possible disbenefits include:

- increased travel time
- travel discomfort

Determine any significant costs of disruption to the wider community during the implementation/construction process.

Transport service user benefits (Appendix A18)

Transport service activities will provide benefits to new and existing transport service users. These may be affected by user charge levels, travel time, quality of service, and additional user costs, and can be positive or negative. Appendix A18 provides guidance on the calculation of transport service user benefits.

Road traffic reduction benefits (Appendix A18)

Transport service activities will generally provide road traffic reduction benefits where congestion is present, through the removal of traffic. Benefits may include travel time cost savings, VOC savings, CO_2 reduction benefits and crash cost savings, and can be positive or negative. Negative benefits may result from a reduction of road capacity for other traffic. Appendix A6 provides guidance on crash cost savings. Appendix A18 provides guidance on the calculation of other road traffic reduction benefits.

Walking and cycling benefits (Appendix A20)

Walking and cycling activity benefits can include the road traffic reduction and health benefits from mode change, and travel time cost, quality, and safety benefits for existing users. Appendix A20 provides guidance on the calculation of walking and cycling benefits.

4.4.6 References

References	1. Australian Transport Council (2006) National guidelines for transport system management in Australia: urban transport. 2. Vincent M (2008) Measurement valuation of public transport reliability. Land Transport New Zealand research report 339.

4.5 Evaluation of walking and cycling

4.5.1 Overview

Introduction

This chapter describes the specific procedures to be used to evaluate the economic efficiency of walking and cycling facilities.

Improvements may be of two types:

- route improvements (provision of new or improved paths, lanes or other facilities for pedestrians or cyclists)
- improvements at hazardous sites (provision of overbridges, underpasses, bridge widening or intersection improvements)

Cycling and walking promotion is addressed in Section 4.6.

Integration with other transport demand management initiatives

For walking and cycling activities to be effective, provision of continuous lanes or paths should be provided with secure cycle parking, signage, maps, education, promotion, marketing and integration of the routes with public transport. All these components should be addressed within a walking and cycling section of a wider transport strategy, that includes an implementation package.

Reference 1 sets out a framework and priorities for development of walking and cycling. Reference 2 provides guidance for cycle network and route planning and reference 3 provides guidance for planning and design for pedestrians.

Because of synergetic impacts, evaluation of walking and cycling should be done at the package level rather than just for individual components.

In this chapter

Section	Topic
4.5.1	Overview
4.5.2	Stages of analysis
4.5.3	Method of evaluation
4.5.4	Benefits of walking and cycling
4.5.5	References

4.5.2 Stages in analysis

Stages

The following table outlines the stages of analysis in the economic efficiency evaluation. It is envisaged that a programme business case [PIKB link: PIKB (programme business case)] will have been completed before commencing evaluation of economic efficiency and applying the standard set of full procedures as set out below for evaluation of walking and cycling activities. The do-minimum and any other options must be assessed at every stage.

Stage	Description	See
1	Complete the activity description including a description of the do-minimum, alternatives and options.	Section 4.5.3
2	Forecast the demand. **Note:** The demand estimate is used for calculating user benefits for new and existing pedestrians/cyclists, and road traffic reduction benefits. Care should be taken to ensure assumptions are compatible with economic evaluation requirements.	Section 4.5.3
3	Calculate the costs of the proposal.	Section 2.4
4	Calculate the annual facility user benefits.	Section 2.2
5	Calculate disbenefits during implementation/construction.	Section 2.2
6	Describe, and quantify where possible, any significant non-monetised effects.	Section 2.2
7	List any national strategic factors relevant to the preferred option. If possible determine the monetary value(s) of any national strategic factors.	Section 2.3
8	Describe equity impacts (particularly those relating to transport disadvantaged) and any other significant impact not covered in stages 4 to 7.	Section 2.2
9	Discount the costs over the period of analysis to obtain the present value (PV) of these costs.	Appendix A1
10	Discount the annual monetised benefits (stages 4 and 5) over the period of analysis and sum them to obtain the PV of net national economic benefits.	Appendix A1
11	Where options being evaluated are mutually exclusive, use incremental analysis to select the preferred option.	Appendix A19
12	Determine the national benefit cost ratio (BCR_N).	Section 2.8
13	Perform sensitivity tests on the preferred option.	Section 4.5.3

4.5.3 Method of evaluation

Consumer surplus basis

Consumer surplus methodology is used to monetise the user benefits of improvements to walking and cycling facilities.

For reduced journey time, user time savings are based on the standard values of time (VOT) for pedestrians and cyclists given in, Appendix A4. The values in Appendix A4 applicable to most pedestrians and cyclists are those for non-work travel purposes (including commuting to and from work). These standard values are derived willingness to pay (WTP) values, ie they are based on consumer surplus methodology.

For other types of walking and cycling improvements (such as improvements to the quality of the facility and journey comfort) WTP values need to be obtained from consumer preference surveys or from the impacts of similar improvements in other areas.

Because charges are not normally made for use of walking and cycling facilities, travel time is usually the measure used to trade off with improved facilities, etc in consumer preference surveys for walking and cycling. The time value is then monetised using the standard values of time referred to above.

Do-minimum

Definition

The do-minimum for evaluation of walking and cycling facilities is usually considered as a continuation of the present transport networks, service levels and facilities in the study area.

The do-minimum shall include any costs and resulting demand implications of committed facility or service improvements. All committed investment plans that relate to the do-minimum during the analysis period must be taken into account. Maintenance, replacement schedules and any planned service changes must also be included. Improvements are committed if they have been assessed in accordance with the NZ Transport Agency's assessment procedures and have been approved for funding.

Any investment plans that are not committed must be included in the evaluation as options.

Where a particular benefit or cost is unchanged among all the alternatives, options and the do-minimum, it does not require validation or inclusion in the economic analysis.

Scope of do-minimum

It is extremely important to:

- not overstate the scope of the do-minimum
- only include, as part of the do-minimum, work which will preserve a minimum acceptable level of service.

Sensitivity analysis

Possible significant factors	Inputs to walking and cycling facility evaluations that should be considered for sensitivity testing include: • demand estimates • major contributors to benefits.
Major contributors to benefits	Benefits critical to the outcome of the evaluation may include: • pedestrian and cyclist volumes, particularly model results, growth rates and the assessment of diverted and generated traffic • crash reduction. For each significant factor the following must be listed: • the assumptions and estimates on which the evaluation has been based • an upper and lower bound of the range of the estimate • the resultant BCR at the upper and lower bound of each estimate.
Incremental analysis	The results of incremental analysis shall be sensitivity tested using an incremental BCR 1.0 higher than the target incremental BCR.
Results of sensitivity tests	The results of the sensitivity tests, along with explanation of any assumptions or choice of test, shall be reported in a format similar to FP Worksheet 6.

Cycle demand analysis

Estimate cycle demand	Worksheet 20.1 in Appendix A20 calculates the demand for a new cycle facility. It is designed to be used when traffic counts have not been carried out or are unreliable or unavailable. The likelihood multiplier is an adjustment for the likelihood of new cyclists using the facility in each buffer. Cyclists further from the facility are less likely to use it. The buffer distances are defined as <0.4, 0.4 - 0.8 and 0.8 - ≤1.6 km. These represent the area from the facility which is likely to be affected by the proposal. When calculating the area of each buffer, the areas of buffers between it and the facility need to be excluded. Appendix A20 contains further detail on estimation of likely demand for cycling facilities.
Cycle demand indicators	The cycle demand indicator table (Appendix A20) is based on journey to work from the New Zealand census 2001 to 2006 by territorial authority area. These indicators were prepared excluding ‘worked at home’ and ‘did not go to work’ modes. The table will be updated once the 2013 census data becomes available. More localised or recent data should be used if available.

4.5.5 References

1. Barnes G, Krizek KJ, Mogush P and Poindexter G (2005) *Guidelines for analysing the benefits and costs of bicycle facilities.*
2. Francis T, Roozenburg AP and Turner SA (2006) *Predicting accident rates for cyclists and pedestrians*. Land Transport New Zealand research report 289.
3. Land Transport Safety Authority (2004) *Cycle network and route planning guide*.
4. Land Transport New Zealand (2006) *Pedestrian planning and design guide.*
5. Ministry of Transport (2005) *Getting there – on foot, by cycle.*
6. Transportation Research Board (2006) *Guidelines for analysis of investments in bicycle facilities*. NCHRP report 552.
7. O'Fallon C and Sullivan C (2006) *Increasing cycling and walking: An analysis of readiness to change*. Land Transport New Zealand research report 294.

4.6 Evaluation of education, promotion and marketing

4.6.1 Overview

Introduction

This chapter describes the specific procedures to be used to evaluate the economic efficiency of education, promotion and marketing activities. These include travel behaviour change (TBhC), road safety promotion, and other education, promotion and marketing-based transport demand management (TDM) programmes.

In this chapter

Section	Topic
4.6.1	Overview
4.6.2	Stage of analysis
4.6.3	Method of evaluation
4.6.4	Costs of education, promotion and marketing
4.6.5	Benefits of education, promotion and marketing
4.6.6	References

4.6.2 Stages of analysis

Stages

The following table outlines the stages of analysis in the economic efficiency evaluation. It is envisaged that a programme business case [PIKB link: PIKB (programme business case)] will have been completed before commencing evaluation of economic efficiency and applying the standard set of full procedures as set out below for evaluation of education, promotion and marketing activities. The do-minimum and any other options must be assessed at every stage.

Stage	Description	See
1	Complete the activity description including a description of the do-minimum, alternatives and options.	Sections 2.1, 2.7
2	Determine the level of diversion. **Note:** The level of diversion is used for calculating user benefits for new and existing pedestrians/cyclists, and road traffic reduction benefits. Care should be taken to ensure assumptions are compatible with economic evaluation requirements.	Appendix A20
3	Calculate the costs of the proposal.	Section 4.6.4
4	Calculate the annual TBhC benefits.	Section 4.6.3
5	Describe, and quantify where possible, any significant non-monetised effects.	Section 2.3
6	List any national strategic factors relevant to the preferred option. If possible determine the monetary value(s) of any national strategic factors.	Section 2.2
7	Describe equity impacts (particularly those relating to transport disadvantaged) and any other significant impact not covered in stages 4 to 6.	Appendix A15
8	Discount the costs over the period of analysis to obtain the present value (PV) of these costs.	Appendix A1
9	Discount the annual monetised benefits (stages 4 and 5) over the period of analysis and sum them to obtain the PV of net national economic benefits.	Appendix A1
10	Where options being evaluated are mutually exclusive, use incremental analysis to select the preferred option.	Appendix A19
11	Determine the national benefit cost ratio (BCR_N).	Section 2.8
12	Perform sensitivity tests on the preferred option.	Section 2.10

4.6.3 Method of evaluation

Period of analysis

A 10 year evaluation period is to be used for travel behaviour change and other education, promotion and marketing-based transport demand management programmes. This reflects the assumption that benefits are sustainable largely without maintenance but there is an absence of experience with the durability of benefits beyond about five years. This could be reviewed in future in light of ongoing monitoring of this type of programme.

Composite evaluation of packages

For the evaluation requirements for the costs and benefits of TBhC packages please refer to Section 4.8.3.

Timing of mode shift and mode shift benefits

Gaining the full mode shift and benefits of the mode shift usually takes around three years to obtain and needs to be adjusted for. Maintaining this mode shift then requires constant investment of staff time and marketing resources in support of the activities.

Non-TBhC component	Benefits to existing users and non-TBhC target population new users	Comments
New or improved public transport service.	Use the appropriate public transport service evaluation procedure to: • calculate benefits for existing users (whether inside or outside the TBhC target population area) • calculate benefits for new users and associated externality (remaining road user) benefits for the population located outside the TBhC target population area.	There is potential for double counting of new user benefits. Care must be taken not to count the TBhC benefits of the target population twice.

Non-TBhC component	Benefits to existing users and non-TBhC target population new users	Comments
New or improved cycle infrastructure.	Use the walking and cycling simplified procedure to: • calculate the cycling benefits for existing users (whether inside or outside the TBhC	

	target population area) • calculate the cycling benefits for any new users from the population located outside the TBhC target population area.	
New or improved walking infrastructure	Consider if more walking trips will be created than is given by the TBhC evaluation diversion rates, the walking and cycling simplified procedure can be used to estimate the additional benefits associated with the extra trips.	There is potential for double counting of new user benefits.
Roading Bus priority lane/high occupancy vehicle lane Road capacity improvements Minor road improvements Traffic calming	Use the relevant procedure to calculate all benefits associated with the roading component.	Minor road improvements include improvements such as intersection treatment, parking changes, road crossings. There is potential for double counting new user benefits where a bus priority lane is proposed – see 'improvements to public transport services' above.

4.6.4 Costs of education, promotion and marketing

Costs

Refer to Section 2.4 for the components of cost that should be considered.

The availability of suitably trained and experienced people to establish and manage travel plans is an important aspect of this type of intervention. This can be a sizeable part of the cost and must be allowed for.

The cost of annual expenditure required to maintain the benefits of travel plans over the evaluation period following completion of the activity should be estimated based on local experience and knowledge. For household/community based activities this is generally zero unless the activity contains specific plans for follow-up measures. For workplace and school travel plans it is likely that some ongoing maintenance expenditure will be required to maintain benefits.

4.6.5 Benefits of education, promotion and marketing

Introduction

Overseas experience shows that the most effective (and lowest cost) way to encourage people to change their travel behaviour is to provide them with customised information about what is available locally. Travel plans targeting workplaces, schools, or households and communities are one type of programme for doing this.

The impact on travel is dependent on factors such as:

- actual features of the plan
- commitment of the target population
- availability of material that assists people's understanding of the implications of different forms of travel behaviour
- availability of suitably trained and experienced people to establish and manage the proposal.

Cost efficiencies and effectiveness are enhanced when school, business, household and community initiatives are implemented simultaneously rather than separately in an area. These programmes should, therefore, be implemented by geographic area rather than by type.

Target population for travel plans

The target population is the total population of the workplace, school, or community in which the programme is being implemented. It includes the people who do not participate in the programme and those who participate but do not change their behaviour.

Type of programme	Definition of target population
Workplace	The total workforce (number of employees) at the workplace covered by the travel plan. Make appropriate adjustment if a significant proportion of employees work more or less than the standard five days per week.
School	The total school roll. If this is expected to vary significantly in the next few years use an appropriate average.
Household and community	The total population of the community/suburb/area in which the household or community based programme is being implemented.

Diversion rates

Standard diversion rates between modes have been derived for TBhC activities based on experience to date. These are described in Appendix A20.

When conducting initial indicative evaluations for development funding for workplace and school travel plans the diversion rate should be selected based on the proponent's knowledge of the organisations involved and the area. For the final evaluation for implementation funding the diversion rate will be based on the actual features of the completed plan.

Benefits considered

The evaluation procedure for TBhC activities include the following main benefit categories:

- benefits to people that change their travel behaviour

	• benefits to remaining road users (road traffic reduction and safety) • health • other monetised impacts including environmental effects.
Road construction, maintenance and operating cost savings	These are assumed to be negligible for the number of private vehicle trips and/or vehicle kilometres that are likely to be removed by TBhC activities.

4.6.6 References

1. Land Transport New Zealand/Energy Efficiency and Conservation Authority (2004) *Travel behaviour change guidance handbook*.

4.7 Evaluation of private sector financing and road tolling

4.7.1 Overview

Introduction

This chapter describes the specific procedures to be used to evaluate the economic efficiency of activities involving private sector financing, and road tolling activities.

Private sector financing and tolling provide alternatives to government funded transport infrastructure. Reference 3 provides guidance on private sector participation in provision of public infrastructure.

In New Zealand, road tolling can currently only be used in conjunction with a new road and this will generally be within a network of otherwise 'free' roads. This has implications for:

- traffic distribution/assignment
- environmental impacts
- economic efficiency
- financial – toll level and fundability of the new road
- design of the new road and toll facility.

In this chapter

Section	Topic
4.7.1	Overview
4.7.2	Stages of analysis
4.7.3	Method of evaluation
4.7.4	Benefits of private sector financing and road tolling
4.7.5	References

4.7.2 Stages of analysis

Stages

The following are essential steps for consideration of a road tolling proposal:

- ensure that the need for the activity and the benefits to the community have been identified and maximised
- explore alternative solutions, including non-capital options
- identify risks and returns and determine appropriate allocation among relevant parties
- establish the nature and extent of community support likely to be required.

Concession agreements

The purpose of private sector activities is to involve private sector funds in community facilities. When considering private sector financing of a facility, a concession agreement, the following steps should be taken:

- ensure that any private sector involvement is commercially feasible and offers a more cost-effective solution that the traditional public sector approach
- only private sector options that reduce public sector costs should remain in the final set of options under consideration
- ensure that any commercial arrangement with the private sector is appropriate and that any probity and accountability requirements have been met
- identify the degree to which risks can be shared with, or assumed by, private sector participants.

Options with private sector financing can lead to an earlier start date, depending on the ability of the private sector to raise funds. Also, there is usually an incentive for early completion of privately financed activities since revenue starts to accrue upon completion of work.

Concessionaries may propose arrangements where the government provides substantial initial funding for which repayments are made over time, generally from the activity income. This type of arrangement is, in effect, a loan and should be identified as such.

4.7.3 Method of evaluation

Introduction

As well as economic efficiency, social and environmental objectives, financial considerations must be taken into account when evaluating activities involving private sector financing and activities with road tolling. An effective community consultation process is essential for road tolling activities.

In principle, the economic efficiency evaluation of toll options is no different from that for other (non-pricing) options for any proposal. However, the following issues warrant particular attention:

- the range of options considered
- the treatment of value of time savings
- the composition and application of benefit cost ratios.

Consumer surplus

Consumer surplus methodology must be used for evaluation of road tolling activities because motorists' behaviour in response to various levels of tolls (including no toll) must be determined and therefore a measure of the willingness to pay. Stated preference (SP) surveys or possibly, revealed preference (RP) data, need to be used to give a general cost equation (combining travel time, vehicle operating cost (VOC) and toll charge).

Range of options

Economic efficiency evaluation of road tolling activities must be undertaken with and without the tolls in place, as alternatives and options are required to be considered under the Land Transport Management Act 2003. As well, financial analysis is required of the toll options.

Financial analysis is used to determine the optimum tolls, choices of debt financing, optimum borrowing, and timeframe for implementing tolls. The imposition of tolls has consequences in terms of changing the demand for the facility, diverting traffic onto other facilities, increasing the costs due to toll collection, and other issues.

Methods of setting tolls

There are a number of approaches to setting charges for a toll road where other routes are 'free'. Three of the most common approaches are:

- a pricing policy where economic welfare as defined by the benefit cost ratio (BCR) is maximised
- a revenue maximising pricing policy where service provider revenue is maximised
- a 'network optimisation' pricing level which seeks to optimise the performance of the network in terms of total travel times or average network speeds.

In practice, all these three considerations and possibly others may need be taken into account in reaching a toll regime which that meets the overall objectives of the proposal.

Value of travel time

For most transport activities, an average value of time is used in economic efficiency evaluations, ie the same unit values are used for motorists from more affluent households and for those from less affluent households. This is essentially an 'equity' approach (to avoid favouring activities used by higher income groups). It also makes the economic evaluation easier. This averaging approach is not of major consequence for most situations.

However, it has important implications for toll roads, particularly when comparing the economic merits of tolled vs. untolled options. An 'equity' value of time will substantially over-estimate the perceived disbenefits of tolling. The extent of distortion is directly related to the spread of the behavioural value of travel time.

Evaluation of toll roads (including tolling policies) must use a distribution of values of travel time consistent with users' willingness to pay (WTP) values established through SP surveys or other means. A consistent distribution of values of travel time must be used in both the traffic modelling and economic efficiency evaluation.

When investigating options and alternatives, behavioural values can be used to calculate initial user benefits, with the overall results adjusted to the average value of travel time between the behavioural and equity values for consistency with other activities.

Do-minimum

The do-minimum for evaluating activities with public sector financing and/or road tolling is typically the existing road network with minor improvements and the provision of the new road at a much later date.

Costs

Costs (Section 2.4) need to be viewed from both an economic and financing point of view.

Effect of public sector financing and tolling

The public sector financing and/or toll charges reduce the effective activity costs to the government.

Even if a activity is totally funded by the private sector, there will still be some costs to government agencies, such as contract preparation and ongoing contract management and monitoring. The cost of these activities should be included in the cost of the option involving private sector financing.

Similarly the additional cost of toll infrastructure and toll collection must be included in the tolling option.

Period of analysis

Timing of construction start is an important consideration for activities involving private sector financing and/or road tolling. These strategies are often used to allow an earlier start for the activity than that which would apply without these funding sources. The analysis period should be extended to capture the activity benefits over the useful life of all the options.

With activities involving private sector financing, and particularly tolling, there is usually also an incentive for early completion of the activity as revenue starts to accrue upon completion of the proposal.

Financial evaluation

Financial analysis is a method to evaluate the viability of an activity by assessing its cash flows. This differs from economic evaluation in the:

- scope of investigation
- range of input
- methodology used.

Financial analysis views the costs and revenues of the activity from a 'commercial' investment point of view, ie the cash flow impact on government and any private sector party. By contrast economic efficiency analysis also considers external benefits and costs of the activity whether or not they involve monetary payments.

Other differences include:

- Market prices and valuations are used in assessing benefits and costs in financial analysis, instead of measures such as willingness to pay and opportunity cost used in economic analysis. Market prices include all applicable taxes, tariffs, trade mark-ups and commissions.

- The discount rate used in financial analysis represents the weighted average costs of debt and equity capital rather than the estimated social opportunity cost of capital.
- The discount rate used in financial analysis and the cash flows to which it is applied are usually specified in nominal terms (allowing for future inflation), as the cost of debt and equity are observed only in nominal terms.

Undertaking an economic evaluation does not remove the need for a financial evaluation.

Feasibility of private sector financing

Where consideration is being given to private sector involvement in financing land transport infrastructure, it is important to ensure that the involvement is commercially feasible and that it offers a more cost-effective solution that the traditional public sector funding approach.

Cash flows to be measured

All incremental costs, revenues and risks associated with an activity and its best alternative should be identified and measured as nominal cash flows in the period in which they occur. Cash flows should be on an after tax basis. An estimate of the asset's salvage value must be included at the end of the analysis period to represent the asset's remaining service potential. The salvage value should not be such as to bias the viability of the proposal.

Typical inward cash flows to be considered include:

- operating revenues
- subsidies from external parties
- operational savings occurring in other areas as a result of the proposal
- sale of surplus assets
- residual values of assets.

Typical cash outflows to be considered include:

- capital costs (including land, equipment, buildings)
- maintenance and operating costs
- taxes, where appropriate
- operating lease payments
- contract termination payments
- revenue losses to existing operations affected by the proposal
- the opportunity cost of resources (including land) that would otherwise be available for sale or lease.

Treatment of specific items

Financing costs (interest) should be excluded in the cash flows because the opportunity cost of debt is accounted for in the weighted average cost of capital (WACC).

Accounting, depreciation, economic multiplier effect and sunk costs should be excluded in the financial analysis.

The effect of dividend imputation needs to be taken into account in the financial analysis.

Operating leases should be evaluated in the form of a series of regular payments and compared to an outright purchase alternative, with consideration for the value of options such as renewal or purchase rights if these features are present. Financing

	leases do not form part of a financial analysis as these are merely an alternative means of financing the proposal.
Weighted average cost of capital	The WACC is used in financial analysis. The WACC is the weighted average of the required return on equity and the (interest) cost of any debt financing. The WACC should reflect the appropriate risk and norms associated with the industry.

Summary measures of commercial merit

The more common measures for evaluating the financial viability of an activity are, for example:

- net present value (NPV) of cash flows
- NPV per $ of capital invested (NPVI)
- internal rate of return (IRR) of cash flows
- payback period
- profitability indices.

Measures used in commercial evaluations will vary between activities and private sector proponents. Specialist advice should be sought on financial evaluations and detailed descriptions of these evaluations are not included here.

Cost benefit analysis

While the basic principles of economic appraisal apply to the evaluation of toll road activities and activities involving private sector financing, some adjustment is required to the composition and application of benefit cost ratios.

Present value of tolls

In PV calculations, all government costs and user costs and benefits are presumed to include escalation. When this is the case, the discount rate is used to determine the PV of unescalated costs and benefits in economic analysis, and no adjustment is made for inflation.

With private sector financed activities, a rise and fall clause relating to tolls is likely to be included in the conditions. The gross toll collections for each vehicle category for each year of the activity will need to be estimated. If tolls are regularly changed in line with general inflation in the economy, then the normal inflation free discount rate can be used to determine present values only if the escalating effects of the clauses are first removed from the cash flow estimates.

If tolls are not linked to the general economy inflation rate, some other analysis of the PV of toll revenues may be required.

National benefit cost ratio for a toll road

From the national economic point of view tolls are transfer payments and therefore not taken into account in the national benefit cost ratio (BCR_N), which is the same irrespective of whether the toll road is private sector funded or not.

$$BCR_G = \frac{\text{PV of national economic benefits} - \text{PV of tolls}}{\text{PV of net government costs}}$$

National economic benefits = net direct and indirect benefits and disbenefits to all affected transport users plus all other monetised impacts.

Net government costs = net costs to the NZ TRANSPORT AGENCY and approved organisations.

Tolls = gross toll collections.

First year rate of return for a toll road

The first year rate of return (FYRR) for a tolled road activity is

$$FYRR = \frac{\text{PV of national economic benefits} - \text{PV of tolls}}{\text{PV of net government costs}}$$

[1] In the first year of operation.

[2] To the end of the first year.

Alternatives and options

Tolling must be evaluated as an option compared with the case of no tolls.

A number of other options aimed at optimisation of the transport system should also be assessed, including:

- revenue maximisation tolls
- level of tolls and other measures maximising social welfare
- level of tolls and other measures maximising traffic diversion from sensitive areas
- level of tolls and other measures to optimise level of service.

When considering private sector financing options, only options that reduce public sector costs should remain in the final set of options.

Sensitivity and risk analysis

Sensitivity analysis applies to both financial analysis and economic efficiency analysis.

Identification of risks

Risks are different between options with and without private sector financing and/or operation. Technical capacity, financial backing, business acumen, activity life and government exposure are very important considerations where there is private sector involvement.

Identification, quantification and assignment of risks among relevant parties are essential for activities involving private sector financing and for road tolling activities. This should include preparation of a risk management plan.

For private sector financing, it is essential to ensure that the commercial arrangement with the private sector is appropriate and that any probity and accountability requirements are met. The degree to which risks can be shared with, or assumed by, private sector participants must be identified. Details of likely contractual obligations as they affect pricing, ongoing risk to government, terms of the contract, termination arrangements and debt and equity contributions of each party should be clearly specified.

Test assumptions

The impact of risks (their probability or likelihood of occurrence and the consequence) on the results must be tested by sensitivity analysis. Critical assumptions that could be varied should be altered one at a time.

Test effect on cash flows

For financial analysis, analyse the sensitivity to variations associated with cash flows for each option, eg changes to key variables by ±20% and different combinations of key variables which taken together represent an alternative, plausible and consistent view of the future.

Calculate and present summary financial measures for the best and worst cases and for specific changes to key variables that are deemed highly probable. Break even points (at which the activity begins to lose money) should be identified.

4.7.4 Benefits of private sector financing and road tolling

Introduction

The Transport Agency's *Implementation guide for finance and toll proposals* provides guidance on the traffic/toll modelling requirements and methods for assessing toll route feasibility.

Traffic modelling

Traffic modelling for a tolled road (and the surrounding road network) is an essential input to evaluation. The main purpose of the assignment part of the traffic modelling is to forecast traffic volumes (and corresponding traffic speeds) on each part of the road network and particularly on the toll road. The toll road traffic volumes in turn determine toll revenues.

For accurate forecasting of route choice between the toll road and alternative routes, it is important to take into account the full range of behavioural preferences of potential users of the toll road. This generally requires more sophisticated choice models and a better understanding of motorists preferences than is the cases in standard traffic models.

Traffic modelling used for road tolling activities should take into account behavioural responses such as:

- peak spreading/contraction
- trip end redistribution
- modal shift
- trip generation/suppression.

The split of traffic between the toll road and alternative routes is likely to be sensitive to the level of congestion on the road network and the mix of trip purposes by time of day/day of week. Therefore, detailed traffic modelling must separately consider periods with differing levels of congestion. Expansion or annualisation factors need to be applied separately to the results for each of these periods based on the characteristics of the toll route traffic rather than the traffic volumes in general.

Benefits

Once traffic impacts have been determined, the calculation of national economic benefits follows in the normal manner but using the disaggregated WTP values for travel time for benefits or disbenefits (see Section 4.2).

Tolled versus untolled roads

When users are required to pay tolls on a route, some will choose to avoid the toll by using alternative routes if they are available. The toll charges change the benefits that would otherwise be received by road users in the following ways:

- for those motorists that continue to use the toll road, benefits are reduced by the extent of the toll charge
- the benefits to users on the toll road may be increased due to less congestion on the tolled facility
- for those that would have used the new road if it was not tolled but decide to divert to a 'free' road because of the toll, travel time and perhaps vehicle operating costs are likely to increase
- for those that would have continued to use alternative routes even if the new road was not tolled, benefits are likely to be reduced because of more congestion.

Environmental and community benefits may also change with a tolled road compared to leaving the road untolled. Possibilities include:

- overall vehicle use
- use of carpools
- level of public transport use
- options to develop public transport
- overall pollution
- degree of decentralisation
- local area traffic management
- timing of infrastructure provision.

It may not be possible to put values on all these items, but they need to be considered for a tolled facility.

Tolls

Tolls are payment by road users for the right to travel on a particular road. In economic efficiency terms the tolls can be viewed in three ways:

- If the facility is government funded, the tolls are simply a transfer payment between those motorists who pay them and the government.
- If the facility is privately financed and the concessionaire (with its toll level proposal) is selected by competitive tendering, then the toll charges also represent a true market price, ie the resource cost, for that part of the activities. Any government contribution or expenditure is also part of the activity cost.
- Alternatively, tolls can be related to negative benefits (disbenefits). The effect of the toll is to reduce overall public benefits. If a particular road user would achieve a benefit of say $3 by using a new toll road, but must pay a toll of $2, then the net benefit is only $1 if the tolled road is used. The loss of benefits by those who continue to use the 'free' route will be somewhere between zero (because there would be no benefit in using the tolled route even if there was no toll) and the cost of the toll ($2).

The present value (PV) of gross toll collections is the same, regardless of which way they are viewed. Provided that tolls are not double counted, the net PV of the activity (PV of benefits minus PV of costs) is also independent of the way tolls are viewed.

Road traffic reduction

Some trips that would use the new route if it was 'free' will be deterred from its use by the charges and will continue to use the existing network. Hence the extent of traffic reduction on existing roads, provided by the new route is less than would be achieved if the new route were 'free'.

Disbenefits during construction

The costs of dislocation and traffic disruption during construction should be included as negative benefits for all options. These may be different for an untolled road compared to a tolled road (particularly if the construction period is different).

4.7.5 References

1. New South Wales Department of State and Regional Development (1997) *Guidelines for private sector participation in the provision of public infrastructure*.
2. Transit New Zealand (2003) *Finance and toll projects – implementation guide*. (Draft).
3. Wallis I (2005) *Implications of selected urban road tolling policies for New Zealand.* Land Transport New Zealand research report No 270.

4.8 Packages

4.8.1 Road packages

Evaluation of road packages

Where a package of activities includes a series of interdependent proposals that form a strategic long-term plan for a road corridor or area network, the following procedure should be used to determine the most cost-effective package of activities.

a. Develop options comprising alternative combinations, staging and sequences of components

b. Calculate the optimal start date for each component using a target FYRR as the criteria. The target FYRR is based on the target incremental BCR divided by 15 and expressed as a percentage (ie if the target incremental BCR is 2.0 the target FYRR will be 13%, etc). The procedures to use for determining the year when each activity in each option is likely to qualify for funding are as follows:

   i. starting with the first activity in the sequence of activities in each option, calculate the PV of the benefits in each year and the PV of the activity costs, and on this basis determine the timing of this activity which will yield a FYRR above the target FYRR

   ii. include the first activity in the do-minimum and repeat (i) above to determine the timing of the second activity, which will yield a FYRR above the target FYRR for this next activity.

   iii. repeat this process for each activity in order.

c. Calculate the benefits for each year and option, based on the year when each activity will qualify for funding under (b) above.

d. Calculate the PV of the benefits and costs of the activities in each strategy option.

e. Calculate the incremental BCR of each option in accordance with the procedures set out in Section 2.8.

f. Select the package with the highest NPV which has an incremental BCR equal to or greater than the target incremental BCR.

Evaluating packages of activities will generally be undertaken over the full life of the activities. Accordingly, it may sometimes be necessary to extend the evaluation period to capture the benefits of all the activities during their expected useful lives.

It should be noted that options may consist of varying numbers of activities. Some options may consist of just one activity, in which case the year when this activity is likely to qualify for funding should be determined as the basis for comparing this option with other options..

Sequenced components

When considering packages of activities that are to be sequenced over time, the FYRR should be used to confirm the appropriate start time of each individual component of the package.

4.8.2 TDM packages involving substantial infrastructure

TDM packages

The procedure for evaluating roading packages in Section 4.8.1, involving analysis of the timing of individual components, is not appropriate to TDM packages unless the package contains substantial infrastructure or public transport components.

If a TDM package contains substantial infrastructure or public transport components then a composite evaluation is necessary. Road infrastructure components of a package should be evaluated using the procedures in Section 4.2 and the public transport and other TDM components evaluated using relevant procedures in Section 4.4. The results are then aggregated, taking care to avoid double counting of benefits.

Procedures for composite evaluation of packages involving travel behaviour change (TBhC) are given in Section 4.8.3.

There are essentially two types of consumer preference surveys – revealed preference (RP) surveys and stated preference (SP) surveys:

1. RP surveys observe actual behaviour under varying conditions, for example the modes of travel used by household members relative to the level of service of public transport. This information is then analysed to identify and quantify the factors that influence travel decisions.
2. SP methods ask individuals how they would respond to various situations. Two techniques used in SP analyses are contingent valuation and conjoint analysis. Contingent valuation (attitudinal) surveys ask respondents directly how they would respond to various situations, or asks them to rate or rank their preferences for various levels of service, facility or situation. This often gives values several times higher than what they would be in reality because people often do not do what they say they would do. This type of survey tends to be better suited to evaluating relative preferences and for estimating the maximum possible response to an action, than to predicting actual changes in travel.

Conjoint analysis (hypothetical choice) surveys require respondents to make choices between hypothetical alternatives with varying attributes. It is necessary to have forced trade-offs so that a better environment might be coupled with higher costs or a higher travel time. This forces the respondent to relate the value of each component of preference.

SP surveys need to be stratified by audience: current users versus potential users. Current users should be asked to respond to questions about factors that would provide for a more comfortable or attractive journey through different types of environments, facilities or levels of service.

For potential users, it is important to create scenarios based on constructed markets. For example, questions could be what mode they would choose for work and non-work trips based on the quality of the transport environment, including travel by private vehicle, public transport, walking, and cycling. It would query residents about the degree to which they perceive different levels of service or facilities will improve the conditions of their commute, recreational activities and so forth. By measuring how demand might change, one can ascertain the preferences of current non-users, some of whom would become users if certain improvements were made.

Evaluators may wish to consult other sources for guidance as to the design and implementation of SP surveys to derive WTP values. The NZ Transport Agency may be able to provide some assistance in this regard.

4.8.3 TDM packages involving travel behaviour change infrastructure

Composite evaluation costs	Irrespective of the TBhC package composition, the total costs for all components of the package are included in the denominator of the benefit cost ratio. Where a new or improved public transport service is involved, the costs include the ’funding assistance‘ (the cost that needs to be funded by local and central government if the activity is to proceed).
Composite evaluation benefits	For the TBhC components in a package, the appropriate composite benefit value in Appendix A20 is used to calculate the ’new user’ benefits for the TBhC target population/area. The following procedure provides guidance as to the appropriate evaluation method to calculate benefits for existing users, and for new users from the population outside the TBhC target population/area, for: • new or improved public transport services • new or improved walking or cycling facilities • new or improved roading infrastructure of various types. The numerator of the benefit cost ratio for a composite TBhC package is the sum of the TBhC benefits and the non-TBhC benefits.

4.9 Demand estimates and modal share

4.9.1 Overview

Introduction

This chapter describes the methods to estimate how various types of changes to transport systems are likely to affect travel behaviour and therefore the demand for a mode, service or facility.

In this chapter

.4.9.2 Demand estimates

Definition

A demand estimate is a prediction of the future use of a transport facility, service or mode. Use can be influenced by the user charges, the attractiveness to users, and the availability and quality of alternative routes, services or modes.

Calculating the potential demand for a new or improved service or facility will generally be based on willingness to pay (WTP) values (derived from a stated preference (SP) survey) combined with data on current users, and existing and proposed user charges.

In some cases, it will be possible to calculate the demand based on international or New Zealand experience, including use of validated models.

Elasticity and cross-elasticity

Economists measure changes in consumption (use) using elasticities defined as the percentage change in consumption of a 'good' caused by a 1% change in its price or other characteristic (such as traffic speed or comfort).

For example, an elasticity of –0.5 for vehicle use with respect to vehicle operating costs means that each1% increase in these costs results in a 0.5% reduction in vehicle distance or trips. Similarly, public transport elasticity is defined as the percentage change in patronage resulting from each 1% change in transport service, such as bus kilometres or frequency. A negative sign indicates that the effect operates in the opposite direction from the cause (eg an increase in price causes a reduction in travel).

Cross-elasticities refer to the percentage change in the consumption of a good resulting from a price change in another, related good. For example, an increase in the cost of driving tends to reduce demand for parking and increase demand for public transport travel.

Transport elasticities tend to increase over time as consumers have more opportunities to take prices into account when making long-term decisions. For example, if consumers anticipate low private vehicle use prices they are more likely to choose a private vehicle dependent suburban home, but if they anticipate significant increases in driving costs they might place a greater premium on having alternatives, such as access to public transport and shops within convenient walking distance. These long-term decisions, in turn, affect the options that are available. It may take many years for the full effect of a price change to be felt. Long-run travel demand elasticities are typically two to three times short-run elasticities.

Appendix A14 provides some elasticity and cross elasticity values that may be used for freight or public transport services.

Nature of demand

The demand for a new or improved service or facility depends on several factors:

- current or 'base' average user charge
- the nature of the change in service
- the WTP of existing users for the service change
- the responsiveness of demand to changes in user charges (the user charge elasticity) or another journey attribute (eg in vehicle or walking time).

Factors affecting price elasticities

The following factors can affect how much a change in prices impacts travel activity:

- Type of price change. Vehicle purchase and registration fees can affect the number and type of vehicles purchased. Fuel prices and emission fees affect the type of vehicle used. A road toll may shift some trips to other routes and destinations. Congestion pricing may shift travel times as well as changing mode and the total number of trips that occur. Residential parking fees are likely to affect vehicle ownership. A time-variable parking fee can affect when trips occur.

- Type of trip and traveller. Commute trips tend to be less sensitive than shopping or recreational trips. Weekday trips may have very different elasticities than weekend trips. Urban peak period trips tend to be price insensitive because congestion discourages lower value trips. Travellers with higher incomes tend to be less price sensitive than lower income travellers. Business travellers tend to be less price sensitive than those travelling for personal activities.
- Quality and price of alternative routes, modes and destinations. Price sensitivity tends to increase if alternative routes, modes and destinations are good quality and affordable.
- Scale and scope of pricing, in general narrowly defined transport (eg peak period travel on a particular road) is more sensitive than more broadly defined transport (eg total personal travel), because consumers have more alternatives in the narrowly defined case.

Modal share

The mode share is a function of the difference in generalised costs between the modes. The relationship can be used in reverse to determine the change in generalised cost difference that is required to achieve an observed change in mode share.

Because mode share relationships are calibrated to actual behaviour, the generalised cost difference can be equated to the perceived benefit associated with a given change in mode share. Strategic transportation planning models contain such mode share relationships.

Rules

Demand estimates must be completed for all TDM economic evaluations.

Proposed activities for new transport services or for major improvements to an existing service, and any activities entailing a subsidy or price change, may require a specially commissioned study to assess WTP and elasticity of demand.

For small alterations to existing services or where the required amount of financial assistance is small, the demand estimates may be produced using WTP values drawn from other comparable services.

4.9.3 Forecasting the demand

Introduction

There are two distinct procedures for forecasting the demand for transport services or facilities, depending on whether the proposed activity is for a new service or facility or an improvement to an existing service or facility.

Note: The estimated future demand for the do-minimum and each option, including the proposal, must be calculated. Appendix A20 can be used to assess demand for a cycle facility when traffic counts have not been carried out in the area.

Procedure for new service or facility

Where a new transport service or facility is proposed, the evaluator could undertake a consumer preference survey and develop a demand estimate using a methodology appropriate to the proposed service or facility.

The basis of the survey and demand estimate and any underlying assumptions, particularly those related to traffic growth rates, shall be clearly stated in the evaluation report.

Procedure for improvement to service or facility

Forecasting demand for improvements to transport services or facilities involves the following:

Step	Action
1	Estimate the WTP and elasticity of demand for the particular quality improvement to an existing service or facility: • If the activity is for a major improvement to an existing service or facility then a specially commissioned SP survey could be undertaken to assess WTP and the elasticity of demand. • If the activity is for a relatively small change to an existing service or facility then inference of the WTP for the specific service quality and its elasticity of demand may be drawn from other comparable services or facilities. **Note**: Where information from a comparable service or facility is used, details of the comparison must be provided.
2	Identify the relevant elasticity and cross elasticity values for the user charges and service quality change, either from the SP survey or using values from other sources. Some values applicable to New Zealand are provided in Appendix A14.
3	Calculate the demand for the service where there is an increase in the user charge: Total number of new and existing users: $Q_{price} = [((P_1 - P_{new}) / P_1) \times UCE \times Q_1] + Q_1$ Where: Q_1 = existing number of users. P_1 = existing average user charge. P_{new} = new average user charge. UCE = user charge elasticity.
4	Calculate the demand for the service or facility based on the change in service quality: • Use the relevant elasticity value derived from the SP survey or from

	an alternative source. • Multiply the elasticity value by the number of new and existing users (Q_{price}) as calculated in step 3, to derive the total demand for the improved service ($Q_{quality}$).
5	Determine the proportion of new users transferring from road and from other sources. Use cross-elasticity values for road to alternate services where available or use other sources (ie surveys). Appendix A19 may provide appropriate indicative values. The diversion rates given in Appendix A21 for workplace travel plans with public transport improvements may be applicable.
6	Test the results by varying the user charge levels and service quality elasticity for the impact on the demand. From this testing, a more complete demand curve can be derived.
7	Compare the results of the demand estimate with other similar services, where feasible, to ascertain that the estimate is credible.

4.9.4 Sensitivity testing of the demand estimates

Introduction

The demand estimates will involve making assumptions and estimates, which may involve uncertainty or be subjective in nature. Assessments of the sensitivity of the demand estimates to critical assumptions shall be undertaken on the preferred option.

Required sensitivity tests

There are two sensitivity tests that should be performed on the demand estimates:

- Differing levels of user charges.
- Estimated user demand levels, including growth rates, and the assessment of diverted road trips and generated demand.

Each of these is described below.

User charges

Some testing on the effect of varying user charges on the demand for the proposed service and on service provider revenues must be done in developing the demand forecast.

The final evaluation must report the user charge levels that:

- maximise the service provider's revenue from user charges
- produce the highest economic return as indicated by the benefit cost ratio (BCR)
- maximise welfare (the fare level at which the present value (PV) of road traffic reduction benefits plus public transport user benefits minus costs is maximised).

The evaluation must state any practical or institutional limits on user charges.

Demand levels

If significant changes in user charges are envisaged in the proposal, the use of a constant elasticity could result in gross errors. Where significant changes in user charges are envisaged, the elasticity values should be varied and the effect on user demand, the funding gap, the activity benefits and the BCR reported.

In addition, upper and lower bounds of the estimated growth rates for the service should be established and the effect of these on user demand, the funding gap, the activity benefits and the BCR reported.

4.9.5 Reporting of estimates

Introduction

Regardless of what methodology is undertaken to complete a demand forecast, there are several pieces of information that must be derived, and reported in the evaluator's report, in order to be able to complete the evaluation procedures described in this manual. Each of these is described below.

Assumptions

Any assumptions made, particularly regarding future traffic and growth rates, must be clearly stated.

Peak period

Reporting of service use, road use and road trips is limited to the peak period. The peak period appropriate to the particular activity shall be defined and justified.

Except for freight services, in most cases new or improved transport services will be limited to the peak periods. Where a new or improved public transport service includes an off-peak component (such as crash reduction benefits) this shall be fully explained and justified in the evaluation.

Transport service or facility usage

The following data about the users of the service or facility is required:

- In the case of an existing service or facility:
  - the base or existing number of users
  - the one-off change in users as a result of implementing the proposal
  - the current trend for number of users.
- In the case of a new service or facility:
  - the projected number of users
  - the predicted future trend of use after the initial change or introduction of the new service or facility.
- The source(s) of new users of a service or facility:
  - transferred from other modes
  - transferred from private vehicles as either drivers or passengers
  - newly generated trips.

Road trips

Where there is an existing road or road network that will be affected by the improvement or implementation of a service or facility, the following data shall be presented:

- the existing number of road trips (by vehicle type where relevant)
- the change in number of road trips (by vehicle type where relevant)
- the new level of road trips following the implementation of the improved or new service or facility.

This information may be presented as actual number of road trips, total number of vehicle kilometres and/or total number of vehicle minutes, depending on the nature of the proposal.

The number of private vehicles can be estimated from the average vehicle occupancy rates, while the number of buses may be determined by using the service schedule then dividing by the average loading.

User charges

In the case of improvements to an existing transport service, the following information is required:

- the base (or existing) average user charge
- the proposed new user charge
- the maximum charge users would be WTP for the service improvement.

In the case of a new service, the information required is:

- the proposed new user charge
- the maximum charge users would be WTP for the new service.

For the purposes of this manual, the maximum user charge is considered to be that price above which no one would use the service under consideration.

4.9.6 References

1. Bureau of transport and regional economics. BTRE transport elasticities database online. Canberra. (dynamic.dotars.gov.au/bte/tedb/index.cfm).
2. TRL Limited (2004) *The demand for public transport: a practical guide.* TRL report TRL593.
3. Wallis I, Booz Allen and Hamilton (2004) *Review of passenger transport demand elasticities*. Transfund New Zealand research report 248.

4.10 Risk and uncertainty

Introduction

Cost benefit analysis of transport activities will involve making assumptions and estimates, which may involve uncertainty or be subjective in nature. The input value of significant factors must be subject to sensitivity testing (and a risk analysis if appropriate) for the effect on the economic efficiency of the activity.

See Section 2.10 for discussion and application of sensitivity analysis and risk analysis.

Significant inputs

Inputs to transport activities that should be considered for testing include:

- maintenance costs, particularly where there are significant savings
- traffic volumes, particularly model results, growth rates, and the assessment of diverted and induced traffic
- demand forecasts for transport services
- travel speeds
- road roughness
- crash reductions.

For each significant input the following shall be listed:

- the assumptions and estimates on which the evaluation has been based
- an upper and lower bound of the range of the estimate, and the resultant BCR at the upper and lower bound of each estimate.

Risk analysis for road activities

Risk analysis must be undertaken for all road activities with any of the following characteristics:

- the principal objective of the activity is reduction or elimination of an unpredictable event (eg a landslip or crash)
- there is a significant element of uncertainty
- the capital value of the activity exceeds $5 million.

Appendix A13 outlines the procedures for risk analysis of road activities and gives examples. These risk analysis procedures are not intended for activities subject to minor risks, such as occasional small slips from adjacent hills onto the road, etc.

Risk analysis for transport services

This section identifies how the risk analysis guidelines may be applied to other transport infrastructure and transport services, in particular public transport. The guidance modifies the description of the risk categories in FP Worksheet 19.1, summary of risks, to reflect the particular features of public transport activities. Because of the diversity of transport, modelling techniques, benefit sources and cost items, this guidance should be adapted to suit the particular context.

All evaluations for passenger and freight transport activities with a present value (PV) of the funding gap of greater than five million dollars are required to include a detailed risk analysis. The NZ Transport Agency encourages all activities with a net cost greater than one million dollars to include a risk analysis as part of the evaluation.

Note: Where an activity with a PV funding less than five million dollars warrants it, the NZ Transport Agency may request a risk analysis.

Appendix A13 outlines the procedures for risk analysis of transport services activities and gives examples.

5.0 Appendices

A1 Discounting and present worth factors

A1.1 Introduction

Introduction

This appendix provides tables of present worth factors for use in discounting. A discussion on the economic principles of discounted cash flow and present worth is contained in chapter 2 of this manual.

In this appendix

	Topic
A1.1	Introduction
A1.2	Discounting
A1.3	Single payment present worth factor
A1.4	Uniform series present worth factor
A1.5	Arithmetic growth present worth factor
A1.6	Annual present worth factors
A1.7	Quarterly present worth factors

A1.2 Discounting

Discounting

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value (PV) they need to be discounted back to time zero. Based on a discount rate of 6%, sets of present worth factors have been calculated to convert future benefits and costs to their PVs (see table A1.1 and A1.2). Tables for discount rates of 4% and 8% are also provided for use sensitivity testing.

Some benefits and costs occur at a single point in time in which case single payment present worth factors (SPPWF) shall be used to discount the amounts to their PV. Other benefits and costs occur continuously over a number of years in which case either uniform series (USPWF) or arithmetic growth present worth factors (AGPWF) shall be used to discount the amounts to a PV, depending on whether the amounts are uniform or increase arithmetically over time (eg traffic and patronage growth).

When discounting accident benefits the traffic growth rate will need to be adjusted in accordance with the procedures in Appendix A6 to determine the appropriate arithmetic growth rate to apply. External impacts are assumed to remain constant so the uniform present worth series should be used to obtain the PV of monetised impacts.

When discounting benefits or costs determined from a transportation model, the present worth factors specified in this appendix shall be used. If necessary, adjust values to time zero equivalents. Traffic growth rate may require a similar adjustment to time zero.

A1.3 Single payment present worth factor

Single payment present worth factor (SPPWF)

Where a single benefit or cost arises at some future time, a single payment present worth factor (SPPWF) shall be applied to calculate its PV.

The formula for determining SPPWF factors is:

$$SPPWF^i_n = \frac{1}{(1+i)^n} = \frac{1}{1.06^n} \quad \text{for a 6\% discount rate}$$

where:

n = time in years after time zero, and

i = is the discount rate in percent.

The PV of a single benefit or cost at time n shall be calculated as follows:

PV of benefit (or cost) = $SPPWF^i_n$ x benefit (or cost)

Example 1

For a section of road resealed 15 years after time zero at a cost of $50,000, the PV of the reseal cost using a discount rate of 6% is:

PV = $50,000 x $SPPWF^6_{15}$

= $50,000 x 0.4173

= $20,865

Example 2

A project costing $2 million with a implementation period of 15 months starting in the 8^{th} month after time zero, has the following cash flow for expenditure:

2^{nd} half of year 1

Month	7	8	9	10	11	12	Total
$ (000's)	0	50	50	50	100	150	400

1^{st} half of year 2

Month	13	14	15	16	17	18	Total
$ (000's)	200	200	300	300	200	100	1300

2^{nd} half of year 2

Month	19	20	21	22	23	24	Total
$ (000's)	50	50	100	100	0	0	300

The PV of the implementation expenditure is:

Using annual SPPWF from table A1.1

PV = ($400,000 + $1,300,000) x $SPPWF^{6}_{1}$ + $300,000 x $SPPWF^{6}_{2}$

= $1,700,000 x 0.9434 + $300,000 x 0.8900

= $1,870,780

A more accurate calculation using quarterly SPPWF from table A1.2

PV = $150,000 x $SPPWF^{6}_{0.75}$ + $450,000 x $SPPWF^{6}_{1.00}$

+ $800,000 x $SPPWF^{6}_{1.25}$ + $350,000 x $SPPWF^{6}_{1.50}$

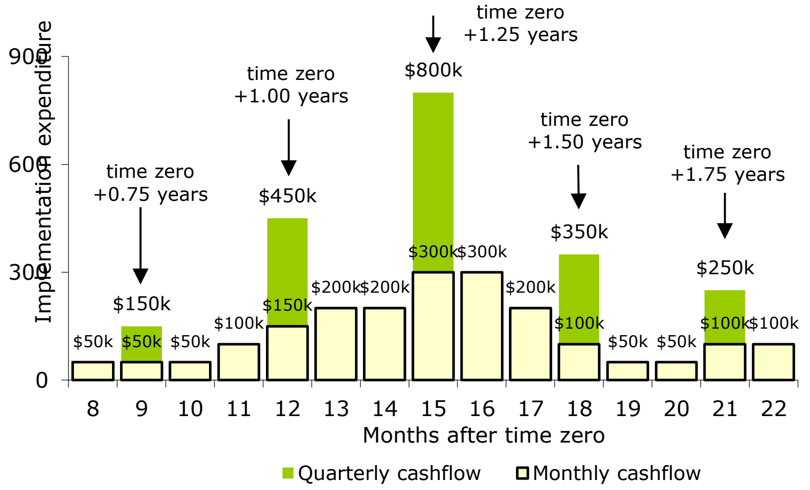
+ $250,000 x $SPPWF^{6}_{1.75}$

= $150,000 x 0.9572 + $450,000 x 0.9433

+ $800,000 x 0.9298 + $350,000 x 0.9163

+ $250,000 x 0.9031

= $1,858,385



A1.4 Uniform series present worth factor

Uniform series present worth factor (USPWF)

Where a series of equal benefits or costs arise each year or continuously over a period, uniform series present worth factors (USPWF) shall be applied to calculate their PV.

The USPWF factors shown in table A1.1 assume that the annual benefits or costs are evenly spread over each year and are continuously compounded.

The formula for determining these USPWF factors is:

$$USPWF^{i}_{n} = \frac{(1- (1 + i)^{-n})}{\log_e(1 + i)}$$

where:

n = time in years after time zero, and

i = is the discount rate in percent.

The PV of a time stream of equal annual benefits or costs shall be calculated as follows:

PV of benefits (or costs) = Annual benefit (or cost) x ($USPWF_e$- $USPWF_s$)

where:

s = the start year, and

e = the end year of the cost or benefit stream.

Example

If maintenance costs for the do minimum are \$30,000 a year over a 42 year evaluation period (40 years plus two years to the start of construction), the PV of the maintenance costs is:

PV = \$30,000 x ($USPWF^{6}_{42}$ - $USPWF^{6}_{0}$)

= \$30,000 x (15.677 - 0)

= \$470,310

A1.5 Arithmetic growth present worth factor

Arithmetic growth present worth factor (AGPWF)

Where costs or benefits increase (or decrease) each year arithmetically, arithmetic growth present worth factors (AGPWF) together with the corresponding USPWF factors shall be applied to calculate their PVs. It shall be assumed that traffic growth is arithmetic.

The AGPWF factors shown in table A1.1 assume that the annual benefits or costs occur continuously throughout the year and are continuously compounded.

The formula for determining these AGPWF factors is:

$$AGPWF^{i}_{n} = [\log_e (1 + i)]^{-2} - n.(1 + i)^{-n}. [\log_e (1 + i)]^{-1} - (1 + i)^{-n}. [\log_e (1 + i)]^{-2}$$

where:

n = time in years after time zero, and

i = is the discount rate in percent.

The PV of a time stream of benefits or costs which increase or decrease arithmetically shall be calculated as follows:

$$\text{PV of benefits (or costs)} = \text{Annual benefits (or costs)} \times \{(USPWF_e - USPWF_s) + (R \times (AGPWF_e - AGPWF_s))\}$$

where:

R = the arithmetic growth rate at time zero,

s = the start year, and

e = the end year of the cost or benefit stream.

Example

If vehicle operating costs are $70,000 with traffic growth of 1% at time zero, and construction finishes two years from time zero, the PV of the vehicle operating costs on the new construction is:

$$PV = \$70,000 \times [(USPWF^{6}_{42} - USPWF^{6}_{2}) + 0.01 \times (AGPWF^{6}_{42} - AGPWF^{6}_{2})]$$

$$= \$70,000 \times [(15.677 - 1.888) + 0.01 \times (206.674 - 1.851)]$$

$$= \$1,108,606$$

A1.6 Annual present worth factors

Table A1.1(a) Annual present worth factors for 6% discount rate (base case)

Time	Single payment SPPWF[1]	Time (years from time zero)	Uniform series USPWF[2]	Arithmetic growth AGPWF[2]
0	1.0000	0	0.0000	0.0000
1	0.9434	1	0.9714	0.4810
2	0.8900	2	1.8879	1.8512
3	0.8396	3	2.7524	4.0084
4	0.7921	4	3.5680	6.8591
5	0.7473	5	4.3375	10.3180
6	0.7050	6	5.0634	14.3069
7	0.6651	7	5.7482	18.7549
8	0.6274	8	6.3943	23.5971
9	0.5919	9	7.0038	28.7748
10	0.5584	10	7.5787	34.2343
11	0.5268	11	8.1212	39.9273
12	0.4970	12	8.6329	45.8098
13	0.4688	13	9.1157	51.8420
14	0.4423	14	9.5711	57.9883
15	0.4173	15	10.0008	64.2163
16	0.3936	16	10.4061	70.4971
17	0.3714	17	10.7885	76.8048
18	0.3503	18	11.1493	83.1162
19	0.3305	19	11.4896	89.4107
20	0.3118	20	11.8107	95.6699
21	0.2942	21	12.1136	101.8778
22	0.2775	22	12.3993	108.0200
23	0.2618	23	12.6689	114.0842
24	0.2470	24	12.9232	120.0593
25	0.2330	25	13.1631	125.9362
26	0.2198	26	13.3895	131.7068
27	0.2074	27	13.6030	137.3643
28	0.1956	28	13.8044	142.9030
29	0.1846	29	13.9945	148.3182
30	0.1741	30	14.1738	153.6061
31	0.1643	31	14.3429	158.7639
32	0.1550	32	14.5025	163.7893
33	0.1462	33	14.6530	168.6808
34	0.1379	34	14.7950	173.4374
35	0.1301	35	14.9290	178.0587
36	0.1227	36	15.0554	182.5449
37	0.1158	37	15.1746	186.8963
38	0.1092	38	15.2871	191.1139
39	0.1031	39	15.3932	195.1989
40	0.0972	40	15.4933	199.1528
41	0.0917	41	15.5877	202.9773
42	0.0865	42	15.6768	206.6744
43	0.0816	43	15.7609	210.2463
44	0.0770	44	15.8402	213.6954
45	0.0727	45	15.9150	217.0240
46	0.0685	46	15.9856	220.2348
47	0.0647	47	16.0522	223.3304
48	0.0610	48	16.1150	226.3136
49	0.0575	49	16.1742	229.1872
50	0.0543	50	16.2301	231.9540

Table A1.1(b) Annual present worth factors for 4% discount rate (sensitivity testing)

Time	Single payment SPPWF[1]	Time (years from time zero)	Uniform series USPWF[2]	Arithmetic growth AGPWF[2]
0	1.0000	0	0.0000	0.0000
1	0.9615	1	0.9806	0.4871
2	0.9246	2	1.9236	1.8984
3	0.8890	3	2.8302	4.1621
4	0.8548	4	3.7020	7.2105
5	0.8219	5	4.5403	10.9799
6	0.7903	6	5.3463	15.4104
7	0.7599	7	6.1213	20.4455
8	0.7307	8	6.8665	26.0321
9	0.7026	9	7.5831	32.1204
10	0.6756	10	8.2721	38.6635
11	0.6496	11	8.9345	45.6175
12	0.6246	12	9.5715	52.9410
13	0.6006	13	10.1841	60.5953
14	0.5775	14	10.7730	68.5442
15	0.5553	15	11.3393	76.7537
16	0.5339	16	11.8838	85.1919
17	0.5134	17	12.4074	93.8292
18	0.4936	18	12.9108	102.6376
19	0.4746	19	13.3949	111.5914
20	0.4564	20	13.8604	120.6663
21	0.4388	21	14.3079	129.8396
22	0.4220	22	14.7382	139.0905
23	0.4057	23	15.1520	148.3994
24	0.3901	24	15.5499	157.7481
25	0.3751	25	15.9325	167.1198
26	0.3607	26	16.3003	176.4990
27	0.3468	27	16.6540	185.8711
28	0.3335	28	16.9941	195.2228
29	0.3207	29	17.3212	204.5419
30	0.3083	30	17.6356	213.8170
31	0.2965	31	17.9380	223.0377
32	0.2851	32	18.2287	232.1944
33	0.2741	33	18.5082	241.2786
34	0.2636	34	18.7770	250.2821
35	0.2534	35	19.0355	259.1978
36	0.2437	36	19.2840	268.0191
37	0.2343	37	19.5229	276.7401
38	0.2253	38	19.7527	285.3554
39	0.2166	39	19.9736	293.8603
40	0.2083	40	20.1860	302.2505
41	0.2003	41	20.3903	310.5222
42	0.1926	42	20.5867	318.6723
43	0.1852	43	20.7755	326.6977
44	0.1780	44	20.9571	334.5960
45	0.1712	45	21.1317	342.3651
46	0.1646	46	21.2996	350.0033
47	0.1583	47	21.4610	357.5091
48	0.1522	48	21.6163	364.8815
49	0.1463	49	21.7655	372.1196
50	0.1407	50	21.9090	379.2228

Table A1.1(c) Annual present worth factors for 8% discount rate (sensitivity testing)

Time	Single payment SPPWF[1]	Time (years from time zero)	Uniform series USPWF[2]	Arithmetic growth AGPWF[2]
0	1.0000	0	0.0000	0.0000
1	0.9259	1	0.9625	0.4751
2	0.8573	2	1.8537	1.8061
3	0.7938	3	2.6789	3.8638
4	0.7350	4	3.4429	6.5331
5	0.6806	5	4.1504	9.7121
6	0.6302	6	4.8054	13.3107
7	0.5835	7	5.4120	17.2493
8	0.5403	8	5.9736	21.4577
9	0.5002	9	6.4936	25.8744
10	0.4632	10	6.9750	30.4454
11	0.4289	11	7.4209	35.1236
12	0.3971	12	7.8337	39.8681
13	0.3677	13	8.2159	44.6434
14	0.3405	14	8.5698	49.4188
15	0.3152	15	8.8975	54.1682
16	0.2919	16	9.2009	58.8692
17	0.2703	17	9.4818	63.5029
18	0.2502	18	9.7420	68.0536
19	0.2317	19	9.9828	72.5079
20	0.2145	20	10.2058	76.8554
21	0.1987	21	10.4123	81.0873
22	0.1839	22	10.6035	85.1970
23	0.1703	23	10.7806	89.1793
24	0.1577	24	10.9445	93.0305
25	0.1460	25	11.0963	96.7482
26	0.1352	26	11.2368	100.3311
27	0.1252	27	11.3670	103.7787
28	0.1159	28	11.4875	107.0914
29	0.1073	29	11.5990	110.2703
30	0.0994	30	11.7023	113.3171
31	0.0920	31	11.7980	116.2338
32	0.0852	32	11.8865	119.0230
33	0.0789	33	11.9685	121.6876
34	0.0730	34	12.0445	124.2307
35	0.0676	35	12.1148	126.6558
36	0.0626	36	12.1799	128.9663
37	0.0580	37	12.2401	131.1660
38	0.0537	38	12.2960	133.2586
39	0.0497	39	12.3476	135.2478
40	0.0460	40	12.3955	137.1375
41	0.0426	41	12.4398	138.9315
42	0.0395	42	12.4808	140.6337
43	0.0365	43	12.5188	142.2477
44	0.0338	44	12.5540	143.7774
45	0.0313	45	12.5865	145.2263
46	0.0290	46	12.6167	146.5981
47	0.0269	47	12.6446	147.8962
48	0.0249	48	12.6704	149.1239
49	0.0230	49	12.6944	150.2847
50	0.0213	50	12.7165	151.3816

[1] assuming cost or benefit occurs at end of year

[2] assuming costs or benefits for year occur continuously throughout the year and are continuously compounded.

A1.7 Quarterly present worth factors

Table A1.2 Quarterly single payment present worth factors

Time (years from time zero in quarters from 1 July to 30 June)	SPPWF six% discount rate	SPPWF four% discount rate (sensitivity)	SPPWF eight% discount rate (sensitivity)
0	1.0000	1.000	1.000
0.25	0.9855	0.9902	0.9809
0.50	0.9713	0.9806	0.9623
0.75	0.9572	0.9710	0.9439
1.00	0.9433	0.9615	0.9259
1.25	0.9298	0.9522	0.9083
1.50	0.9163	0.9429	0.8910
1.75	0.9031	0.9337	0.8740
2.00	0.8900	0.9246	0.8573
2.25	0.8771	0.9155	0.8410
2.50	0.8644	0.9066	0.8250
2.75	0.8519	0.8978	0.8093
3.00	0.8396	0.8890	0.7938
3.25	0.8275	0.8803	0.7787
3.50	0.8155	0.8717	0.7639
3.75	0.8037	0.8632	0.7493
4.00	0.7921	0.8548	0.7350
4.25	0.7806	0.8465	0.7210
4.50	0.7693	0.8382	0.7073
4.75	0.7582	0.8300	0.6938
5.00	0.7473	0.8219	0.6806
5.25	0.7365	0.8139	0.6676
5.50	0.7258	0.8060	0.6549
5.75	0.7153	0.7981	0.6424
6.00	0.7050	0.7903	0.6302
6.25	0.6948	0.7826	0.6182
6.50	0.6847	0.7750	0.6064
6.75	0.6748	0.7674	0.5948
7.00	0.6651	0.7599	0.5835
7.25	0.6554	0.7525	0.5724
7.50	0.6460	0.7452	0.5615
7.75	0.6366	0.7379	0.5508
8.00	0.6274	0.7307	0.5403

A2 Traffic data

A2.1 Introduction

Introduction

This appendix provides standard values for traffic composition (based on the vehicle classes listed below), vehicle occupancy and trip purpose. Guidance is also provided on measuring and estimation traffic volumes, traffic growth and speed.

These procedures can be used to provide traffic data for:

- the procedures in Appendix A3 for estimating travel time
- in the absence of measured data or
- in the absence of data from calibrated and validated transportation models.

Use of measured data

Wherever practical, measured data shall be used in preference to the default values given in the tables.

In this appendix

	Topic
A2.1	Introduction
A2.2	Traffic composition
A2.3	Separating the project into its component sections
A2.4	Dividing the year into time periods
A2.5	Vehicle occupancy and travel purpose
A2.6	Traffic volumes
A2.7	Traffic growth rates
A2.8	Future traffic volumes
A2.9	Travel times and speed
A2.10	References

A2.2 Traffic composition

Vehicle classes

The definitions for vehicle classes are provided in table A2.1.

Road categories

Road categories for the traffic data classifications in this appendix are provided in table A2.2.

Table A2.1 Vehicle classes

Vehicle classes	Vehicle class composition
Passenger cars	Cars and station wagons, with a wheelbase of less than 3.2 metres
Light commercial vehicles (LCV)	Vans, utilities and light trucks up to 3.5 tonnes gross laden weight. LCVs mainly have single rear tyres but include some small trucks with dual rear tyres
Medium commercial vehicle (MCV)	Two axle heavy trucks without a trailer, over 3.5 tonnes gross laden weight
Heavy commercial vehicle I (HCV I)	Rigid trucks with or without a trailer, or articulated vehicle with three or four axles in total
Heavy commercial vehicle II (HCV II)	Trucks and trailers and articulated vehicles with or without trailers with five or more axles in total
Buses	Buses, excluding minibuses

Table A2.2 Road categories

Road categories	Definition
Urban arterial	Arterial and collector roads within urban areas carrying traffic volumes of greater than 7,000 vehicles/day
Urban other	Other urban roads, carrying less than 7,000 vehicles/day
Rural strategic	Arterial or collector roads, connecting main centres of population and carrying over 2,500 vehicles/day
Rural other	Other roads outside urban areas

Standard traffic composition

Table A2.3 provides standard traffic compositions. For larger projects or sites with unusual traffic characteristics, classification counts are required. Bus numbers are site dependent and are not included in the standard traffic composition.

Note: that traffic composition data is not provided for strategic routes on the fringes of large population centres (ie populations greater than 40,000). Such routes are characterised by predominantly rural strategic traffic mixes but with high commuter peaks more typical of an urban arterial road. On these routes individual surveys of traffic composition will normally be required. Also traffic stream compositions are likely to vary throughout the day, and the result of a single period survey may not accurately reflect the daily traffic composition – if this is the case more surveys through the day will be required.

Table A2.3 Traffic composition (%)

Road category and time period	Vehicle class				
	Car	LCV	MCV	HCV I	HCV II
Urban arterial					
Morning commuter peak	85	10	2	1	2
Daytime inter-peak	84	11	2	1	2
Afternoon commuter peak	84	11	2	2	1
Evening/night-time	85	9	2	1	3
Weekday all periods	85	10	2	1	2
Weekend/holiday	87	8	3	1	1
All periods	85	10	2	1	2
Urban other					
Weekday	86	8	3	2	1
Weekend/holiday	87	9	2	1	1
All Periods	86	8	3	2	1
Rural strategic					
Weekday	75	12	4	4	5
Weekend/holiday	83	5	5	4	3
All periods	78	10	4	4	4
Rural other					
Weekday	78	11	3	4	4
Weekend/holiday	84	6	4	4	2
All Periods	81	9	3	4	3

A2.3 Separating the activity into its component sections

Procedure

Follow the steps below to separate the activity into its component sections:

Step	Action
1	Separate the project into: motorway sections multilane roads two-lane rural roads other urban roads signalised intersections priority intersections roundabouts.
2	Identify any bottleneck locations

General guidance

Sections must be chosen so as to ensure conservation of vehicle movements (ie the sum of the flows into a section must equal the sum of the flows out).

Section lengths may be divided into sub-sections when it comes to calculating vehicle operating costs.

Guidance for motorways and multilane roads

Each motorway section or multilane road section shall consist of a length of road with:

- uniform design speed
- one direction of travel
- uniform number of through lanes
- boundaries which generally extend between major interchanges where significant flows leave or join the section.

Guidance for two-lane rural roads

Each two-lane rural road section shall be at least 1km and not more than 5km in length. The two-lane rural road section to be analysed may be longer than the activity length.

A2.4 Dividing the year into time periods

Days of the year

Each year is defined as having 365 days comprising:

- 245 weekdays
- 52 Saturdays
- 68 Sundays and public holidays.
- Weekends and holiday periods cover Saturday and Sunday, all public holidays and two weeks over Christmas and New Year. These account for 120 days per year.

Time periods

The default weekday time periods are:

- morning commuter peak (0700 – 0900)
- daytime interpeak (0900 – 1600)
- evening commuter peak (1600 – 1800)
- evening/nighttime (1800 – 0700).
- Saturdays and Sundays do not usually need to be divided into time periods unless there are substantial demands.

Procedure

Follow the steps below to divide the year into time periods:

Step	Action	
1	Divide the year into the days specified above	
2	Divide each day type into time periods as follows:	
	If there…	Then…
	are only very low levels of vehicle interaction throughout any day	no division of the day is necessary
	is significant levels of vehicle interaction	divide each day into a number of time periods to allow analysis at different flow levels, such that: operating conditions (such as proportion of traffic turning, percent working and vehicle composition) are essentially constant the period is long enough to ensure sufficient total capacity is available, even though for some of the time the capacity is exceeded.

A2.5 Vehicle occupancy and travel purpose

Vehicle occupancy and travel purpose

Standard vehicle occupancy and travel purpose figures are provided in table A2.4. For large activities or sites with unusual traffic characteristics, vehicle occupancy surveys shall be conducted by roadside observation of the traffic stream in conjunction with classification counts. Vehicle occupancy counts shall include drivers and passengers.

'Working' refers to trips carried out in the course of paid employment, 'commuting' refers to trips between home and work, while ‘other’ refers to all other non-work trips (ie, other than commuting).

Travel purposes is a difficult characteristic to survey and recourse to the standard values provided in table A2.4 will be required in most cases. At present there is no accepted method of differentiating between work and non-work trips by observing moving traffic stream. Field surveys of trip purpose require roadside interviews. Survey results from urban transportation studies can be used where appropriate. The values in table A2.4 have been derived from the National Household Travel Survey.

Table A2.4 Vehicle occupancy and travel purpose

Road category	Car				LCV				MCV and HCV			
	Occupancy	Travel purpose %			Occupancy	Travel purpose %			Occupancy	Travel purpose %		
		Work	Commute	Other		Work	Commute	Other		Work	Commute	Other
Urban arterial												
AM Peak	1.4	10	50	40	1.4	65	20	15	1.2	90	5	5
Daytime inter-peak	1.3	30	10	60	1.4	65	5	30	1.2	90	0	10
PM peak	1.4	10	30	60	1.4	65	15	20	1.2	90	5	5
Evening/ night-time	1.4	10	5	85	1.4	65	15	20	1.2	90	5	5
Weekday all periods	1.4	20	20	60	1.4	65	10	25	1.2	90	5	5
Weekend	1.7	5	5	90	1.7	10	10	80	1.6	75	5	20
All periods	1.5	15	15	70	1.5	50	10	40	1.3	85	5	10
Urban other												
Weekday	1.4	20	20	60	1.6	65	10	25	1.2	90	5	5
Weekend	1.7	5	5	90	2.0	10	10	80	1.6	75	5	20
All periods	1.5	15	15	70	1.7	45	10	45	1.3	85	5	10
Rural strategic and rural other roads												
Weekday	1.6	40	10	50	1.6	75	5	20	1.3	90	5	5
Weekend	2.2	5	5	90	2.0	10	10	80	1.8	75	5	20
All periods	1.7	30	10	60	1.7	55	5	40	1.4	85	5	10

A2.6 Traffic volumes

Use of transportation models to predict traffic volumes

Wherever properly calibrated and validated transportation models are available in urban areas, they shall be used to assess the effects of the activity on traffic volumes and predict future traffic volumes. As well as the normal validation required to ensure that the models are operating satisfactorily, they shall also be validated in the local area containing the activity. Transportation models usually account for but do not separately identify normal and diverted traffic. In determining the do-minimum traffic volumes, models shall be iterated from distribution to assignment until convergence is achieved. The same trip matrix shall then normally be used for evaluating the do-minimum and the activity options.

In highly congested activity option networks, variable matrix methods (see Appendix A11) need to be applied.

Traffic volumes

Traffic volumes are generally expressed in terms of annual average daily traffic (AADT) and average weekday, average weekend/holiday, average hour or average quarter hour volumes. The methods given below for determining traffic volumes based on traffic counts are derived from the NZ Transport Agency's *Guide to Estimating AADT and Traffic Growth.*

Method for estimating AADT

To estimate AADT from a sample count it is necessary to adjust the count data for a number of factors. Count data shall be checked for consistency and reasonableness and axle pair counts (eg from tube counters) shall be corrected by applying an adjustment factor to convert from axle pair counts vehicle counts.

Daily counts for less than a week shall be adjusted by applying day factors (for the appropriate typical traffic pattern) to derive weekly average daily traffic. Weekly average daily traffic figures shall then be adjusted by applying the appropriate week factors to derive AADTs. If more than one week is counted, the AADT shall be determined for each week, and then averaged.

To determine day and week factors, the appropriate traffic pattern control group shall be identified from the NZ Transport Agency's *Guide to Estimating AADT and Traffic Growth*. Alternatively these factors may be derived from rigorous local traffic counting programmes.

Method for estimating weekday or weekend/ holiday volume

The weekday, Saturday and Sunday/holiday volumes shall be derived from AADTs by applying locally derived day factors where these are available, or the factors in the NZ Transport Agency's *Guide to Estimating AADT and Traffic Growth* if local data is not available. The Saturday and Sunday/holiday volumes so obtained shall be averaged to derive an average weekend/holiday daily volume.

Method for estimating hourly or quarter hourly directional volumes

Where traffic volumes are required for shorter time periods than a day, then these shall be obtained from directional counts.

Counts done to produce estimates of the AADT will usually have been obtained from traffic counters that record volumes by 60 or 15 minute intervals. Week factors shall be applied to these counts to obtain estimates of 60 or 15 minute traffic volumes.

For intersection volumes, manual counts of turning movements should be consistent with the requirements of NZS 5431:1973 clause 5.4.

Axle pair adjustment

Wherever possible measured data shall be used to determine the axle pair adjustment factors, but in absence of such data the following factors shall be used. To convert axle pairs to

factors

vehicles, multiply by the appropriate factor.

Axle pair adjustment factors

Road category	Axle pair adjustment factor
Urban	0.91
Rural	0.83

A2.7 Traffic growth rates

Traffic growth rates

Traffic growth rates shall be arithmetic growth rates (not geometric growth rates) and expressed as a percentage of the predicted traffic volume at the time zero.

Actual traffic counts at the site (or at adjacent sites) shall be used to determine current traffic growth rates wherever possible. This requires at least four counts in the last six years sufficient to estimate traffic volumes (or seven or more counts in the last 10 years). This information shall be checked for consistency with traffic counts at nearby sites and with the default values provided in table A2.5. The traffic volume and the average traffic growth rate at time zero shall then be determined using linear regression to best fit the traffic volume data.

To estimate the traffic growth rate for several sites combined, traffic growth rates shall be calculated for each site for which count data are available, and a weighted average calculated (where the traffic growth rate for each site is weighted by its traffic volume at time zero).

It might not be appropriate to assume continuation of current traffic growth rates over the whole project analysis period. The current traffic growth rate shall be adjusted, as appropriate, to account for the influences described in Appendix A2.8.

A2.8 Future traffic volumes

Future traffic volumes

In predicting future traffic volumes, normal traffic growth, diverted traffic, generated and redistributed traffic, and intermittent traffic shall be taken into account. The procedure adopted for estimating future traffic volumes must fulfil the requirement that demand is in approximate equilibrium with supply.

Normal traffic growth

Traffic growth rates determined in accordance with Appendix A2.7 are considered to provide a sound basis for predicting future traffic demands provided there are no traffic restraints.

If there are capacity restrictions in the system then the traffic volume shall not exceed capacity available within the time period under analysis, taking into account the potential for trip diversion, peak spreading and trip suppression.

If the level of service is low, peak spreading should be considered. Appendix A11 provides guidance on the treatment of peak spreading.

If the site is upstream or downstream of a bottleneck and the bottleneck is not being relieved by the activity, the volume at the site will be constrained by the capacity of the bottleneck, and therefore traffic volumes and traffic growth rate at the activity site shall reflect this restriction on growth, subject to peak spreading.

In some situations changing land use patterns can significantly alter the traffic volumes at a site. For example the development of large supermarket in an urban area may cause a one off upward step in traffic volumes.

Diverted traffic

Diverted traffic to or from the route(s) served by the activity occurs when:

- traffic re-routes from another route because the activity (or another activity on the route) now makes this the preferred route
- traffic re-routes to another route because an activity on that route now makes it the preferred route
- capacity restraints at the activity site or elsewhere on the route cause traffic to re-route to other routes
- capacity restraints on other routes cause traffic to re-route to the route.

These effects shall be taken into account in estimating future traffic volumes.

Induced traffic

In general it shall be assumed that activities do not induce any new trips or causes are distribution to new destinations. In cases where the effect of excluding induced or redistributed trips are expected to significantly affect the evaluation, then a variable matrix approach should be adopted (see Appendix A11).

Intermittent traffic

Intermittent traffic is traffic that will not occur over the full life of the project. Examples include traffic from forestry lots which produce a short term demand at logging time, or traffic generated by major construction project such as a power station which produces traffic for duration of the construction period. In calculating future traffic volumes, intermittent traffic shall be taken into account.

A2.9 Travel times and speed

Travel times and speed

Travel time and/or speeds shall be measured where required. Suitable methods for measuring average travel times or speed depending on circumstances include:

- floating car survey
- number plate survey
- spot measurement of speed.

The floating car and number plates survey methods measure the average travel time over a length of road.

The floating car survey method is relatively cheap and convenient method but will not readily differentiate the average travel times of light and heavy traffic. It is only suitable for higher traffic volumes in excess of 500 vehicles/hour/lane.

The number plate method is a larger undertaking but potentially more accurate and has ability to give data on the average travel times of individual or categories of vehicle. Several software packages are available for analysing number plate survey data as are electronic field-book programmes for facilitating the data input.

The average travel time over a section of road may not provide sufficient information for calculating vehicle operating costs if one or more speed change cycles occur within the section. Speed change cycles should be separately identified in urban areas where speeds reduce to below 20km/h and for rural areas where vehicles slow down for example to negotiate a sharp bend or at an intersection.

In such cases, spot measurement of speed will be required at a sufficient number of other locations to establish the average cruise speed for the road section and at the points of minimum speed. If vehicles stop at any point on the road section, then the average length of stopped time will also be required for the operating cost calculations. An alternative to spot measurements of speed will be to arrange number plate survey points such that they do not contain speed change cycles within their length.

When averaging the results of speed spot measurements, the space mean speed should be calculated using the following formula:

$$v = \frac{n}{\left[\frac{1}{v_1} + \frac{1}{v_2} + \frac{1}{v_3} + \frac{1}{v_4} + \ldots + \frac{1}{v_n}\right]}$$

where

v_i = spot speed measurement

n = total number of spot speed measurements

A2.10 References

1. Bennet, CR (1985) *A methodology for conducting traffic surveys for use with TRARR analyses*, Roading Directorate report RRS-005,National Roads Board.
2. Carpenter P,Mara M, Morgan Y, Tate F and Wilkie S (2004), *Monitoring and Data Management Protocol: Environmental Indicators for Transport,* Ministry for the Environment New Zealand
3. Standards NZ (1973) *NZS 5431*: *Specification for traffic signals*
4. Transfund New Zealand, *Update and enhancement of traffic count guide*, Transfund New Zealand research report 202, 2000.
5. Transfund New Zealand, *Guide to estimates and monitoring of traffic counting and traffic growth,* Transfund New Zealand research report 205, 2000.
6. Transit New Zealand, *Guide on estimating AADT and traffic growth,* November 1994.

A3 Travel time estimation procedures

A3.1 Use of travel time estimation procedures

Introduction

Travel times shall be estimated according to the procedures in this appendix. Definitions for classifying traffic data and default traffic data values are provided in Appendix A2. Where a specific procedure is not given, the travel time shall be determined according to a recognised procedure compatible with the manuals and procedures referred to in this appendix.

The methods are capable of application by hand, spreadsheet and within transportation models. The methodology gives a reasonable approximation for travel time without having to analyse dynamic queuing situations. More precise methods are not precluded.

Use of measured data

Wherever practical, measured data shall be used in preference to the default values given in the tables.

Basis of methodology

The procedures for road sections are based on and are consistent with the Highway capacity manual (HCM)[1].

The procedures for intersections are drawn from Akcelik and Rouphail[2], ARRB internal report 367-1[3], ARRB research report 123[4], Kimber and Hollis[5] and Austroads *Guide to traffic engineering practice, part 6 - roundabouts*.

Transportation models

When a transportation model is used for activity analysis, the model shall have been satisfactorily validated on both traffic volumes and travel times. Checklists for validating transportation models are provided in FP Worksheet 8 of the full procedures.

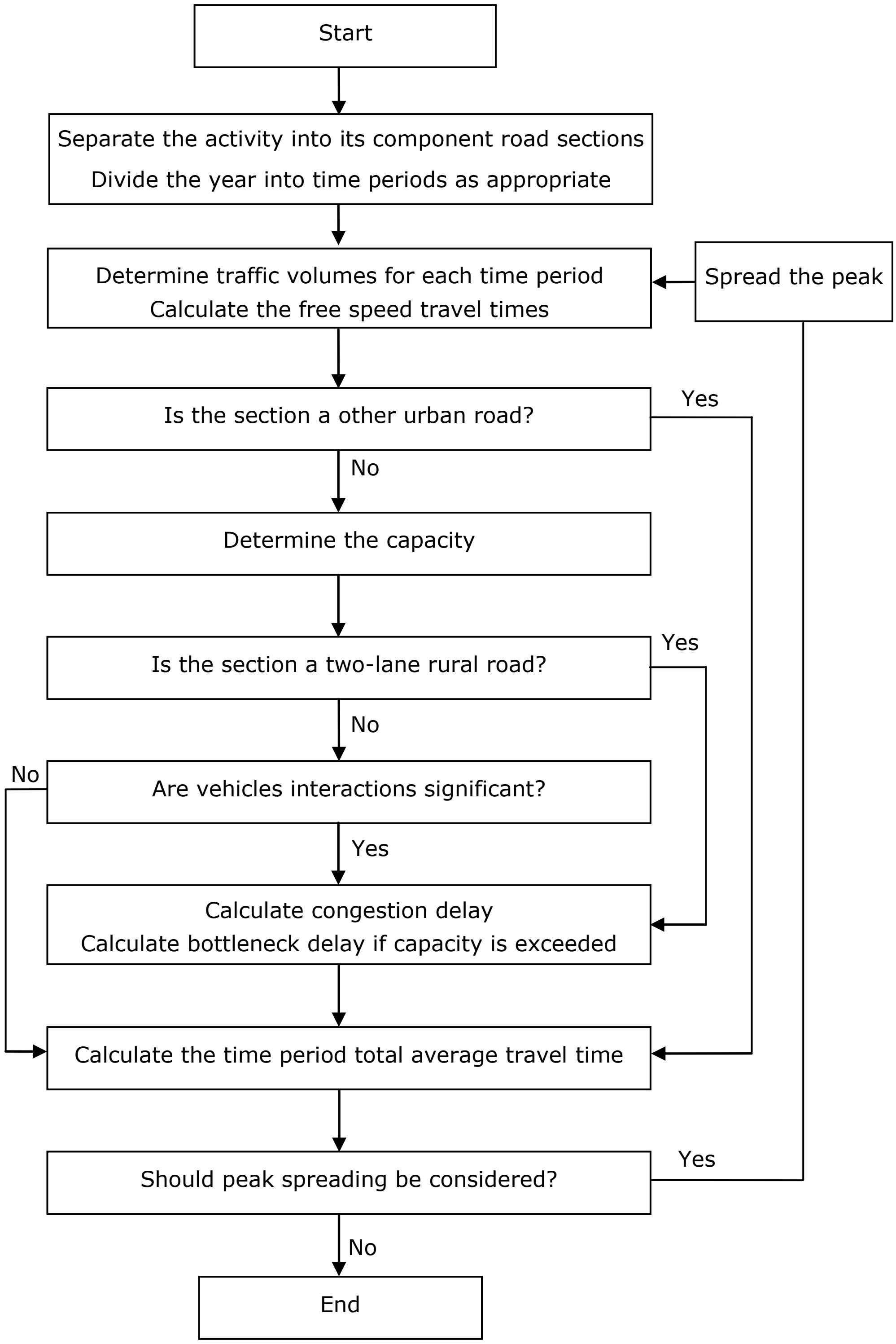
It is necessary that the travel times used by the model to derive the flows must be consistent with the travel times estimated by using this appendix during evaluation. To adhere to this it is suggested that the functions implied by the procedures in this appendix be used as a starting point, and modified as necessary to get a satisfactory validation.

In this appendix

A3.2 The stages for estimating travel time

Flow chart for estimating travel time

The flow chart below shows the basic stages for estimating road section travel time (the stages are slightly different for intersections).



A3.3 Determining traffic volumes

Introduction

This procedure details the base and future year traffic volumes that need to be determined for estimating travel time.

In some cases, growth constraint methods may be needed to estimate the do-minimum and activity option matrices where high future levels of congestion are anticipated, usually because the network(s) have insufficient capacity to meet unrestrained travel demands. In some cases, variable matrix methods may be needed to estimate the do-minimum and activity option matrices (refer to Appendix A11)

Definition

The *base traffic volumes* are the traffic volumes as at either:

- a recent census year adjusted to time zero, or
- a year at which the transportation model has been calibrated to time zero.

Procedure

Follow the steps below to determine traffic volumes:

Step	Action	
1	Determine the base traffic volumes for each section using the procedure outlined in Appendix A2.6, or by means of a transportation model.	
2	Estimate the traffic volumes for each section for at least two future years using a suitable prediction method. **Note:** The method adopted for estimating future traffic volumes must satisfy the requirement that demand is in approximate equilibrium with supply.	
3	Judge whether future year capacity problems occur. **Note:** This step requires an estimate of the capacity that is not determined until appendix A3.8. A first iteration of this whole procedure may be used before judging whether this step is relevant.	
	If there is…	**Then…**
	Sufficient capacity for future year traffic volumes in the do minimum and activity option	Generally apply standard fixed trip matrices and evaluation procedures.
	Adequate levels of service for future year traffic volumes in the activity option, but not in the do-minimum (typically a do-minimum level of service of E or F)	Generally improve the capacity of the do-minimum network and/or apply growth constraint techniques to the do-minimum matrix (see Appendix A11.1); When evaluating activity benefits, use the procedures in worksheet 3.

	High congestion (typically level of service E or F) in both the do-minimum and activity options	Generally apply variable matrix methods (see Appendix A11.9); When evaluating activity benefits, use the procedures in worksheet 3; For verification purposes, carry out a fixed matrix analysis using growth constraint techniques (Appendix A11.2).

A3.4 Calculating free speed travel time

When to use

Use this procedure for all road section types.

Procedure

Follow the steps below to calculate the free speed travel time:

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td>1</td><td colspan="2">Take measurements of free speed in the field at flow rates below 600 veh/h per lane.
Alternatively, measurements of free speed from a similar road section in the locality, with similar characteristics, can be used.
Note: To proceed with a preliminary value of free speed before measurements have been collected or if the road section is part of a proposed facility, then follow step 2.</td></tr>
<tr><td rowspan="6">2</td><td colspan="2">If measured speeds are not available, then determine the free speed using the appropriate procedure as follows:</td></tr>
<tr><th>If the road section is…</th><th>Then use the procedure in…</th></tr>
<tr><td>a motorway section</td><td>105 km/h
where design speed > 110 kmh</td></tr>
<tr><td>a multlilane road</td><td>Appendix A3.5</td></tr>
<tr><td>a two-lane rural road</td><td>Appendix A3.6</td></tr>
<tr><td>other urban road</td><td>Appendix A3.7</td></tr>
<tr><td>3</td><td colspan="2">Using the free speed determined in either step 1 or 2, calculate the travel time in minutes per kilometre.
Example:
Free speed = 100 km/h
Free speed travel time = 60/100
= 0.600 mins/km</td></tr>
<tr><td>4</td><td colspan="2">Determine the capacity from Appendix A3.8.
Other urban road capacity is not required for calculating travel time but is used in determining additional vehicle operating cost of congestion.</td></tr>
</table>

A3.5 Determining the free speed of multi-lane roads

When to use

This procedure is for required for analysis of activities to which Appendix A3.4 applies.

The free speed of proposed or existing facilities for which there is no measured data is estimated by adjusting the basic free speed under ideal conditions.

Adjustments to the basic free speed are made for:

- dividing medians
- lane width
- lateral clearance
- density of access points

Lateral clearance

The lateral clearance is the sum of any median shoulder and sealed left hand shoulder widths beyond the edge of the through lanes that are continuously available.

Procedure

Follow the steps below to determine the free speed of a multilane road section.

Step	Action	
1	If measured speeds are not available, then determine the **basic free speed** for the multilane road section as follows:	
	If the section has a posted speed limit of…	**Then use a basic free speed of…**
	100 km/h	105 km/h
	80 km/h	90 km/h
	70 km/h	80 km/h
	50 km/h	60 km/h
2	Adjust the basic free speed to account for **dividing medians** as follows:	
	Dividing median	**Adjustment to basic free speed**
	Has a dividing median	No reduction
	No dividing median	Reduce by 3 km/h
3	Adjust the basic free speed to account for **lane widths** as follows:	
	If lane widths are…	**Adjustment to basic free speed**
	3.5 metres or greater	No reduction
	Less than 3.5 metres	Reduce by 3 km/h

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="6">4</td><td colspan="2">Adjust the basic free speed to account for lateral clearance as follows:</td></tr>
<tr><th>If the section has lateral clearance of…</th><th>Adjustment to basic free speed</th></tr>
<tr><td>3m or greater</td><td>No reduction</td></tr>
<tr><td>Less than 3m but at least 2m</td><td>Reduce by 2 km/h</td></tr>
<tr><td>Less than 2m but at least 1m</td><td>Reduce by 4 km/h</td></tr>
<tr><td>Less than 1m</td><td>Reduce by 9 km/h</td></tr>
<tr><td rowspan="4">5</td><td colspan="2">Adjust the basic free speed to account for density of access points along the section as follows:</td></tr>
<tr><th>If the section has a density of access points per km of…</th><th>Adjustment to basic free speed</th></tr>
<tr><td>Less than 40</td><td>0.4 km/h per access point</td></tr>
<tr><td>40 or more</td><td>16km/h</td></tr>
</table>

Example calculation

Below is an example calculation for the free speed of a multilane road section where measured speeds are not available.

Example:

Posted speed limit	=	70 km/h
Median divided	=	yes
Lane width	=	3.5 metres
Lateral clearance	=	1.0 metres
Access points density	=	10 per km
Basic free speed	=	80 km/h
Dividing median speed reduction	=	0 km/h
Lane width speed reduction	=	0 km/h
Lateral clearance speed reduction	=	4 km/h
Access point speed reduction	=	10 × 0.4 = 4 km/h
Free speed	=	80 – 0 – 0 – 4 – 4 = 72 km/h

A3.6 Determining the free speed of two-lane rural roads

When to use

This procedure is called from A4 and should be used if no measured speeds are available.

Option for more detailed methodology

The procedure adopted in this section provides a realistic but approximate method for assessing travel times. Alternatively the HCM provides a more detailed methodology for the evaluation of local improvements, such as design speed increases and climbing and passing lanes, and the computer programme TRARR may be used for detailed analyses.

Design speed

The definition of design speed used in this section is that used by the HCM and the Austroads *Guide to traffic engineering practice part 2 roadway capacity.*

Procedure

The free speed of a two-lane rural road is determined by the speed environment that can be approximated by the average design speed of the road section under consideration and the associated approaches.

Follow the steps below to determine the free speed of a two-lane rural road section.

Step	Action
1	Obtain the following basic data for the road section: length of road section centreline length of each curve including transitions length of each straight (tangent) design speed of the straights (tangents) design speed of the curves.
2	Calculate the travel time for each curve and straight, as per steps 3 and 4. **Note:** it is acceptable to assume an abrupt change in speed where straights and curves meet.
3	Calculate the travel time on curves (including transitions). Example: Curve 1 length = 0.200 km Curve 1 design speed = 80 km/h Curve 1 travel time = 0.2/80 × 60 = 0.150 minutes Curve 2 length = 0.150 km Curve 2 design speed = 70 km/h Curve 2 travel time = 0.15/70 × 60 = 0.129 minutes Curve 3 length = 0.100 km Curve 3 design speed = 70 km/h Curve 3 travel time = 0.10/70 × 60 = 0.086 minutes Total curve travel times = 0.150 + 0.129 + 0.086 = 0.365 minutes

4	Calculate the travel time on the straights (tangents) **Note:** unless constrained by other design criteria the design speed for straights (tangents) should be assumed to be 100 km/h in severe terrain and a maximum of 120 km/h in gentler country (Austroads Rural Road Design) Example: Tangent length = 0.550 km Tangent design speed = 120 km/h Tangent travel time = 0.550/120 × 60 = 0.275 minutes
5	Calculate the total travel time on the road section. Example: Travel time on curves = 0.365 minutes Travel time on straights = 0.275 minutes Total travel time = 0.365 + 0.275 = 0.640 minutes
6	Calculate the average design speed for the road section. Example: Road section length = 1.000 km Total travel time = 0.640 minutes Average design speed = 1.000/0.640 × 60 = 93.75 km/h
7	Determine the free speed as follows:

If the average design speed is …	Then the free speed is…
above 100 km/h	105 km/h
below 100 km/h	105 km/h minus 13 km/h for every 18 km/h reduction in design speed below 100 km/h

Example:

Average design speed	=	93.75 km/h
Free speed	=	105 – ([(100 – 93.75) / 18] × 13)
	=	100.5 km/h

A3.7 Determining the free speed of other urban roads

When to use

This procedure is called from Appendix A3.4 and should be used if no measured speeds are available.

Procedure

Follow the steps below to determine the free speed of an 'other urban road'.

Step	Action			
1	Determine the classification of the other urban road section as follows:			
	If the design category of the road section is …	**And the functional category is…**	**Then the road classification is…**	
	suburban	principal	Class I	
	suburban	minor	Class II	
	intermediate	principal	Class II	
	intermediate	minor	Class II or III	
	urban	principal	Class II or III	
	urban	minor	Class III	
	Design category			
	Criterion	**Suburban**	**Intermediate**	**Urban**
	Driveway/access density	Low density	Moderate density	High density
	Arterial type	Multilane divided, undivided or two-lane with shoulders	Multilane divided or undivided, one-way, two-lane	Undivided one-way, two-way, two or more lanes
	Parking	No	Some	Significant
	Separate right-turn lanes	Yes	Usually	Some
	Signals/km	0.6–3.0	2–6	4–8
	Pedestrian activity	Little	Some	Usually
	Roadside development density	Low to medium	Medium to moderate	High

Step	Action		
	Functional category		
	Criterion	**Principal**	**Minor**
	Mobility function	Very important	Important
	Access function	Very minor	Substantial
	Points connected	Motorways, important activity centres, major traffic generators	Principal arterials
	Predominant trips served	Relatively long trips between major points and through-trips entering, leaving, and passing through the city	Trips of moderate length within relatively small geographical areas
2	Determine the **free speed** for the road section as follows:		
	If the road classification is…	**Then the range of likely free speeds are between…**	**And a typical free speed would be…**
	Class I	60 and 65 km/h	63 km/h
	Class II	50 and 60 km/h	55 km/h
	Class III	45 and 55 km/h	50 km/h

A3.8 Determining the capacity of road sections

Introduction

In the absence of measured capacities, the capacity of a road section shall be determined by the methods specified in this appendix for each facility type according to the conditions that prevail during the time interval. For example, when estimating capacity: the proportion of commercial vehicles, the average intensity of conflicting flows, and the performance of traffic control devices during the time interval shall be taken into account.

For other road types not covered by these procedures refer to the HCM.

In fulfilling the requirement that demand is in approximate equilibrium with supply, the procedure adopted for estimating future traffic volumes must ensure that in particular, the estimated traffic volume over any time period is less than the total available capacity for the time period of all road sections and intersections located within and near the project under analysis

Blocking back onto upstream sections

Where traffic volumes exceed capacity, the resulting queues may block back onto upstream links. In such circumstances care must be taken that the delays arising on the under-capacity section are not double counted on any upstream section.

Selecting the appropriate procedure

Follow the steps below to select the appropriate procedure for determining the capacity of each road section.

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td rowspan="10">1</td><td colspan="3">Select the appropriate procedure for determining the capacity of each road section as follows:</td></tr>
<tr><th>If the road section is….</th><th colspan="2">Then go to…</th></tr>
<tr><td>a motorway section</td><td colspan="2">Appendix A3.9</td></tr>
<tr><td>a multilane road</td><td colspan="2">Appendix A3.10</td></tr>
<tr><td>a two-lane rural road</td><td colspan="2">Appendix A3.11</td></tr>
<tr><td rowspan="5">other urban road</td><td colspan="2">Appendix A3.22
It is not necessary to determine capacity for travel time. However the capacities below are required when determining the additional congestion vehicle operating cost.</td></tr>
<tr><th>Road class</th><th>Capacity</th></tr>
<tr><td>Class I</td><td>1200 veh/lane/hour</td></tr>
<tr><td>Class II</td><td>900 veh/lane/hour</td></tr>
<tr><td>Class III</td><td>600 veh/lane/hour</td></tr>
<tr><td>2</td><td colspan="3">Once the capacity has been determined go to Appendix A3.12.</td></tr>
</table>

A3.9 Determining the capacity of motorways

When to use

This procedure is called from Appendix A3.8.

Procedure

Following the steps below to determine the capacity of a motorway section where each direction of travel is a separate motorway section component (See Appendix A2.3). Capacities are expressed as passenger car equivalents (pcu).

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="4">1</td><td colspan="2">Determine the basic capacity for the motorway section as follows:</td></tr>
<tr><td>If the road section has...</td><td>Then use a basic capacity of…</td></tr>
<tr><td>2 through lanes
3 through lanes
4 through lanes</td><td>4,500 pcu/h
6,900 pcu/h
9,600 pcu/h</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="3">2</td><td colspan="2">Determine the passenger car equivalent to be used for trucks for the motorway section as follows:</td></tr>
<tr><td>If the terrain type is…</td><td>Then use a passenger car equivalent for trucks (E_t) of…</td></tr>
<tr><td>level
rolling
mountainous</td><td>1.7 pcu
4.0 pcu
8.0 pcu</td></tr>
<tr><td>3</td><td colspan="2">Calculate the adjustment factor for trucks using the passenger car equivalent for trucks (E_t) determined in step 2.
Adjustment factor (f_t) = $1/ (1 + P_t \times (E_t - 1))$
where P_t = the proportion of trucks in the traffic stream during the peak period.
Example:
Terrain type = rolling
Proportion of trucks (P_t) = 0.12
Pcu for trucks (E_t) = 4.0 pcu
Adjustment factor (f_t) = $1/(1 + 0.12 \times (4.0 – 1))$
= 0.735</td></tr>
</table>

4	Calculate the motorway section capacity by multiplying the basic capacity, determined in step 1, by the adjustment factor for trucks (f_t) determined in step 3. Motorway section capacity = Basic capacity x f_t Example: Through lanes = 3 lanes Basic capacity = 6,900 pcu/h Adjustment factor (f_t) = 0.735 Motorway section capacity = 6,900 × 0.735 = 5072 veh/h

Using field measurements

If actual field measurements at the site give a different capacity from that which is determined above, then the field measurements should be used. However, if field measurements are used, then the analyst must prove that the measurements are representative of the average capacity in a variety of conditions.

Accounting for auxiliary lanes

Auxiliary lanes within road sections may contribute to the road's capacity in which case the detailed procedures of the HCM shall be used. Otherwise the auxiliary lanes shall be considered not to contribute to the capacity.

A3.10 Determining the capacity of multilane roads

When to use

This procedure is called from Appendix A3.8.

Procedure

Follow the steps below to determine the capacity of a multilane road.

Step	Action
1	Obtain 'the sum of the basic free speed reductions' for the multilane road section, as determined in Appendix A3.8. Example: Free speed reductions for: dividing median = 0 km/h lane width = 0 km/h lateral clearance = 4 km/h access points = 4 km/h Sum of the basic free speed reductions = 8 km/h Note: If the free speed for the multilane road section was measured rather than estimated, then use step 1 of the procedure in Appendix A3.8 to determine the multilane road basic free speed, and subtract the measured free speed to obtain the equivalent of 'the sum of the basic free speed reductions'.
2	Determine the capacity of the multilane road section as follows:

If the sum of the basic free speed reduction is…	Then use a capacity of…
zero	2,200 veh/h per lane
between 0 and 30 km/h	2,200 veh/h per lane minus 10 veh/h per lane for every km/h of basic free speed reductions
above 30 km/h	1,900 veh/h per lane

Example:

Sum of the basic free speed reductions = 8 km/h

Road section capacity = 2,200 – 8 × 10

= 2,120 veh/h per lane

A3.11 Determining the capacity of two-lane rural roads

When to use

This procedure is called from Appendix A3.8.

The capacity of the road section shall be calculated by adjusting the ideal capacity of 2,800 veh/h (total in both directions of travel) to account for the following factors:

- directional distribution of traffic during the time period
- the presence of narrow lanes and restricted shoulders
- the proportion of heavy vehicles in the flow.

Procedure

Follow the steps below to determine the capacity of a two-lane rural road section.

Step	Action	
1	Determine the adjustment factor for traffic **directional distribution** during the time period as follows:	
	If the directional distribution is…	**Then use an adjustment factor of:**
	100/0	0.71
	90/10	0.77
	80/20	0.83
	70/30	0.89
	60/40	0.94
	50/50	1.00
2	Determine the total roadway width. The total roadway width equals the lane width(s) plus sealed shoulder width. Round to the nearest metre.	
3	With the total roadway width determined in step 2 determine the adjustment factor for **trafficable width** as follows:	
	If the total roadway width is…	**Then use an adjustment factor of:**
	8 metres or greater	1.00
	7 metres	0.91
	6 metres	0.82
	5 metres	0.73
	4 metres	0.65
	less than 4 metres	0.60

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="5">4</td><td colspan="2">Determine the passenger car equivalent for trucks for the road section as follows:</td></tr>
<tr><td>If the terrain type is…</td><td>Then use a passenger car equivalent for trucks (E_t) of:</td></tr>
<tr><td>level</td><td>2.2 pcu</td></tr>
<tr><td>rolling</td><td>5.0 pcu</td></tr>
<tr><td>mountainous</td><td>10.0 pcu</td></tr>
<tr><td>5</td><td colspan="2">Calculate the adjustment factor for trucks using the passenger car equivalent for trucks (E_t) determined in step 4.
Adjustment factor (f_t) = 1/(1 + Pt x (E_t- 1))
Where P_t is the proportion of trucks in the traffic stream during the time period
Example:
Terrain type = rolling
Proportion of trucks (P_t) = 0.10
pcu for trucks (E_t) = 5.0 pcu
Adjustment factor (f_t) = 1/[1 + 0.10 × (5.0 – 1))]
= 0.714</td></tr>
<tr><td>6</td><td colspan="2">Calculate the road section capacity by multiplying the ideal two-way capacity of 2,800 veh/h by the adjustment factors determined in steps 1, 3 and 5.
Road section capacity = Ideal capacity x adjustment factor for directional distribution x adjustment factor for trafficable width x f_t
Example:
Directional distribution = 70/30
Trafficable width = 7.0 metres
Adjustment factors:
directional distribution = 0.89
trafficable width = 0.91
trucks = 0.714
Road section capacity = 2800 × 0.89 × 0.91 × 0.714
= 1620 veh/h</td></tr>
<tr><td>7</td><td colspan="2">Calculate the peak direction capacity using the road section capacity determined in step 6.
Peak direction capacity = road section capacity x proportion of traffic in the peak direction
Example:
Proportion of traffic in peak direction = 0.7
Peak direction capacity = 1620 × 0.7
= 1134 veh/h</td></tr>
</table>

A3.12 Determining whether vehicle interactions are significant

Introduction

When the effects of vehicle interactions are significant on road sections it is necessary to calculate the additional travel time caused by those interactions. Vehicle interactions do not apply to other urban roads.

Procedure

Follow the steps below to determine whether the effects of vehicle interactions are significant:

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td>1</td><td colspan="3">Use the capacity for the road section determined in Appendix A3.8.</td></tr>
<tr><td>2</td><td colspan="3">Take a time period with its corresponding traffic volume (demand) as determined in Appendix A3.3.</td></tr>
<tr><td>3</td><td colspan="3">Calculate the volume to capacity ratio.
Example:
Time period = 0700 to 0900
Time period traffic vol = 6202 vehicles
Traffic flow = 6202/2
= 3101 veh/h
Capacity = 4300 veh/h
Volume to capacity ratio = 3101 / 4300
= 0.72</td></tr>
<tr><td rowspan="8">4</td><td colspan="3">Determine whether the effects of vehicle interactions are significant as follows:</td></tr>
<tr><th>If the road section is a…</th><th>And the volume to capacity ratio is…</th><th>Then vehicle interactions…</th></tr>
<tr><td>motorway section</td><td>greater than 0.7</td><td>shall be considered
(go to Appendix A3.13)</td></tr>
<tr><td>motorway section</td><td>0.7 or less</td><td>are not considered
(go to Appendix A3.21)</td></tr>
<tr><td>multilane road</td><td>greater than 0.7</td><td>shall be considered
(go to Appendix A3.13)</td></tr>
<tr><td>multilane road</td><td>0.7 or less</td><td>are not considered
(go to Appendix A3.21)</td></tr>
<tr><td>two-lane rural road</td><td>greater than 0.7</td><td>shall be considered
(go to Appendix A3.13)</td></tr>
<tr><td>two-lane rural road</td><td>0.7 or less</td><td>are not considered
(go to Appendix A3.21)</td></tr>
<tr><td>5</td><td colspan="3">Repeat steps 2 to 4 for any other time periods in which traffic volumes are likely to result in significant vehicle interactions.</td></tr>
</table>

A3.13 Types of delays

Introduction

This section describes the difference between vehicle interaction delay and bottleneck delay, explaining why the two types of delay require different procedures to calculate their levels.

Definition of vehicle interaction delay

Vehicle interaction delay is the delay that occurs as demand approaches capacity, and each vehicle's progress is impeded by the proximity of other vehicles.

Ideally, no delay would occur when demand was below capacity, but variations in driver behaviour and differences in speed between individual vehicles mean that delay does occur. Because the actual delay depends on the many variable factors, vehicle interaction delay is also known as *random delay*.

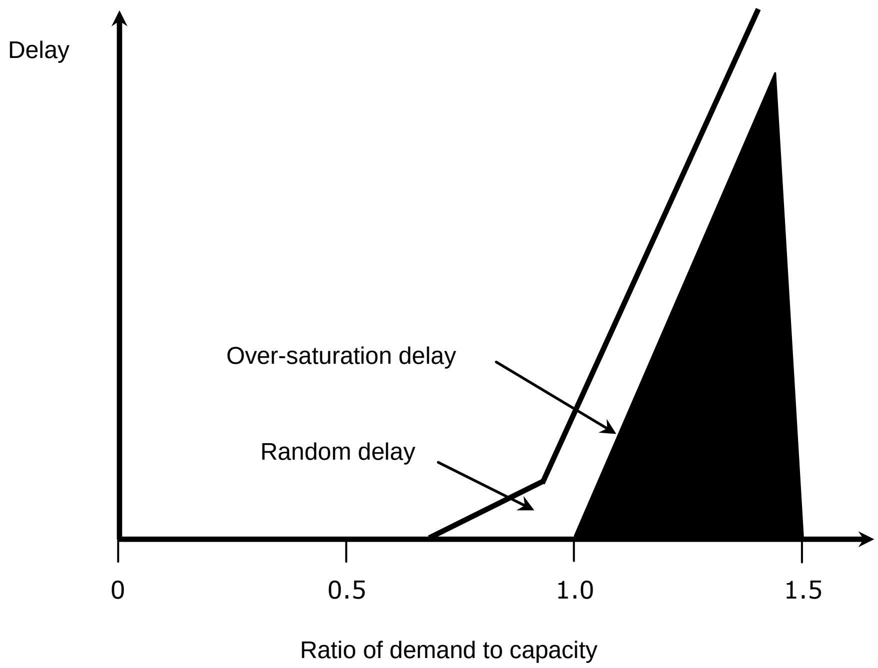
Definition of bottleneck delay

Bottleneck delay is the delay which is experienced when the demand at some location exceeds the capacity of the road at the location. Such delays occur at a point on the road section where the capacity is below that of the upstream capacity, and equal to or less than the downstream capacity.

Because bottleneck delay occurs when demand exceeds capacity (ie, when the volume to capacity ratio exceeds 1.0), it is also known as *over-saturation delay*.

Diagram

The diagram below shows approximately when vehicle interaction (or random) delay and bottleneck (or over-saturation) delay occur.



A3.14 Average peak interval traffic intensity

Background

As traffic volumes on a road increase vehicle interactions increase, and as a result the average travel time per vehicle increases. The additional travel time that results from vehicle interactions is a function of the volume to capacity flow ratio (VC ratio), where VC ratio is the ratio of demand volume to road capacity averaged over a period of time. When predicting the average travel time to traverse a section of road, the extent to which averaging smoothes the flow profile will affect the accuracy of the estimate of the additional travel time due to vehicle interactions. Peak interval analysis is one method of correcting for potential loss of accuracy.

Average time period traffic intensity

The average time period traffic intensity is the average traffic flow for the time period under analysis. It is generally reported as vehicles per hour, or vehicles per x minutes.

Peak interval

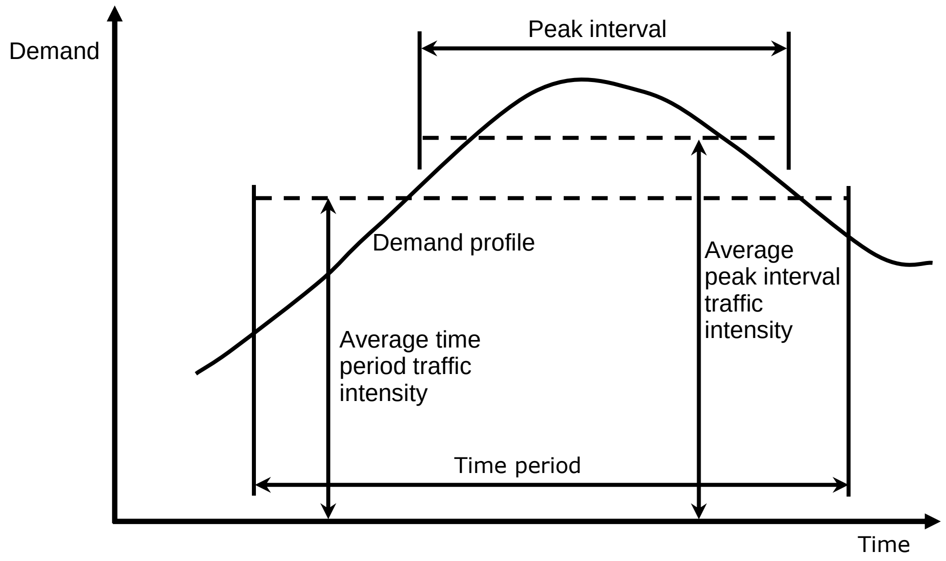
The peak interval (in minutes) is that portion of the time period over which the demand is greater than the average time period traffic intensity.

Average peak interval traffic intensity

The average peak interval traffic intensity is the average traffic flow for the peak interval. The average peak interval traffic intensity is used in the analysis to determine delays. Generally average peak interval traffic intensity is reported in vehicles per hour.

Peak interval diagram

The diagram below shows the relationship between the time period and the peak interval, and the relationship between the average traffic intensities for the time period and the peak interval.



A3.15 Determining the peak interval

When to use

Use this procedure if the conclusion from the procedure in Appendix A3.12 'determining whether vehicle interactions are significant' was that vehicle interactions shall be considered.

Procedure

Follow the steps below to determine the peak interval.

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>Select a time period to be analysed (usually the weekday morning or evening commuter peak). See Appendix A2.4.
Note: The time period must be long enough to ensure sufficient capacity, even though for some time that capacity is exceeded.</td></tr>
<tr><td>2</td><td>Identify the time interval that traffic data for the time period has been collected (usually five, 10 or 15 minute intervals).</td></tr>
<tr><td>3</td><td>Set out the traffic data for the time period.
Example:
<table>
<tr><th>Time</th><th>Observed traffic volume</th></tr>
<tr><td>7:00 – 7:15</td><td>800</td></tr>
<tr><td>7:15 – 7:30</td><td>1,040</td></tr>
<tr><td>7:30 – 7:45</td><td>1,200</td></tr>
<tr><td>7:45 – 8:00</td><td>1,280</td></tr>
<tr><td>8:00 – 8:15</td><td>1,240</td></tr>
<tr><td>8:15 – 8:30</td><td>1,140</td></tr>
<tr><td>8:30 – 8:45</td><td>1,020</td></tr>
<tr><td>8:45 – 9:00</td><td>840</td></tr>
</table></td></tr>
<tr><td>4</td><td>Calculate the average time period traffic intensity (F_{tp}) (see definition in Appendix A3.14)
Example:
Time period traffic volume = 8,560 vehicles
Length of time period = 2 hours
Traffic data time interval = 15 minutes
Average time period traffic intensity (F_{tp})
= 8,560 / (2 × 60 / 15)
= 1,070 per 15 minutes</td></tr>
</table>

5	Identify when the observed traffic volume rose above the average time period traffic intensity (F_{tp}) Example: From step 3, the interval 7:30-7:45 was the first interval with an observed traffic volume greater than the average time period traffic intensity (F_{tp}) Start time of interval (t_i) = 7:30 Volume in interval (v_i) = 1,200 vehicles Volume in prior interval (v_{i-1}) = 1,040 vehicles
6	Calculate the peak interval start, which is the notional time at which the flow rate rose above the average time period traffic intensity (F_{tp}). Peak interval start = $t_i + (F_{tp} - v_{i-1})/v_i - v_{i-1}) \times$ interval from step 2 Example: Peak interval start = 7:30 + (1,070 - 1,040)/(1,200 - 1,040) × 15 = 7:32.8
7	Identify when the observed traffic volume fell below the average time period traffic intensity (F_{tp}). Example: From step 3, the interval 8:30 – 8:45 was the first interval after the peak with an observed traffic volume lower than the average time period traffic intensity (F_{tp}). Start time of interval (t_i) = 8:30 Volume in interval (v_i) = 1,020 vehicles Volume in prior interval (v_{i-1}) = 1,140 vehicles
8	Calculate the peak interval end, which is the notional time at which the flow rate fell below the average time period traffic intensity (F_{tp}). Peak interval end = $t_i + (v_{i-1} - F_{tp})/(v_{i-1} - v_i)$ x interval Example: Peak interval end = 8:30 + (1140 - 1070)/(1140 - 1020) × 15 = 8:38.8
9	Calculate the length of the peak interval. Example: Peak interval start = 7:32.8 Peak interval end = 8:38.8 Length of peak interval = 8:38.8 – 7:32.8 = 66.0 minutes

A3.16 Calculating the average peak interval traffic intensity

When to use

Use this procedure after having determined the peak interval in Appendix A3.15.

Procedure

Follow the steps below to calculate the average peak interval traffic intensity.

Step	Action
1	Calculate the peak interval traffic volume. Example: Peak interval start = 7:32.8 Peak interval end = 8:38.8 Volume 7:30 – 7:45 = 1200 vehicles Volume 7:45 – 8:00 = 1280 vehicles Volume 8.00 – 8.15 = 1240 vehicles Volume 8:15 – 8:30 = 1140 vehicles Volume 8:30 – 8:45 = 1020 vehicles Peak interval traffic vol = (7:45 – 7:32.8)/15 × 1200 + 1280 + 1240 + 1140 + (8:38.8 – 8:30)/15 × 1020 = 5234 vehicles
2	Calculate the average peak interval traffic intensity (F_{pi}). Example: Length of peak interval = 66.0 minutes Average peak interval traffic intensity (F_{pi}) = 5234 × 60/66.0 = 4758 veh/h

A3.17 Calculating the volume to capacity ratio

When to use

The volume to capacity ratio is also known as the saturation ratio.

Procedure

Follow the steps below to determine the volume to capacity ratio (VC ratio).

Step	Action	
1	Determine the appropriate **capacity** for calculating the volume to capacity ratio as follows:	
	If the road section is a…	**Then use the…**
	motorway section	capacity determined in Appendix A3.9
	multilane highway	capacity determined in Appendix A3.10
	two-lane rural road	peak direction capacity determined in Appendix A3.11
	other urban road	capacity specified in Appendix A3.8
2	Obtain the average peak interval traffic intensity (F_{pi}) as determined in Appendix A3.16, and use this volume in step 3. **Note:** If the volume to capacity ratio is being calculated for a time period for which it is not appropriate to calculate F_{pi}, then use an appropriate peak volume.	
3	Calculate the volume to capacity ratio using the appropriate capacity and traffic volume determined in steps 1 and 2. Example: Volume to capacity ratio = volume/capacity = 4758/5072 = 0.938	

A3.18 Calculating the additional travel time

Introduction

The average additional travel time above that experienced when travelling at the free speed shall be determined as a function of the volume to capacity ratio during the peak interval of a given time period.

The additional travel time calculated for the peak interval is also used as the value for time period additional travel time.

Procedure

Follow the steps below to calculate the additional travel time.

Step	Action	
1	Determine the appropriate procedure for the road section as follows	
	If the road section is a…	**Then go to…**
	motorway section	step 2, and then step 4
	multilane highway	step 2, and then step 4
	two-lane rural road	step 3, and then step 4
2	Calculate the **peak interval additional travel time factor**, using the volume to capacity ratio determined in Appendix A3.17, as follows (for motorways and multilane roads only):	
	If the peak interval volume to capacity ratio is…	**Then the peak interval additional travel time factor (F_{dr}) equals…**
	less than or equal to 0.7	0
	between 0.7 and 1.0	0.27 × (VC ratio – 0.70)
	equal to or greater than 1.0	0.081
	Go to step 4.	
3	Determine the peak interval additional travel time factor from the tables below, using the volume to capacity ratio determined in Appendix A3.17 for two-lane rural roads only. **Additional travel time factor for level terrain**	

VC ratio	Percent no-passing					
	0	**20**	**40**	**60**	**80**	**100**
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.04	0.04	0.05	0.05	0.06	0.06
0.20	0.08	0.08	0.09	0.10	0.10	0.11
0.30	0.11	0.12	0.12	0.13	0.14	0.14
0.40	0.14	0.14	0.15	0.16	0.16	0.17
0.50	0.16	0.16	0.17	0.18	0.18	0.19
0.60	0.18	0.19	0.19	0.20	0.20	0.21
0.70	0.21	0.21	0.21	0.22	0.22	0.23
0.80	0.24	0.24	0.24	0.25	0.25	0.25
0.90	0.27	0.27	0.28	0.28	0.28	0.28
1.00	0.32	0.32	0.32	0.32	0.32	0.32

Step	Action						
.	**Additional travel time factor for rolling terrain**						
	VC ratio	**Percent no-passing**					
		0	**20**	**40**	**60**	**80**	**100**
	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.10	0.06	0.06	0.07	0.08	0.09	0.09
	0.20	0.11	0.12	0.13	0.13	0.14	0.15
	0.30	0.14	0.15	0.16	0.17	0.18	0.18
	0.40	0.16	0.17	0.19	0.20	0.20	0.20
	0.50	0.18	0.19	0.21	0.22	0.23	0.23
	0.60	0.20	0.22	0.24	0.25	0.26	0.26
	0.70	0.23	0.26	0.28	0.30	0.31	0.31
	0.80	0.29	0.32	0.35	0.37	0.38	0.39
	0.90	0.38	0.42	0.45	0.47	0.49	0.50
	1.00	0.50	0.55	0.59	0.62	0.64	0.65
	Additional travel time factor for mountainous terrain						
	VC ratio	**Percent no-passing**					
		0	**20**	**40**	**60**	**80**	**100**
	0.00	0.00	0.00	0.01	0.02	0.03	0.03
	0.10	0.06	0.09	0.11	0.12	0.13	0.14
	0.20	0.13	0.16	0.19	0.20	0.22	0.23
	0.30	0.19	0.22	0.25	0.27	0.29	0.30
	0.40	0.24	0.28	0.31	0.33	0.35	0.37
	0.50	0.29	0.33	0.36	0.39	0.42	0.44
	0.60	0.35	0.40	0.43	0.47	0.50	0.53
	0.70	0.43	0.48	0.52	0.56	0.59	0.63
	0.80	0.54	0.59	0.64	0.68	0.72	0.75
	0.90	0.68	0.73	0.78	0.83	0.87	0.92
	1.00	0.86	0.92	0.98	1.03	1.07	1.12

Step	Action			
	Alternatively calculate F_{dr} directly using the expression: F_{dr} = min(a + b.P_{NP}+ d.P_{Np}^2 g.P_{NP}^3 + c.VC ratio + e.VC $ratio^2$ + h.VC $ratio^3$ + f.P_{NP}.VC ratio + i.P_{NP}.VC $ratio^2$ + j.P_{NP}^2.VC ratio ,0) where: VC ratio = the volume to capacity flow ratio P_{NP} = the percent no passing And the coefficients a to j are given below			
	Coefficient	**Level terrain**	**Rolling terrain**	**Mountainous terrain**
	a	-1.906×10^{-2}	-2.658×10^{-2}	-3.039×10^{-2}
	b	1.420×10^{-4}	1.640×10^{-4}	1.480×10^{-3}
	c	0.617	1.008	1.059
	d	3.260×10^{-6}	3.610×10^{-6}	1.378×10^{-5}
	e	-0.771	-1.918	-1.515
	f	6.43×10^{-4}	6.220×10^{-4}	1.570×10^{-3}
	g	-2.42×10^{-8}	-9.470×10^{-9}	5.260×10^{-8}
	h	0.496	1.440	1.346
	i	-8.70×10^{-4}	-1.748×10^{-3}	2.897×10^{-4}
	j	-6.49×10^{-7}	-1.320×10^{-5}	-1.379×10^{-6}

Step	Action		
4	Calculate the peak interval additional travel time by multiplying the free speed travel time in Appendix A3.4 by the factor from step 2 or 3.		
	Peak interval additional peak interval	=	free speed travel time x
			travel time additional travel time factor (F_{dr})
	Example 1: (motorway or multilane highway):		
	Free speed travel time	=	0.571 mins/km
	Volume to capacity ratio	=	0.938
	F_{dr} (from step 2)	=	0.27 × (0.938 – 0.70)
		=	0.0643
	Peak interval		
	additional travel time	=	0.571 × 0.0643
		=	0.037 mins/km
	Time period additional travel time		
		=	Peak interval additional travel time
		=	0.037 mins/km
	Example 2: (two-lane rural road):		
	Free speed travel time	=	0.636 mins/km
	Terrain type	=	rolling
	Percent no-passing	=	60%
	Volume to capacity ratio	=	1.10
	F_{dr} (from tables in step 3)	=	0.62
	Peak interval		
	additional travel time	=	0.636 × 0.62
		=	0.394 mins/km
	Time period additional travel time		
		=	Peak interval additional travel time
		=	0.394 mins/km

A3.19 Calculating bottleneck delay

When to use

Use this procedure for all time periods during which demand exceeds capacity (volume to capacity ratio greater than one) at some time.

Blocking back onto upstream sections

Where traffic volumes exceed capacity, the resulting queues may block back onto upstream links. In such circumstances care must be taken to ensure that the delays that arise on the under-capacity section are not double counted on any upstream section.

Procedure

Follow the steps below to calculate bottleneck delay.

Step	Action
1	Select a time period to be analysed (usually the weekday morning or evening commuter peak).
2	Determine the capacity of the road section. See Appendix A3.8.
3	Identify the time interval step that traffic data for the time period has been collected (usually 5, 10 or 15 minute periods).
4	Set out the traffic data for the time period. Example:

Time interval	Observed traffic volume
7:00 – 7:15	264
7:15 – 7:30	475
7:30 – 7:45	591
7:45 – 8:00	600
8:00 – 8:15	591
8:15 – 8:30	475
8:30 – 8:45	264
8:45 – 9:00	250
9:00 – 9:15	234

Step	Action
5	At each time interval, calculate the cumulative demand with a running total of observed traffic volume since the time period start. Cumulative demand at time interval = sum of observed traffic volume since time period start. Example from step 4: Cumulative demand for time interval 8:00 to 8:15 = 264 + 475 + 591 + 600 + 591 = 2521

Step	Action
6	At each time interval, calculate the vehicles discharged. If the traffic volume for the time interval is below the road section capacity then all the traffic is discharged. Only the number of vehicles equivalent to the road section capacity is discharged if the traffic volume exceeds capacity. Example from step 4: Time interval = 8:00 to 8:15 Capacity = 500 vehicles Traffic volume = 591 vehicles Vehicles discharged = minimum of traffic volume or capacity = minimum (591, 500) = 500
7	At each time interval, calculate the cumulative discharge with a running total of vehicles discharged since the time period start. Cumulative discharge at time interval = sum of vehicles discharged since time period start
8	At each time interval, calculate the queue at the end of the interval when traffic volume exceeds capacity. Example from step 4: Time interval = 7:30 - 7:45 Traffic volume = 591 vehicles Capacity = 500 vehicles Queue at end of interval = traffic volume – capacity, if traffic volume > capacity = 0, if traffic volume ≤ capacity = 591 – 500 = 91 vehicles
9	At each time interval, calculate the queue at the start of the interval. This is the queue at the end of the previous interval. Time interval = 7:30 - 7:45 Queue at start of interval = queue at end of previous interval = 91 vehicles
10	At each time interval, calculate the average delay in vehicle minutes. Average delay = interval time step x(queue at end of interval + queue at start of interval)/2

Step	Action
11	Sum the average delays over the entire time period to obtain the time period total delay.
12	Calculate the time period average delay per vehicle from the time period total delay divided by the cumulative discharge of vehicles at the time period end. Average delay per vehicle = total delay / cumulative discharge of vehicles at the time period end

Example

An example of the bottleneck delay calculation using the data from step 4 and a road capacity of 500 vehicles.

Start time	Demand (veh)	Cumulative demand (veh)	Vehicles discharged (veh)	Cumulative discharge (veh)	Queue at end of interval	Queue at start of interval	Average delay (veh-min)
Step	**4**	**5**	**6**	**7**	**8**	**9**	**10**
7:00	264	264	264	264	0	0	0.0
7:15	475	739	475	739	0	0	0.0
7:30	591	1330	500	1239	91	0	682.5
7:45	600	1930	500	1739	191	91	2115.0
8:00	591	2521	500	2239	282	191	3547.5
8:15	475	2996	500	2739	257	282	4042.5
8:30	264	3260	500	3239	21	257	2085.0
8:45	250	3510	271	3510	0	21	157.5
9:00	234	3744	234	3744	0	0	0.0

Step 11. Time period total delay

= 682.5 + 2115 + 3547.5 + 4042.5 + 2085 + 157.5

= 12630 veh-mins

Step 12. Time period average delay per vehicle

= 12630 / 3744

= 3.37 min/veh

A3.20 Determining whether to consider peak spreading

Introduction

Some peak spreading may occur at low levels of bottleneck delay, but in general, drivers will only begin to refine their trips when bottleneck delays are severe.

Procedure

Follow the steps below to determine whether peak spreading should be considered.

Step	Action		
1	Calculate the average delay per delayed vehicle, using the time period average delay per vehicle determined in Appendix A3.19. Average delay per delayed vehicle = Time period average delay per vehicle x (Time period traffic volume/ sum of traffic volumes of intervals with an end queue) Example (using the example in Appendix A3.19): Average delay per delayed vehicle = 3.37 x (3744 / (591 + 600 + 591 + 475 + 264)) = 3.37 x (3744 / 2521) = 5.0 mins/veh		
2	Determine whether peak spreading should be considered as follows:		
	If the average minutes delay per delayed vehicle is…	**And there is…**	**Then peak spreading…**
	between 0 and 15		does not need to be considered
	between 15 and 25	an alternative route	does not need to be considered
	between 15 and 25	no alternative route	shall be considered, use Appendix A11.2
	25 or greater		shall be considered, use Appendix A11.2

A3.21 Determining the additional travel time resulting from speed change cycles

Introduction

If vehicles are required to slow to negotiate some isolated feature and then accelerate back to cruise speed the travel time estimated above must be increased to account for the time lost during this speed change cycle. Where the initial cruise speed and the minimum speed are available, tables in Appendix A5.7 provide the amount of additional travel time in seconds for speed change cycles.

In the absence of measured data, the additional travel time that occurs as a result of having to slow for substandard horizontal curves can be approximated using this procedure.

Procedure

Follow the steps below to determine the additional travel time resulting from speed change cycles associated with substandard curves.

Step	Action
1	Determine the curve negotiating speed for each vehicle type in the traffic mix. The desired negotiation speed for an isolated curve (S_c) is related to the ideal approach speed (S_a) and the curve radius (R) by the following equation: $S_c = a_0 + a_1.S_a + a_2 / R$ Where: $S_a = f_1.F_S$ F_s is the average free speed determined from appendices A3.4 to A3.7 and the coefficients f_1,a_0, a_1, and a_2 are as follows:

Vehicle type	f_1	a_0	a_1	a_2
Car	1.00	45.21	0.5833	-3892
LCV	0.97	54.51	0.4531	-3337
MCV	0.89	51.77	0.4744	-3245
HCV I	0.91	59.16	0.4068	-3506
HCV II	0.91	69.57	0.3085	-3768
Bus	0.91	59.16	0.4068	-3506

Example:

A horizontal curve of radius 100m exists within a road section where the free speed is estimated at 94.33 km/h.

Ideal approach speed	=	0.89 × 94.33
For MCV	=	84 km/h
Desired negotiation speed for MCV		
	=	51.77 + 0.4744 × 84 - 3245/100
	=	59 km/h

2	Determine the initial operating speed of the road section. The operating speed is the sum of the free speed travel time and the time period additional travel time all divided by the section length. This accounts for the reduction in the ideal approach speed as a result of traffic interactions. Initial operating speed = length/(TT_{FS} + TT_{ATT}) Example: 1 km at free speed travel time = 0.636 mins/km 1 km additional travel time for vehicle interactions (Appendix A3.18) = 0.636 × 0.2 = 0.127 mins/km Initial operating speed = 1.00 / (0.636+0.127) × 60 = 1.00/0.763 × 60 = 79 km/hr
3	The additional travel time associated with speed change cycles is then determined from the appropriate table in Appendix A5.7. **Note:** Where the desired negotiating speed is greater than the operating speed no speed change will occur. Example: Using table A5.28 Initial cruise speed for all vehicles = 79 km/h Curve speed for MCV = 59 km/h MCV additional travel time per speed change = 2.0 seconds
4	Calculate the total speed change cycle travel time for a road section with the additional following information. Traffic volume for the time period Traffic composition (default values available in Appendix A2.2) For each vehicle type: proportion in traffic from traffic composition number of vehicles = traffic volume x proportion in traffic additional travel time = number of vehicles x additional travel time for speed change cycles Sum over all vehicle types to obtain the total additional travel time.

A3.22 Calculating the time period total average travel time

When to use

Use this procedure once free speed and delays caused by vehicle interactions and speed changes have been calculated.

Note: For 'other urban roads', this procedure is used in conjunction with Appendix A3.8.

Procedure

Follow the steps below to calculate the time period total average travel time per vehicle.

Step	Action
1	Use the following previously calculated values: • free speed travel time (Appendix A3.4) • time period additional travel time (Appendix A3.18) • time period average delay per vehicle (Appendix A3.19) • additional travel time due to speed changes (Appendix A3.21) **Note:** • 'Other urban roads' only have a free speed travel time. 'Other urban roads' do not exhibit reductions in travel times with increasing traffic volumes. All delays due to increasing traffic volumes can be attributed to intersections as calculated in Appendices A3.23 to A3.25. • time period additional travel time is only calculated if the volume to capacity ratio exceeds 0.7 (see Appendix A3.12) • bottleneck delay is only calculated if demand exceeds capacity at some time during the time period.
2	Multiply the free speed travel time and the time period additional travel time by the road section length.
3	Sum the values in step 2 with the bottleneck delay and additional travel time due to speed change to get the time period total average travel time per vehicle.

Example

Section length = 1.00 km

Free speed travel time = 0.636 mins/km

Time period additional travel time = 0.232 mins/km

Speed change additional travel time = 0.003 mins

Bottleneck delay per vehicle = 1.5 mins/veh

Time period total average travel time

= $(TT_{FS} + TT_{ATT}) \times$length + bottleneck delay + speed change

= (0.636 + 0.232) ×1.00 + 1.5 + 0.003

= 2.371 mins/veh

A3.23 Traffic signals

Traffic signals

Travel time delays associated with traffic signals are the result of a complex interaction between arrivals on opposing phases, the response of the signal controller to detector impulses and external control commands, and vehicle driver responses. The physical layout, location, and phasing strategy also affect operations.

Commonly available analysis procedures are based on simplifying assumptions that reduce an essentially dynamic and stochastic process to a deterministic approximation of real events. Reliable estimates of delay require the careful selection of values for the governing variables and a thorough understanding of traffic operations at each site.

While the procedures of the HCM provide a useful guide, the more commonly understood methods of the ARRB publication ARR 123 should be followed.

This appendix uses HCM to derive a major modification to the ARR 123 methods to account for the proximity of other signals including linking or coordination.

Capacity or saturation flow rate

The average delay to all vehicles, irrespective of the turns made, shall be the basis of the analysis. Thus the methodology is approach based, not movement based.

Ideally, saturation flow rates for each approach should be determined from direct observation at the site. Approach saturation flow rates for the relevant lane groups can be estimated as specified below.

The procedure consists of adjusting an ideal saturation flow rate of 2,000 passenger cars units per hour of green by the factors tabulated in the following tables.

Parking movements refers to the number of such movements, in and out, within a length of 50 metres on either side of the intersection.

Table A3.1 Lane width factors

Lane width (metres)	Factor
3.5	1.00
3.4	0.99
3.3	0.98
3.2	0.97
3.1	0.96
3.0	0.95

Table A3.2 Approach grade factors

Gradient %	Factor
-4	1.02
-2	1.01
0	1.00
+2	0.99
+4	0.98

Table A3.3 Parking factors

Parking movements (number/hour)	Approach lanes		
	1	2	3
0	0.90	0.95	0.97
10	0.85	0.92	0.95
20	0.80	0.89	0.93
30	0.75	0.87	0.85
40	0.70	0.85	0.89

Table A3.4 Locality factors

Type of street	Factor
CBD Shopping	0.90
Suburban Shopping	0.95
Other	1.00

Cycle times and phase splits

Appropriate cycle times and phase splits shall be determined according to the conditions that prevail during the peak interval. In particular, the influence of minimum phase times for parallel pedestrian facilities, actual all-red periods, and other influences on lost-time shall be included.

Peak interval average travel time

The peak interval average travel time shall be the average delay calculated by the methods of ARR 123 adjusted to account for controller type and the arrival pattern of platoons produced by nearby intersections by applying the relevant delay adjustment factor specified below.

The arrival type is best observed in the field, but can be assessed by examining time-space diagrams for the arterial or street on which the approach is located.

It should be noted that fully vehicle actuated controllers, remote from other signals, produce delays 15% below that estimated by the methods of ARR 123.

Care must be exercised in applying the adjustment factors. Arrival types one and five will seldom occur unless either unfavourable or efficient linking control is imposed.

Platoons released by upstream signals will disperse according to the prevailing speed environment and the distance between successive signal controlled intersections. The following table provides a broad guide to such effects.

Table A3.5 Arrival type

Arrival type	Condition
1	Dense platoon arriving at the commencement of red.
2	Dense platoon arriving near the middle of the red phase, or Dispersed platoon arriving at the commencement of red.
3	Random arrivals or dispersed platoons arriving throughout both the green and red phases. This condition applies to isolated intersections or those with cycle times differing from nearby signal controlled intersections.

4	Dense platoon arriving near the middle of the green phase, or Dispersed platoon arriving throughout the green phase.
5	Dense platoon arriving at the commencement of the green phase.

Table A3.6 Delay adjustment factor

Type of signal	Volume to capacity ratio	Adjustment factor				
		Arrival type				
		1	2	3	4	5
Pre-timed	≤ 0.6	1.85	1.35	1.00	0.72	0.53
	0.8	1.50	1.22	1.00	0.82	0.67
	1.0	1.40	1.18	1.00	0.90	0.82
Actuated	≤ 0.6	1.54	1.08	0.85	0.62	0.40
	0.8	1.25	0.98	0.85	0.71	0.50
	1.0	1.16	0.94	0.85	0.78	0.61
Semi-actuated on main road approach	≤ 0.6	1.85	1.35	1.00	0.72	0.42
	0.8	1.50	1.22	1.00	0.82	0.53
	1.0	1.40	1.18	1.00	0.90	0.65
Semi-actuated on side road approach	≤ 0.6	1.48	1.18	1.00	0.86	0.70
	0.8	1.20	1.07	1.00	0.98	0.89
	1.0	1.12	1.04	1.00	1.00	1.00

Table A3.7 Platoon dispersal distances (m)

Platoon type	Speed environment (km/h)	
	50 – 64	65 – 105
Dense	< 100	< 300
Dispersed	150 – 500	350 – 1000
Random	> 1000	> 2000

Intersection departure delay

The HCM specifies reductions in the free speed according to the distance between signal controlled intersections along the route. This amounts to a nearly constant delay of six seconds (0.10 minutes) at each intersection. The effect can be represented by adding this constant delay in addition to actual intersection delays.

Time period total average travel time

The time period total average travel time for the intersection is approximated by the peak interval time period delay obtained plus the intersection departure delay as described in the previous sections of this appendix.

Application of traffic models

Delays associated with traffic signals can be estimated by traffic models, provided:

- input parameters such as running speeds and saturation flow rates are determined in a manner consistent with this appendix

- the delay calculated by the model is consistent with the definitions of this appendix, ie the average delay per vehicle over the relevant approach
- the delay outputs of the model are based on the general procedure and delay equations of ARR 123 and this appendix.

Worked example

Basic data	
Lane width	3.3 m
Number of lanes	2
Approach grade	+2%
Parking movements/h	20
Locality	CBD
Arrival type	Random
Signal type	Actuated

Lane width factor (from table A3.1)	=	0.98
Approach grade factor (from table A3.2)	=	0.99
Parking factor (from table A3.3)	=	0.89
Locality factor (from table A3.4)	=	0.90
Saturation flow rate	=	2000 × 0.98 × 0.99× 0.89 × 0.90
	=	1554 pcu/h
Arrival type (from table A3.5)	=	3
Delay adjustment factor (from table A3.6)	=	0.85

In using a traffic model to analyse this example intersection, a saturation flow rate of 1554 pcu/h shall be used, and the resulting delays multiplied by 0.85.

A3.24 Priority intersections

Priority intersections

Priority intersections include all intersections where entry is not controlled by traffic signals. Roundabouts are a particular class, and are separately considered in Appendix A3.25.

Travel time delays are only incurred by movements where the priority of entry is controlled by stop signs, give way signs, or by the general intersection driving rules. Three levels of priority are involved:

- movements that have priority
- movements that yield the right-of-way to the priority flows
- movements that must give way to both the above categories.

Only priority levels (b) and (c) will experience delay.

Minimum headway in conflicting flow

The distribution of headways in the opposing traffic streams in turn depends on other variables, and is influenced by the proximity of signal controlled intersections. When the priority intersection is remote from traffic signals and the conflicting flows well below the capacities of their approach roadways, the distribution of headways in the conflicting traffic flows can be assumed to be random with a minimum headway of either 2.0 seconds (single lane conflict) or 0.5 seconds in other cases.

Capacity

The capacity of a non-priority movement shall be determined as a function of the following variables:

- the distribution of headways, being the time between successive users of the conflict area
- the critical gap in the opposing traffic flow through which a non-priority movement vehicle will move
- the follow-up headway being the time interval between successive vehicles which use the same gap in the opposing traffic stream.

The capacity of the non-priority movement shall be then estimated from:

$$c = (3600 / T_f) \times \exp(-V \times T_o / 3600)$$

where	c	=	capacity
	T_o	=	$T_g - H_m$ (H_m = 0.5 or 2.0)
	H_m	=	minimum headway in conflicting flow
	T_g	=	critical gap
	T_f	=	follow-up headway
	V	=	conflicting volume during peak interval, vehs/hr.

T_o, T_g, H_m and T_f are expressed in seconds, and c and V are expressed in vehicles per hour.

Critical gap and follow up headways

The critical gap (T_g) and follow-up headway (T_f) are related and depend on the speed of the conflicting traffic flow, the class of control, and the movement type. In the absence of actual values determined by observations at the site or similar sites elsewhere in New Zealand, the values in table A3.8 should be used.

Modifying critical gap

Where the turning movement is required to cross more than one lane, a further 0.5 seconds shall be added to the values of the table.

If the left turn from a minor road is provided with an acceleration lane, the critical gap of the table shall be reduced by 1.0 seconds.

Follow-up headway (T_f)

The follow-up headway is related to the critical gap, by the expression:
$T_f = 2.0 + 0.2\ T_g$

Table A3.8 Critical gap (T_g)

Movement and control	Average speed (km/h)	
	<60	≥60
Right turn from		
major road	4.5	5.0
Stop sign on minor road:		
left turn	5.0	6.0
through	5.5	7.0
right turn	6.0	7.5
Give way on minor road:		
Left turn	4.5	5.0
Through	5.0	6.0
Right turn	5.5	6.5

Volume to capacity ratio

The movement volume to capacity ratio is the ratio of the average movement traffic demand for that movement during the peak interval divided by the capacity.

Peak interval average travel time

The peak interval average travel time is equivalent to the delay for each movement. This delay depends on the volume to capacity ratio as tabulated in the table next page.

Time period total average travel time

The total average travel for the intersection is approximated by the peak interval time period.

Application of traffic models

The provisions of Appendix A3.23 shall also apply to traffic models used to calculate delays at priority intersections.

Table A3.9 Average peak interval delay

Volume to capacity ratio	Ave peak interval delay (mins/vehicle)
0.20	0.05
0.30	0.06
0.40	0.07
0.50	0.10
0.60	0.12
0.70	0.17
0.80	0.28
0.90	0.58
1.00	2.75
1.05	5.70
1.10	10.2
>1.10	12.0

A3.25 Roundabouts

Roundabouts	Roundabouts are a special case of a priority intersection. Delays at each approach can be estimated in a manner similar to that of Appendix A3.24, ie each approach can be considered as an independent elemental intersection with one-way conflicting flows circulating round the central island.
Capacity	The procedures and methods of Austroads *Guide to traffic engineering practice, Part 6 – roundabouts* shall be used to obtain the capacities of each approach lane.
Volume to capacity ratio	The volume to capacity ratio for each approach lane shall be estimated as the expected average flow during the peak interval using that lane divided by the capacity.
Peak interval average travel time	The peak interval travel time is equivalent to the peak interval average delay for each lane. The peak interval delay shall be estimated from table A3.9 up to a maximum volume to capacity ratio of 1.05, and the average peak period delay for the approach shall be estimated as the weighted average of the individual approach lanes. The performance of a roundabout becomes indeterminate for high flows, much beyond the capacity of an approach, due to a tendency for the flows to 'lock' round the central island.
Time period total average travel time	The time period total average travel time is the average delay during the time period, and shall be estimated from the peak interval delay.
Application of traffic models	The provisions of Appendix A3.23 shall also apply to traffic models used to calculate delays at roundabouts.

A3.26 References

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A4 Travel time values

A4.1 Introduction

Introduction

This appendix contains travel time values for vehicle occupants, passenger transport users, pedestrians, cyclists, and freight vehicle travel time. The road user values are used to produce composite travel time values for the different road categories for uncongested and congested traffic conditions. Values and procedures are also provided to calculate the values for changes in road user journey time reliability.

The travel time benefits for a project option shall be calculated as the difference between the do minimum and option travel time costs as follows:

Total travel time savings	=	base travel time benefits for improved flow
	+	travel time benefits for reduced traffic congestion (if applicable)
	+	travel time benefits for improved trip reliability (if applicable).

In this appendix

	Topic
A4.1	Introduction
A4.2	Base values for travel time
A4.3	Composite values of travel time and congestion
A4.4	Traffic congestion values
A4.5	Benefits from improved trip time reliability
A4.6	Worked examples of trip reliability procedure

A4.2 Base values for travel time

Base values for travel time

For vehicle occupants, separate values are given for travel during the course of paid employment (work travel), commuting to and from work, and for other non-work travel purposes. Table A4.1(a) gives behavioural values of time for transport modelling purposes for vehicle drivers and vehicle passengers, for seated and standing bus passengers, pedestrians and cyclists. This table also gives the maximum values for congestion (denoted as CRV), which may be added to these values of time for transport users, as described in Appendix A4.4.

Table A4.1(b) gives base values of time by trip purpose for calculating travel times benefits.

Table A4.2 gives values of travel time for vehicles and freight.

Table A4.1(a) Behavioural values of time for vehicle occupants in $/h (all road categories; all time periods – July 2002)

Vehicle occupant	Work travel purpose	Commuting to/from work	Other non-work travel purposes
Base values of time for uncongested traffic ($/h)			
Car, motorcycle driver	23.85	7.80	6.90
Car, motorcycle passenger	21.70	5.85	5.20
Light commercial driver	23.45	7.80	6.90
Light commercial passenger	21.70	5.85	5.20
Medium/heavy commercial driver	20.10	7.80	6.90
Medium/heavy commercial passenger	20.10	5.85	5.20
Seated bus and train passenger	21.70	4.70	3.05
Standing bus and train passenger	21.70	6.60	4.25
Pedestrian and cyclist	21.70	6.60	4.25
Maximum increment for congestion (CRV, $/h)			
Car, motorcycle driver	3.15		2.75
Car, motorcycle passenger	2.35		2.05
Commercial vehicle driver	3.15		2.75
Commercial vehicle passenger	2.35		2.05

Table A4.1(b) Base values for vehicle and freight time in $/h (July 2002) by purpose for calculating travel time benefits

Trip Purpose	Base value of time ($/h)	Maximum increments for congestion (CRV $/h)
Work Travel Purpose	23.85	3.15
Commuting to/from work	7.80	3.15
Other non-work travel purpose	6.90	2.75

Table A4.2 Base values for vehicle and freight time in $/h (July 2002) for vehicles used for work purposes

Vehicle type	Vehicle and freight time ($/h)
Passenger car	0.50
Light commercial vehicle	1.70
Medium commercial vehicle	6.10
Heavy commercial vehicle I	17.10
Heavy commercial vehicle II	28.10
Bus	17.10

A4.3 Composite values of travel time and congestion

Composite values of travel time and congestion

Travel time values combining passenger and commercial (including freight) occupants, and vehicle types for standard traffic compositions are given in table A4.3. These include different time periods for the four road categories defined in Appendix A2.2. The right-hand column gives the maximum additional values for traffic congestion (CRV), to be applied as described in Appendix A4.4.

Table A4.3 Composite values of travel time in $/h (all occupants and vehicle types combined – July 2002)

Road category and time period	Base value of time ($/h)	Maximum increments for congestion (CRV $/h)
Urban arterial		
Morning commuter peak	15.13	3.88
Daytime inter-peak	17.95	3.60
Afternoon commuter peak	14.96	3.79
Evening/night-time	14.93	3.68
Weekday all periods	16.83	3.79
Weekend/holiday	14.09	4.26
All periods	16.27	3.95
Urban other		
Weekday	16.89	3.82
Weekend/holiday	14.10	4.32
All periods	16.23	3.98
Rural strategic		
Weekday	25.34	4.23
Weekend/holiday	19.21	5.22
All periods	23.25	4.39
Rural other		
Weekday	24.84	4.24
Weekend/holiday	18.59	5.23
All periods	22.72	4.40

A4.4 Traffic congestion values

Introduction

Road users value relief from congested traffic conditions over and above their value of travel time saving. The maximum increments for congestion values apply to vehicle occupants or road category and time periods as indicated in tables A4.1, A4.2 and A4.3. The actual additional value for congestion used in the evaluation is adjusted according to the requirements set out below.

Treatment of passing lane projects

An exception to the procedures below is made in the case of passing lane projects evaluated using the procedures in Appendix A7 of this manual. The procedures in Appendix A7 include a separate value for the reduction in driver frustration and the effect of reducing travel time variability. When evaluating passing lanes using the procedures in Appendix A7, no additional allowance shall be made for congestion or improvements in trip reliability. Similarly, if passing lanes are evaluated using the values for congestion and/or reliability outlined in this appendix, and then no allowance can be included for driver frustration.

Congested traffic conditions - rural two-lane highways

To allow for congestion, the following addition should be made on sections of rural two-lane highways. Section lengths for this analysis should normally be greater than two kilometres.

Peak traffic intensity and volume to capacity ratio (VC ratio) are first calculated in the normal manner (see Appendix A3.17). Using the VC ratio, terrain type and percentage no-passing for the road section, the percentage of time delayed (PTD) following slower vehicles is selected from figure A4.1 or table A4.4. Alternatively, the formulae shown in figure A4.1 can be used to calculate PTD, within a limiting range of PTD greater than or equal to 30%. For lower values of PTD the curves are linear.

Incremental value for congestion = CRV × PTD/90 ($/h)

where CRV is the value for congestion (in $/h) and is given in table A4.1 for drivers or passengers, and in table A4.3 for standard traffic compositions.

Percentage of time delayed has a maximum limit of 90%, for situations where PTD is ≥90%, the maximum increment for congestion (CRV) should be added to the base value of travel time.

Congested traffic conditions - urban roads, multi-lane rural highways and motorways

To allow for congestion, the following addition should be made to road section travel time values where the time period VC ratio exceeds 70%.

Incremental value for congestion =

CRV x (road section traffic volume - 70% of road section capacity volume) ($/h)30% of road section capacity volume

Bottleneck delay

For all bottleneck delay, the maximum increment for congestion from table A4.1 or table A4.3 should be added to the base value of travel time.

Worked examples

Four worked examples are given below of the calculations for the value of congestion. In each case, the example describes the calculation for a single time period and for the base year. For a full project evaluation, the calculations would be made for each flow period and for future year traffic forecasts as necessary.

Example 1 –

An activity involves the realignment of a busy two kilometre section of rural highway, which

Rural highway: realignment

improves sight distances, providing more overtaking opportunities for following traffic. The road is classified as rolling terrain.

From calculations in Appendix A2 and/or A3, the road section carries 12,500 veh/day, with a peak interval intensity of 1,000 veh/h, 60/40 directional split and 12% heavy truck component. In the do-minimum, the alignment offers no passing opportunities (0% overtaking sight distance), and after realignment there is no restriction on overtaking sight distance (100% overtaking sight distance). The hourly capacity of the road in the do-minimum is calculated as:

$2{,}800 \times f_t \times f_d = 2{,}800 \times 0.675 \times 0.94 = 1{,}775$ veh/h

where: 2,800 is the ideal capacity of the road section; f_t and f_d are adjustment factors for directional distribution and the proportion of trucks (see Appendix A3.11). The peak interval traffic intensity (1,000 veh/h) divided by capacity gives a VC ratio of 56%.

From figure A4.1(b), the PTD in the do-minimum is 79%, and 71.5% after realignment. The maximum increment for congestion (CRV) for rural strategic roads is $4.23 per veh/h (from table A4.3).

The incremental values for congestion for the do-minimum and project option are calculated as follows:

Do-minimum:	4.23 × 79/<u>90</u>	=	$3.71 per veh-hr
Activity option:	4.23 × 71.5/90	=	$3.36 per veh-hr

The time period total average travel time for the road section is calculated using the procedures in Appendix A3.22 (based on component values calculated in other sections of Appendix A3). For this example, the average travel times per vehicle have been calculated as 1.70 and 1.30 min/veh for the do-minimum and realignment option, respectively.

The congestion cost savings are calculated by multiplying the peak interval traffic intensity by the incremental value for congestion and the time period average travel time divided by 60. For example:

Do-minimum = 1,000 × 3.71 × 1.70/60 = $105.1/h

Project option = 1,000 × 3.36 × 1.30/60 = $72.8/h

Congestion cost saving = $105.1 - $72.8 = $32.3/h over the peak period.

Example two – Rural highway: four laning

A section of two lane rural strategic road is approaching capacity. One option is four lane. The road carries 20,000 veh/day in rolling terrain with 20% overtaking sight distance, peak interval traffic intensity of 2,050 veh/h, 70/30 directional split and 7$ heavy truck component. The ideal capacity for a two lane rural road is 2,800 vehicles/hour (total in both direction of travel).

For the do-minimum, the congestion cost is calculated in the same way as an example 1. The capacity is $2{,}800 \times f_d \times f_t = 2{,}800 \times 0.89 \times 0.92 = 2{,}290$. This compares with a traffic volume of 2,050, which gives a VC ratio of 0.90. The percentage of time delayed is 90% from table A4.4. The incremental value of congestion is therefore equal to is the maximum incremental value of $4.23 per veh-hr from table A4.3.

For the four lane option, assuming there are no restrictions requiring a reduction in the lane capacity, a capacity of 2,200 veh/h/lane is applicable (See Appendix A3.10). The VC ratio is 2,050/(4 × 2,200) = 0.23, which is below 70%, so congestion costs are not applicable.

The saving in congestion costs over the peak period is $4.23 per veh-hr multiplied by the

section traffic volume and time period average travel time for the do-minimum.

Example 3 – Urban arterial road: additional traffic lanes

A project provides a four lane clearway in the peak direction for an urban arterial road and improves the capacity of a signalised intersection half-way along the project length.

The morning peak interval traffic intensity is 1,000 veh/h in the peak flow direction (from Appendix A3.16). Capacity has been established to be 1,250 veh/h for the do-minimum and 2,000 veh/h with the clearway project (based on the multilane road capacity procedure in Appendix A3). The road section VC ratio reduces from 80% to 50% as a result of the project.

Intersection stopped delay will be reduced from 15 s/veh in the do-minimum to 6 s/veh after widening for the 2,000 veh/h through the intersection.

The incremental value of congestion for the road section in the do-minimum for the peak direction of flow is given by:

$$\$3.88 \times \frac{(1{,}000 - 0.7 \times 1{,}250)}{0.3 \times 1{,}250} = \$1.29 \text{ per veh-hr}$$

where: $3.88 per veh-hr is the CRV value from table A4.3.

With the clearway, the VC ratio in the peak direction is below 70%, so no incremental value for congestion is applicable. The congestion cost saving for the road section travel time is therefore $1.29 per veh-hr multiplied by the traffic volume and average vehicle travel time for the section.

For the bottleneck delay, the incremental value for congestion is given by:

Do-minimum = $3.88 ×15/3600 = $0.0162/veh through the intersection

Intersection improvement = $3.88 ×6/3600 = $0.0065/veh through the intersection.

Congestion cost saving per vehicle = $0.0162 - $0.0065= $0.0097/veh through the intersection.

The congestion cost saving attributable to reduction in bottleneck delay is $0.0097/veh multiplied by 2000 veh/h using the intersection = $19.40/h over the peak period.

Example 4 – Urban intersection improvement

A project proposal will reduce delay and improve safety at a priority-controlled T-intersection through the installation of a roundabout. Traffic volumes on the three approaches to the intersection are evenly balanced, there is a high proportion of turning traffic and the configuration of the site is such that a roundabout can be constructed without additional land take.

Bottleneck delay to side road traffic during the peak interval of the morning peak period has been observed to average 35 s/veh for the 500 veh/h on the side road approach, and 5 s/veh for the 300 veh/h turning off the main road. With the roundabout, traffic volume and bottleneck delay for the three approaches has been modeled at: 500 veh/h and 7 s/veh; 700 veh/h and 5.5 s/veh; and 600 veh/h and 6 s/veh.

Total bottleneck delay is calculated as:

Do-minimum = (500 ×35 + 300 ×5) / 3600 = 5.28 veh-hr

Roundabout option = (500 ×7 + 700 ×5.5 + 600 ×6) / 3600 = 3.04 veh-hr

Reduction in bottleneck delay = 5.28 – 3.04 = 2.24 veh-hr

Congestion cost saving = 2.24 ×CRV = 2.24 ×$3.88 = $8.68/h over time period.

Table A4.4(a) VC ratios for level terrain, overtaking sight distance and percentage of time delayed (PTD) following slow vehicles

PTD %	Level terrain - percentage of overtaking sight distance										
	100	90	80	70	60	50	40	30	20	10	0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.5	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00
15.0	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.01	0.01	0.00
22.5	0.11	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.02
30.0	0.15	0.13	0.11	0.10	0.09	0.07	0.06	0.06	0.05	0.04	0.04
37.5	0.18	0.16	0.15	0.14	0.12	0.11	0.10	0.09	0.09	0.08	0.07
45.0	0.23	0.22	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12
52.5	0.30	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.21	0.20
60.0	0.39	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.30
67.5	0.50	0.49	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.42
75.0	0.64	0.63	0.63	0.62	0.61	0.61	0.60	0.60	0.59	0.58	0.58
82.5	0.80	0.80	0.80	0.79	0.79	0.79	0.78	0.78	0.78	0.77	0.77
90.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A4.4(b) VC ratios for rolling terrain, overtaking sight distance and percentage of time delayed (PTD) following slow vehicles

PTD %	Rolling terrain - percentage of overtaking sight distance										
	100	90	80	70	60	50	40	30	20	10	0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.5	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00
15.0	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00
22.5	0.11	0.09	0.07	0.06	0.05	0.03	0.02	0.02	0.01	0.01	0.01
30.0	0.15	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.02
37.5	0.18	0.15	0.13	0.11	0.10	0.09	0.07	0.06	0.06	0.05	0.04
45.0	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08
52.5	0.30	0.27	0.25	0.23	0.21	0.20	0.18	0.17	0.16	0.15	0.13
60.0	0.38	0.36	0.33	0.32	0.30	0.28	0.27	0.25	0.24	0.23	0.21
67.5	0.49	0.47	0.44	0.42	0.41	0.39	0.38	0.36	0.35	0.34	0.32
75.0	0.62	0.60	0.58	0.56	0.54	0.53	0.52	0.51	0.49	0.48	0.47
82.5	0.78	0.76	0.74	0.73	0.71	0.70	0.69	0.68	0.67	0.67	0.66
90.0	0.97	0.96	0.94	0.93	0.92	0.92	0.91	0.91	0.90	0.90	0.89

Table A4.4(c) VC ratios for mountainous terrain, overtaking sight distance and PTD following slow vehicles

PTD %	Mountainous terrain - percentage of overtaking sight distance										
	100	90	80	70	60	50	40	30	20	10	0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.5	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
15.0	0.07	0.05	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00
22.5	0.10	0.08	0.06	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00
30.0	0.14	0.10	0.07	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01
37.5	0.17	0.13	0.11	0.08	0.07	0.05	0.04	0.03	0.03	0.02	0.02
45.0	0.22	0.18	0.15	0.13	0.11	0.09	0.08	0.06	0.05	0.05	0.04
52.5	0.28	0.24	0.21	0.18	0.16	0.14	0.13	0.11	0.10	0.09	0.08
60.0	0.36	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15	0.13
67.5	0.46	0.42	0.39	0.36	0.34	0.31	0.29	0.27	0.26	0.24	0.22
75.0	0.58	0.55	0.52	0.49	0.47	0.45	0.43	0.41	0.39	0.37	0.35
82.5	0.73	0.70	0.68	0.65	0.63	0.62	0.60	0.58	0.57	0.55	0.53
90.0	0.91	0.89	0.87	0.86	0.84	0.83	0.82	0.81	0.80	0.79	0.78

Figure A4.1(a) **Percentage of time delayed (PTD) two lane rural roads, level terrain**

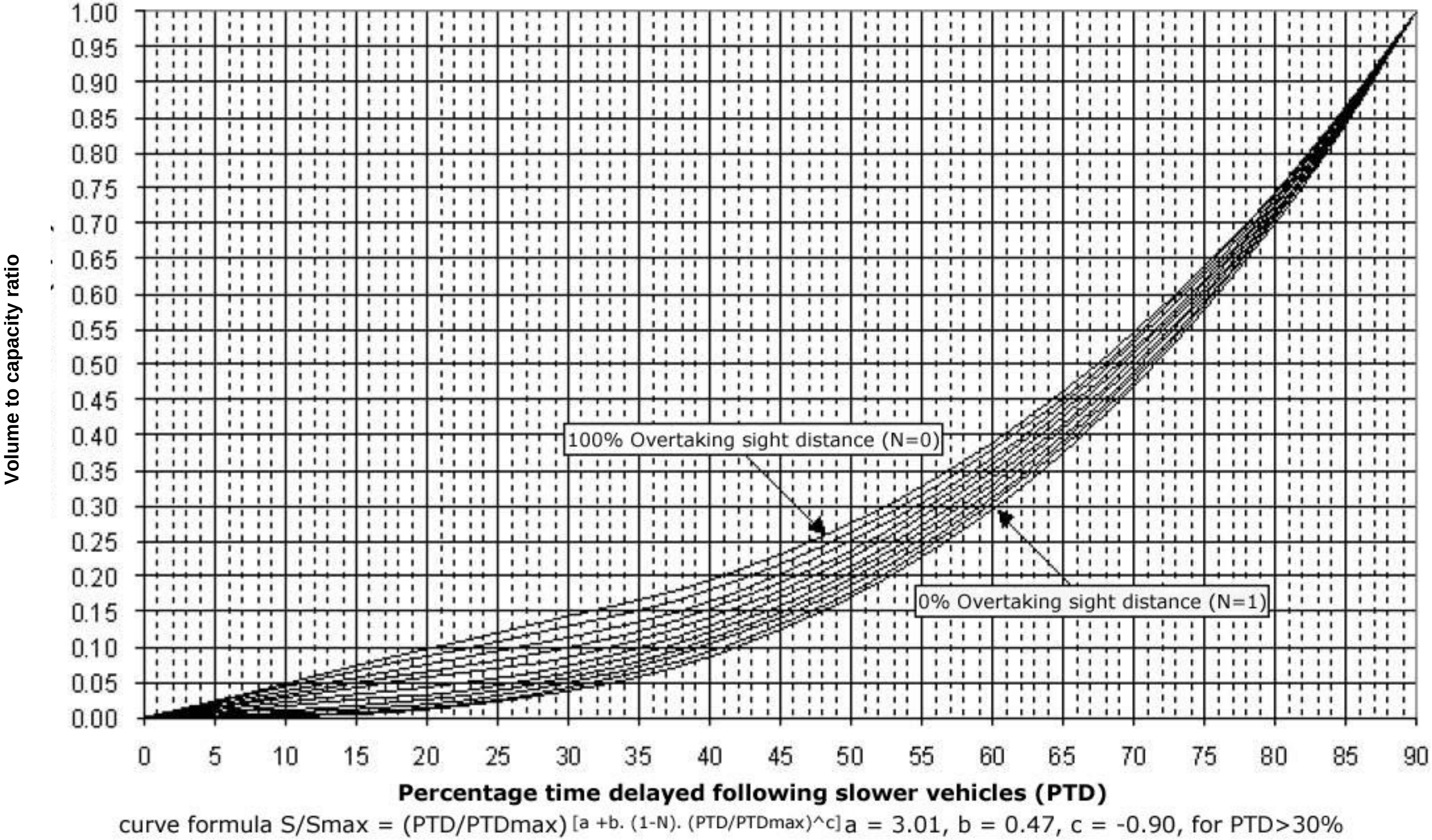
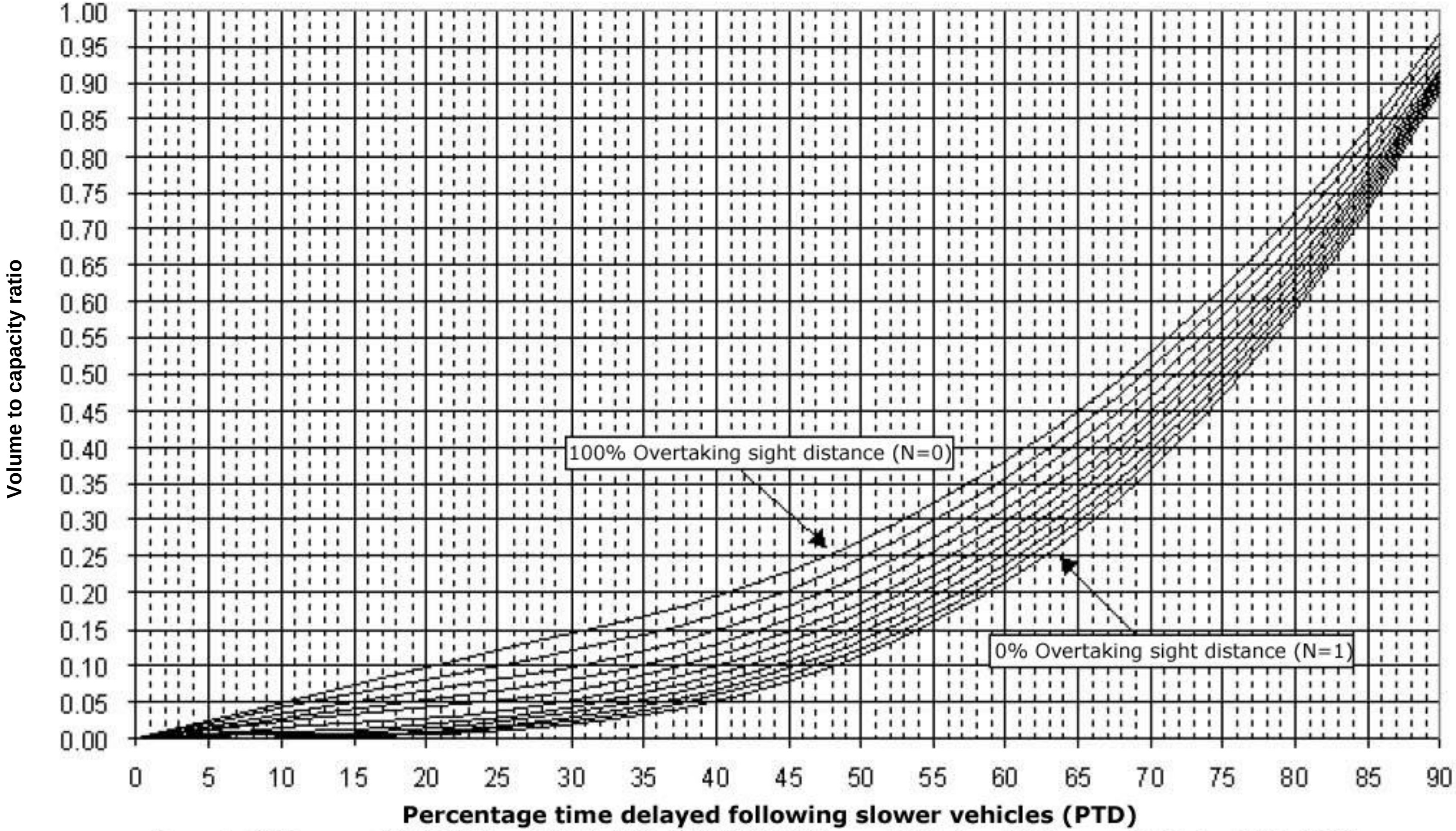
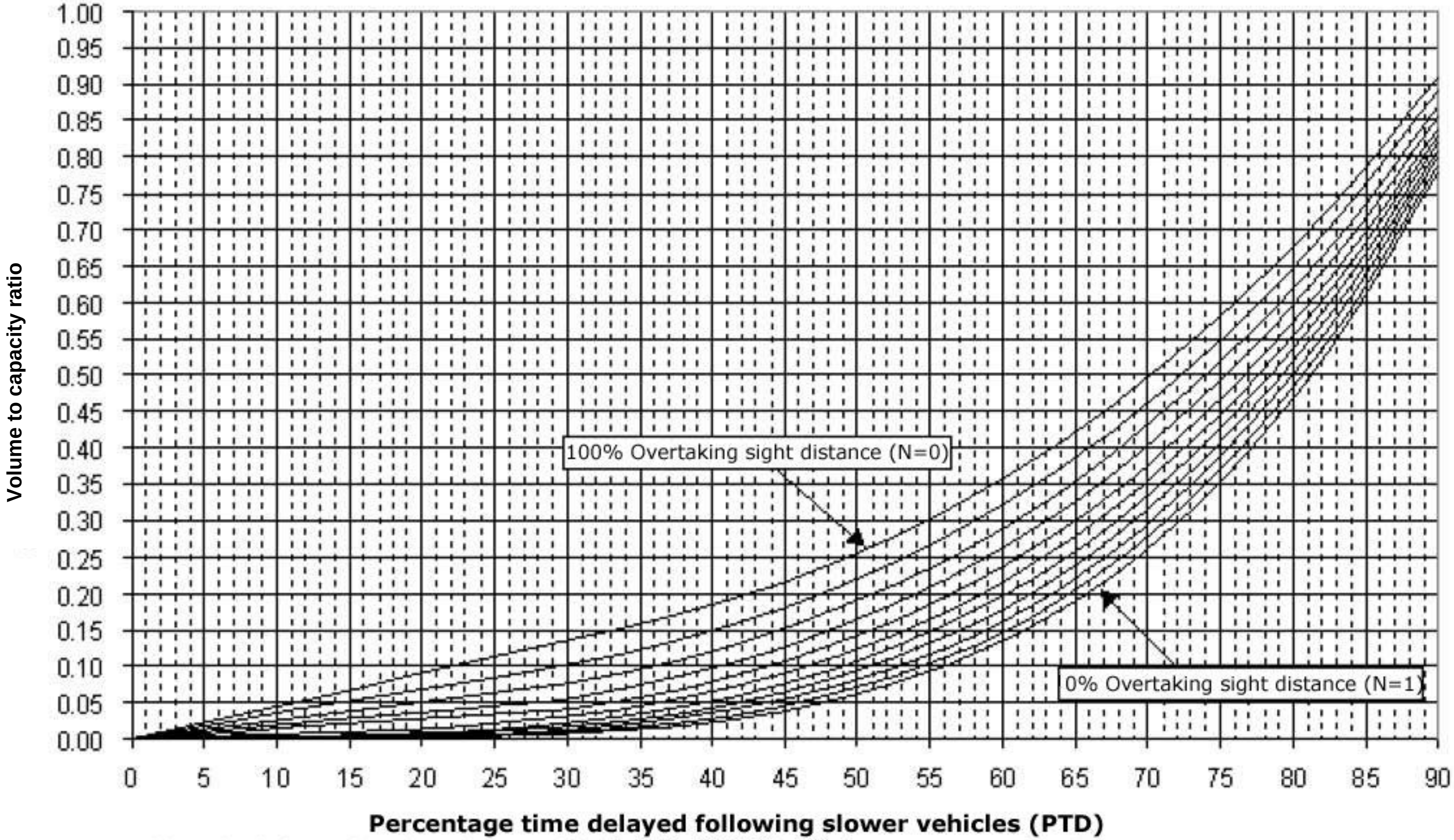


Figure A4.1(b) PTD for two lane rural roads, rolling terrain



curve formula $S/Smax = (PTD/PTDmax)^{[a + b. (1-N). (PTD/PTDmax)\hat{}c]}$ a = 3.51, b = 0.94, c = -0.59, for PTD>30%

Figure A4.1(c) **PTD for two lane rural roads, mountainous terrain**



curve formula (S/Smax) = (PTD/PTDmax)[a + b.(1-N). (PTD/PTDmax)^c] a =4.34, b = 1.75, c = -0.37, for PTD>30%)

A4.5 Benefits from improved trip time reliability

Introduction

This section outlines how likely variations in journey time can be assessed and the benefits from improvements to trip time reliability incorporated into project evaluation. Trip time reliability is measured by the unpredictable variations in journey times, which are experienced for a journey undertaken at broadly the same time every day. The impact is related to the day-to-day variations in traffic congestion, typically as a result of day-to-day variations in flow. This is distinct from the variations in individual journey times, which occur within a particular period.

Travel time reliability is in principle calculated for a complete journey and the total network variability is the sum of the travel time variability for all journeys on the network. In practice, models may not represent the full length of journeys and this is accounted for in the procedure.

Travel time variability is expressed as the standard deviation of travel time. The sources of variability are road sections and intersections. Reduced variability arises from a reduction in congestion on links and at intersections along a route. For a single section or intersection approach the standard deviation of travel time can be calculated using that section or intersection movement's VC ratio:

$$\text{Standard deviation of travel time} = s_0 + \frac{(s - s_0)}{1 + e^{b\left(\frac{v}{c} - a\right)}} \quad \text{(min)}$$

where: the VC ratio is represented by s, s_0, *b* and *a* are taken from table A4.5

Major incidents

The travel time variability that may result from major incidents on the road network is not accounted for in this procedure. For example, where there are high levels of congestion on motorways, a major incident will produce large travel time delays. These delays are not included in the day-to-day variability calculations.

The effect of a major incident will be related to the amount of spare capacity at the location. A specific analysis should be undertaken to determine the economic cost of delays from major incidents.

Reliability benefits calculation

The claimable benefits from improving trip reliability are calculated as:

0.9	×	travel time value ($/h) (table A4.1, A4.2 or A4.3)
	×	(reduction in the network variability (in min) / 60)
	×	traffic volume for time period (veh/h)
	×	correction factor (table A4.6)

Where the reduction in network variability is the difference between the sums of the variability for all journeys in the modelled area for the do-minimum and project option. The 0.9 factor is the value of reliability based on a typical urban traffic mix. For projects with a significantly different vehicle mix, evaluators should use 0.8 for cars and 1.2 for commercial vehicles.

Table A4.5 Coefficients to calculate standard deviation of travel time

Context	S	b	a	S_0
Motorway/multilane highway (70 - 100 km/h)	0.90	-52	1	0.083
Urban arterial	0.89	-28	1	0.117
Urban retail	0.87	-16	1	0.150
Urban other (50 km/h)	1.17	-19	1	0.050
Rural highway (70 - 100 km/h) (2 lanes in direction of travel)	1.03	-22	1	0.033
Signalised intersection	1.25	-32	1	0.120
Unsignalised intersection	1.20	-22	1	0.017

Note: Evaluations of small retail areas on 50 km/h sections of a rural highway should use the urban other (50 km/h) context.

Adjustment factor for variability calculations

In many cases, an activity evaluation will consider a defined area which does not represent the full length of most journeys. As a result, the changes in journey time reliability will be overestimated. In these cases the variability estimates need to be adjusted. Table A4.6 gives some illustrative contexts where different factors might apply. An estimation of the variance of journey times which occurs outside of the evaluation area must be made and the appropriate correction factor in table A4.6 applied.

The trip time reliability benefit is adjusted by multiplying the calculated variability benefit by the factor.

Table A4.6 Adjustment factors to apply to variability calculations

Percentage of variance outside of study area	Factor for benefit calculation	Indicative transport network model coverage
<20 %	100 %	Regional model
20 %	90 %	Sub-regional model
50 %	70 %	Area model
75 %	50 %	Corridor model
90 %	30 %	Intersection model, individual passing lane

Process for evaluating reliability benefits

1. Calculate standard deviation of travel time on each link between intersections and for each intersection movement or approach.
2. Square the standard deviations to produce variances.
3. Sum variances along each origin-destination path to obtain the total variance for journeys between each origin and destination.
4. Take the square root of the aggregated variance for a journey to give the standard deviation of the journey time.
5. Multiply the total trips for each origin-destination pair by the standard deviation of travel time and sum over the matrix to give the network-wide estimate of the variability.

6. Calculate the difference in variability between the project and do-minimum networks.

7. Assess the percentage of variance occurring outside of the selected study area and select the adjustment factor.

8. Calculate the benefit from improving trip reliability using the formula provided above, namely: 0.9 × travel time value × reduction in the network variability/60 × traffic volume for time period (veh/h) ×adjustment factor.

Network models with origin-destination information

Intersections should be analysed by movement at traffic signals and by movement or by approach for roundabouts and priority intersections. Variability for the uncontrolled movements at priority intersections should be set to zero.

For road sections, the calculation of the standard deviation of travel time assumes there is only one link between junctions or between changes in link context. If the model has more than one link between junctions then variability associated with such artificial network nodes should be set to zero.

Network skims compatible with the assigned flows should be used to aggregate travel time variances (square of standard deviation) along paths to create a matrix (or matrices where multiple paths are used) of journey time variance for origin-destination pairs. The square root of each cell in the resulting matrix will provide the variability (standard deviation) of travel time for that journey.

The total network variability is the sum of the products of the number of journeys between origin-destination pairs and the standard deviation of travel time for that journey.

It is important to note that the process above produces estimates of travel time variability as a function of VC ratio, reflecting the impact of day-to-day variations in travel demand. This is not the same as variations in individual journey times within a modelled period, a possible output of micro-simulation models. The variation in individual journey times from such models will be influenced by the driver, vehicle type, and generation factors used in the stochastic processes used in the model.

Evaluations without origin destination information

For individual intersection upgrades, the turning movements can be used as a proxy origin-destination matrix with the movement-weighted standard deviation being calculated for the intersection.

For project areas with more than a single congested intersection or link, an estimate of the proportion of trips that travel through more than one of these sources of variability must be made in order to approximate the total study area variability.

Two sources of variability

For two sources of variability, the reliability estimate for each trip direction is the sum of:

Variability for trips which travel only through source *x*: $\left(F_x\right)\left(SD_x\right)$

and, for trips travelling through both source *x* and *y*: $\left(F_{x.y}\right)\sqrt{\left(SD_x\right)^2 + \left(SD_y\right)^2}$

where: F_x = trips that travel through only source *x*

$F_{x.y}$ = trips that travel through both *x* and *y*

SD_x = standard deviation of travel time for trip at source *x*

SD_y = standard deviation of travel time for trip at source y

Note: The result of the above method should be multiplied by a correction factor from table A4.6.

Three sources of variability

For each of the three sources of variability, the reliability estimate is the sum of the individual components below:

Through source *x* only: $\left(F_x\right)\left(SD_x\right)$

Through sources *x* and *y* only: $\left(F_{x,y}\right)\sqrt{\left(SD_x\right)^2 + \left(SD_y\right)^2}$

Through sources *x* and z only: $\left(F_{x,z}\right)\sqrt{\left(SD_x\right)^2 + \left(SD_z\right)^2}$

Through sources *x*, *y* and *z* only: $\left(F_{x,y,z}\right)\sqrt{\left(SD_x\right)^2 + \left(SD_y\right)^2 + \left(SD_z\right)^2}$

Where: $F_{x,y,z}$ = trips that travel through all three sources *x, y* and *z*.

The result should be multiplied by a correction factor from table A4.6.

If traffic passes through more than three sources of significant congestion in the modelled area then evaluators must estimate the trip matrix and perform the calculation using the aggregation of journey variance method (with the correction factor from table A4.6).

Rural 2 lane roads

Table A4.7 contains travel time variability values for rural two lane roads of varying terrain and the volume to capacity ratio (see Appendix A3.17). The time period used to calculate the VC ratio must contain a relatively constant level of traffic volume.

Table A4.7(a) Travel time variability - rural two lane road, level terrain

Standard deviation of travel time (minutes) - percent no-passing for level terrain						
VC ratio	**0 %**	**20 %**	**40 %**	**60 %**	**80 %**	**100 %**
0.00	0.01	0.04	0.07	0.11	0.13	0.14
0.10	0.07	0.07	0.08	0.09	0.10	0.11
0.20	0.09	0.08	0.08	0.08	0.08	0.08
0.30	0.09	0.08	0.08	0.07	0.07	0.06
0.40	0.07	0.06	0.06	0.05	0.05	0.04
0.50	0.05	0.05	0.05	0.04	0.04	0.03
0.60	0.03	0.03	0.03	0.03	0.03	0.03
0.70	0.03	0.03	0.03	0.04	0.03	0.03
0.80	0.05	0.05	0.05	0.05	0.04	0.06
0.90	0.10	0.10	0.09	0.09	0.08	0.10
1.00	0.18	0.18	0.15	0.15	0.17	0.18

Table A4.7(b) Travel time variability – rural two lane road, rolling terrain

Standard deviation of travel time (minutes) - percent no-passing for rolling terrain						
VC ratio	**0 %**	**20 %**	**40 %**	**60 %**	**80 %**	**100 %**
0.00	0.03	0.09	0.15	0.17	0.24	0.27
0.10	0.11	0.13	0.15	0.17	0.17	0.18
0.20	0.13	0.13	0.12	0.13	0.12	0.12
0.30	0.12	0.10	0.09	0.09	0.08	0.08
0.40	0.09	0.07	0.06	0.06	0.06	0.05
0.50	0.06	0.05	0.05	0.05	0.06	0.06
0.60	0.05	0.06	0.07	0.08	0.09	0.08
0.70	0.07	0.10	0.12	0.14	0.15	0.14
0.80	0.14	0.18	0.21	0.23	0.23	0.22
0.90	0.26	0.29	0.32	0.34	0.34	0.34
1.00	0.43	0.44	0.47	0.46	0.47	0.49

Table A4.7(c) Travel time variability - rural two lane road, mountainous terrain

Standard deviation of travel time (minutes) - percent no-passing for mountainous terrain						
VC ratio	**0 %**	**20 %**	**40 %**	**60 %**	**80 %**	**100 %**
0.00	0.13	0.25	0.32	0.40	0.51	0.65
0.10	0.18	0.21	0.26	0.28	0.32	0.33
0.20	0.17	0.17	0.20	0.21	0.20	0.18
0.30	0.15	0.15	0.17	0.16	0.15	0.13
0.40	0.14	0.15	0.16	0.16	0.15	0.15
0.50	0.15	0.18	0.18	0.18	0.18	0.20
0.60	0.21	0.23	0.22	0.23	0.24	0.26
0.70	0.28	0.30	0.29	0.30	0.32	0.34
0.80	0.37	0.36	0.37	0.38	0.41	0.43
0.90	0.43	0.40	0.44	0.45	0.50	0.55
1.00	0.43	0.39	0.50	0.51	0.59	0.73

A4.6 Worked examples of trip reliability procedure

Introduction

Three worked examples of the calculations for trip reliability benefits are given below.

Example 1 – signalised intersection upgrade

An urban arterial project involves the addition of traffic lanes to the north and south approaches of a four leg intersection. This will improve the reliability of travel time. The traffic volumes for the north, south, east and west approaches are 1,506 veh/h, 168 veh/h, 1,662 veh/h and 57 veh/h respectively.

The average delay for do-minimum is 30 seconds and average delay for the project option is 20.8 seconds. Total flow is 3,393 veh/h.

Travel time savings

Travel time savings = $15.13 × 3393 × (30 - 20.8) / 3600 = $131.19/h
where $15.13 is value of travel time for morning commuter peak hour (table A4.3)

Trip reliability savings

The standard deviation of delay (in min) is calculated by:

$SD(TT) = S_0 + (S - S_0) / (1 + e^{b*(VC\ ratio\ -\ a)})$

For signalised intersections: $S = 1.25$, $b = -32$, $a = 1$, $S_0 = 0.120$ (table A4.5).

Do-minimum

Approach	Lane no	Movement	Traffic volume (veh/h)	VC ratio	SD(TT) (min)	SD(TT) x volume (veh-min)
South	1	LT	1370	0.901	0.166	226.924
	2	R	136	1.09	1.190	161.832
East	1	L	44	0.163	0.120	5.280
	2	TR	124	1.179	1.246	154.546
North	1	L	416	0.551	0.120	49.920
	2	T	1232	0.868	0.136	167.927
	3	R	14	0.149	0.120	1.680
West	1	LTR	57	0.626	0.120	6.840
						774.950

For the do-minimum, the total standard deviation in delay for the intersection is 774.950 veh-min.

Activity option

Approach	Lane no	Movement	Traffic volume (veh/h)	VC ratio	SD(TT) (min)	SD(TT) x volume (veh-min)
South	1	LT	702	0.807	0.122	85.886
	*2	T	668	0.807	0.122	81.726
	3	R	136	0.837	0.126	17.150
East	1	L	44	0.103	0.120	5.280
	2	TR	124	0.324	0.120	14.880
North	1	L	416	0.487	0.120	49.920
	2	T	616	0.743	0.120	74.107
	*3	T	616	0.743	0.120	74.107
	4	R	14	0.097	0.120	-1.680
West	1	LTR	57	0.417	0.120	6.840
* Additional traffic lane						411.574

With additional traffic lanes for the north and south approaches, the standard deviation drops to 411.574 veh-min.

The drop in standard deviation of delays is due to:

- Increase in capacity for North and South approaches as an extra lane is added for the through traffic.
- Increase in capacity for East and West approaches as the signal controller can allocate a higher proportion of cycle time to movements on these approaches.

Variability benefits per hour of the time period are calculated as:

0.9 × $15.13 × (774.950 – 411.574) / 60 × 30 % = $24.74/h.

Where $15.13 is the value of travel time for morning commuter peak hour (table A4.3), 0.9 is the variability travel time factor and the correction factor for an intersection model of 30% has been judged to be appropriate.

Example 2 – rural highway: four-laning

A section of rural strategic road is approaching capacity. One option is four-laning part of this section. The road carries 20,000 veh/day in level terrain, with a peak period intensity of 2,050 veh/h, 70/30 directional split, 7% heavy truck component and has 60% no-passing.

For the do-minimum, the capacity is calculated as 2800 × f_d × f_t = 2,800 × 0.89 × 0.92 = 2,290 veh/h. The values for f_d and f_t are drawn from Appendix A3.11. With a traffic volume of 2,050 veh/h, the VC ratio = 2,050 / 2,290 = 0.90. The standard deviation of travel time (denoted as SD(TT)) is 0.09 min (from table A4.7).

For the activity option, assuming there are no restrictions requiring a reduction in the lane capacity, a capacity of 2,200 veh/h/lane is applicable (see appendix A3.10). The VC ratio is 2,050 / (4 × 2,200) = 0.23.

The standard deviation of delay (in min) is calculated by:

$$SD(TT) = S_0 + (S - S_0) / (1 + e^{b* (VC\ ratio\ -\ a)})$$

For a rural highway (two lanes in each direction of travel):

$S = 1.03$, $b = -22$, $a = 1$, $S_0 = 0.033$ (from table A4.5)

$SD(TT) = 0.033 + (1.030 - 0.033) / (1 + e^{-22 * (0.23–1)})$
$= 0.033$ min

Variability benefits per hour are calculated as:

0.9 × \$25.34 × (0.09 - 0.033) × 2,050 / 60 × 30 % = \$13.32/h

where: \$25.34 is the value of travel time for weekday period for rural strategic roads (from table A4.3)

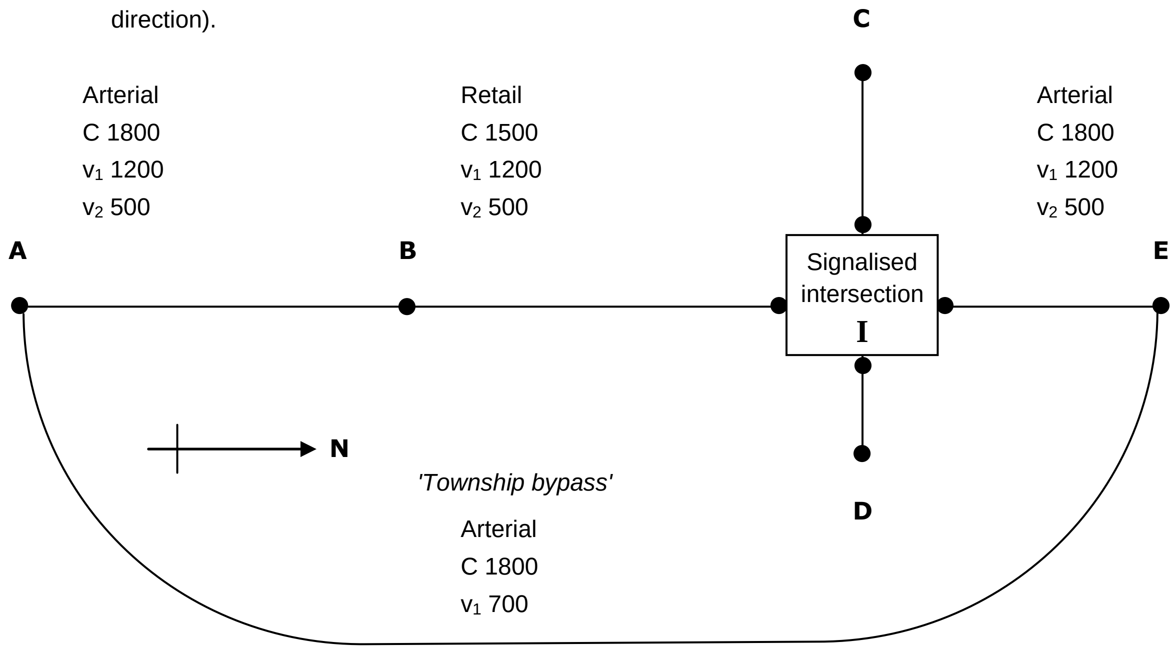
0.9 is the variability travel time factor and

30% is selected as the appropriate adjustment factor

(from table A4.6).

Example 3 – township bypass project

An activity provides a township (urban arterial) bypass from A to E to remove through traffic from the town centre. The existing through-traffic between A and E is 2,400 veh/h with 1,200 vehicles in each direction. It is expected that the traffic volumes between A and E will remain the same once the bypass is built, but 1400 vehicles will use the new bypass each hour (700 in each direction).



Traffic volume and VC ratio at the signalised intersection I are summarised on the following page.

Do-minimum

Approach	Lane no.	Movement	Traffic volume (veh/h)	VC ratio
South (B)	1	LT	1121	0.840
	2	R	82	0.595
East (D)	1	L	249	0.706
	2	TR	62	0.442
North (E)	1	L	252	0.271
	2	T	947	0.774
	3	R	9	0.072
West (C)	1	LTR	35	0.290

Activity option

Approach	Lane no.	Movement	Traffic volume (veh/h)	VC ratio
South (B)	1	LT	421	0.664
	2	R	82	0.330
East (D)	1	L	249	0.286
	2	TR	62	0.246
North (E)	1	L	252	0.237
	2	T	247	0.433
	3	R	9	0.040
West (C)	1	LTR	35	0.161

Matrices of flows

Do-minimum		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0	0	1	82	1120	0	1203
	B	0	0	0	0	0	0	0
	C	4	0	0	11	20	0	35
	D	249	0	2	0	60	0	311
	E via Town	947	0	9	252	0	0	1208
	E via bypass	0	0	0	0	0	0	0
Sum		1200	0	12	345	1200	0	2757

Activity option		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0	0	1	82	420	700	1203
	B	0	0	0	0	0	0	0
	C	4	0	0	11	20	0	35
	D	249	0	2	0	60	0	311
	E via Town	247	0	9	252	0	0	508
	E via bypass	700	0	0	0	0	0	700
Sum		1200	0	12	345	500	700	2757

For road section, standard deviations of travel times in minutes are calculated by:

SD(TT) $= S_0 + (S - S_0) / (1 + e^{b*(VC\ ratio\ -\ a)})$

For urban arterial: S $= 0.89$, $b = -28$, $a = 1$, $S_0 = 0.117$ (table A4.5)

For urban retail road: S $= 0.87$, $b = -16$, $a = 1$, $S_0 = 0.150$ (table A4.5)

From	To	Do-minimum	Activity option
A	B	0.117	0.117
B	I	0.178	0.150
I	E	0.117	0.117
A	E	-	0.117

For intersection C, standard deviations of delays in minutes for each movement are calculated by:

SD(TT) $= S_0 + (S - S_0) / (1 + e^{b*(VC\ ratio\ -\ a)})$

For signalised intersection: $S = 1.25$, $b = -32$, $a = 1$, $S_0 = 0.120$ (table A4.5)

From	To	Do-minimum	Activity option
B	C	0.127	0.120
B	E	0.127	0.120
B	D	0.120	0.120
D	B	0.120	0.120
D	C	0.120	0.120
D	E	0.120	0.120
E	D	0.120	0.120
E	B	0.121	0.120
E	C	0.120	0.120
C	E	0.120	0.120
C	D	0.120	0.120
C	B	0.120	0.120

The total variability is the square root of the sum of individual link / intersection variability. For instance, from origin A to destination C, the total variability for ‘do-minimum’ and ’activity option’ are calculated by:

Variability A-C $_{\text{do-minimum}}$ $\sqrt{(SD_{Link(AB)})^2 + (SD_{Link(BI)})^2 + (SD_{Intersection(BC)})^2}$

$= \sqrt{0.117^2 + 0.178^2 + 0.127^2}$

= 0.248 min

Variability A-C activity $_{\text{option}}$ $= \sqrt{0.117^2 + 0.150^2 + 0.120^2}$

= 0.225 min

Matrices of standard deviations of travel times

Do-minimum	To A	To B	To C	To D	To E via town	To E via bypass
From A	0	0	0.248	0.244	0.274	0
B	0	0	0	0	0	0
C	0.244	0	0	0.120	0.168	0
D	0.244	0	0.120	0	0.168	0
E via town	0.271	0	0.168	0.168	0	0
E via bypass	0	0	0	0	0	0

Activity option	To A	To B	To C	To D	To E via town	To E via bypass
From A	0	0	0.225	0.225	0.254	0.117
B	0	0	0	0	0	0
C	0.225	0	0	0.120	0.168	0
D	0.225	0	0.120	0	0.168	0
E via town	0.254	0	0.168	0.168	0	0
E via bypass	0.117	0	0	0	0	0

Network-wide estimate of variability

Multiply the element in the flow matrix with the corresponding element in the standard deviation matrix to derive the variability for each movement. Sum each line to get the total for the approach. Add the final column together to derive the network-wide variability.

Matrices of flow × standard deviation of travel time

Do-minimum		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0	0	0.248	20.008	306.880	0	327.136
	B	0	0	0	0	0	0	0.000
	C	0.976	0	0	1.320	3.360	0	5.656
	D	60.756	0	0.240	0	10.080	0	71.076
Town	E via	256.637	0	1.512	42.336	0	0	300.485
bypass	E via	0	0	0	0	0	0	0.000
Sum		318.369	0	2.000	63.664	320.320	0	704.353

Activity option		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0	0	0.225	18.450	106.680	81.9	207.255
	B	0	0	0	0	0	0	0.000
	C	0.900	0	0	1.320	3.360	0	5.580
	D	56.025	0	0.240	0	10.080	0	66.345
Town	E via	62.738	0	1.512	42.336	0	0	106.586
bypass	E via	81.9	0	0	0	0	0	81.900
Sum		201.563	0	1.977	62.106	120.120	81.900	467.666

The total variability for 'do-minimum' is 704.353 veh-min and for 'activity option' is 467.666 veh/min. Variability benefits per peak hour are calculated as:

0.9 × \$15.13 × (704.353 – 467.666) / 60 × 30 % = \$16.11/h

Where \$15.13 is the value of travel time for morning commuter peak hour for urban arterial (table A4.3), 0.9 is the variability travel time factor, and 30% is the adjustment factor as there is only one major source of variability.

A5 Vehicle operating costs

A5.1 Introduction

Introduction

This appendix provides values for vehicle operating costs (VOC) categorised into running costs, road surface related costs, speed change cycle costs, congestion costs, and costs while at a stop. Values are provided by vehicle classes and for standard traffic compositions on four different road categories.

Vehicle classes

The vehicle classes are defined in Appendix A2.2. The VOC for each vehicle class are based on the weighted average costs of the vehicles of different types within each class.

Standard traffic compositions

The VOC are given for the standard traffic compositions using the four road categories defined in Appendix A2.2, namely: urban arterial, urban other, rural strategic and rural other. The road category costs contained in the tables in this appendix are for the 'all time periods' traffic mix.

Nature of costs in this appendix

The VOC in this appendix are provided as resource costs, ie exclusive of duties and indirect taxation, such as excise and other taxes on fuel, import duties, and GST on all cost inputs.

In this appendix

Regression equations

To assist analysts, regression equations are provided which can be used to predict the VOC when using spreadsheets or other applications.

Note: The regression coefficients vary between vehicle classes and road categories.

The regression equations were used to generate the corresponding VOC tables so the results will be consistent, irrespective of which approach is used.

Minor differences will arise when calculating road category costs from individual vehicle class costs due to the regression equations being developed from the road category data. Where high precision is required, the vehicle class equations should be summed and used in preference to the road category equations.

Components of VOC

The total VOC are calculated by adding the following components:

VOC	=	base running costs by speed and gradient
	+	road roughness costs (if appropriate)
	+	road surface texture costs (if appropriate)
	+	pavement elastic deflection costs (if appropriate)
	+	congestion costs (if appropriate)
	+	bottleneck costs (if appropriate)
	+	speed change cycle costs (if appropriate).

All components except the base running costs are marginal costs that reflect the additional cost due to that component.

A5.2 Base VOC and VOC by speed and gradient

Base vehicle operating costs

The base vehicle operating costs (base VOC) comprise fuel, tyres, repairs and maintenance, oil, and the proportion of depreciation related to vehicle use. Standing charges, ie those incurred irrespective of use, are excluded from these costs. Such charges are included in the travel time costs for vehicle types (table A4.2) and the composite travel time values (table A4.3).

The breakdown of the base VOC by component is given in table A5.0(a) below.

Table A5.0(a) Breakdown of base VOC by component

Vehicle class	Percentage of total base VOC by component			
	Fuel and oil	Tyres	Maintenance and repairs	Depreciation
PC	30.0	7.0	29.3	33.7
LCV	32.3	8.3	27.3	32.1
MCV	30.4	7.2	45.4	17.0
HCVI	34.7	10.5	44.3	10.5
HCVII	31.3	13.5	43.4	11.8
BUS	29.9	6.3	45.5	18.3
Road type				
Urban arterial	30.3	7.2	29.9	32.5
Urban other	30.3	7.2	30.1	32.4
Rural strategic	30.5	7.5	30.9	31.1
Rural other	30.4	7.5	30.6	31.5

VOC by speed and gradient

Tables for VOC by speed (between 10 and 120 km/h) and gradients (between 0 and 12%) are provided in tables A5.1 to A5.10. The regression coefficients for running costs by speed and gradient are provided in table A5.11. Each table is accompanied by a graph. The tables give calculated values for each 5 km/h and percentage gradient.

The values are the average of the uphill and downhill gradient costs. While VOC are provided for all vehicle classes over the speed and gradient ranges, certain combinations of vehicle class, speed and gradient do not occur in practice, eg, sustained operation of laden heavy vehicles at high speed on steep gradients. VOC estimates at these extremes are less reliable than those in the range of normal operation.

Intermediate values should be interpolated or predicted using the regression equation. To use the graphs, the line of average traffic speed on the X-axis shall be read upwards to where it intersects with the appropriate gradient curve and then the running costs read off the Y-axis.

For all vehicle classes and road categories, the graph curves slope steeply upwards at low speeds. This arises because as vehicle speeds decrease the fuel consumption is governed by the minimum fuel consumption of the vehicle. As vehicle speeds increase above 60-70 km/h the graph curves start to rise due to the effects of increasing aerodynamic drag.

Tables A5.1 to A5.6 provide VOC for individual vehicle classes for use when an evaluation requires costs for a particular vehicle class or road category and where the traffic composition does not fall into one of the four standard road categories. One set of tables is provided for each vehicle class and these combine the VOC for both urban and rural road categories.

Where a non-standard traffic composition is considered, the combined VOC are estimated from the costs of the individual vehicle classes, and the mean speed of each vehicle class shall be used rather than the mean speed of the traffic stream as a whole.

Tables A5.7 to A5.10 provide the VOC for standard traffic compositions in the four road categories.

Buses

Buses are not included in these standard traffic compositions. If buses form a significant component of the traffic stream they shall be included in proportion to their representation.

A5.3 Additional VOC due to road surface conditions

Road roughness

For some projects, road surface roughness is an important contributor to VOC. Projects for which roughness measurements are necessary include shape correction, seal extension and any other work in which the riding characteristic of the road surface is changed by the project. The base VOC and VOC by speed and gradient outlined in Appendix A5.2 are calculated assuming zero road roughness (as measured on the IRI m/km scale) and shall be supplemented for the additional costs caused by road roughness when relevant to the project evaluation.

Roughness costs are made up of two components: vehicle costs and values for vehicle occupants' willingness to pay (WTP) to avoid rough road conditions. The WTP values reflect the preference of road users for driving on smooth roads and are based on New Zealand research. The WTP values indicate that road users on rural roads have a higher WTP value for a given roughness than urban users because of their higher average speeds. However, at very high roughness levels the WTP values are the same for both urban and rural road users. These two components are combined in tables A5.12 to A5.15.

Tables A5.12 and A5.13 provide the additional costs due to road roughness for individual vehicle classes for urban and rural conditions. Table A5.14 provides the costs for the standard traffic composition on the four road categories and table A5.15 provides the regression coefficients for predicting the roughness costs.

Note: if the current average roughness is less than 100 NAASRA then there is no actual benefit. Benefits calculated for pavements with initial roughness less than 100 NAASRA (3.8 IMI) must not be used in any BCR calculation.

Measurement of road roughness

To use the VOC tables for road roughness requires the measurement of road roughness. Previously, NAASRA counts/km was the primary measure but with the increased use of profilometers the International Roughness Index (IRI) has been adopted as the primary measure. The NAASRA roughness can be estimated from the IRI using the conversion 1 NAASRA counts/km = 26.49 x IRI m/km -1.27.

Road surface texture

A vehicle's rolling resistance is influenced by the macrotexture of the road surface and impacts on fuel and tyre consumption. The base VOC and VOC by speed and gradient provided in Appendix A5.2 are calculated on the basis of 0 texture.

The effect of surface texture on VOC is as follows:

1 mm increase in surface macro texture = 0.15 cents/ km / vehicle (all vehicle classes combined)

Macrotexture is expressed in mm either as a mean profile depth (MPD) or a sand circle (SS). The conversion between the two measures are:

SS = 0.2 + 0.8 MPD

The additional VOC due to road surface texture is added to the VOC in tables A5.2 to A5.11 and is applied to the total traffic volume using the road.

Pavement elastic deflection

Most road pavements in New Zealand are of a bituminous flexible construction. Pavement elastic deformation under heavy wheel loads depends on the type and strength of the pavement layers and sub-grade. It influences rolling resistance and therefore fuel and tyre consumption.

The pavement elastic deformation costs from table A5.0(b) are added to the VOC in tables A5.3 to A5.11 for MCV, HCVI, HCVII and buses and the four road categories.

Use of these costs should be accompanied by an adequate statistical sample of Benkelman beam test results for existing pavements, or Benkelman beam equivalent values from another recognised non-destructive test method.

Table A5.0(b) Increase in vehicle operating costs per vehicle-kilometre per 1 mm increase in Benkelman beam deflection (July 2002)

Vehicle class	Cents/veh/km
MCV	1.9
HCVI	3.0
HCVII	4.0
Bus	3.0
Road category	
Urban arterial	0.15
Urban other	0.16
Rural strategic	0.35
Rural other	0.29

A5.4 Additional VOC due to congestion

Congestion costs

The congestion costs are the additional VOCs due to vehicle accelerations and decelerations arising from traffic congestion. At low volume-to-capacity ratios (VC ratio) there are few accelerations or decelerations so the congestion values are relatively low, but they increase with increasing VC ratio, eventually becoming asymptotic as traffic flows approach capacity (VC ratio = 1.0).

The congestion costs by vehicle class are supplied in tables A5.16 to A5.18 for three different types of operating conditions:

- urban arterial and urban other roads.
- rural strategic and rural other roads.
- motorways.

Motorway costs are based on the rural strategic traffic composition.

Road category costs (all vehicle classes combined) are also provided in table A5.19, while table A5.20 provides regression coefficients for predicting the congestion costs by vehicle class and table A5.21 by road category.

When considering congestion costs, the analyst must take into account the amount of time over the year when traffic is at different levels of congestion (ie different VC ratio) must be accounted for. A minimum of five different one-hourly flow periods should be adopted, reflecting low to high flows, and the number of hours per year the traffic is at each flow level calculated (summing to 8760 h/year).

Procedure

The procedure for using the costs is as follows:

- Determine the capacity of the road (see Appendix A3.8)
- For each of the hourly flow periods, determine the traffic flow in pcu/hr and the corresponding VC ratio (see Appendix A3.17).
- From Appendix A3, determine the speed for each of the hourly flow periods.
- Using the VOC tables, determine the unadjusted VOC (including roughness, texture and deflection) for each of the hourly flow period speeds.
- For each of the hourly flow periods, determine the congestion cost corresponding to the VC ratio from tables A5.16 to A5.19.
- Determine the total VOC for each flow period as the sum of the unadjusted VOC and the congestion costs.
- Determine the total annual VOC by weighting the costs for each flow period by the percentage of the year that flow is experienced.

A5.5 Additional VOC due to bottleneck delay

Additional VOC during bottleneck delay

Tables A5.22 and A5.23 show the additional VOC by vehicle class and road category for a vehicle while experiencing bottleneck delay (ie VC ratio ≥1.0). They are calculated from the fuel consumption while idling and are in cents/minute.

A5.6 Additional VOC due to speed change cycles

Additional VOC due to speed change cycle

When a vehicle travelling at its cruise speed has this speed interrupted due to road geometry or other road features (eg one-lane bridges or intersections), it decelerates to a minimum speed (which may be a complete stop) before accelerating back to its original cruise speed. The speed change cycle values are the difference in travel time and VOC for travelling the distance of the speed cycle at the original cruise speed versus through the speed cycle.

Additional VOC due to speed change cycles are only to be used for specific situations where traffic follows a speed cycle comprised of a single deceleration from an initial cruise speed to a minimum speed before returning to the original cruise speed. These situations typically consist of:

- curves
- traffic signals
- one-lane bridges
- intersections
- work zones.

Tables A5.24 to A5.43 provide additional travel time (in seconds per speed cycle) and additional VOC (in cents per speed cycle) due to a speed change cycle for (1) the individual vehicle classes and (2) the standard traffic compositions in the four road categories.

Since the speed change cycle costs are additional VOC, care must be taken to ensure that there is no double counting of travel time benefits. For example, when considering traffic signals, the average speed excluding delays at traffic signals would be used to calculate the travel time and VOC. For those vehicles delayed by traffic signals, the additional time and additional VOC associated with the speed change would then be added. In the case of one-lane bridges, the average speed excluding the delay at the bridge would be used to calculate the travel time and VOC. The additional time and additional VOC due to the bridge would then be added.

A5.7 Vehicle operating cost tables

Table A5.1: Passenger car VOC by speed and gradient (cents/km – July 2008)

Speed(km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	43.9	44.0	44.1	44.2	44.2	44.3	44.4	44.5	44.7	45.0	45.2	45.6	46.1
15	38.2	38.3	38.5	38.6	38.7	38.9	39.1	39.3	39.6	39.9	40.4	40.9	41.5
20	34.0	34.2	34.3	34.5	34.6	34.9	35.1	35.4	35.7	36.1	36.6	37.2	37.9
25	31.0	31.1	31.3	31.5	31.7	31.9	32.2	32.5	32.9	33.3	33.9	34.5	35.3
30	28.8	28.9	29.1	29.2	29.5	29.7	30.0	30.3	30.8	31.3	31.9	32.6	33.4
35	27.1	27.3	27.4	27.6	27.8	28.1	28.4	28.8	29.2	29.7	30.4	31.1	31.9
40	26.0	26.1	26.3	26.4	26.7	26.9	27.2	27.6	28.1	28.6	29.3	30.1	30.9
45	25.1	25.3	25.4	25.6	25.8	26.1	26.4	26.8	27.3	27.9	28.5	29.3	30.2
50	24.6	24.7	24.9	25.1	25.3	25.5	25.9	26.3	26.8	27.4	28.0	28.8	29.8
55	24.3	24.4	24.5	24.7	24.9	25.2	25.5	26.0	26.5	27.0	27.7	28.6	29.5
60	24.1	24.3	24.4	24.6	24.8	25.1	25.4	25.8	26.3	26.9	27.6	28.4	29.4
65	24.2	24.3	24.4	24.6	24.8	25.0	25.4	25.8	26.3	26.9	27.6	28.5	29.4
70	24.3	24.4	24.5	24.7	24.9	25.2	25.5	25.9	26.4	27.0	27.8	28.6	29.6
75	24.5	24.6	24.7	24.9	25.1	25.4	25.7	26.1	26.6	27.3	28.0	28.9	29.8
80	24.9	24.9	25.1	25.2	25.4	25.7	26.0	26.4	26.9	27.6	28.3	29.2	30.2
85	25.3	25.3	25.4	25.6	25.8	26.0	26.4	26.8	27.3	28.0	28.7	29.6	30.6
90	25.7	25.8	25.9	26.0	26.2	26.5	26.8	27.2	27.8	28.4	29.1	30.0	31.0
95	26.3	26.3	26.4	26.5	26.7	27.0	27.3	27.7	28.3	28.9	29.6	30.5	31.6
100	26.8	26.9	27.0	27.1	27.3	27.5	27.9	28.3	28.8	29.4	30.2	31.1	32.1
105	27.5	27.5	27.6	27.7	27.9	28.1	28.4	28.9	29.4	30.0	30.8	31.7	32.7
110	28.1	28.1	28.2	28.3	28.5	28.7	29.1	29.5	30.0	30.6	31.4	32.3	33.3
115	28.8	28.8	28.9	29.0	29.1	29.4	29.7	30.1	30.7	31.3	32.1	33.0	34.0
120	29.5	29.5	29.6	29.7	29.8	30.1	30.4	30.8	31.3	32.0	32.7	33.6	34.7

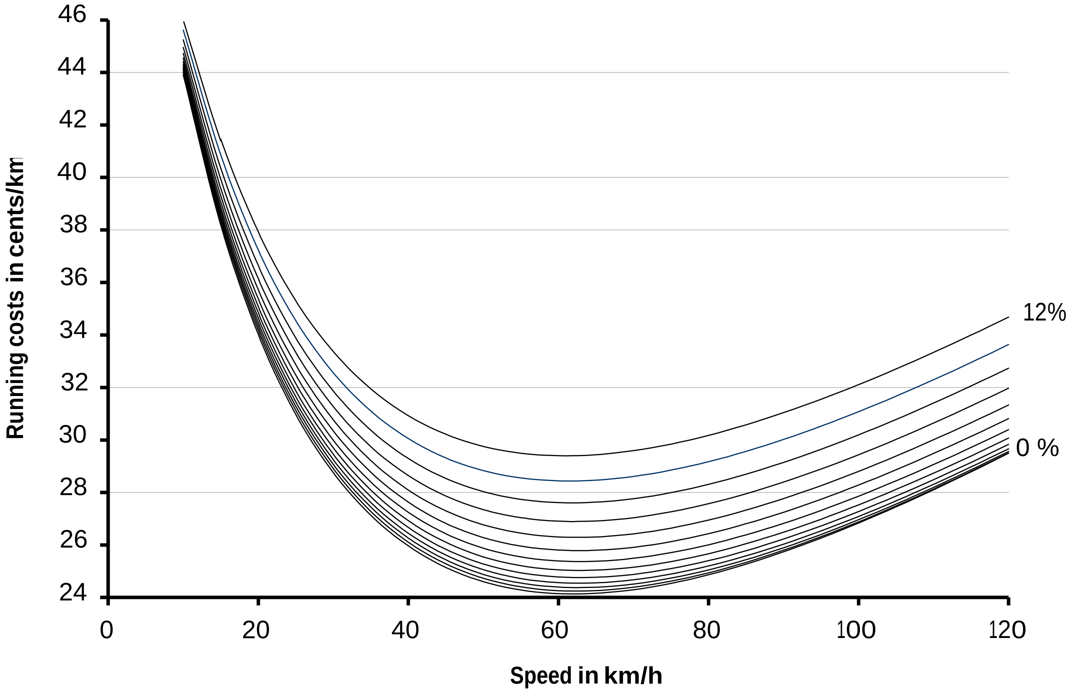


Table A5.2: LCV VOC by speed and gradient (cents/km – July 2008)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	49.8	49.8	49.8	49.9	50.1	50.3	50.7	51.1	51.6	52.3	53.0	53.9	54.9
15	42.8	42.9	43.0	43.2	43.5	43.9	44.4	45.0	45.7	46.5	47.4	48.5	49.7
20	37.7	37.8	38.0	38.3	38.6	39.1	39.6	40.3	41.1	42.0	43.1	44.3	45.7
25	34.0	34.2	34.4	34.7	35.0	35.6	36.2	36.9	37.8	38.8	39.9	41.2	42.7
30	31.4	31.5	31.7	32.0	32.5	33.0	33.7	34.4	35.3	36.4	37.6	39.0	40.5
35	29.5	29.6	29.9	30.2	30.6	31.2	31.9	32.7	33.6	34.7	36.0	37.4	39.0
40	28.2	28.4	28.6	28.9	29.4	29.9	30.6	31.5	32.4	33.6	34.8	36.3	37.9
45	27.4	27.5	27.7	28.1	28.5	29.1	29.8	30.7	31.7	32.8	34.1	35.6	37.3
50	26.9	27.0	27.3	27.6	28.1	28.6	29.4	30.2	31.2	32.4	33.7	35.2	36.9
55	26.7	26.9	27.1	27.4	27.9	28.4	29.2	30.0	31.1	32.2	33.6	35.1	36.8
60	26.8	26.9	27.1	27.4	27.9	28.5	29.2	30.1	31.1	32.3	33.7	35.2	37.0
65	27.0	27.1	27.3	27.6	28.1	28.7	29.4	30.3	31.3	32.6	33.9	35.5	37.2
70	27.4	27.5	27.7	28.0	28.5	29.1	29.8	30.7	31.7	32.9	34.3	35.9	37.7
75	28.0	28.0	28.2	28.5	29.0	29.6	30.3	31.2	32.2	33.5	34.9	36.5	38.2
80	28.6	28.7	28.9	29.2	29.6	30.2	30.9	31.8	32.9	34.1	35.5	37.1	38.9
85	29.4	29.4	29.6	29.9	30.3	30.9	31.6	32.5	33.6	34.8	36.2	37.8	39.6
90	30.2	30.2	30.4	30.7	31.1	31.7	32.4	33.3	34.4	35.6	37.0	38.6	40.4
95	31.1	31.1	31.3	31.6	32.0	32.5	33.3	34.2	35.2	36.5	37.9	39.5	41.3
100	32.1	32.1	32.2	32.5	32.9	33.5	34.2	35.1	36.1	37.4	38.8	40.4	42.3
105	33.1	33.1	33.2	33.5	33.9	34.4	35.2	36.0	37.1	38.4	39.8	41.4	43.2
110	34.1	34.1	34.2	34.5	34.9	35.5	36.2	37.1	38.1	39.4	40.8	42.4	44.3
115	35.2	35.2	35.3	35.6	36.0	36.5	37.2	38.1	39.2	40.4	41.8	43.5	45.3
120	36.4	36.3	36.4	36.7	37.1	37.6	38.3	39.2	40.3	41.5	42.9	44.6	46.4

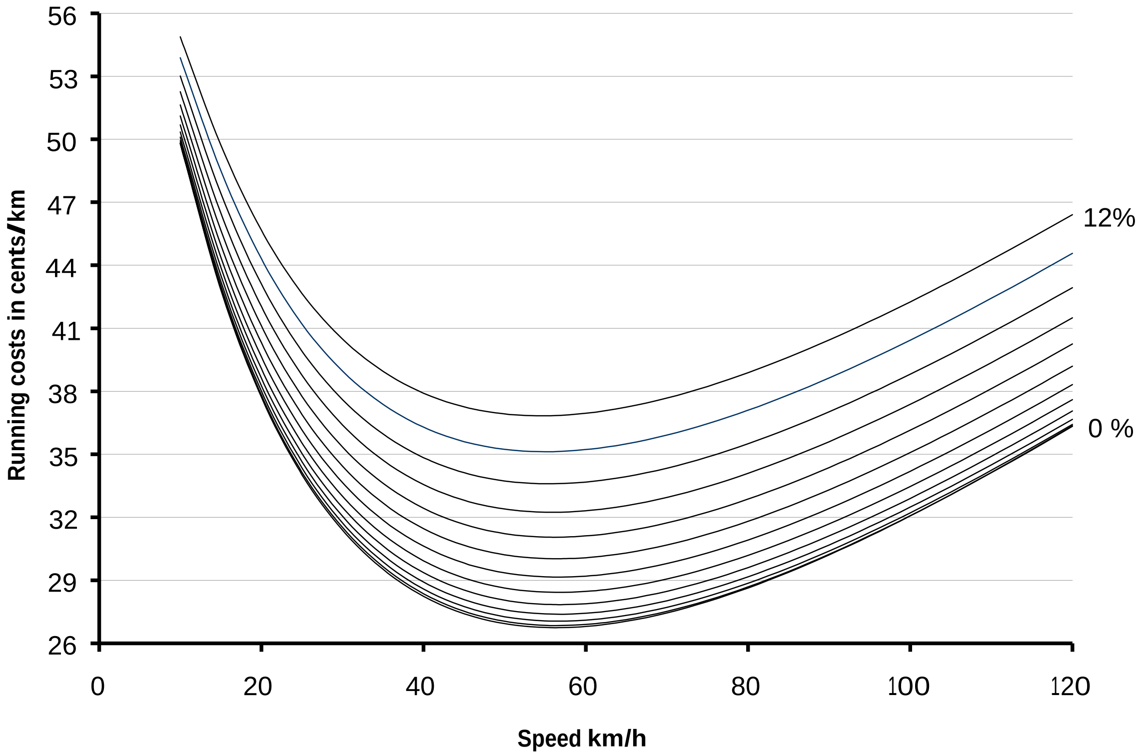


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Table A5.3: MCV VOC by speed and gradient (cents/km – July 2008)

Speed(km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	71.8	72.0	72.9	74.5	76.5	79.0	81.8	84.8	87.9	91.0	94.1	97.0	99.6
15	64.3	64.4	65.3	66.9	69.1	71.7	74.6	77.9	81.3	84.7	88.2	91.5	94.6
20	58.8	58.9	59.8	61.4	63.6	66.2	69.3	72.7	76.3	79.9	83.6	87.2	90.6
25	55.1	55.1	55.9	57.5	59.7	62.4	65.5	69.0	72.7	76.5	80.4	84.1	87.7
30	52.5	52.5	53.3	54.8	57.0	59.7	62.9	66.4	70.2	74.2	78.1	82.1	85.8
35	50.9	50.8	51.6	53.1	55.2	58.0	61.2	64.8	68.6	72.6	76.7	80.7	84.7
40	50.0	49.8	50.5	52.0	54.2	56.9	60.1	63.8	67.6	71.7	75.9	80.0	84.0
45	49.6	49.4	50.0	51.5	53.6	56.4	59.6	63.3	67.2	71.3	75.5	79.8	83.9
50	49.6	49.3	50.0	51.4	53.5	56.3	59.5	63.2	67.1	71.3	75.6	79.9	84.1
55	50.0	49.7	50.2	51.6	53.7	56.5	59.7	63.4	67.4	71.6	75.9	80.3	84.5
60	50.6	50.2	50.8	52.2	54.2	57.0	60.2	63.9	67.9	72.1	76.5	80.9	85.3
65	51.5	51.1	51.6	52.9	55.0	57.7	60.9	64.6	68.6	72.9	77.3	81.8	86.2
70	52.5	52.1	52.5	53.8	55.9	58.6	61.8	65.5	69.6	73.9	78.3	82.8	87.2
75	53.7	53.2	53.6	54.9	56.9	59.6	62.9	66.6	70.6	74.9	79.4	83.9	88.4
80	55.1	54.5	54.9	56.1	58.1	60.8	64.1	67.8	71.8	76.1	80.6	85.2	89.7
85	56.5	55.9	56.2	57.5	59.4	62.1	65.3	69.0	73.1	77.5	82.0	86.6	91.1
90	58.0	57.4	57.7	58.9	60.8	63.5	66.7	70.4	74.5	78.9	83.4	88.0	92.6
95	59.6	58.9	59.2	60.4	62.3	65.0	68.2	71.9	76.0	80.3	84.9	89.5	94.2
100	61.3	60.5	60.8	61.9	63.9	66.5	69.7	73.4	77.5	81.9	86.4	91.1	95.8
105	63.0	62.2	62.4	63.6	65.5	68.1	71.3	75.0	79.1	83.5	88.1	92.7	97.4
110	64.7	63.9	64.1	65.2	67.1	69.7	72.9	76.6	80.7	85.1	89.7	94.4	99.1
115	66.5	65.7	65.9	67.0	68.8	71.4	74.6	78.3	82.4	86.8	91.4	96.1	100.8
120	68.4	67.5	67.7	68.7	70.6	73.1	76.3	80.0	84.1	88.5	93.1	97.9	102.6

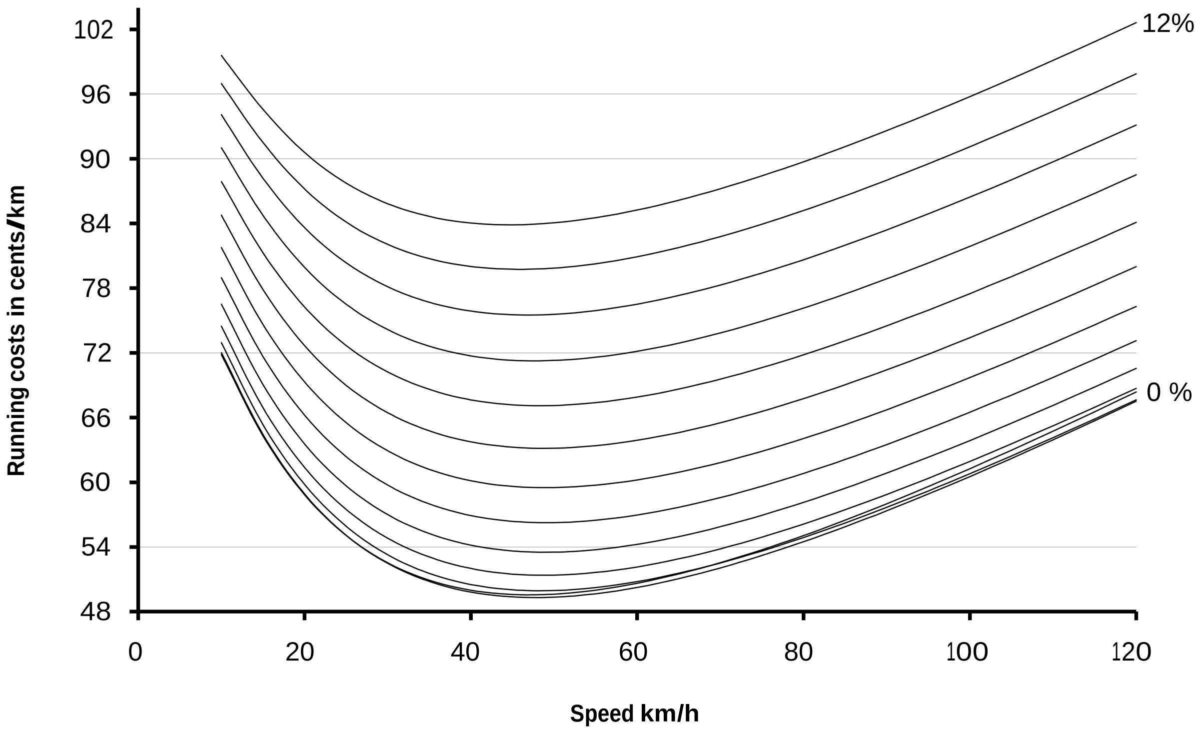


Table A5.4: HCVI VOC by speed and gradient (cents/km – July 2008)

Speed(km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	134.6	135.0	137.7	142.4	148.6	156.1	164.5	173.4	182.4	191.3	199.5	206.8	212.7
15	124.3	124.4	126.9	131.5	137.9	145.7	154.5	163.9	173.6	183.3	192.5	200.8	208.0
20	115.3	115.1	117.6	122.2	128.6	136.6	145.7	155.5	165.6	175.8	185.7	194.8	202.9
25	108.6	108.2	110.6	115.2	121.7	129.8	139.0	149.1	159.7	170.3	180.7	190.4	199.1
30	103.8	103.4	105.6	110.2	116.7	124.9	134.4	144.7	155.5	166.5	177.3	187.5	196.8
35	100.7	100.1	102.3	106.8	113.4	121.7	131.3	141.8	152.9	164.1	175.3	185.9	195.6
40	98.9	98.1	100.2	104.8	111.4	119.8	129.4	140.1	151.4	162.9	174.4	185.3	195.4
45	98.0	97.2	99.3	103.8	110.4	118.8	128.6	139.4	150.9	162.7	174.4	185.6	196.1
50	98.0	97.1	99.1	103.6	110.3	118.7	128.6	139.5	151.2	163.1	175.1	186.6	197.4
55	98.7	97.7	99.6	104.1	110.8	119.3	129.3	140.3	152.1	164.2	176.4	188.1	199.2
60	99.9	98.8	100.7	105.2	111.9	120.4	130.5	141.6	153.5	165.8	178.2	190.1	201.4
65	101.5	100.4	102.3	106.7	113.4	122.0	132.1	143.3	155.4	167.8	180.3	192.5	204.1
70	103.6	102.4	104.2	108.6	115.3	124.0	134.1	145.5	157.6	170.2	182.9	195.2	207.0
75	105.9	104.7	106.5	110.9	117.6	126.3	136.5	147.9	160.1	172.8	185.7	198.2	210.2
80	108.6	107.3	109.0	113.4	120.1	128.8	139.1	150.6	162.9	175.8	188.7	201.4	213.5
85	111.4	110.1	111.8	116.2	122.9	131.6	141.9	153.5	165.9	178.9	192.0	204.8	217.1
90	114.5	113.1	114.7	119.1	125.9	134.6	145.0	156.6	169.1	182.2	195.4	208.4	220.8
95	117.7	116.2	117.9	122.2	129.0	137.8	148.2	159.8	172.4	185.6	198.9	212.1	224.7
100	121.1	119.6	121.2	125.5	132.3	141.1	151.5	163.3	175.9	189.2	202.6	215.9	228.6
105	124.6	123.0	124.6	128.9	135.7	144.5	155.0	166.8	179.5	192.9	206.4	219.8	232.7
110	128.2	126.6	128.1	132.5	139.2	148.0	158.6	170.4	183.2	196.6	210.3	223.8	236.8
115	131.9	130.2	131.7	136.1	142.8	151.7	162.2	174.1	187.0	200.5	214.2	227.9	241.0
120	135.6	133.9	135.4	139.8	146.5	155.4	166.0	177.9	190.9	204.4	218.3	232.0	245.3

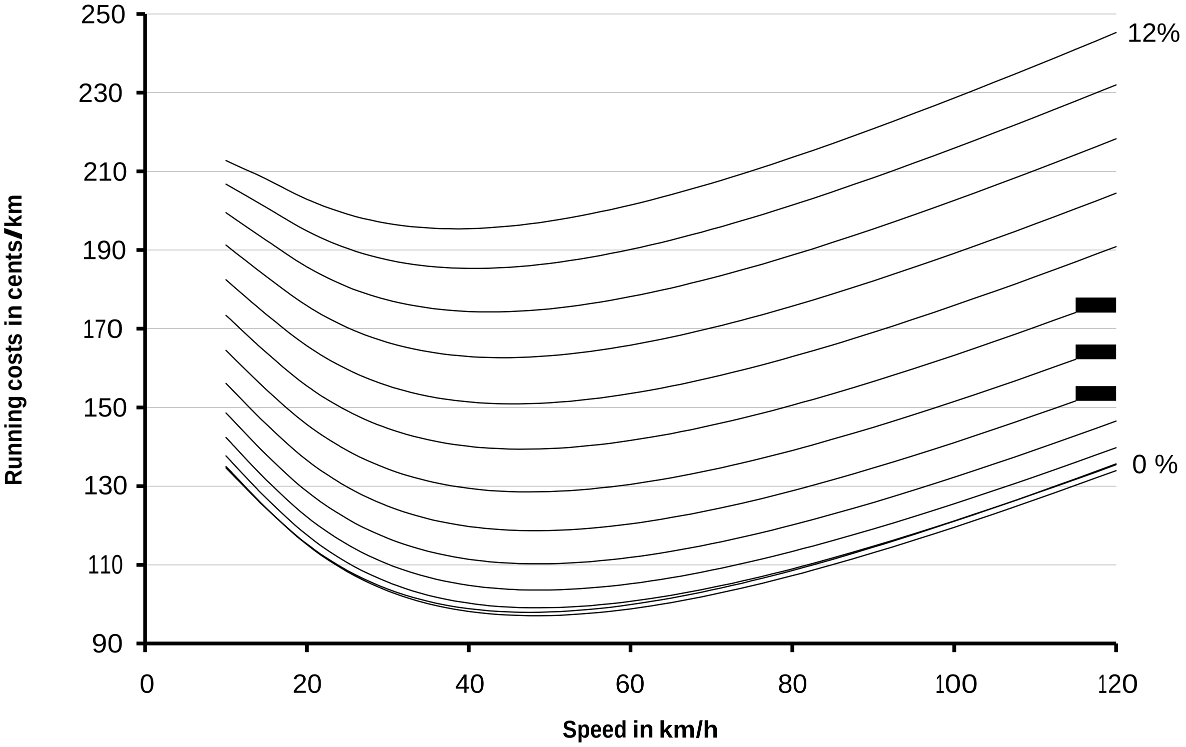


Table A5.5: HCVII VOC by speed and gradient (cents/km – July 2008)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	180.0	186.0	196.4	210.5	227.5	246.7	267.2	288.3	309.1	328.9	347.0	362.5	374.6
15	177.2	181.1	190.0	202.9	219.1	237.8	258.3	279.7	301.3	322.3	341.8	359.3	373.7
20	170.8	173.6	181.7	194.0	210.0	228.8	249.6	271.6	294.1	316.3	337.3	356.5	372.9
25	165.0	167.3	174.9	187.1	203.1	222.1	243.4	266.1	289.5	312.8	335.1	355.8	374.1
30	160.8	162.6	170.0	182.2	198.4	217.7	239.5	262.9	287.1	311.5	335.1	357.2	377.0
35	157.9	159.5	166.9	179.1	195.5	215.2	237.5	261.6	286.7	312.0	336.7	360.1	381.3
40	156.3	157.8	165.2	177.5	194.2	214.3	237.1	261.9	287.7	313.9	339.7	364.3	386.8
45	155.8	157.3	164.6	177.2	194.1	214.7	238.0	263.4	290.0	317.0	343.8	369.4	393.2
50	156.2	157.6	165.1	177.9	195.1	216.0	239.9	265.8	293.2	321.0	348.7	375.4	400.2
55	157.4	158.8	166.4	179.4	196.9	218.2	242.6	269.1	297.1	325.8	354.3	381.9	407.8
60	159.1	160.7	168.4	181.6	199.4	221.1	245.9	273.0	301.7	331.1	360.4	388.9	415.8
65	161.5	163.1	170.9	184.3	202.5	224.6	249.9	277.5	306.8	336.8	367.0	396.3	424.2
70	164.3	165.9	174.0	187.6	206.0	228.5	254.2	282.4	312.3	343.0	373.9	404.0	432.8
75	167.4	169.2	177.4	191.3	210.0	232.9	259.0	287.7	318.1	349.5	381.0	412.0	441.5
80	170.9	172.8	181.2	195.3	214.3	237.5	264.1	293.3	324.2	356.2	388.5	420.1	450.5
85	174.7	176.7	185.3	199.6	218.9	242.5	269.5	299.1	330.6	363.2	396.1	428.5	459.6
90	178.8	180.9	189.6	204.2	223.8	247.7	275.1	305.2	337.2	370.3	403.8	436.9	468.7
95	183.0	185.3	194.2	209.0	228.9	253.1	280.9	311.4	343.9	377.6	411.7	445.4	478.0
100	187.5	189.9	198.9	214.0	234.1	258.7	286.8	317.8	350.8	385.0	419.7	454.0	487.2
105	192.1	194.6	203.8	219.1	239.5	264.4	292.9	324.3	357.8	392.5	427.7	462.7	496.6
110	196.8	199.5	208.9	224.4	245.1	270.3	299.2	330.9	364.8	400.0	435.8	471.4	505.9
115	201.7	204.5	214.1	229.8	250.8	276.3	305.5	337.6	372.0	407.7	444.0	480.1	515.2
120	206.7	209.6	219.4	235.3	256.5	282.3	311.9	344.4	379.2	415.4	452.2	488.8	524.5

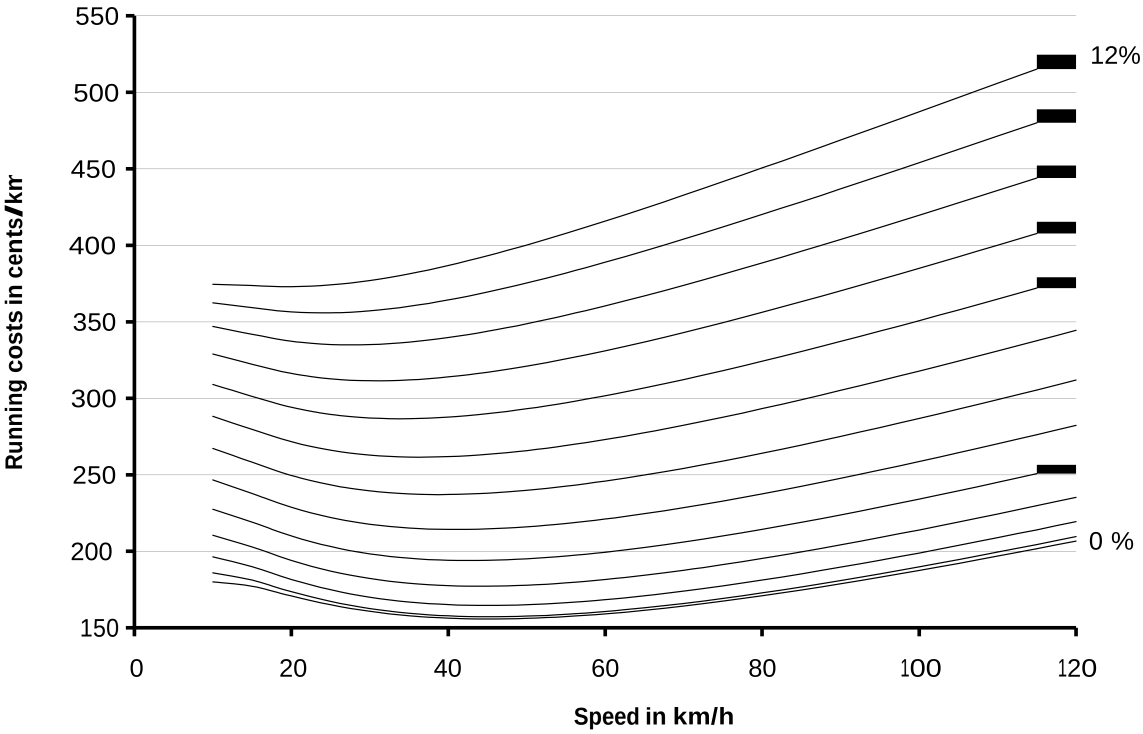


Table A5.6: Bus VOC by speed and gradient (cents/km – July 2008)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	104.2	105.1	107.6	111.4	116.3	122.1	128.6	135.3	142.2	149.0	155.4	161.1	166.0
15	97.0	97.6	100.0	103.8	108.9	114.9	121.7	129.0	136.6	144.1	151.4	158.2	164.2
20	90.2	90.6	92.8	96.6	101.7	107.9	114.9	122.5	130.4	138.4	146.3	153.7	160.5
25	85.2	85.4	87.4	91.1	96.2	102.4	109.6	117.4	125.6	133.9	142.2	150.1	157.5
30	81.9	81.9	83.8	87.4	92.4	98.7	105.9	113.8	122.2	130.9	139.4	147.7	155.5
35	80.0	79.8	81.5	85.0	90.0	96.3	103.6	111.6	120.2	129.0	137.8	146.4	154.5
40	79.2	78.8	80.4	83.8	88.8	95.1	102.4	110.5	119.1	128.1	137.1	146.0	154.4
45	79.4	78.8	80.3	83.6	88.5	94.7	102.0	110.2	119.0	128.1	137.3	146.3	155.0
50	80.2	79.5	80.8	84.0	88.9	95.1	102.4	110.7	119.5	128.7	138.0	147.3	156.1
55	81.7	80.7	82.0	85.1	89.9	96.1	103.5	111.7	120.6	129.9	139.4	148.7	157.8
60	83.6	82.5	83.7	86.7	91.5	97.6	105.0	113.2	122.2	131.6	141.1	150.6	159.8
65	85.9	84.7	85.8	88.7	93.4	99.5	106.9	115.1	124.1	133.6	143.3	152.9	162.2
70	88.6	87.3	88.2	91.1	95.7	101.8	109.1	117.4	126.5	136.0	145.7	155.5	164.9
75	91.5	90.1	90.9	93.7	98.3	104.4	111.7	120.0	129.0	138.6	148.4	158.3	167.9
80	94.7	93.2	93.9	96.6	101.1	107.2	114.5	122.8	131.9	141.5	151.4	161.3	171.0
85	98.1	96.4	97.1	99.7	104.2	110.2	117.5	125.8	134.9	144.5	154.5	164.5	174.3
90	101.6	99.9	100.4	103.0	107.4	113.4	120.6	129.0	138.1	147.8	157.8	167.9	177.8
95	105.3	103.5	103.9	106.5	110.8	116.7	124.0	132.3	141.4	151.2	161.2	171.4	181.3
100	109.1	107.2	107.6	110.0	114.3	120.2	127.4	135.8	144.9	154.7	164.8	175.0	185.0
105	113.1	111.0	111.3	113.7	118.0	123.8	131.0	139.3	148.5	158.3	168.4	178.7	188.8
110	117.1	114.9	115.2	117.5	121.7	127.5	134.7	143.0	152.2	162.0	172.2	182.5	192.7
115	121.2	118.9	119.1	121.3	125.5	131.3	138.4	146.7	155.9	165.8	176.0	186.4	196.6
120	125.3	123.0	123.1	125.3	129.4	135.1	142.3	150.6	159.8	169.6	179.9	190.3	200.6

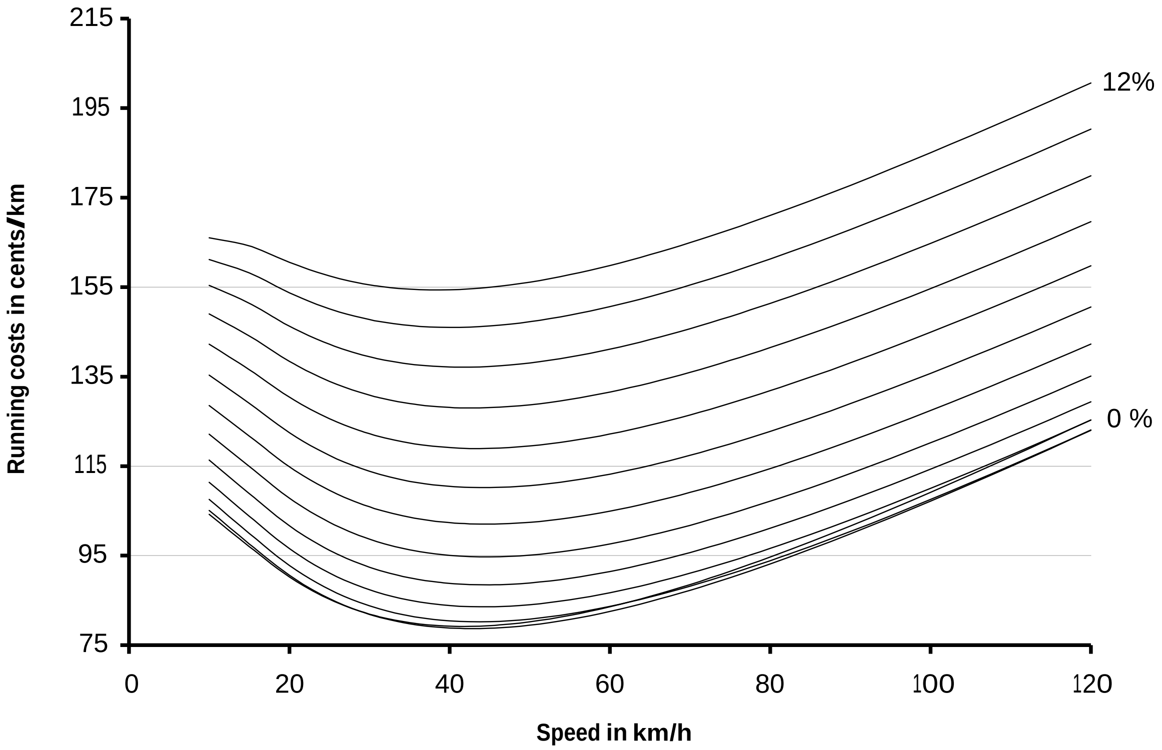


Table A5.7: Urban arterial VOC by speed and gradient (cents/km – July 2008)

Speed(km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	49.9	50.1	50.5	51.0	51.7	52.5	53.5	54.7	55.9	57.4	58.9	60.6	62.5
15	43.9	44.2	44.5	45.1	45.9	46.8	47.9	49.1	50.6	52.1	53.9	55.8	57.9
20	39.5	39.7	40.1	40.7	41.4	42.4	43.6	44.9	46.4	48.1	50.0	52.1	54.3
25	36.2	36.4	36.8	37.4	38.2	39.2	40.4	41.8	43.4	45.2	47.2	49.3	51.7
30	33.9	34.0	34.4	35.0	35.9	36.9	38.1	39.6	41.2	43.1	45.1	47.4	49.8
35	32.2	32.3	32.7	33.3	34.1	35.2	36.5	38.0	39.6	41.6	43.7	46.0	48.5
40	31.0	31.1	31.5	32.1	32.9	34.0	35.3	36.8	38.6	40.5	42.7	45.1	47.6
45	30.2	30.3	30.7	31.3	32.1	33.2	34.5	36.1	37.8	39.8	42.0	44.5	47.1
50	29.7	29.8	30.2	30.8	31.6	32.7	34.1	35.6	37.4	39.5	41.7	44.2	46.9
55	29.4	29.6	29.9	30.5	31.4	32.5	33.8	35.4	37.3	39.3	41.6	44.1	46.9
60	29.4	29.5	29.9	30.5	31.4	32.5	33.8	35.4	37.3	39.4	41.7	44.2	47.0
65	29.6	29.6	30.0	30.6	31.5	32.6	34.0	35.6	37.5	39.6	41.9	44.5	47.3
70	29.8	29.9	30.3	30.9	31.7	32.9	34.3	35.9	37.8	39.9	42.3	44.9	47.8
75	30.2	30.3	30.7	31.3	32.1	33.3	34.7	36.3	38.2	40.4	42.8	45.4	48.3
80	30.7	30.8	31.1	31.7	32.6	33.8	35.2	36.8	38.7	40.9	43.3	46.0	48.9
85	31.3	31.4	31.7	32.3	33.2	34.3	35.7	37.4	39.3	41.5	44.0	46.7	49.6
90	32.0	32.0	32.4	33.0	33.8	35.0	36.4	38.1	40.0	42.2	44.7	47.4	50.4
95	32.7	32.7	33.1	33.7	34.6	35.7	37.1	38.8	40.8	43.0	45.5	48.2	51.2
100	33.5	33.5	33.8	34.4	35.3	36.5	37.9	39.6	41.6	43.8	46.3	49.1	52.1
105	34.3	34.3	34.7	35.2	36.1	37.3	38.7	40.4	42.4	44.7	47.2	49.9	53.0
110	35.2	35.2	35.5	36.1	37.0	38.1	39.6	41.3	43.3	45.5	48.1	50.9	53.9
115	36.1	36.1	36.4	37.0	37.9	39.0	40.5	42.2	44.2	46.5	49.0	51.8	54.9
120	37.0	37.0	37.3	37.9	38.8	40.0	41.4	43.1	45.1	47.4	50.0	52.8	55.9

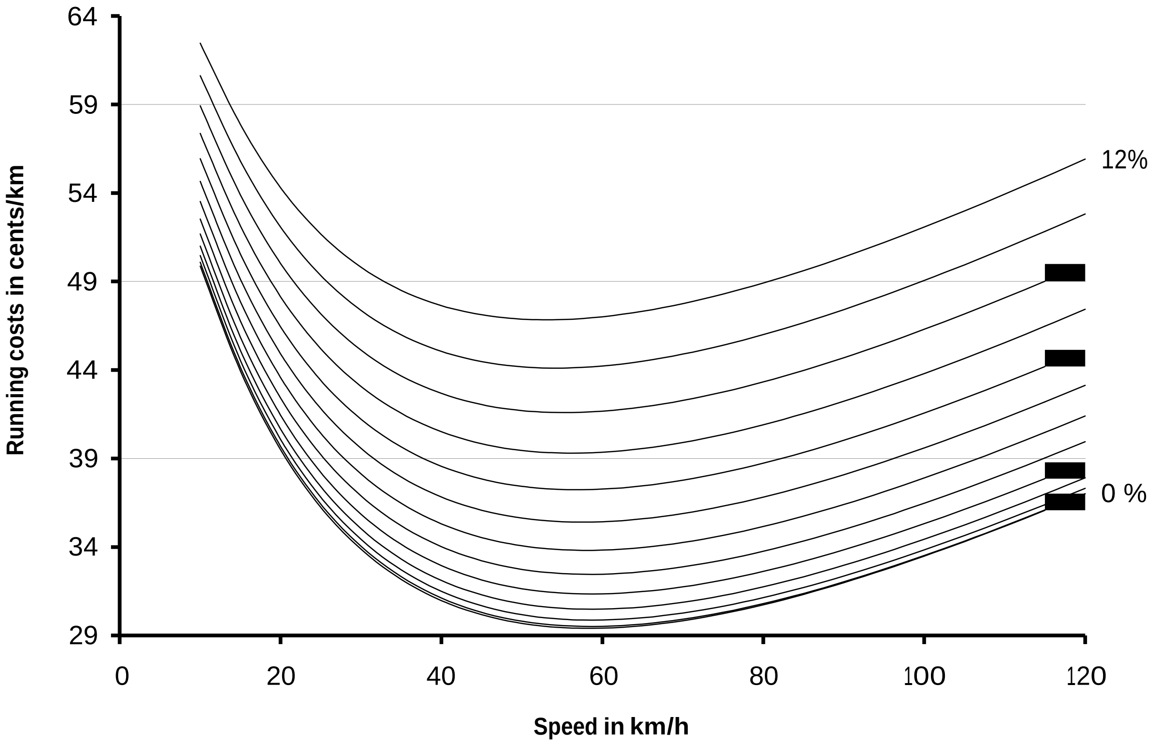


Table A5.8: Urban other VOC by speed and gradient (cents/km – July 2008)

Speed(km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	47.0	47.1	47.4	47.6	48.0	48.3	48.8	49.3	49.8	50.4	51.0	51.6	52.3
15	41.1	41.3	41.5	41.9	42.3	42.7	43.3	43.9	44.5	45.2	46.0	46.8	47.7
20	36.8	37.0	37.2	37.6	38.0	38.5	39.1	39.8	40.5	41.3	42.2	43.1	44.2
25	33.6	33.8	34.0	34.4	34.9	35.4	36.0	36.7	37.5	38.4	39.4	40.4	41.5
30	31.3	31.5	31.7	32.1	32.6	33.1	33.8	34.5	35.4	36.3	37.3	38.4	39.6
35	29.6	29.8	30.0	30.4	30.9	31.5	32.2	32.9	33.8	34.8	35.8	37.0	38.2
40	28.4	28.6	28.8	29.2	29.7	30.3	31.0	31.8	32.7	33.7	34.8	36.0	37.3
45	27.6	27.8	28.0	28.4	28.9	29.5	30.2	31.0	32.0	33.0	34.1	35.3	36.7
50	27.1	27.2	27.5	27.9	28.4	29.0	29.7	30.5	31.5	32.5	33.7	35.0	36.3
55	26.8	27.0	27.2	27.6	28.1	28.7	29.4	30.3	31.2	32.3	33.5	34.8	36.2
60	26.8	26.9	27.1	27.5	28.0	28.6	29.3	30.2	31.2	32.3	33.5	34.8	36.2
65	26.8	26.9	27.2	27.5	28.0	28.7	29.4	30.3	31.3	32.4	33.6	35.0	36.4
70	27.1	27.1	27.4	27.7	28.2	28.9	29.6	30.5	31.5	32.6	33.9	35.2	36.7
75	27.4	27.5	27.7	28.0	28.5	29.2	29.9	30.8	31.8	33.0	34.2	35.6	37.1
80	27.8	27.9	28.1	28.4	28.9	29.6	30.3	31.2	32.3	33.4	34.7	36.1	37.6
85	28.3	28.4	28.6	28.9	29.4	30.1	30.8	31.7	32.8	33.9	35.2	36.6	38.1
90	28.9	28.9	29.1	29.5	30.0	30.6	31.4	32.3	33.3	34.5	35.8	37.2	38.8
95	29.5	29.6	29.8	30.1	30.6	31.2	32.0	32.9	34.0	35.1	36.5	37.9	39.4
100	30.2	30.2	30.4	30.8	31.3	31.9	32.7	33.6	34.6	35.8	37.1	38.6	40.2
105	30.9	31.0	31.1	31.5	32.0	32.6	33.4	34.3	35.4	36.6	37.9	39.3	40.9
110	31.7	31.7	31.9	32.2	32.7	33.4	34.1	35.1	36.1	37.3	38.7	40.1	41.7
115	32.5	32.5	32.7	33.0	33.5	34.1	34.9	35.8	36.9	38.1	39.5	41.0	42.6
120	33.3	33.3	33.5	33.8	34.3	35.0	35.7	36.7	37.7	39.0	40.3	41.8	43.4

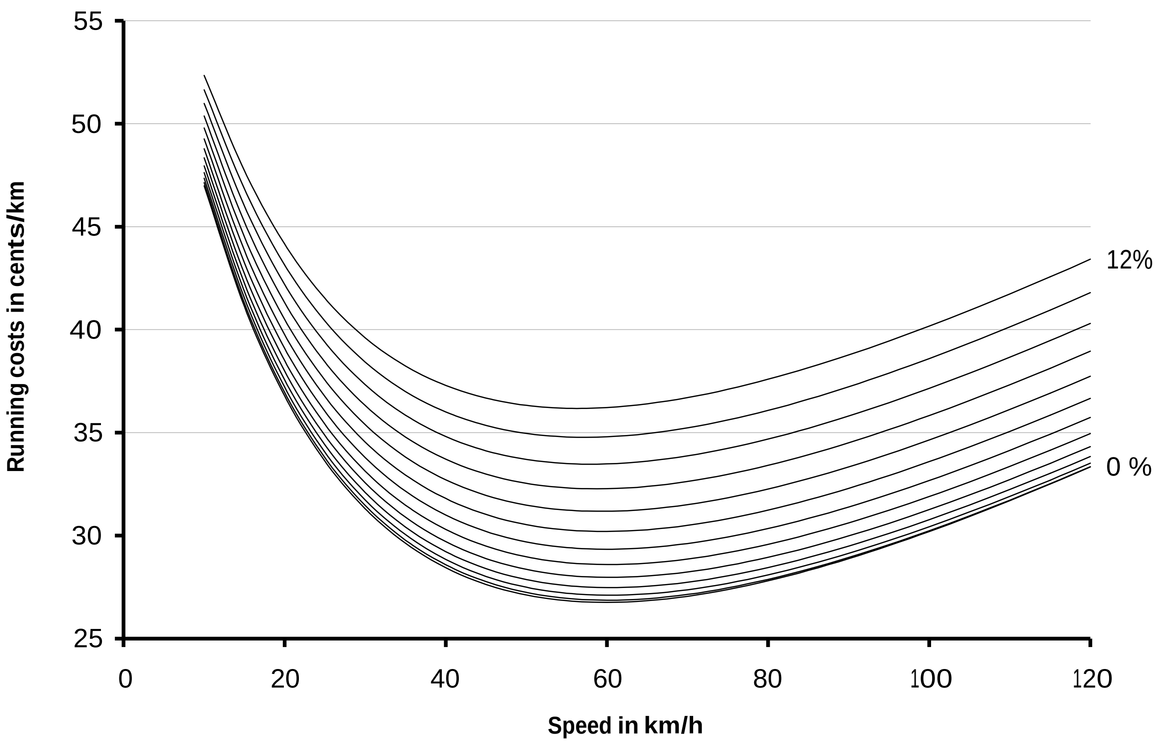


Table A5.9: Rural strategic VOC by speed and gradient (cents/km – July 2008)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	56.3	56.7	57.4	58.4	59.7	61.2	62.8	64.5	66.2	68.0	69.6	71.2	72.6
15	50.3	50.6	51.3	52.4	53.7	55.2	56.9	58.7	60.7	62.6	64.5	66.4	68.1
20	45.7	46.0	46.6	47.6	49.0	50.6	52.4	54.3	56.4	58.5	60.6	62.6	64.6
25	42.3	42.5	43.2	44.2	45.5	47.2	49.0	51.1	53.2	55.4	57.7	59.9	62.1
30	39.8	40.0	40.6	41.7	43.0	44.7	46.6	48.7	51.0	53.3	55.7	58.0	60.3
35	38.0	38.2	38.8	39.9	41.3	43.0	44.9	47.1	49.4	51.8	54.3	56.8	59.2
40	36.8	37.0	37.6	38.6	40.0	41.8	43.8	46.0	48.4	50.9	53.4	56.0	58.6
45	36.0	36.2	36.8	37.8	39.3	41.0	43.1	45.3	47.8	50.3	53.0	55.7	58.3
50	35.6	35.7	36.3	37.4	38.8	40.6	42.7	45.0	47.5	50.1	52.8	55.6	58.3
55	35.4	35.5	36.2	37.2	38.7	40.5	42.6	44.9	47.5	50.2	52.9	55.8	58.6
60	35.5	35.6	36.2	37.3	38.8	40.6	42.7	45.1	47.7	50.4	53.3	56.2	59.1
65	35.7	35.8	36.5	37.5	39.0	40.9	43.0	45.4	48.1	50.9	53.8	56.7	59.7
70	36.2	36.3	36.9	37.9	39.4	41.3	43.5	45.9	48.6	51.4	54.4	57.4	60.5
75	36.7	36.8	37.4	38.5	40.0	41.9	44.1	46.6	49.3	52.1	55.1	58.2	61.3
80	37.4	37.4	38.1	39.1	40.7	42.6	44.8	47.3	50.0	52.9	56.0	59.1	62.3
85	38.1	38.2	38.8	39.9	41.4	43.3	45.6	48.1	50.9	53.8	56.9	60.1	63.3
90	39.0	39.0	39.6	40.7	42.3	44.2	46.5	49.0	51.8	54.8	58.0	61.2	64.4
95	39.9	39.9	40.5	41.6	43.2	45.1	47.4	50.0	52.8	55.9	59.0	62.3	65.6
100	40.8	40.9	41.5	42.6	44.2	46.1	48.4	51.0	53.9	56.9	60.2	63.5	66.8
105	41.9	41.9	42.5	43.6	45.2	47.2	49.5	52.1	55.0	58.1	61.3	64.7	68.1
110	42.9	43.0	43.6	44.7	46.3	48.2	50.6	53.2	56.1	59.3	62.5	65.9	69.4
115	44.0	44.1	44.7	45.8	47.4	49.4	51.7	54.4	57.3	60.5	63.8	67.2	70.7
120	45.2	45.2	45.8	46.9	48.5	50.5	52.9	55.6	58.6	61.7	65.1	68.5	72.1

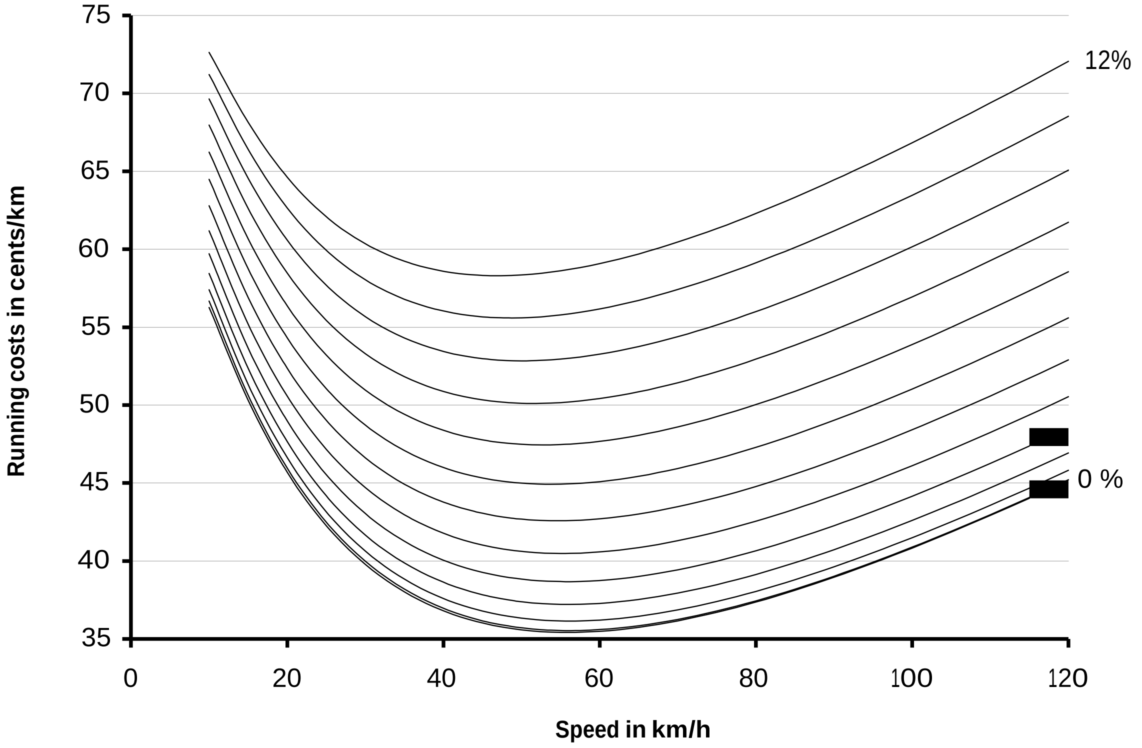


Table A5.10: Rural other VOC by speed and gradient (cents/km – July 2008)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	52.1	52.4	52.8	53.5	54.4	55.3	56.4	57.5	58.7	59.9	61.1	62.2	63.3
15	46.1	46.4	46.9	47.6	48.5	49.5	50.7	51.9	53.3	54.6	56.0	57.4	58.8
20	41.6	41.9	42.3	43.0	44.0	45.0	46.3	47.6	49.1	50.6	52.1	53.7	55.2
25	38.3	38.5	39.0	39.7	40.6	41.8	43.1	44.5	46.0	47.6	49.3	50.9	52.6
30	35.9	36.1	36.6	37.3	38.2	39.4	40.7	42.2	43.8	45.5	47.2	49.0	50.8
35	34.2	34.4	34.8	35.5	36.5	37.7	39.1	40.6	42.2	44.0	45.8	47.7	49.5
40	33.0	33.1	33.6	34.3	35.3	36.5	37.9	39.5	41.2	43.0	44.9	46.8	48.8
45	32.2	32.3	32.8	33.5	34.5	35.7	37.1	38.7	40.5	42.3	44.3	46.3	48.3
50	31.7	31.8	32.3	33.0	34.0	35.3	36.7	38.3	40.1	42.0	44.0	46.1	48.2
55	31.5	31.6	32.1	32.8	33.8	35.1	36.5	38.2	40.0	41.9	44.0	46.1	48.2
60	31.5	31.6	32.0	32.8	33.8	35.1	36.5	38.2	40.1	42.0	44.1	46.3	48.5
65	31.7	31.8	32.2	32.9	34.0	35.2	36.7	38.4	40.3	42.3	44.4	46.7	48.9
70	32.0	32.1	32.5	33.3	34.3	35.6	37.1	38.8	40.7	42.7	44.9	47.2	49.5
75	32.4	32.5	32.9	33.7	34.7	36.0	37.6	39.3	41.2	43.3	45.5	47.8	50.1
80	33.0	33.1	33.5	34.2	35.3	36.6	38.1	39.9	41.8	43.9	46.1	48.5	50.9
85	33.6	33.7	34.1	34.9	35.9	37.2	38.8	40.6	42.5	44.6	46.9	49.2	51.7
90	34.4	34.4	34.8	35.6	36.6	37.9	39.5	41.3	43.3	45.4	47.7	50.1	52.6
95	35.1	35.2	35.6	36.3	37.4	38.7	40.3	42.1	44.1	46.3	48.6	51.0	53.5
100	36.0	36.0	36.4	37.2	38.2	39.6	41.2	43.0	45.0	47.2	49.5	52.0	54.5
105	36.9	36.9	37.3	38.1	39.1	40.5	42.1	43.9	45.9	48.1	50.5	53.0	55.5
110	37.8	37.8	38.2	39.0	40.0	41.4	43.0	44.9	46.9	49.1	51.5	54.0	56.6
115	38.8	38.8	39.2	39.9	41.0	42.4	44.0	45.8	47.9	50.1	52.5	55.1	57.7
120	39.8	39.8	40.2	40.9	42.0	43.4	45.0	46.9	48.9	51.2	53.6	56.2	58.8

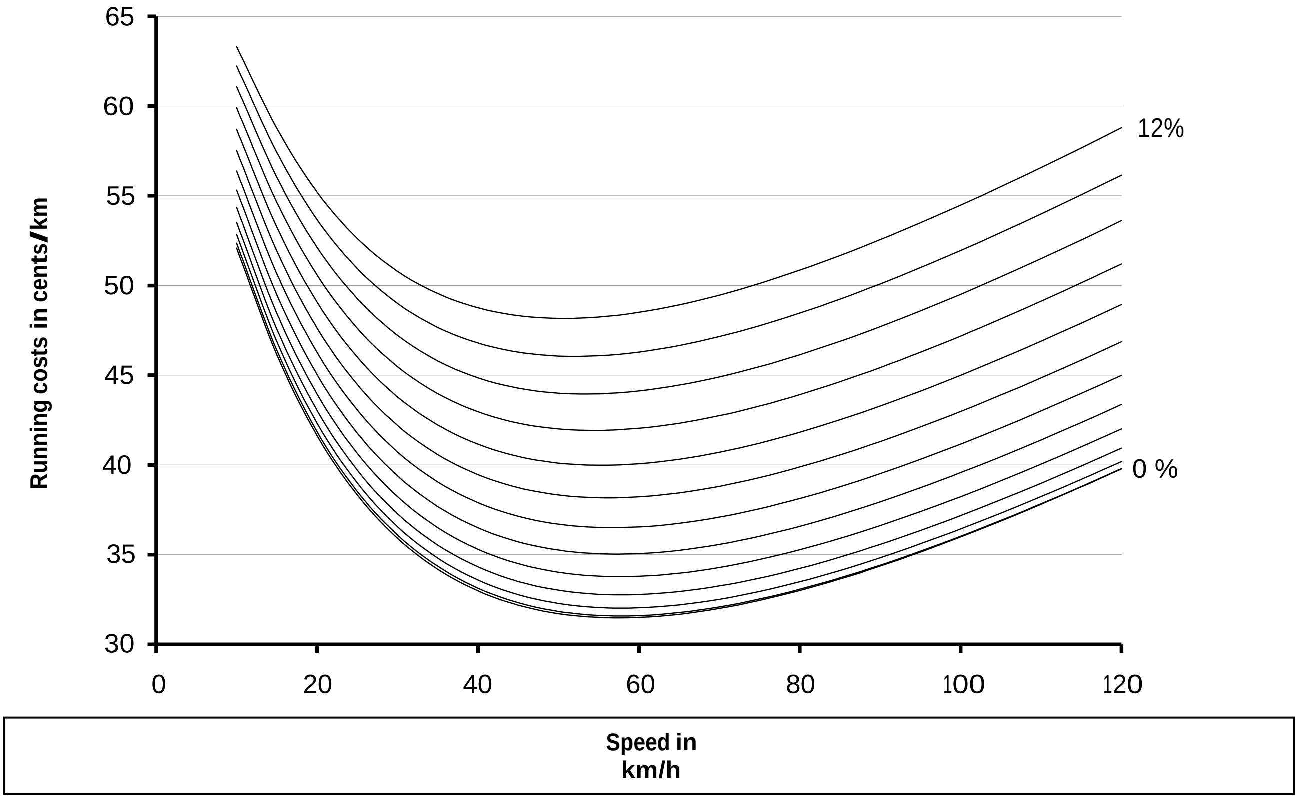


Table A5.11: Running cost by speed and gradient regression coefficients (cents/km – July 2008)

$$VOC_B = a + b \times GR + c \times \ln(S) + d \times GR^2 + e \times [\ln(S)] + f \times GR \times \ln(S) + g \times GR + h \times [\ln(S)] + i \times GR \times [\ln(S)] + j \times GR \times \ln(S)$$

Regression coefficient	Vehicle class						Road category			
	PC	LCV	MCV	HCVI	HCVII	Bus	Urban arterial	Urban other	Rural strategic	Rural other
a	24.616	15.852	20.230	-75.602	-263.90	-125.50	15.837	19.898	5.1705	12.034
b ($\times 10^{-2}$)	-44.832	-109.65	-70.181	82.435	2722.4	-21.363	5.8087	-21.958	91.522	35.415
c	43.489	64.641	87.808	263.07	469.66	272.77	59.846	52.292	77.703	66.095
d ($\times 10^{-4}$)	-445.63	-118.58	2731.4	9566.1	15069	5637.9	193.04	-129.24	918.9	444.87
E	-21.157	-30.064	-39.668	-101.34	-159.79	-102.10	-26.979	-24.332	-33.024	-29.079
f ($\times 10^{-2}$)	38.558	68.678	55.741	-65.136	-1446.2	81.726	10.316	25.549	-36.259	-5.8716
g ($\times 10^{-4}$)	17.595	12.105	-165.84	-608.65	-1306.0	-413.78	-4.2281	-27.46	-83.300	-46.897
h	2.5663	3.6463	4.8935	11.615	17.174	11.711	3.2172	2.9233	3.8723	3.4431
i ($\times 10^{-3}$)	-61.237	-99.936	-147.07	-48.388	1796.9	-318.64	-30.26	-46.859	24.414	-11.163
j ($\times 10^{-3}$)	12.523	15.750	58.615	171.01	488.06	157.89	26.908	19.615	45.233	33.217

Notes:

VOC_B = base vehicle operating costs in cents/km

GR = absolute value of average gradient (ie >0) over range of 0 – 12 percent

S = speed in km/h over range of 10 – 120km/h

ln = natural logarithm.

Sample equation for passenger cars (PC):

$$VOC_B = 24.616 - 44.832 \times 10^{-2} \times GR + 43.489 \times \ln(S) - 445.63 \times 10^{-4} \times GR^2 - 21.157 \times [\ln(S)]^2 + 38.558 \times 10^{-2} \times GR \times \ln(S) + 17.595 \times 10^{-4} \times GR^3 + 2.5663 \times [\ln(S)]^3 - 61.237 \times 10^{-3} \times GR \times [\ln(S)]^2 + 12.523 \times 10^{-3} \times GR^2 \times \ln(S)$$

Table A5.12: Urban additional VOC due to roughness by vehicle class (cents/km – July 2008)

Roughness		Additional VOC in cents/km by vehicle class					
IRI (m/km)	NAASRA (count/km)	PC	LCV	MCV	HCVI	HCVII	Bus
0 – 2.5	0 – 66	0.0	0.0	0.0	0.0	0.0	0.0
3.0	79	0.3	0.3	0.5	0.9	1.5	0.8
3.5	92	0.7	0.6	1.7	2.5	4.1	2.5
4.0	106	1.4	1.3	3.5	5.1	7.8	5.0
4.5	119	2.4	2.3	5.8	8.4	12.3	8.0
5.0	132	3.7	3.7	8.5	12.3	17.4	11.4
5.5	145	5.1	5.4	11.5	16.6	22.9	15.1
6.0	158	6.7	7.3	14.7	21.2	28.7	19.0
6.5	172	8.3	9.3	18.0	25.9	34.7	23.0
7.0	185	10.1	11.4	21.4	30.8	40.8	27.0
7.5	198	11.8	13.6	24.8	35.7	46.9	31.1
8.0	211	13.5	15.7	28.2	40.6	53.0	35.1
8.5	224	15.3	17.9	31.6	45.4	59.0	39.1
9.0	238	16.9	19.9	34.9	50.2	65.0	43.0
9.5	251	18.6	22.0	38.1	54.9	70.9	46.9
10.0	264	20.2	23.9	41.2	59.4	76.6	50.7
10.5	277	21.7	25.7	44.3	63.9	82.3	54.3
11.0	290	22.6	26.6	46.0	66.3	85.8	56.7
11.5	304	23.3	27.3	47.5	68.4	89.1	58.8
12.0	317	24.0	28.0	49.0	70.5	92.3	60.9
12.5	330	24.8	28.7	50.5	72.7	95.6	63.0
13.0	343	25.5	29.4	52.0	74.8	98.9	65.1
13.5	356	26.3	30.1	53.5	76.9	102.2	67.2
14.0	370	27.0	30.7	55.0	79.0	105.5	69.3
14.5	383	27.7	31.4	56.5	81.2	108.7	71.5
15.0	396	28.5	32.1	58.0	83.3	112.0	73.6

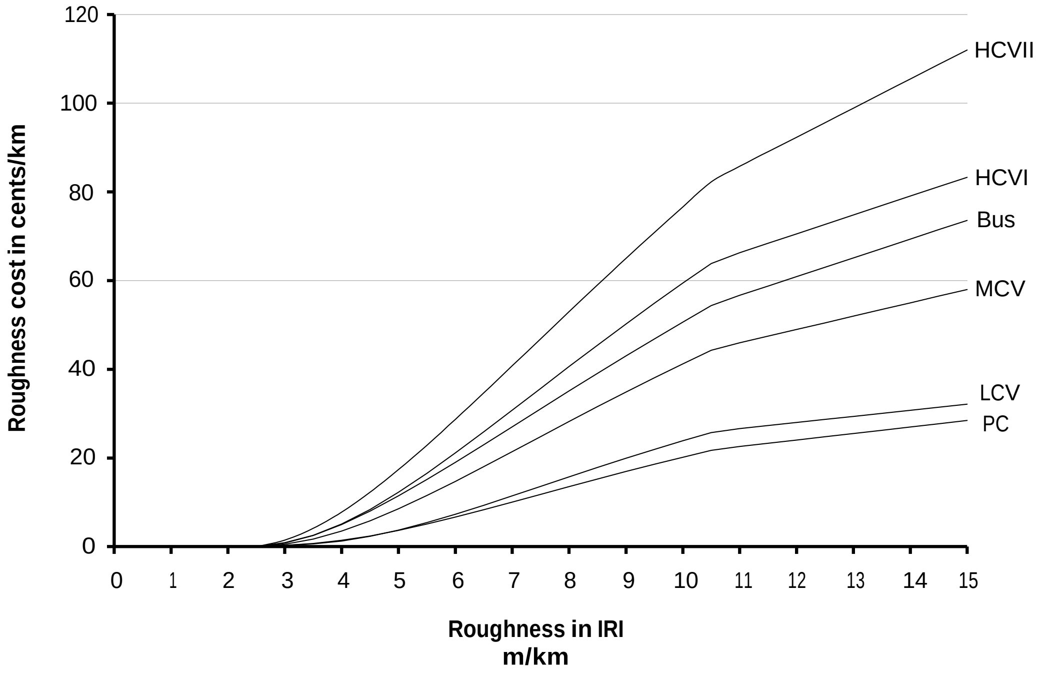


Table A5.13: Rural additional VOC due to roughness by vehicle class (cents/km – July 2008)

Roughness		Additional VOC in cents/km by vehicle class					
IRI (m/km)	NAASRA (count/km)	PC	LCV	MCV	HCVI	HCVII	Bus
0 – 2.5	0 – 66	0.0	0.0	0.0	0.0	0.0	0.0
3.0	79	0.2	0.3	0.4	0.6	1.1	0.5
3.5	92	0.8	0.8	2.0	2.9	4.4	2.7
4.0	106	2.2	2.5	5.2	7.5	10.2	6.6
4.5	119	4.1	5.0	9.4	13.6	17.4	11.5
5.0	132	6.2	7.8	13.9	20.1	25.1	16.6
5.5	145	8.4	10.6	18.4	26.6	32.8	21.8
6.0	158	10.5	13.3	22.7	32.8	40.2	26.8
6.5	172	12.6	16.0	26.9	38.9	47.4	31.6
7.0	185	14.7	18.7	31.1	44.9	54.6	36.4
7.5	198	16.9	21.6	35.4	51.2	62.1	41.4
8.0	211	17.9	22.3	36.9	53.6	66.0	43.8
8.5	224	18.7	23.0	38.4	55.7	69.3	45.9
9.0	238	19.5	23.7	39.9	57.8	72.6	48.1
9.5	251	20.2	24.4	41.4	60.0	75.9	50.2
10.0	264	21.0	25.1	42.9	62.1	79.2	52.3
10.5	277	21.7	25.8	44.4	64.2	82.4	54.5
11.0	290	22.5	26.6	45.9	66.3	85.7	56.6
11.5	304	23.2	27.3	47.5	68.4	89.0	58.7
12.0	317	24.0	28.0	49.0	70.6	92.3	60.9
12.5	330	24.8	28.7	50.5	72.7	95.6	63.0
13.0	343	25.5	29.4	52.0	74.8	98.9	65.1
13.5	356	26.3	30.1	53.5	76.9	102.2	67.2
14.0	370	27.0	30.8	55.0	79.0	105.5	69.4
14.5	383	27.8	31.5	56.5	81.2	108.8	71.5
15.0	396	28.5	32.2	58.0	83.3	112.1	73.6

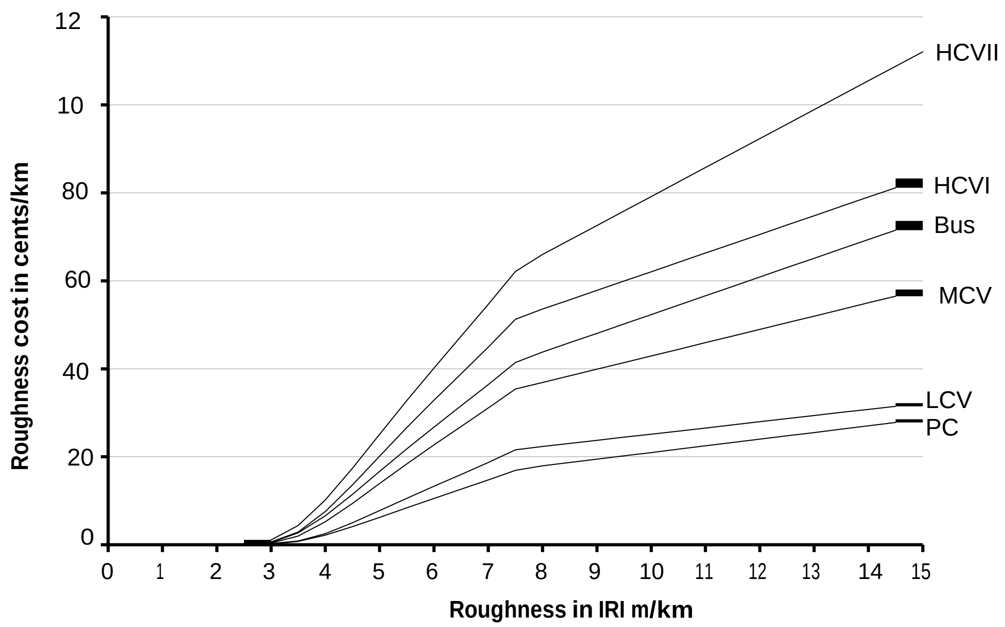


Table A5.14: Additional VOC due to roughness by road category (cents/km – July 2008)

Roughness		Additional VOC in cents/km by vehicle class		
IRI (m/km)	NAASRA (count/km)	Urban	Rural strategic	Rural other
0 – 2.5	0 – 66	0.0	0.0	0.0
3.0	79	0.3	0.2	0.3
3.5	92	0.8	1.0	1.1
4.0	106	1.6	2.8	2.9
4.5	119	2.8	5.2	5.3
5.0	132	4.2	7.9	7.9
5.5	145	5.8	10.6	10.6
6.0	158	7.6	13.2	13.2
6.5	172	9.4	15.8	15.8
7.0	185	11.3	18.4	18.3
7.5	198	13.3	21.1	20.9
8.0	211	15.2	22.5	21.8
8.5	224	17.1	23.4	22.7
9.0	238	19.0	24.4	23.6
9.5	251	20.9	25.3	24.5
10.0	264	22.6	26.2	25.4
10.5	277	24.3	27.2	26.3
11.0	290	25.3	28.1	27.2
11.5	304	26.1	29.1	28.1
12.0	317	27.0	30.0	29.0
12.5	330	27.8	30.9	29.9
13.0	343	28.6	31.9	30.8
13.5	356	29.4	32.8	31.7
14.0	370	30.2	33.7	32.6
14.5	383	31.1	34.7	33.5
15.0	396	31.9	35.6	34.4

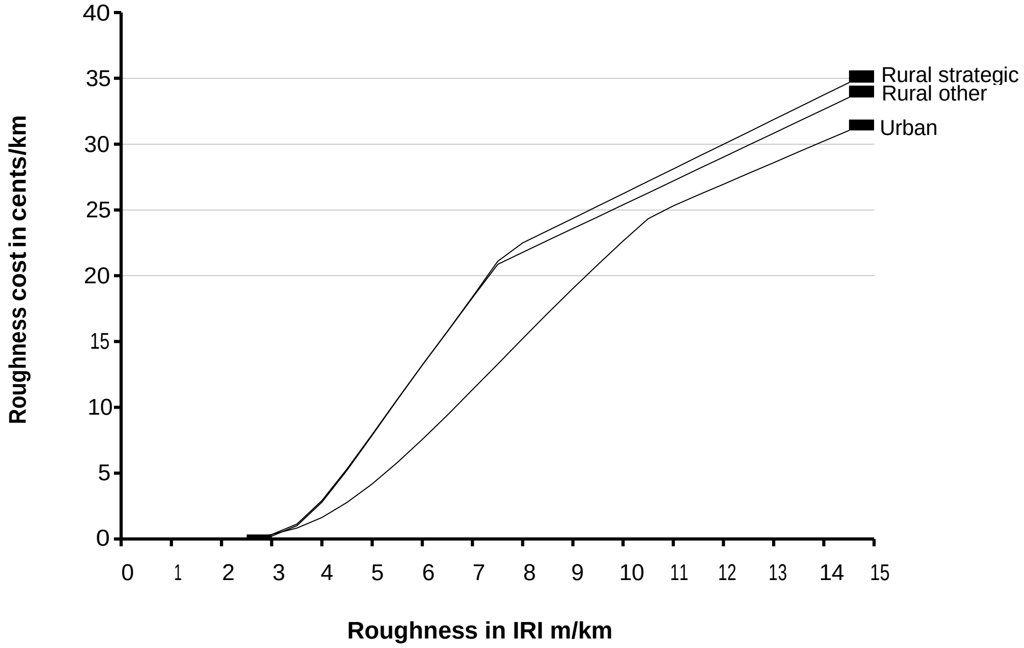


Table A5.15: Additional VOC due to roughness – regression coefficients (cents/km – July 2008)

$VOC_{RI} = \min(\{a + b \times \ln(RI) + c \times [\ln(RI)]^2 + d \times [\ln(RI)] + e \times [\ln(RI)] + f \times [\ln(RI)]\}, \{g \times RI + h\})$

Road category	Vehicle Class	Regression coefficient							
		a	b	c	d	e	f	g	h
Urban	PC	-.24.870	77.057	-86.517	40.422	-5.9464	0	1.4693	6.4171
	LCV	-42.613	129.35	-141.25	64.156	-9.4511	0	1.3664	11.607
	MCV	-19.987	71.074	-91.411	47.557	-7.0566	0	3.0007	12.965
	HCVI	-32.755	112.15	-139.97	71.388	-10.510	0	4.2510	19.534
	HCVII	-20.627	77.632	-108.24	60.487	-8.7532	0	6.5590	13.630
	Bus	-6.1144	33.037	-56.239	34.664	-5.1337	0	4.2313	10.108
Rural	PC	-226.98	846.70	-224.6	854.94	-287.91	37.983	1.5141	5.8313
	LCV	-370.44	1370.8	-1968.1	1366.6	-459.01	60.422	1.4080	11.062
	MCV	-431.90	1640.9	-2414.8	1712.2	-584.01	77.823	3.0157	12.770
	HCVI	-668.55	2530.7	-3713.6	2628.4	-895.94	119.35	4.2419	19.655
	HCVII	-610.68	2335.4	-3461.4	2469.7	-845.66	113.09	6.5815	13.338
	Bus	-389.20	1502.1	-2242.3	1607.8	-552.26	74.008	4.2594	9.7426
Urban	All	-25.935	80.862	-91.461	43.021	-6.3290	0	1.6381	7.2991
Rural strategic	All	-282.21	1056.6	-1533.9	1074.7	-363.08	48.024	1.8754	7.4853
Rural other	All	-275.08	1029.2	-1493.1	1045.6	-353.07	46.681	1.8108	7.2878

Notes: VOC_{RI} = additional vehicle operating costs due to roughness in cents/km

RI = max (2.5, roughness in IRI m/km)

ln = natural logarithm.

Table A5.16: Urban arterial and urban other – additional VOC due to congestion by vehicle class (cents/km – July 2008)

VC Ratio	Additional cost in cents/km					
	PC	LCV	MCV	HCVI	HCVII	Bus
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	0.0	0.0
0.25	0.0	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0	0.2
0.35	0.0	0.0	0.0	0.0	0.9	0.3
0.40	0.0	0.0	0.0	0.0	1.4	0.1
0.45	0.0	0.0	0.2	0.2	1.4	0.0
0.50	0.1	0.0	0.1	1.2	2.3	0.2
0.55	0.1	0.1	0.3	1.7	5.4	0.9
0.60	0.2	0.7	0.9	3.6	11.8	2.2
0.65	0.6	1.4	1.9	7.5	22.2	4.3
0.70	1.2	2.2	3.5	13.1	37.2	7.3
0.75	1.9	3.1	5.6	19.8	57.2	11.1
0.80	2.7	4.0	8.1	27.1	69.2	15.8
0.85	3.4	4.9	9.5	27.1	69.2	18.5
0.90	3.9	5.7	9.5	27.1	69.2	18.5
0.95	4.1	6.4	9.5	27.1	69.2	18.5
1.00	4.1	7.1	9.5	27.1	69.2	18.5
1.05	4.1	7.1	9.5	27.1	69.2	18.5
1.10	4.1	7.1	9.5	27.1	69.2	18.5
1.15	4.1	7.1	9.5	27.1	69.2	18.5
1.20	4.1	7.1	9.5	27.1	69.2	18.5

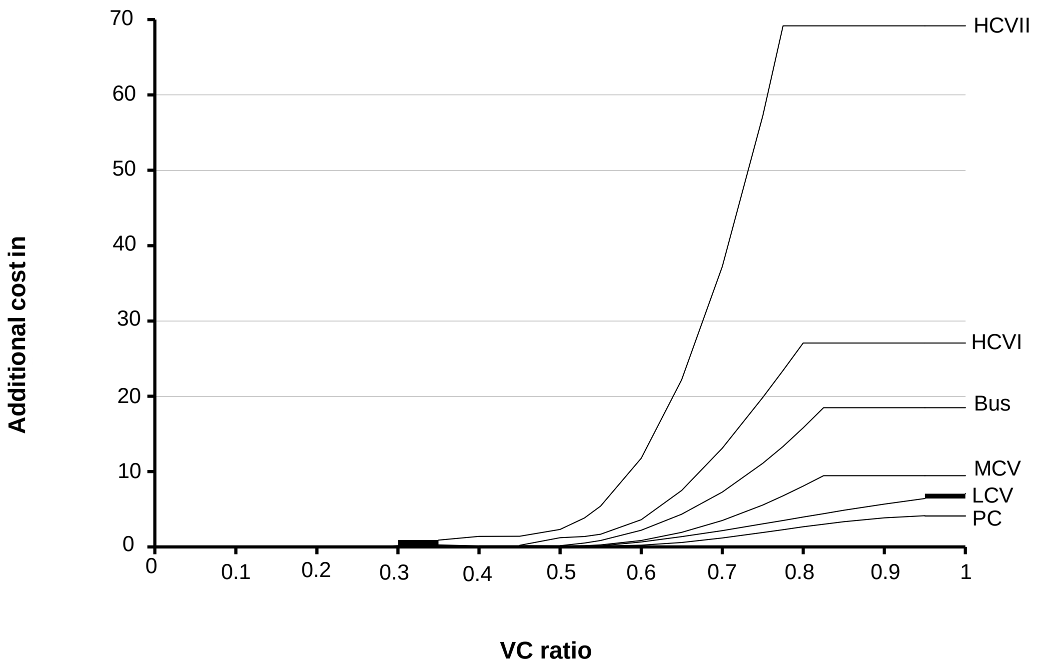


Table A5.17: Rural strategic and rural other – additional VOC due to congestion by vehicle class (cents/km – July 2008)

VC Ratio	Additional cost in cents/km					
	PC	LCV	MCV	HCVI	HCVII	Bus
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	1.1	0.0
0.25	0.0	0.0	0.0	0.0	1.8	0.0
0.30	0.0	0.0	0.0	0.0	3.3	0.0
0.35	0.0	0.0	0.0	0.0	6.4	0.0
0.40	0.0	0.0	0.0	0.0	11.5	0.0
0.45	0.0	0.0	0.1	2.6	18.9	0.0
0.50	0.0	0.0	0.8	6.5	28.3	1.4
0.55	0.0	0.0	2.0	10.4	39.7	4.0
0.60	0.0	0.1	3.2	13.8	52.8	6.5
0.65	0.2	0.3	4.2	16.4	67.4	8.4
0.70	0.5	0.7	5.1	18.4	67.4	9.9
0.75	0.7	0.9	5.7	19.8	67.4	10.9
0.80	0.6	0.9	6.1	20.8	67.4	11.5
0.85	0.6	1.0	6.4	21.4	67.4	11.9
0.90	0.7	1.5	6.6	21.8	67.4	12.2
0.95	1.5	2.9	6.8	22.1	67.4	12.5
1.00	3.3	5.5	7.0	22.5	67.4	12.9
1.05	3.3	5.5	7.0	22.5	67.4	12.9
1.10	3.3	5.5	7.0	22.5	67.4	12.9
1.15	3.3	5.5	7.0	22.5	67.4	12.9
1.20	3.3	5.5	7.0	22.5	67.4	12.9

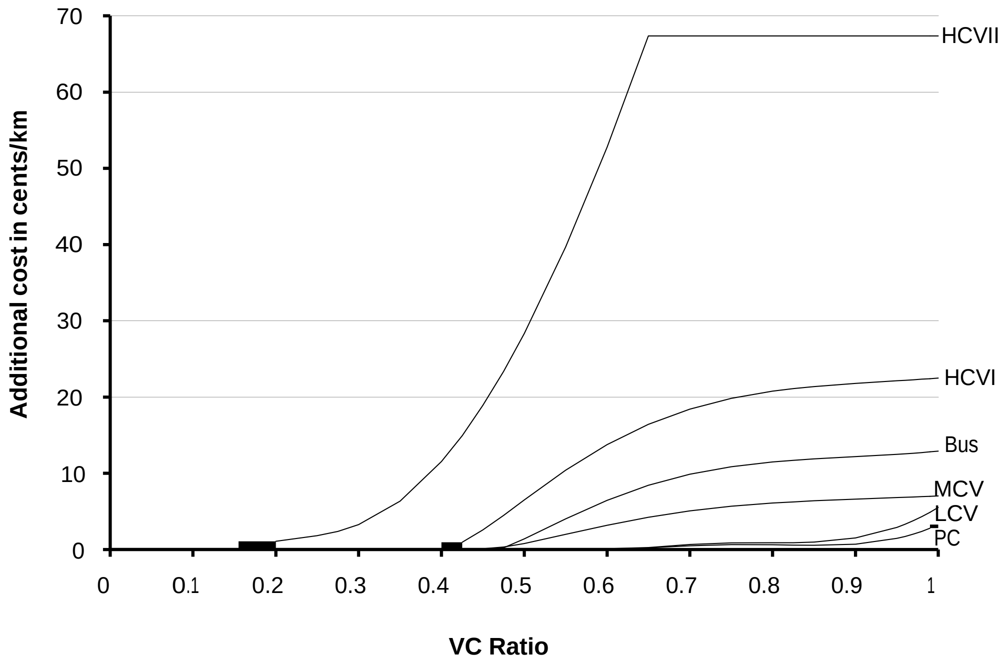


Table A5.18: Motorway – additional VOC due to congestion by vehicle class (cents/km – July 2008)

VC Ratios	Additional cost in cents/km					
	PC	LCV	MCV	HCVI	HCVII	Bus
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.05	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0	0.0	0.0
0.25	0.0	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0	0.0
0.35	0.0	0.0	0.0	0.0	0.0	0.0
0.40	0.0	0.0	0.0	0.0	0.0	0.0
0.45	0.0	0.0	0.0	0.0	0.0	0.0
0.50	0.0	0.0	0.0	0.0	0.0	0.0
0.55	0.0	0.0	0.0	0.1	0.0	0.0
0.60	0.0	0.0	0.0	0.1	0.0	0.0
0.65	0.0	0.0	0.1	0.3	1.8	0.1
0.70	0.0	0.0	0.3	1.1	6.2	0.7
0.75	0.0	0.0	0.9	2.9	14.8	1.9
0.80	0.0	0.0	2.2	6.4	29.5	4.0
0.85	0.1	0.1	4.8	12.5	52.2	7.3
0.90	0.5	0.6	6.7	22.2	67.3	12.4
0.95	1.3	1.8	6.7	22.2	67.3	12.4
1.00	2.7	4.4	6.7	22.2	67.3	12.4
1.05	2.7	4.4	6.7	22.2	67.3	12.4
1.10	2.7	4.4	6.7	22.2	67.3	12.4
1.15	2.7	4.4	6.7	22.2	67.3	12.4
1.20	2.7	4.4	6.7	22.2	67.3	12.4

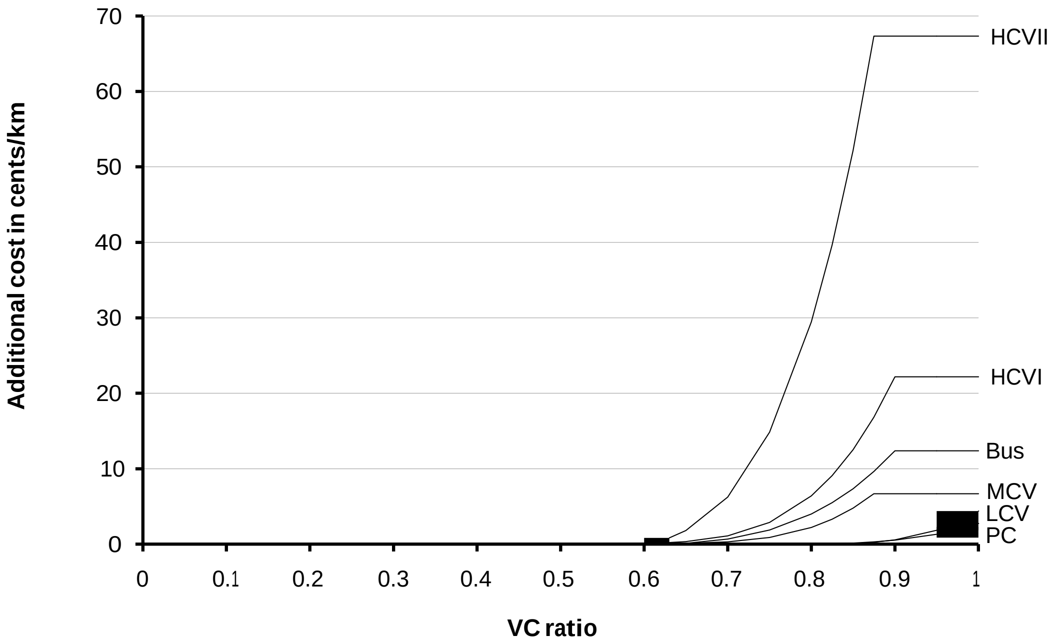


Table A5.19: Additional VOC due to congestion by road category (cents/km – July 2008)

VC Ratios	Additional cost in cents/km			
	Urban	Rural strategic	Rural other	Motorway
0.00	0.0	0.0	0.0	0.0
0.05	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0	0.0
0.20	0.0	0.0	0.0	0.0
0.25	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0
0.35	0.0	0.0	0.2	0.0
0.40	0.0	0.1	0.3	0.0
0.45	0.1	0.3	0.7	0.0
0.50	0.2	0.8	1.2	0.0
0.55	0.5	1.4	2.0	0.0
0.60	1.1	2.1	2.9	0.0
0.65	1.9	2.9	3.7	0.0
0.70	3.0	3.6	4.5	0.0
0.75	4.3	4.2	5.2	0.3
0.80	5.6	4.7	5.8	1.5
0.85	6.9	5.2	6.3	3.0
0.90	8.0	5.6	6.6	4.7
0.95	8.8	5.8	6.8	5.9
1.00	9.2	6.0	6.9	6.4
1.05	9.2	6.0	6.9	6.4
1.10	9.2	6.0	6.9	6.4
1.15	9.2	6.0	6.9	6.4
1.20	9.2	6.0	6.9	6.4

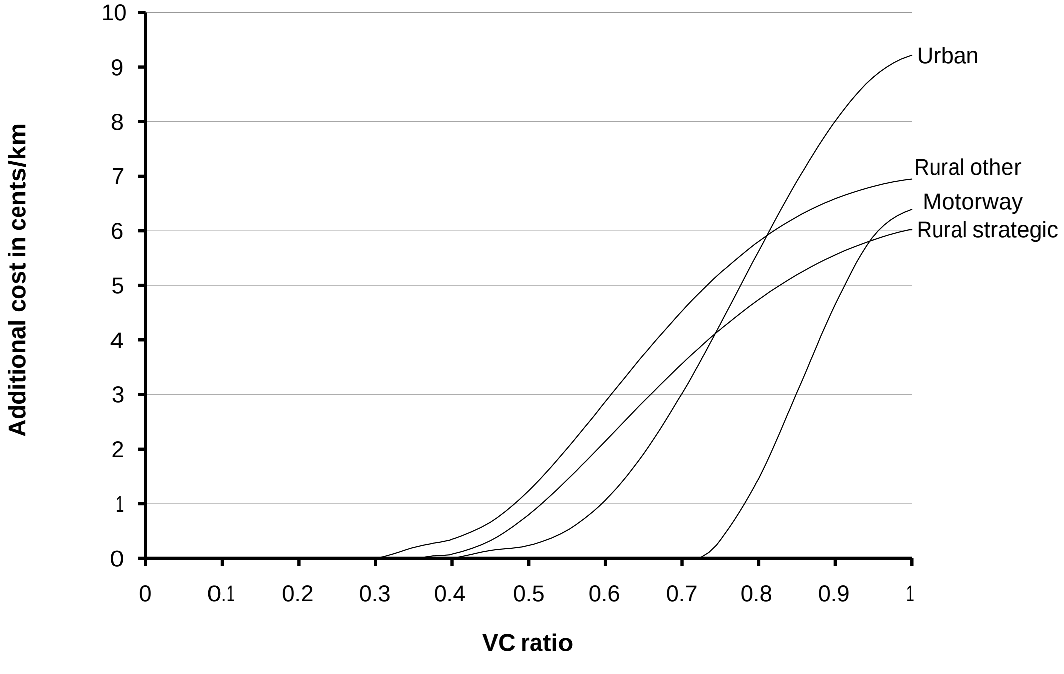


Table A5.20: Additional VOC due to congestion regression coefficient by vehicle class (cents/km – July 2008)

For equation	Use the expression		For VC ratio
All	VOC_{CONG}	= 0	<VC min
A	VOC_{CONG}	$= a + b \times \ln(VC) + c \times \ln(VC)^2 + d \times \ln(VC)^3 + e \times \ln(VC)^4 + f \times \ln(VC)^5$	>VC min
B	VOC_{CONG}	$= a \times VC^4 + b \times VC^3 + c \times VC^2 + d \times VC + e$	>VC min

Notes: VOC_{CONG} = Additional vehicle operating costs due to congestion in cents/km.
VC = volume to capacity ratio

Road type	Parameter	Regression coefficient by vehicle class					
		PC	LCV	MCV	HCVI	HCVII	Bus
Urban	Equation	A	A	A	A	A	A
	a	4.114	7.071	21.331	48.345	236.393	43.163
	b	-4.255	11.447	76.389	41.938	979.206	169.890
	c	-76.636	-19.967	77.207	-413.803	1512.028	243.809
	d	-146.319	-45.604	0.689	-893.843	1022.674	150.698
	e	-81.584	-21.028	-22.212	-506.405	254.673	33.863
	f	-	-	-	-	-	-
	VC max	1.000	1.000	0.825	0.800	0.775	0.825
	VC min	0.500	0.530	0.450	0.450	0.350	0.280
Two-lane highway	Equation	A	A	A	A	A	A
	a	3.276	5.527	7.032397	22.493	198.191	12.907
	b	50.311	67.048	5.143223	7.959	420.886	10.232
	c	339.139	352.392	17.39425	26.291	297.280	46.922
	d	1021.535	786.600	71.2	134.008	48.984	157.182
	e	1382.192	612.745	54.920	93.231	-25.657	109.993
	f	690.034	-	-	-	-8.019	-
	VC max	1.000	1.000	1.000	1.000	0.650	1.000
	VC min	0.600	0.600	0.450	0.425	0.155	0.475
Motorway	Equation	B	B	B	B	B	B
	a	273.8835	853.6372	788.7859	1098.495	2057.76	334.8539
	b	-35.809	-2467.21	-1810.37	-2279.79	-3543.77	-585.505
	c	737.0591	2665.344	1557.907	1764.498	2221.85	369.3951
	d	326.238	-1275.54	-959.179	-602.645	-599.524	-99.1556
	e	53.83505	228.1607	85.11867	76.55681	58.63954	9.519197
	VC max	1	1	0.875	0.9	0.875	0.9
	VC min	0.8	0.825	0.5	0.475	0.6	0.625

Table A5.21: Additional VOC due to congestion regression coefficients by road category (cents/km – July 2008)

$$VOC_{CONG} = a + b \times \ln(VC) + c \times \ln(VC)^2 + d \times \ln(VC)^3 + e \times \ln(VC)^4 + f \times \ln(VC)^5$$

Regression coefficient	Urban	Rural two-lane		Motorway
		Strategic	Other	
a	9.216	6.025	6.948	6.392
b	3.159	3.070	1.908	-0.081
c	-101.456	-13.277	-13.172	-219.002
d	-237.202	-1.806	13.970	-619.356
e	-202.631	18.506	42.589	-300.941
f	-60.838	9.948	20.230	327.808
VC min	0.450	0.375	0.350	0.725
VC max	1.000	1.000	1.000	1.000

Notes: VOC_{CONG} = Additional vehicle operating costs due to congestion in cents/km.

VC ratio = Volume to capacity ratio

Table A5.22: Additional VOC due to bottleneck delay by vehicle class (cents/minute – July 2008)

PC	LCV	MCV	HCVI	HCVII	Bus
2.892	3.73	4.484	6.678	6.678	5.247

Table A5.23: Additional VOC due to bottleneck delay by road category (cents/minute – July 2008)

Rural other	Rural strategic	Urban arterial	Urban other
3.281	3.343	3.175	3.121

Table A5.24: Passenger car additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed (km/h)	Additional travel time in seconds/speed cycle by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.2																							
10	4.1	1.1																						
15	5.8	2.8	0.8																					
20	7.4	4.4	2.1	0.6																				
25	8.9	6.0	3.6	1.7	0.5																			
30	10.4	7.5	5.1	3.0	1.5	0.4																		
35	11.8	9.0	6.5	4.4	2.6	1.3	0.4																	
40	13.1	10.4	8.0	5.8	3.9	2.3	1.1	0.3																
45	13.7	11.4	9.2	7.2	5.2	3.5	2.1	1.0	0.3															
50	14.3	12.1	10.0	8.1	6.3	4.7	3.2	1.9	0.9	0.3														
55	14.9	12.8	10.8	8.9	7.2	5.6	4.2	2.9	1.8	0.9	0.2													
60	15.4	13.4	11.5	9.7	8.1	6.5	5.1	3.8	2.6	1.7	0.8	0.2												
65	15.9	14.0	12.2	10.5	8.9	7.4	5.9	4.6	3.5	2.4	1.5	0.8	0.2											
70	16.4	14.6	12.9	11.2	9.6	8.2	6.8	5.5	4.3	3.2	2.2	1.4	0.7	0.2										
75	16.9	15.2	13.5	11.9	10.4	8.9	7.5	6.2	5.0	3.9	2.9	2.0	1.3	0.7	0.2									
80	17.4	15.7	14.1	12.5	11.1	9.6	8.3	7.0	5.8	4.7	3.7	2.7	1.9	1.2	0.6	0.2								
85	17.8	16.2	14.7	13.2	11.7	10.3	9.0	7.7	6.6	5.4	4.4	3.4	2.5	1.8	1.1	0.6	0.2							
90	18.3	16.7	15.2	13.8	12.4	11.0	9.7	8.5	7.3	6.2	5.1	4.1	3.2	2.4	1.7	1.0	0.5	0.2						
95	18.8	17.2	15.8	14.4	13.0	11.7	10.4	9.1	8.0	6.9	5.8	4.8	3.9	3.0	2.3	1.6	1.0	0.5	0.2					
100	19.2	17.7	16.3	14.9	13.6	12.3	11.0	9.8	8.7	7.5	6.5	5.5	4.6	3.7	2.9	2.1	1.5	0.9	0.5	0.2				
105	19.6	18.2	16.8	15.5	14.2	12.9	11.7	10.5	9.3	8.2	7.2	6.2	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.5	0.1			
110	20.1	18.7	17.3	16.0	14.7	13.5	12.3	11.1	10.0	8.9	7.8	6.8	5.9	5.0	4.1	3.3	2.6	1.9	1.3	0.8	0.4	0.1		
115	20.5	19.1	17.8	16.5	15.3	14.0	12.9	11.7	10.6	9.5	8.5	7.5	6.5	5.6	4.7	3.9	3.2	2.5	1.8	1.3	0.8	0.4	0.1	
120	20.9	19.6	18.3	17.0	15.8	14.6	13.4	12.3	11.2	10.1	9.1	8.1	7.1	6.2	5.4	4.5	3.8	3.0	2.4	1.8	1.2	0.8	0.4	0.1

Table A5.25: Passenger car additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																						
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**
5	0.1																							
10	0.2	0.1																						
15	0.3	0.2	0.1																					
20	0.4	0.3	0.1	0.1																				
25	0.6	0.4	0.3	0.2	0.1																			
30	0.8	0.6	0.5	0.4	0.2	0.1																		
35	0.9	0.8	0.7	0.5	0.4	0.2	0.1																	
40	1.1	1.0	0.9	0.8	0.6	0.4	0.2	0.1																
45	1.4	1.2	1.1	1.0	0.8	0.6	0.4	0.2	0.1															
50	1.6	1.5	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.1														
55	1.8	1.7	1.6	1.5	1.3	1.0	0.8	0.6	0.4	0.2	0.1													
60	2.1	2.0	1.9	1.7	1.6	1.3	1.1	0.8	0.6	0.4	0.2	0.1												
65	2.4	2.3	2.2	2.0	1.8	1.6	1.3	1.1	0.9	0.6	0.4	0.2	0.1											
70	2.7	2.6	2.5	2.3	2.1	1.9	1.6	1.4	1.1	0.9	0.6	0.4	0.2	0.1										
75	3.0	2.9	2.8	2.6	2.4	2.2	1.9	1.7	1.4	1.2	0.9	0.7	0.4	0.2	0.1									
80	3.3	3.2	3.1	2.9	2.7	2.5	2.2	2.0	1.7	1.4	1.2	0.9	0.7	0.4	0.2	0.1								
85	3.6	3.5	3.4	3.3	3.1	2.8	2.5	2.3	2.0	1.7	1.5	1.2	0.9	0.7	0.4	0.2	0.1							
90	4.0	3.9	3.7	3.6	3.4	3.1	2.8	2.6	2.3	2.0	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1						
95	4.3	4.2	4.1	3.9	3.7	3.4	3.1	2.9	2.6	2.3	2.0	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1					
100	4.7	4.5	4.4	4.2	4.0	3.7	3.4	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1				
105	5.0	4.9	4.7	4.6	4.3	4.0	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1			
110	5.4	5.2	5.1	4.9	4.6	4.3	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	0.9	0.7	0.4	0.2	0.1		
115	5.7	5.6	5.4	5.2	5.0	4.7	4.4	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.0	1.8	1.5	1.2	0.9	0.7	0.4	0.2	0.1	
120	6.1	5.9	5.7	5.5	5.3	4.9	4.6	4.3	4.0	3.7	3.4	3.1	2.8	2.6	2.3	2.0	1.7	1.4	1.2	0.9	0.6	0.4	0.2	0.1

Table A5.26: LCV additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed (km/h)	Additional travel time in seconds/speed cycle by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.4																							
10	4.4	1.2																						
15	6.2	3.0	0.8																					
20	8.0	4.8	2.3	0.6																				
25	9.6	6.5	3.9	1.8	0.5																			
30	11.1	8.1	5.4	3.3	1.6	0.4																		
35	12.6	9.7	7.0	4.7	2.8	1.4	0.4																	
40	14.1	11.2	8.6	6.2	4.2	2.5	1.2	0.3																
45	14.8	12.2	9.9	7.7	5.6	3.8	2.3	1.1	0.3															
50	15.4	13.0	10.8	8.7	6.8	5.1	3.5	2.1	1.0	0.3														
55	16.0	13.8	11.6	9.6	7.8	6.1	4.5	3.1	1.9	0.9	0.3													
60	16.6	14.5	12.5	10.5	8.7	7.0	5.5	4.1	2.8	1.8	0.9	0.2												
65	17.2	15.2	13.2	11.4	9.6	8.0	6.4	5.0	3.7	2.6	1.6	0.8	0.2											
70	17.8	15.9	14.0	12.2	10.5	8.8	7.3	5.9	4.6	3.4	2.4	1.5	0.8	0.2										
75	18.4	16.5	14.7	12.9	11.3	9.7	8.2	6.8	5.5	4.3	3.2	2.2	1.4	0.7	0.2									
80	18.9	17.1	15.4	13.7	12.0	10.5	9.0	7.6	6.3	5.1	4.0	3.0	2.1	1.3	0.7	0.2								
85	19.5	17.7	16.0	14.4	12.8	11.3	9.8	8.4	7.1	5.9	4.8	3.7	2.8	1.9	1.2	0.6	0.2							
90	20.0	18.3	16.7	15.1	13.5	12.0	10.6	9.2	7.9	6.7	5.6	4.5	3.5	2.6	1.8	1.1	0.6	0.2						
95	20.5	18.9	17.3	15.7	14.2	12.7	11.3	10.0	8.7	7.5	6.3	5.2	4.2	3.3	2.5	1.7	1.1	0.5	0.2					
100	21.0	19.4	17.9	16.3	14.9	13.4	12.1	10.7	9.5	8.3	7.1	6.0	5.0	4.0	3.1	2.3	1.6	1.0	0.5	0.2				
105	21.5	20.0	18.4	17.0	15.5	14.1	12.8	11.5	10.2	9.0	7.8	6.7	5.7	4.7	3.8	3.0	2.2	1.5	1.0	0.5	0.2			
110	22.0	20.5	19.0	17.6	16.2	14.8	13.5	12.2	10.9	9.7	8.6	7.5	6.4	5.4	4.5	3.6	2.8	2.1	1.5	0.9	0.5	0.1		
115	22.5	21.0	19.6	18.2	16.8	15.4	14.1	12.9	11.6	10.4	9.3	8.2	7.1	6.1	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.4	0.1	
120	23.0	21.5	20.1	18.7	17.4	16.1	14.8	13.5	12.3	11.1	10.0	8.9	7.9	6.8	5.9	5.0	4.1	3.3	2.6	1.9	1.3	0.8	0.4	0.1

Table A5.27: LCV additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed (km/h)	Additional VOC (in cents/speed cycle) by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.2																							
10	0.3	0.1																						
15	0.5	0.2	0.1																					
20	0.6	0.4	0.2	0.1																				
25	0.9	0.7	0.5	0.3	0.1																			
30	1.1	0.9	0.7	0.5	0.3	0.1																		
35	1.4	1.2	1.0	0.8	0.6	0.3	0.1																	
40	1.7	1.5	1.3	1.1	0.9	0.6	0.4	0.2																
45	2.0	1.9	1.7	1.5	1.2	0.9	0.6	0.4	0.2															
50	2.4	2.2	2.0	1.8	1.6	1.2	0.9	0.7	0.4	0.2														
55	2.8	2.6	2.4	2.2	1.9	1.6	1.3	1.0	0.7	0.4	0.2													
60	3.2	3.0	2.8	2.6	2.3	2.0	1.7	1.3	1.0	0.7	0.4	0.2												
65	3.6	3.4	3.3	3.0	2.8	2.4	2.1	1.7	1.4	1.0	0.7	0.4	0.2											
70	4.0	3.9	3.7	3.5	3.2	2.9	2.5	2.1	1.8	1.4	1.1	0.7	0.4	0.2										
75	4.5	4.3	4.2	3.9	3.6	3.3	2.9	2.6	2.2	1.8	1.5	1.1	0.8	0.4	0.2									
80	5.0	4.8	4.6	4.4	4.1	3.7	3.4	3.0	2.6	2.3	1.9	1.5	1.1	0.8	0.4	0.2								
85	5.5	5.3	5.1	4.8	4.5	4.2	3.8	3.4	3.1	2.7	2.3	1.9	1.5	1.2	0.8	0.4	0.1							
90	6.0	5.8	5.6	5.3	5.0	4.6	4.3	3.9	3.5	3.1	2.7	2.3	2.0	1.6	1.2	0.8	0.4	0.1						
95	6.5	6.3	6.0	5.8	5.5	5.1	4.7	4.3	3.9	3.5	3.2	2.8	2.4	2.0	1.6	1.2	0.8	0.4	0.1					
100	7.0	6.8	6.5	6.2	5.9	5.5	5.1	4.7	4.3	3.9	3.6	3.2	2.8	2.4	2.0	1.6	1.2	0.8	0.4	0.1				
105	7.5	7.2	7.0	6.7	6.4	5.9	5.5	5.1	4.7	4.3	3.9	3.5	3.1	2.7	2.4	2.0	1.6	1.2	0.8	0.4	0.1			
110	8.0	7.7	7.4	7.1	6.8	6.4	5.9	5.5	5.1	4.7	4.3	3.9	3.5	3.1	2.7	2.3	1.9	1.5	1.1	0.7	0.4	0.1		
115	8.5	8.2	7.9	7.6	7.2	6.7	6.3	5.9	5.5	5.0	4.6	4.2	3.8	3.4	3.0	2.6	2.3	1.9	1.5	1.1	0.7	0.3	0.1	
120	8.9	8.6	8.3	8.0	7.6	7.1	6.7	6.2	5.8	5.4	4.9	4.5	4.1	3.7	3.3	2.9	2.5	2.2	1.8	1.4	1.0	0.7	0.3	0.1

Table A5.28: MCV additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed (km/h)	Additional travel time in seconds/speed cycle by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.5																							
10	4.6	1.3																						
15	6.5	3.1	0.9																					
20	8.3	5.0	2.4	0.7																				
25	10.0	6.8	4.0	1.9	0.5																			
30	11.6	8.5	5.7	3.4	1.6	0.5																		
35	13.2	10.1	7.3	5.0	3.0	1.4	0.4																	
40	14.7	11.7	9.0	6.5	4.4	2.6	1.3	0.4																
45	15.4	12.8	10.3	8.1	5.9	4.0	2.4	1.1	0.3															
50	16.1	13.6	11.3	9.1	7.1	5.3	3.6	2.2	1.0	0.3														
55	16.8	14.4	12.2	10.1	8.1	6.4	4.7	3.3	2.0	1.0	0.3													
60	17.4	15.2	13.0	11.0	9.1	7.4	5.7	4.3	3.0	1.9	0.9	0.3												
65	18.0	15.9	13.8	11.9	10.1	8.3	6.7	5.2	3.9	2.7	1.7	0.8	0.2											
70	18.6	16.6	14.6	12.7	10.9	9.2	7.7	6.2	4.8	3.6	2.5	1.6	0.8	0.2										
75	19.2	17.3	15.4	13.5	11.8	10.1	8.6	7.1	5.7	4.5	3.3	2.3	1.4	0.7	0.2									
80	19.8	17.9	16.1	14.3	12.6	11.0	9.4	8.0	6.6	5.3	4.2	3.1	2.1	1.3	0.7	0.2								
85	20.4	18.5	16.7	15.0	13.4	11.8	10.3	8.8	7.5	6.2	5.0	3.9	2.9	2.0	1.3	0.6	0.2							
90	20.9	19.1	17.4	15.7	14.1	12.6	11.1	9.7	8.3	7.0	5.8	4.7	3.7	2.7	1.9	1.2	0.6	0.2						
95	21.5	19.7	18.1	16.4	14.9	13.3	11.9	10.5	9.1	7.8	6.6	5.5	4.4	3.5	2.6	1.8	1.1	0.6	0.2					
100	22.0	20.3	18.7	17.1	15.6	14.1	12.6	11.2	9.9	8.6	7.4	6.3	5.2	4.2	3.3	2.4	1.7	1.1	0.5	0.2				
105	22.5	20.9	19.3	17.7	16.2	14.8	13.4	12.0	10.7	9.4	8.2	7.1	6.0	4.9	4.0	3.1	2.3	1.6	1.0	0.5	0.2			
110	23.0	21.4	19.9	18.4	16.9	15.5	14.1	12.7	11.4	10.2	9.0	7.8	6.7	5.7	4.7	3.8	3.0	2.2	1.5	1.0	0.5	0.2		
115	23.5	22.0	20.5	19.0	17.5	16.1	14.8	13.4	12.2	10.9	9.7	8.6	7.5	6.4	5.4	4.5	3.6	2.8	2.1	1.5	0.9	0.5	0.1	
120	24.0	22.5	21.0	19.6	18.2	16.8	15.4	14.1	12.9	11.6	10.5	9.3	8.2	7.2	6.2	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.4	0.1

Table A5.29: MCV additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed (km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.2																							
10	0.5	0.2																						
15	0.8	0.5	0.2																					
20	1.2	0.9	0.6	0.3																				
25	1.8	1.5	1.1	0.8	0.4																			
30	2.4	2.1	1.8	1.4	0.9	0.5																		
35	3.2	2.9	2.5	2.1	1.6	1.1	0.5																	
40	4.0	3.7	3.3	2.9	2.4	1.8	1.2	0.6																
45	4.9	4.6	4.2	3.7	3.2	2.6	2.0	1.3	0.6															
50	6.0	5.7	5.3	4.8	4.2	3.5	2.8	2.1	1.4	0.7														
55	7.1	6.8	6.4	5.9	5.4	4.7	3.9	3.1	2.3	1.5	0.7													
60	8.4	8.1	7.7	7.2	6.6	5.9	5.1	4.3	3.4	2.4	1.6	0.8												
65	9.7	9.4	9.0	8.5	7.9	7.2	6.4	5.6	4.6	3.7	2.6	1.7	0.8											
70	11.2	10.9	10.5	10.0	9.3	8.6	7.8	6.9	6.0	5.0	3.9	2.8	1.7	0.8										
75	12.8	12.4	12.0	11.5	10.9	10.1	9.3	8.4	7.4	6.4	5.3	4.2	3.0	1.8	0.8									
80	14.4	14.1	13.6	13.1	12.4	11.7	10.8	9.9	9.0	7.9	6.8	5.7	4.5	3.2	1.9	0.8								
85	16.2	15.8	15.4	14.8	14.1	13.3	12.5	11.6	10.6	9.5	8.4	7.2	6.0	4.7	3.4	2.0	0.8							
90	18.1	17.7	17.2	16.6	15.9	15.1	14.2	13.3	12.3	11.2	10.1	8.9	7.6	6.3	5.0	3.5	2.1	0.8						
95	20.0	19.6	19.0	18.4	17.7	16.9	16.0	15.0	14.0	12.9	11.8	10.6	9.3	8.0	6.6	5.2	3.7	2.2	0.8					
100	22.0	21.6	21.0	20.4	19.6	18.8	17.9	16.9	15.8	14.7	13.6	12.4	11.1	9.8	8.4	6.9	5.4	3.8	2.3	0.8				
105	24.2	23.7	23.1	22.4	21.6	20.7	19.8	18.8	17.7	16.6	15.4	14.2	12.9	11.6	10.2	8.7	7.2	5.6	4.0	2.3	0.8			
110	26.4	25.8	25.2	24.5	23.7	22.7	21.8	20.7	19.7	18.5	17.3	16.1	14.8	13.4	12.0	10.5	9.0	7.4	5.8	4.1	2.4	0.8		
115	28.7	28.1	27.4	26.6	25.8	24.8	23.8	22.7	21.6	20.5	19.3	18.0	16.7	15.3	13.9	12.4	10.9	9.3	7.6	5.9	4.2	2.5	0.8	
120	31.0	30.4	29.7	28.8	27.9	26.9	25.9	24.8	23.7	22.5	21.2	19.9	18.6	17.2	15.8	14.3	12.8	11.2	9.5	7.8	6.1	4.3	2.5	0.9

Table A5.30: HCVI additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed(km/h)	Additional travel time in seconds/speed cycle by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.9																							
10	5.3	1.5																						
15	7.6	3.6	1.0																					
20	9.6	5.7	2.8	0.8																				
25	11.6	7.8	4.7	2.2	0.6																			
30	13.5	9.8	6.6	3.9	1.9	0.5																		
35	15.3	11.7	8.5	5.7	3.4	1.6	0.5																	
40	17.0	13.5	10.3	7.5	5.1	3.0	1.5	0.4																
45	17.8	14.8	11.9	9.3	6.8	4.6	2.7	1.3	0.4															
50	18.6	15.8	13.0	10.5	8.2	6.1	4.2	2.5	1.2	0.3														
55	19.4	16.7	14.1	11.7	9.4	7.3	5.5	3.8	2.3	1.1	0.3													
60	20.1	17.5	15.1	12.7	10.6	8.5	6.6	4.9	3.4	2.1	1.0	0.3												
65	20.9	18.4	16.0	13.8	11.6	9.6	7.8	6.1	4.5	3.1	2.0	1.0	0.3											
70	21.6	19.2	16.9	14.7	12.7	10.7	8.9	7.1	5.6	4.1	2.9	1.8	0.9	0.3										
75	22.3	20.0	17.8	15.7	13.6	11.7	9.9	8.2	6.6	5.2	3.8	2.7	1.7	0.9	0.2									
80	22.9	20.7	18.6	16.5	14.6	12.7	10.9	9.2	7.6	6.2	4.8	3.6	2.5	1.5	0.8	0.2								
85	23.6	21.5	19.4	17.4	15.5	13.6	11.9	10.2	8.6	7.2	5.8	4.5	3.3	2.3	1.4	0.7	0.2							
90	24.2	22.2	20.2	18.2	16.4	14.6	12.8	11.2	9.6	8.1	6.7	5.4	4.2	3.1	2.2	1.4	0.7	0.2						
95	24.9	22.9	20.9	19.0	17.2	15.4	13.7	12.1	10.6	9.1	7.7	6.4	5.1	4.0	3.0	2.1	1.3	0.7	0.2					
100	25.5	23.5	21.6	19.8	18.0	16.3	14.6	13.0	11.5	10.0	8.6	7.3	6.0	4.9	3.8	2.8	2.0	1.2	0.6	0.2				
105	26.1	24.2	22.4	20.6	18.8	17.1	15.5	13.9	12.4	10.9	9.5	8.2	6.9	5.7	4.6	3.6	2.7	1.9	1.2	0.6	0.2			
110	26.7	24.8	23.0	21.3	19.6	17.9	16.3	14.7	13.2	11.8	10.4	9.1	7.8	6.6	5.5	4.4	3.4	2.6	1.8	1.1	0.6	0.2		
115	27.3	25.5	23.7	22.0	20.3	18.7	17.1	15.6	14.1	12.7	11.3	9.9	8.7	7.4	6.3	5.2	4.2	3.3	2.4	1.7	1.1	0.5	0.2	
120	27.8	26.1	24.4	22.7	21.1	19.5	17.9	16.4	14.9	13.5	12.1	10.8	9.5	8.3	7.1	6.0	5.0	4.0	3.2	2.3	1.6	1.0	0.5	0.2

Table A5.31: HCVI additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**
5	0.4																							
10	1.0	0.5																						
15	1.8	1.2	0.6																					
20	2.7	2.2	1.5	0.7																				
25	4.2	3.6	2.9	2.0	1.0																			
30	5.9	5.4	4.6	3.7	2.5	1.2																		
35	7.9	7.4	6.6	5.6	4.4	2.9	1.5																	
40	10.2	9.6	8.8	7.8	6.5	5.0	3.3	1.7																
45	12.9	12.3	11.4	10.2	8.9	7.3	5.6	3.7	1.8															
50	15.9	15.3	14.4	13.2	11.8	9.9	8.0	6.1	4.1	2.0														
55	19.3	18.7	17.7	16.6	15.0	13.2	11.1	8.8	6.6	4.4	2.2													
60	22.9	22.3	21.4	20.2	18.6	16.7	14.6	12.3	9.8	7.1	4.7	2.3												
65	26.9	26.3	25.3	24.1	22.5	20.5	18.4	16.0	13.4	10.7	7.8	4.9	2.4											
70	31.2	30.5	29.6	28.3	26.7	24.7	22.4	20.0	17.4	14.6	11.6	8.4	5.1	2.5										
75	35.8	35.1	34.1	32.8	31.1	29.1	26.8	24.4	21.7	18.8	15.7	12.5	9.1	5.5	2.5									
80	40.8	40.0	38.9	37.6	35.9	33.8	31.5	29.0	26.2	23.3	20.2	16.9	13.3	9.7	5.9	2.5								
85	46.0	45.2	44.1	42.6	40.9	38.7	36.4	33.8	31.1	28.1	24.9	21.6	18.0	14.2	10.3	6.2	2.5							
90	51.6	50.7	49.5	48.0	46.2	44.0	41.6	39.0	36.2	33.2	29.9	26.5	22.9	19.0	15.0	10.8	6.6	2.5						
95	57.5	56.5	55.2	53.7	51.8	49.5	47.1	44.4	41.5	38.5	35.2	31.7	28.1	24.2	20.1	15.8	11.4	6.9	2.6					
100	63.6	62.6	61.2	59.6	57.6	55.3	52.8	50.1	47.2	44.0	40.7	37.2	33.5	29.6	25.5	21.1	16.6	11.9	7.2	2.6				
105	70.2	69.0	67.5	65.8	63.8	61.4	58.8	56.0	53.0	49.8	46.5	42.9	39.2	35.2	31.1	26.7	22.1	17.4	12.4	7.5	2.7			
110	77.0	75.7	74.1	72.3	70.2	67.7	65.0	62.2	59.1	55.9	52.5	48.9	45.1	41.1	36.9	32.5	27.9	23.1	18.1	12.9	7.7	2.8		
115	84.1	82.7	81.0	79.1	76.9	74.3	71.5	68.6	65.4	62.1	58.7	55.0	51.2	47.1	42.9	38.5	33.9	29.0	24.0	18.8	13.4	8.0	2.8	
120	91.5	90.0	88.2	86.2	83.8	81.1	78.2	75.2	72.0	68.6	65.1	61.3	57.4	53.4	49.1	44.7	40.0	35.2	30.1	24.9	19.4	13.8	8.2	2.9

Table A5.32: HCVII additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed (km/h)	Additional travel time in seconds/speed cycle by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	3.2																							
10	6.0	1.6																						
15	8.4	4.0	1.1																					
20	10.7	6.4	3.1	0.9																				
25	12.9	8.7	5.2	2.5	0.7																			
30	15.0	10.9	7.3	4.4	2.1	0.6																		
35	17.0	13.0	9.4	6.4	3.8	1.8	0.5																	
40	18.9	15.0	11.5	8.4	5.7	3.4	1.6	0.5																
45	19.9	16.5	13.3	10.4	7.5	5.1	3.1	1.5	0.4															
50	20.8	17.6	14.6	11.7	9.2	6.8	4.6	2.8	1.3	0.4														
55	21.7	18.6	15.7	13.0	10.5	8.2	6.1	4.2	2.6	1.2	0.3													
60	22.5	19.6	16.9	14.2	11.8	9.5	7.4	5.5	3.8	2.4	1.2	0.3												
65	23.4	20.6	17.9	15.4	13.0	10.8	8.7	6.8	5.0	3.5	2.2	1.1	0.3											
70	24.2	21.5	18.9	16.5	14.2	12.0	9.9	8.0	6.2	4.6	3.2	2.0	1.0	0.3										
75	24.9	22.4	19.9	17.5	15.3	13.1	11.1	9.2	7.4	5.8	4.3	3.0	1.9	0.9	0.3									
80	25.7	23.2	20.8	18.5	16.3	14.2	12.2	10.3	8.6	6.9	5.4	4.0	2.8	1.7	0.9	0.3								
85	26.5	24.1	21.8	19.5	17.4	15.3	13.3	11.5	9.7	8.0	6.5	5.0	3.7	2.6	1.6	0.8	0.3							
90	27.2	24.9	22.6	20.5	18.4	16.3	14.4	12.5	10.8	9.1	7.5	6.1	4.7	3.5	2.4	1.5	0.8	0.2						
95	27.9	25.7	23.5	21.4	19.3	17.3	15.4	13.6	11.8	10.2	8.6	7.1	5.7	4.5	3.3	2.3	1.4	0.7	0.2					
100	28.6	26.4	24.3	22.2	20.2	18.3	16.4	14.6	12.9	11.2	9.6	8.2	6.8	5.4	4.2	3.2	2.2	1.4	0.7	0.2				
105	29.3	27.2	25.1	23.1	21.1	19.2	17.4	15.6	13.9	12.2	10.7	9.2	7.8	6.4	5.2	4.0	3.0	2.1	1.3	0.7	0.2			
110	30.0	27.9	25.9	23.9	22.0	20.1	18.3	16.6	14.9	13.2	11.7	10.2	8.8	7.4	6.1	4.9	3.9	2.9	2.0	1.2	0.6	0.2		
115	30.7	28.7	26.7	24.7	22.9	21.0	19.2	17.5	15.8	14.2	12.7	11.2	9.7	8.4	7.1	5.9	4.7	3.7	2.7	1.9	1.2	0.6	0.2	
120	31.3	29.4	27.4	25.5	23.7	21.9	20.1	18.4	16.8	15.2	13.6	12.1	10.7	9.3	8.0	6.8	5.6	4.5	3.5	2.6	1.8	1.1	0.6	0.2

Table A5.33: HCVII additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.6																							
10	1.6	0.9																						
15	3.2	2.4	1.3																					
20	5.2	4.4	3.2	1.7																				
25	8.2	7.4	6.1	4.4	2.3																			
30	11.8	11.0	9.7	7.9	5.6	2.9																		
35	16.0	15.2	13.8	12.0	9.6	6.6	3.4																	
40	20.9	20.1	18.7	16.7	14.2	11.2	7.7	3.9																
45	27.0	26.0	24.4	22.1	19.6	16.4	12.8	8.7	4.4															
50	33.9	32.9	31.2	29.0	26.0	22.4	18.5	14.3	9.8	4.9														
55	41.8	40.7	39.0	36.6	33.6	29.9	25.6	20.8	15.9	10.8	5.4													
60	50.5	49.3	47.6	45.2	42.1	38.3	33.9	28.9	23.4	17.4	11.7	5.8												
65	60.1	58.9	57.1	54.6	51.4	47.5	43.0	37.9	32.3	26.1	19.4	12.6	6.2											
70	70.6	69.4	67.5	64.9	61.7	57.6	53.0	47.8	42.0	35.7	28.8	21.3	13.5	6.6										
75	82.2	80.8	78.8	76.2	72.8	68.7	64.0	58.7	52.8	46.3	39.2	31.5	23.3	14.8	6.9									
80	94.7	93.3	91.2	88.4	85.0	80.7	75.9	70.5	64.4	57.8	50.5	42.7	34.3	25.3	16.0	7.2								
85	108.3	106.7	104.5	101.6	98.1	93.7	88.8	83.2	77.1	70.3	62.9	54.9	46.3	37.1	27.3	17.3	7.5							
90	123.0	121.3	118.9	115.9	112.2	107.7	102.6	96.9	90.7	83.7	76.2	68.1	59.3	49.9	39.9	29.4	18.5	7.7						
95	138.8	136.9	134.4	131.2	127.4	122.7	117.5	111.7	105.3	98.2	90.5	82.2	73.3	63.7	53.5	42.8	31.4	19.8	8.2					
100	155.7	153.6	150.9	147.6	143.6	138.8	133.4	127.5	120.9	113.7	105.9	97.4	88.3	78.6	68.2	57.2	45.6	33.5	21.0	8.7				
105	173.8	171.5	168.7	165.2	161.0	156.0	150.4	144.3	137.6	130.2	122.2	113.6	104.4	94.5	84.0	72.8	61.0	48.6	35.6	22.3	9.2			
110	193.1	190.6	187.5	183.8	179.4	174.3	168.5	162.2	155.3	147.8	139.7	130.9	121.5	111.4	100.8	89.4	77.4	64.8	51.5	37.7	23.6	9.7		
115	213.6	211.0	207.6	203.7	199.1	193.7	187.8	181.3	174.2	166.5	158.1	149.2	139.6	129.4	118.6	107.1	94.9	82.1	68.6	54.5	39.9	24.9	10.2	
120	235.5	232.5	229.0	224.8	219.9	214.3	208.2	201.4	194.1	186.2	177.7	168.6	158.9	148.5	137.5	125.8	113.5	100.5	86.8	72.5	57.5	42.0	26.2	10.7

Table A5.34: Bus additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed(km/h)	Additional travel time in seconds/speed cycle by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.5																							
10	4.6	1.3																						
15	6.5	3.1	0.9																					
20	8.3	5.0	2.4	0.7																				
25	10.0	6.8	4.0	1.9	0.5																			
30	11.6	8.5	5.7	3.4	1.6	0.5																		
35	13.2	10.1	7.3	5.0	3.0	1.4	0.4																	
40	14.7	11.7	9.0	6.5	4.4	2.6	1.3	0.4																
45	15.4	12.8	10.3	8.1	5.9	4.0	2.4	1.1	0.3															
50	16.1	13.6	11.3	9.1	7.1	5.3	3.6	2.2	1.0	0.3														
55	16.8	14.4	12.2	10.1	8.1	6.4	4.7	3.3	2.0	1.0	0.3													
60	17.4	15.2	13.0	11.0	9.1	7.4	5.7	4.3	3.0	1.9	0.9	0.3												
65	18.0	15.9	13.8	11.9	10.1	8.3	6.7	5.2	3.9	2.7	1.7	0.8	0.2											
70	18.6	16.6	14.6	12.7	10.9	9.2	7.7	6.2	4.8	3.6	2.5	1.6	0.8	0.2										
75	19.2	17.3	15.4	13.5	11.8	10.1	8.6	7.1	5.7	4.5	3.3	2.3	1.4	0.7	0.2									
80	19.8	17.9	16.1	14.3	12.6	11.0	9.4	8.0	6.6	5.3	4.2	3.1	2.1	1.3	0.7	0.2								
85	20.4	18.5	16.7	15.0	13.4	11.8	10.3	8.8	7.5	6.2	5.0	3.9	2.9	2.0	1.3	0.6	0.2							
90	20.9	19.1	17.4	15.7	14.1	12.6	11.1	9.7	8.3	7.0	5.8	4.7	3.7	2.7	1.9	1.2	0.6	0.2						
95	21.5	19.7	18.1	16.4	14.9	13.3	11.9	10.5	9.1	7.8	6.6	5.5	4.4	3.5	2.6	1.8	1.1	0.6	0.2					
100	22.0	20.3	18.7	17.1	15.6	14.1	12.6	11.2	9.9	8.6	7.4	6.3	5.2	4.2	3.3	2.4	1.7	1.1	0.5	0.2				
105	22.5	20.9	19.3	17.7	16.2	14.8	13.4	12.0	10.7	9.4	8.2	7.1	6.0	4.9	4.0	3.1	2.3	1.6	1.0	0.5	0.2			
110	23.0	21.4	19.9	18.4	16.9	15.5	14.1	12.7	11.4	10.2	9.0	7.8	6.7	5.7	4.7	3.8	3.0	2.2	1.5	1.0	0.5	0.2		
115	23.5	22.0	20.5	19.0	17.5	16.1	14.8	13.4	12.2	10.9	9.7	8.6	7.5	6.4	5.4	4.5	3.6	2.8	2.1	1.5	0.9	0.5	0.1	
120	24.0	22.5	21.0	19.6	18.2	16.8	15.4	14.1	12.9	11.6	10.5	9.3	8.2	7.2	6.2	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.4	0.1

Table A5.35: Bus additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.3																							
10	0.7	0.4																						
15	1.4	1.0	0.5																					
20	2.1	1.7	1.2	0.6																				
25	3.3	2.9	2.3	1.6	0.8																			
30	4.6	4.2	3.6	2.9	2.0	1.0																		
35	6.1	5.7	5.1	4.4	3.4	2.3	1.2																	
40	7.8	7.4	6.8	6.0	5.1	3.9	2.6	1.3																
45	9.9	9.4	8.7	7.8	6.9	5.7	4.3	2.9	1.5															
50	12.2	11.7	11.0	10.1	9.0	7.6	6.2	4.8	3.2	1.6														
55	14.7	14.2	13.5	12.6	11.5	10.1	8.5	6.8	5.1	3.4	1.7													
60	17.5	17.0	16.3	15.3	14.2	12.7	11.1	9.4	7.5	5.5	3.6	1.8												
65	20.5	20.0	19.2	18.3	17.1	15.6	14.0	12.2	10.2	8.1	5.9	3.8	1.8											
70	23.8	23.2	22.4	21.4	20.2	18.7	17.0	15.2	13.2	11.1	8.8	6.4	3.9	1.9										
75	27.2	26.6	25.8	24.8	23.5	22.0	20.3	18.4	16.4	14.2	11.9	9.4	6.8	4.2	1.9									
80	30.9	30.3	29.4	28.3	27.0	25.4	23.7	21.8	19.8	17.6	15.2	12.7	10.0	7.3	4.4	1.9								
85	34.8	34.1	33.2	32.1	30.7	29.1	27.3	25.4	23.3	21.1	18.7	16.2	13.5	10.6	7.7	4.6	1.8							
90	39.0	38.2	37.2	36.0	34.6	33.0	31.2	29.2	27.1	24.8	22.4	19.8	17.1	14.2	11.2	8.0	4.8	1.8						
95	43.3	42.5	41.4	40.2	38.7	37.0	35.1	33.1	31.0	28.7	26.2	23.6	20.9	18.0	14.9	11.7	8.4	5.0	1.8					
100	47.9	47.0	45.9	44.5	43.0	41.2	39.3	37.2	35.0	32.7	30.2	27.6	24.8	21.9	18.8	15.6	12.2	8.7	5.2	1.8				
105	52.7	51.7	50.5	49.1	47.4	45.6	43.6	41.5	39.2	36.8	34.3	31.7	28.9	25.9	22.8	19.6	16.2	12.7	9.0	5.4	1.9			
110	57.6	56.5	55.2	53.7	52.0	50.1	48.1	45.9	43.6	41.1	38.6	35.9	33.0	30.1	27.0	23.7	20.3	16.8	13.1	9.3	5.5	1.9		
115	62.8	61.6	60.2	58.6	56.8	54.8	52.7	50.4	48.0	45.5	42.9	40.2	37.3	34.3	31.2	28.0	24.6	21.0	17.3	13.5	9.6	5.6	1.9	
120	68.2	66.8	65.3	63.6	61.7	59.6	57.4	55.0	52.6	50.0	47.4	44.6	41.7	38.7	35.5	32.3	28.9	25.3	21.6	17.8	13.9	9.8	5.7	1.9

Table A5.36: Urban arterial additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed(km/h)	Additional travel time in seconds/speed cycle by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.3																							
10	4.2	1.2																						
15	6.0	2.8	0.8																					
20	7.6	4.5	2.2	0.6																				
25	9.1	6.1	3.7	1.8	0.5																			
30	10.6	7.7	5.2	3.1	1.5	0.4																		
35	12.0	9.2	6.7	4.5	2.7	1.3	0.4																	
40	13.4	10.7	8.2	5.9	4.0	2.4	1.2	0.3																
45	14.0	11.6	9.4	7.3	5.3	3.6	2.2	1.0	0.3															
50	14.6	12.4	10.2	8.3	6.5	4.8	3.3	2.0	1.0	0.3														
55	15.2	13.1	11.0	9.2	7.4	5.8	4.3	3.0	1.8	0.9	0.2													
60	15.7	13.7	11.8	10.0	8.3	6.7	5.2	3.9	2.7	1.7	0.8	0.2												
65	16.3	14.3	12.5	10.7	9.1	7.5	6.1	4.7	3.5	2.5	1.5	0.8	0.2											
70	16.8	14.9	13.2	11.5	9.9	8.3	6.9	5.6	4.4	3.2	2.3	1.4	0.7	0.2										
75	17.3	15.5	13.8	12.2	10.6	9.1	7.7	6.4	5.2	4.0	3.0	2.1	1.3	0.7	0.2									
80	17.8	16.1	14.4	12.9	11.3	9.9	8.5	7.2	5.9	4.8	3.7	2.8	1.9	1.2	0.6	0.2								
85	18.3	16.6	15.0	13.5	12.0	10.6	9.2	7.9	6.7	5.6	4.5	3.5	2.6	1.8	1.1	0.6	0.2							
90	18.8	17.2	15.6	14.1	12.7	11.3	9.9	8.7	7.5	6.3	5.2	4.2	3.3	2.4	1.7	1.1	0.5	0.2						
95	19.2	17.7	16.2	14.7	13.3	12.0	10.6	9.4	8.2	7.0	5.9	4.9	4.0	3.1	2.3	1.6	1.0	0.5	0.2					
100	19.7	18.2	16.7	15.3	13.9	12.6	11.3	10.1	8.9	7.7	6.7	5.6	4.7	3.8	2.9	2.2	1.5	1.0	0.5	0.2				
105	20.1	18.7	17.3	15.9	14.5	13.2	12.0	10.7	9.6	8.4	7.3	6.3	5.3	4.4	3.6	2.8	2.1	1.4	0.9	0.5	0.1			
110	20.6	19.2	17.8	16.4	15.1	13.8	12.6	11.4	10.2	9.1	8.0	7.0	6.0	5.1	4.2	3.4	2.7	2.0	1.4	0.9	0.4	0.1		
115	21.0	19.6	18.3	17.0	15.7	14.4	13.2	12.0	10.9	9.8	8.7	7.7	6.7	5.7	4.9	4.0	3.3	2.5	1.9	1.3	0.8	0.4	0.1	
120	21.4	20.1	18.8	17.5	16.2	15.0	13.8	12.6	11.5	10.4	9.3	8.3	7.3	6.4	5.5	4.7	3.9	3.1	2.4	1.8	1.3	0.8	0.4	0.1

Table A5.37: Urban arterial additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**
5	0.1																							
10	0.3	0.1																						
15	0.4	0.2	0.1																					
20	0.6	0.4	0.2	0.1																				
25	0.9	0.7	0.5	0.3	0.2																			
30	1.2	1.0	0.8	0.6	0.4	0.2																		
35	1.5	1.3	1.2	1.0	0.7	0.4	0.2																	
40	1.9	1.7	1.5	1.3	1.1	0.8	0.5	0.2																
45	2.3	2.1	1.9	1.7	1.5	1.1	0.8	0.5	0.2															
50	2.7	2.6	2.4	2.2	1.9	1.5	1.2	0.9	0.6	0.3														
55	3.2	3.1	2.9	2.7	2.4	2.0	1.7	1.3	0.9	0.6	0.3													
60	3.8	3.6	3.5	3.2	2.9	2.6	2.2	1.8	1.4	1.0	0.6	0.3												
65	4.4	4.2	4.1	3.8	3.5	3.1	2.7	2.3	1.9	1.5	1.0	0.6	0.3											
70	5.0	4.9	4.7	4.4	4.1	3.7	3.3	2.9	2.5	2.0	1.6	1.1	0.6	0.3										
75	5.7	5.5	5.3	5.1	4.8	4.4	4.0	3.6	3.1	2.6	2.2	1.7	1.2	0.7	0.3									
80	6.4	6.2	6.0	5.8	5.5	5.1	4.7	4.2	3.8	3.3	2.8	2.3	1.8	1.2	0.7	0.3								
85	7.1	7.0	6.8	6.5	6.2	5.8	5.4	4.9	4.4	4.0	3.5	2.9	2.4	1.9	1.3	0.8	0.3							
90	7.9	7.8	7.5	7.3	6.9	6.5	6.1	5.6	5.2	4.7	4.2	3.6	3.1	2.5	1.9	1.4	0.8	0.3						
95	8.8	8.6	8.3	8.1	7.7	7.3	6.8	6.4	5.9	5.4	4.9	4.3	3.8	3.2	2.6	2.0	1.4	0.8	0.3					
100	9.6	9.4	9.2	8.9	8.5	8.1	7.6	7.2	6.7	6.2	5.6	5.1	4.5	3.9	3.3	2.7	2.1	1.5	0.8	0.3				
105	10.5	10.3	10.0	9.7	9.4	8.9	8.4	8.0	7.5	6.9	6.4	5.9	5.3	4.7	4.1	3.5	2.8	2.2	1.5	0.9	0.3			
110	11.5	11.2	10.9	10.6	10.2	9.8	9.3	8.8	8.3	7.7	7.2	6.6	6.1	5.5	4.9	4.2	3.6	2.9	2.2	1.6	0.9	0.3		
115	12.4	12.2	11.9	11.5	11.1	10.6	10.1	9.6	9.1	8.6	8.0	7.4	6.9	6.3	5.6	5.0	4.3	3.7	3.0	2.3	1.6	0.9	0.3	
120	13.4	13.1	12.8	12.5	12.0	11.5	11.0	10.5	10.0	9.4	8.8	8.3	7.7	7.0	6.4	5.8	5.1	4.5	3.8	3.1	2.3	1.6	0.9	0.4

Table A5.38: Urban other additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed(km/h)	Additional travel time in seconds/speed cycle by final speed																						
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.3																							
10	4.2	1.2																						
15	5.9	2.8	0.8																					
20	7.6	4.5	2.2	0.6																				
25	9.1	6.1	3.7	1.8	0.5																			
30	10.6	7.7	5.2	3.1	1.5	0.4																		
35	12.0	9.2	6.7	4.5	2.7	1.3	0.4																	
40	13.4	10.6	8.1	5.9	4.0	2.4	1.2	0.3																
45	14.0	11.6	9.4	7.3	5.3	3.6	2.2	1.0	0.3															
50	14.6	12.3	10.2	8.3	6.5	4.8	3.3	2.0	1.0	0.3														
55	15.2	13.0	11.0	9.1	7.4	5.8	4.3	3.0	1.8	0.9	0.2													
60	15.7	13.7	11.8	10.0	8.2	6.7	5.2	3.9	2.7	1.7	0.8	0.2												
65	16.2	14.3	12.5	10.7	9.1	7.5	6.1	4.7	3.5	2.5	1.5	0.8	0.2											
70	16.8	14.9	13.2	11.5	9.9	8.3	6.9	5.6	4.3	3.2	2.3	1.4	0.7	0.2										
75	17.3	15.5	13.8	12.2	10.6	9.1	7.7	6.4	5.2	4.0	3.0	2.1	1.3	0.7	0.2									
80	17.8	16.1	14.4	12.8	11.3	9.9	8.5	7.2	5.9	4.8	3.7	2.8	1.9	1.2	0.6	0.2								
85	18.3	16.6	15.0	13.5	12.0	10.6	9.2	7.9	6.7	5.5	4.5	3.5	2.6	1.8	1.1	0.6	0.2							
90	18.7	17.1	15.6	14.1	12.7	11.3	9.9	8.7	7.4	6.3	5.2	4.2	3.3	2.4	1.7	1.1	0.5	0.2						
95	19.2	17.6	16.1	14.7	13.3	11.9	10.6	9.4	8.2	7.0	5.9	4.9	4.0	3.1	2.3	1.6	1.0	0.5	0.2					
100	19.6	18.1	16.7	15.3	13.9	12.6	11.3	10.0	8.9	7.7	6.6	5.6	4.7	3.8	2.9	2.2	1.5	0.9	0.5	0.2				
105	20.1	18.6	17.2	15.8	14.5	13.2	11.9	10.7	9.5	8.4	7.3	6.3	5.3	4.4	3.6	2.8	2.1	1.4	0.9	0.5	0.1			
110	20.5	19.1	17.7	16.4	15.1	13.8	12.6	11.4	10.2	9.1	8.0	7.0	6.0	5.1	4.2	3.4	2.7	2.0	1.4	0.9	0.4	0.1		
115	21.0	19.6	18.2	16.9	15.6	14.4	13.2	12.0	10.8	9.7	8.7	7.6	6.7	5.7	4.9	4.0	3.3	2.5	1.9	1.3	0.8	0.4	0.1	
120	21.4	20.0	18.7	17.4	16.2	15.0	13.8	12.6	11.5	10.4	9.3	8.3	7.3	6.4	5.5	4.6	3.9	3.1	2.4	1.8	1.3	0.8	0.4	0.1

Table A5.39: Urban other additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.1																							
10	0.3	0.1																						
15	0.4	0.2	0.1																					
20	0.5	0.4	0.2	0.1																				
25	0.8	0.6	0.5	0.3	0.1																			
30	1.0	0.9	0.7	0.5	0.3	0.1																		
35	1.3	1.2	1.0	0.8	0.6	0.4	0.2																	
40	1.6	1.5	1.3	1.2	0.9	0.6	0.4	0.2																
45	2.0	1.9	1.7	1.5	1.3	1.0	0.7	0.4	0.2															
50	2.4	2.3	2.1	1.9	1.6	1.3	1.0	0.7	0.5	0.2														
55	2.8	2.7	2.5	2.3	2.1	1.7	1.4	1.1	0.8	0.5	0.2													
60	3.3	3.2	3.0	2.8	2.5	2.2	1.8	1.5	1.1	0.8	0.5	0.2												
65	3.8	3.6	3.5	3.3	3.0	2.7	2.3	1.9	1.6	1.2	0.8	0.5	0.2											
70	4.3	4.2	4.0	3.8	3.5	3.2	2.8	2.4	2.1	1.7	1.3	0.9	0.5	0.2										
75	4.9	4.7	4.5	4.3	4.1	3.7	3.3	3.0	2.6	2.2	1.8	1.4	0.9	0.5	0.2									
80	5.4	5.3	5.1	4.9	4.6	4.3	3.9	3.5	3.1	2.7	2.3	1.9	1.4	1.0	0.6	0.2								
85	6.1	5.9	5.7	5.5	5.2	4.8	4.5	4.1	3.7	3.3	2.8	2.4	1.9	1.5	1.0	0.6	0.2							
90	6.7	6.5	6.3	6.1	5.8	5.4	5.1	4.7	4.3	3.8	3.4	2.9	2.5	2.0	1.5	1.1	0.6	0.2						
95	7.4	7.2	7.0	6.8	6.4	6.1	5.7	5.3	4.8	4.4	4.0	3.5	3.1	2.6	2.1	1.6	1.1	0.6	0.2					
100	8.1	7.9	7.7	7.4	7.1	6.7	6.3	5.9	5.5	5.0	4.6	4.1	3.6	3.2	2.7	2.2	1.6	1.1	0.6	0.2				
105	8.8	8.6	8.4	8.1	7.8	7.4	6.9	6.5	6.1	5.6	5.2	4.7	4.2	3.8	3.3	2.7	2.2	1.7	1.2	0.6	0.2			
110	9.5	9.3	9.1	8.8	8.4	8.0	7.6	7.2	6.7	6.3	5.8	5.3	4.8	4.4	3.8	3.3	2.8	2.3	1.7	1.2	0.7	0.2		
115	10.3	10.1	9.8	9.5	9.1	8.7	8.3	7.8	7.4	6.9	6.4	6.0	5.5	5.0	4.4	3.9	3.4	2.9	2.3	1.8	1.2	0.7	0.2	
120	11.1	10.8	10.5	10.2	9.8	9.4	8.9	8.5	8.0	7.5	7.1	6.6	6.1	5.6	5.1	4.5	4.0	3.5	2.9	2.3	1.8	1.2	0.7	0.3

Table A5.40: Rural strategic additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed(km/h)	Additional travel time in seconds/speed cycle by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.3																							
10	4.3	1.2																						
15	6.1	2.9	0.8																					
20	7.7	4.6	2.2	0.6																				
25	9.3	6.3	3.7	1.8	0.5																			
30	10.8	7.9	5.3	3.2	1.5	0.4																		
35	12.3	9.4	6.8	4.6	2.8	1.3	0.4																	
40	13.7	10.9	8.3	6.0	4.1	2.4	1.2	0.3																
45	14.3	11.9	9.6	7.5	5.4	3.7	2.2	1.1	0.3															
50	14.9	12.6	10.5	8.4	6.6	4.9	3.4	2.0	1.0	0.3														
55	15.5	13.3	11.3	9.3	7.5	5.9	4.4	3.1	1.9	0.9	0.3													
60	16.1	14.0	12.0	10.2	8.4	6.8	5.3	4.0	2.8	1.7	0.8	0.2												
65	16.6	14.6	12.8	11.0	9.3	7.7	6.2	4.8	3.6	2.5	1.6	0.8	0.2											
70	17.2	15.3	13.5	11.7	10.1	8.5	7.1	5.7	4.4	3.3	2.3	1.4	0.7	0.2										
75	17.7	15.9	14.1	12.4	10.8	9.3	7.9	6.5	5.3	4.1	3.1	2.1	1.3	0.7	0.2									
80	18.2	16.4	14.8	13.1	11.6	10.1	8.7	7.3	6.1	4.9	3.8	2.8	2.0	1.2	0.6	0.2								
85	18.7	17.0	15.4	13.8	12.3	10.8	9.4	8.1	6.9	5.7	4.6	3.6	2.7	1.9	1.2	0.6	0.2							
90	19.2	17.5	16.0	14.4	13.0	11.5	10.2	8.9	7.6	6.4	5.3	4.3	3.4	2.5	1.7	1.1	0.6	0.2						
95	19.7	18.1	16.5	15.0	13.6	12.2	10.9	9.6	8.4	7.2	6.1	5.0	4.1	3.2	2.4	1.6	1.0	0.5	0.2					
100	20.1	18.6	17.1	15.6	14.2	12.9	11.6	10.3	9.1	7.9	6.8	5.8	4.8	3.8	3.0	2.2	1.6	1.0	0.5	0.2				
105	20.6	19.1	17.6	16.2	14.8	13.5	12.2	11.0	9.8	8.6	7.5	6.5	5.5	4.5	3.7	2.9	2.1	1.5	0.9	0.5	0.1			
110	21.0	19.6	18.2	16.8	15.4	14.1	12.9	11.6	10.4	9.3	8.2	7.2	6.2	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.5	0.1		
115	21.5	20.1	18.7	17.3	16.0	14.7	13.5	12.3	11.1	10.0	8.9	7.8	6.8	5.9	5.0	4.1	3.3	2.6	1.9	1.3	0.8	0.4	0.1	
120	21.9	20.5	19.2	17.9	16.6	15.3	14.1	12.9	11.7	10.6	9.5	8.5	7.5	6.5	5.6	4.8	3.9	3.2	2.5	1.9	1.3	0.8	0.4	0.1

Table A5.41: Rural strategic additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.2																							
10	0.3	0.1																						
15	0.5	0.3	0.1																					
20	0.7	0.5	0.3	0.2																				
25	1.1	0.9	0.7	0.5	0.2																			
30	1.5	1.3	1.1	0.8	0.6	0.3																		
35	2.0	1.8	1.6	1.3	1.0	0.6	0.3																	
40	2.5	2.3	2.1	1.8	1.5	1.1	0.7	0.3																
45	3.0	2.9	2.6	2.3	2.0	1.6	1.2	0.8	0.4															
50	3.7	3.5	3.3	3.0	2.6	2.2	1.7	1.3	0.8	0.4														
55	4.4	4.3	4.0	3.7	3.4	2.9	2.4	1.9	1.4	0.9	0.4													
60	5.2	5.1	4.8	4.5	4.1	3.7	3.1	2.6	2.0	1.5	0.9	0.4												
65	6.1	5.9	5.7	5.4	5.0	4.5	4.0	3.4	2.8	2.2	1.6	1.0	0.5											
70	7.0	6.8	6.6	6.3	5.9	5.4	4.9	4.3	3.7	3.0	2.4	1.7	1.0	0.5										
75	8.0	7.8	7.6	7.3	6.9	6.3	5.8	5.2	4.6	3.9	3.3	2.6	1.8	1.1	0.5									
80	9.1	8.9	8.6	8.3	7.9	7.4	6.8	6.2	5.6	4.9	4.2	3.5	2.7	1.9	1.2	0.5								
85	10.2	10.0	9.7	9.4	9.0	8.4	7.9	7.3	6.6	5.9	5.2	4.5	3.7	2.9	2.1	1.2	0.5							
90	11.4	11.2	10.9	10.5	10.1	9.6	9.0	8.4	7.7	7.0	6.3	5.5	4.7	3.9	3.1	2.2	1.3	0.5						
95	12.7	12.4	12.1	11.7	11.3	10.7	10.1	9.5	8.8	8.2	7.4	6.6	5.8	5.0	4.1	3.2	2.3	1.4	0.5					
100	14.0	13.7	13.4	13.0	12.6	12.0	11.4	10.7	10.0	9.3	8.6	7.8	7.0	6.1	5.2	4.3	3.4	2.4	1.4	0.5				
105	15.4	15.1	14.8	14.4	13.9	13.3	12.6	12.0	11.3	10.6	9.8	9.0	8.2	7.3	6.4	5.5	4.5	3.5	2.5	1.5	0.6			
110	16.9	16.5	16.2	15.7	15.2	14.6	14.0	13.3	12.6	11.8	11.1	10.3	9.4	8.6	7.6	6.7	5.7	4.7	3.7	2.6	1.5	0.6		
115	18.4	18.0	17.6	17.2	16.7	16.0	15.3	14.7	13.9	13.2	12.4	11.6	10.7	9.8	8.9	7.9	7.0	5.9	4.9	3.8	2.7	1.6	0.6	
120	20.0	19.6	19.2	18.7	18.1	17.5	16.8	16.1	15.3	14.5	13.7	12.9	12.0	11.1	10.2	9.2	8.2	7.2	6.1	5.0	3.9	2.8	1.6	0.6

Table A5.42: Rural other additional travel time due to speed change cycles (seconds/speed cycle)

Initial speed(km/h)	Additional travel time in seconds/speed cycle by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	2.3																							
10	4.3	1.2																						
15	6.0	2.9	0.8																					
20	7.7	4.6	2.2	0.6																				
25	9.2	6.2	3.7	1.8	0.5																			
30	10.7	7.8	5.3	3.1	1.5	0.4																		
35	12.2	9.3	6.8	4.6	2.7	1.3	0.4																	
40	13.6	10.8	8.3	6.0	4.1	2.4	1.2	0.3																
45	14.2	11.8	9.5	7.4	5.4	3.7	2.2	1.1	0.3															
50	14.8	12.5	10.4	8.4	6.6	4.9	3.3	2.0	1.0	0.3														
55	15.4	13.2	11.2	9.3	7.5	5.8	4.4	3.0	1.8	0.9	0.3													
60	16.0	13.9	12.0	10.1	8.4	6.8	5.3	3.9	2.7	1.7	0.8	0.2												
65	16.5	14.5	12.7	10.9	9.2	7.6	6.2	4.8	3.6	2.5	1.6	0.8	0.2											
70	17.0	15.2	13.4	11.6	10.0	8.5	7.0	5.7	4.4	3.3	2.3	1.4	0.7	0.2										
75	17.6	15.8	14.0	12.4	10.8	9.3	7.8	6.5	5.2	4.1	3.0	2.1	1.3	0.7	0.2									
80	18.1	16.3	14.7	13.0	11.5	10.0	8.6	7.3	6.0	4.9	3.8	2.8	2.0	1.2	0.6	0.2								
85	18.6	16.9	15.3	13.7	12.2	10.7	9.4	8.1	6.8	5.6	4.6	3.6	2.6	1.8	1.1	0.6	0.2							
90	19.0	17.4	15.8	14.3	12.9	11.4	10.1	8.8	7.6	6.4	5.3	4.3	3.3	2.5	1.7	1.1	0.6	0.2						
95	19.5	17.9	16.4	14.9	13.5	12.1	10.8	9.5	8.3	7.1	6.0	5.0	4.0	3.1	2.3	1.6	1.0	0.5	0.2					
100	20.0	18.5	17.0	15.5	14.1	12.8	11.5	10.2	9.0	7.9	6.8	5.7	4.7	3.8	3.0	2.2	1.5	1.0	0.5	0.2				
105	20.4	19.0	17.5	16.1	14.7	13.4	12.1	10.9	9.7	8.6	7.5	6.4	5.4	4.5	3.6	2.8	2.1	1.5	0.9	0.5	0.1			
110	20.9	19.4	18.0	16.7	15.3	14.0	12.8	11.6	10.4	9.2	8.1	7.1	6.1	5.2	4.3	3.5	2.7	2.0	1.4	0.9	0.4	0.1		
115	21.3	19.9	18.6	17.2	15.9	14.6	13.4	12.2	11.0	9.9	8.8	7.8	6.8	5.8	4.9	4.1	3.3	2.6	1.9	1.3	0.8	0.4	0.1	
120	21.8	20.4	19.1	17.7	16.5	15.2	14.0	12.8	11.7	10.6	9.5	8.4	7.4	6.5	5.6	4.7	3.9	3.2	2.5	1.8	1.3	0.8	0.4	0.1

Table A5.43: Rural other additional VOC due to speed change cycles (cents/speed cycle – July 2008)

Initial speed(km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.1																							
10	0.3	0.1																						
15	0.5	0.3	0.1																					
20	0.7	0.5	0.3	0.1																				
25	1.0	0.8	0.6	0.4	0.2																			
30	1.4	1.2	1.0	0.8	0.5	0.2																		
35	1.8	1.6	1.4	1.2	0.9	0.6	0.3																	
40	2.2	2.1	1.9	1.6	1.3	1.0	0.6	0.3																
45	2.8	2.6	2.4	2.1	1.8	1.4	1.0	0.7	0.3															
50	3.3	3.2	3.0	2.7	2.4	1.9	1.5	1.1	0.7	0.3														
55	4.0	3.8	3.6	3.3	3.0	2.6	2.1	1.6	1.2	0.8	0.4													
60	4.7	4.5	4.3	4.0	3.7	3.2	2.8	2.3	1.8	1.3	0.8	0.4												
65	5.4	5.3	5.1	4.8	4.4	4.0	3.5	3.0	2.5	1.9	1.4	0.8	0.4											
70	6.2	6.1	5.9	5.6	5.2	4.8	4.3	3.8	3.2	2.7	2.1	1.5	0.9	0.4										
75	7.1	6.9	6.7	6.4	6.1	5.6	5.1	4.6	4.0	3.4	2.8	2.2	1.6	0.9	0.4									
80	8.0	7.9	7.6	7.3	6.9	6.5	6.0	5.4	4.9	4.3	3.7	3.0	2.3	1.7	1.0	0.4								
85	9.0	8.8	8.6	8.3	7.9	7.4	6.9	6.3	5.8	5.2	4.5	3.9	3.2	2.5	1.8	1.0	0.4							
90	10.1	9.8	9.6	9.3	8.9	8.4	7.8	7.3	6.7	6.1	5.5	4.8	4.1	3.4	2.6	1.9	1.1	0.4						
95	11.1	10.9	10.6	10.3	9.9	9.4	8.9	8.3	7.7	7.1	6.4	5.7	5.0	4.3	3.5	2.7	1.9	1.1	0.4					
100	12.3	12.1	11.8	11.4	11.0	10.5	9.9	9.3	8.7	8.1	7.4	6.7	6.0	5.3	4.5	3.7	2.9	2.0	1.2	0.5				
105	13.5	13.2	12.9	12.5	12.1	11.6	11.0	10.4	9.8	9.1	8.5	7.8	7.0	6.3	5.5	4.7	3.8	3.0	2.1	1.2	0.5			
110	14.7	14.5	14.1	13.7	13.3	12.7	12.1	11.5	10.9	10.2	9.5	8.8	8.1	7.3	6.5	5.7	4.9	4.0	3.1	2.2	1.3	0.5		
115	16.0	15.7	15.4	15.0	14.5	13.9	13.3	12.7	12.0	11.4	10.7	9.9	9.2	8.4	7.6	6.8	5.9	5.0	4.1	3.2	2.2	1.3	0.5	
120	17.4	17.1	16.7	16.2	15.7	15.1	14.5	13.9	13.2	12.5	11.8	11.1	10.3	9.5	8.7	7.9	7.0	6.1	5.2	4.3	3.3	2.3	1.4	0.5

A6 Crash costs

A6.1 Introduction

Introduction

This appendix gives guidance on calculating crash cost savings for the do-minimum and the options.

For the purposes of this manual, a crash is an event involving one or more road vehicles that results in personal physical injury and/or damage to property.

In this appendix

	Topic
A6.1	Introduction
A6.2	Choosing to undertake a crash analysis
A6.3	Choosing the type of analysis
A6.4	Applying the analysis methods
A6.5	Crash trends
A6.6	Typical injury crash rates and prediction models
A6.7	Typical crash reduction factors
A6.8	Adjusting crash costs to reflect mean speeds
A6.9	Worked example of crash procedures
A6.10	Tables
A6.11	References

A6.2 Choosing to undertake a crash analysis

Introduction

Not all evaluations require a crash analysis. Several factors affect the decision of whether or not to undertake a crash analysis and the choice of method used for that analysis including:

- the nature of the site (eg average annual daily traffic (AADT), length)
- the availability of a reliable crash history for at least five years
- the availability of suitable crash prediction models or exposure-based crash prediction equations; and
- if the option will result in a fundamental change in the site.

When to do a crashcrash analysis

A crash analysis may be appropriate where one or more of the following is true:

a. at intersections or sites less than 1 km in length, within the last five years there have been:
   - five or more injury crashes; and/or
   - two or more serious or fatal crashes;

b. at sites longer than 1 km in length, within the last five years there have been:
   - two or more injury crashes per km; and/or
   - one or more serious or fatal crashes per km;

   Note: For sites on low volume roads, with an AADT less than 1,500 vehicles per day (vpd) that do not meet requirement (a) or (b) above, the last ten year history can be used. The ten year history must be divided by two to obtain an equivalent five year history for analysis.

c. There is some commonality amongst the crashes that have occurred;

d. a recognised crash investigation specialist considers that the site has significant safety deficiencies (eg, high crash risk sites);

e. there is a high level of public concern;

f. there will be a fundamental change in the site where the types of crashes or level of crash severity will change significantly. Fundamental change is defined in Appendix A6.3.

Crash analysis methods

There are three crash analysis methods available:

- method A: Crash by crash analysis
- method B: Crash rate analysis
- method C: Weighted crash procedure.

Application of the methods

Despite being based on historical crashes method A still involves the prediction of future crashes. The five-year observed crash history may or may not be a good indication of the likely crash occurrence over the next 40 years if the site is not upgraded. For any sites/routes method B or C, particularly the latter, may provide a better prediction of future crash occurrence.

General process

The general process for a crash analysis is as follows:

- Select the appropriate analysis procedure(s) using Appendix A6.2 and, depending on the method(s) selected:
    - determine the historic crash performance by analysis of crash records, typically over the last five years, and
    - select the crash prediction models or exposure-based crash prediction equations for the do-minimum and options from Appendix A6.6.
- Assess the annual crash performance and corresponding crash costs for the do-minimum and the options. Adjust for general trends in crash occurrence.
- Calculate the annual crash cost savings. These are the future annual crash costs of the do-minimum less the future annual crash costs of the options.

Guidance

The procedure below gives step-by-step guidance as to when an crash analysis may be required and what method(s) should be applied.

Selecting the crash analysis method

Follow the steps below to determine the need for a crash analysis and the appropriate crash analysis method(s).

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="4">1</td><td colspan="2">Choose the appropriate length of crash history period for the site as follows:</td></tr>
<tr><td>If the section has an AADT of</td><td>Then the crash history period should be at least …</td></tr>
<tr><td><1500 vehicles per day</td><td>ten years.(if the last five year history has insufficient crashes, use 10 year history divided by 2)</td></tr>
<tr><td>>1500 vehicles per day</td><td>five years</td></tr>
<tr><td rowspan="4">2</td><td colspan="2">Crash history should in the first instance be obtained from the Crash Analysis System (CAS). Where necessary, verified local contact crash information can be used to supplement and update CAS. Refer to preceding sections for further description.
Determine whether or not the crash history is adequate as follows:</td></tr>
<tr><td>If the available crash history for the site is …</td><td>Then …</td></tr>
<tr><td>too short / insufficient</td><td>go to step 3</td></tr>
<tr><td>long enough / sufficient</td><td>go to step 4</td></tr>
</table>

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>3</td><td>Where there was a significant change at the site at least three years earlier, a shorter period of crash history may be acceptable if factored up to a five year period as follows:
<table>
<tr><th>If there is</th><th>Then …</th></tr>
<tr><td>at least three years of available crash data</td><td>factor the information to cover a five year period. Go to step 4</td></tr>
<tr><td>less than three years of available crash data</td><td>go to step 8</td></tr>
</table>
Where a shorter time period has been factored for use in the crash analysis, a peer review of the analysis will be required before it is submitted with the evaluation.</td></tr>
<tr><td>4</td><td>Determine whether or not there are the minimum number of crashes at the site as follows:
<table>
<tr><th>If the site is …</th><th>and the minimum number of crashes is …</th><th>Then …</th></tr>
<tr><td>An intersection or road section <1 km long</td><td>≥5 injury crashes
or
≥2 serious and fatal crashes</td><td>Go to step 7</td></tr>
<tr><td>An intersection or road section <1 km long</td><td><5 injury crashes
or
<2 serious and fatal crashes</td><td>Go to step 5</td></tr>
<tr><td>A road section >1 km</td><td>≥3 injury crashes
or
≥1 serious and fatal crashes</td><td>Go to step 7</td></tr>
<tr><td>A road section >1 km</td><td><3 injury crashes
or
<1 serious and fatal crashes</td><td>Go to step 5</td></tr>
</table></td></tr>
<tr><td>5</td><td>Consider whether or not an crash analysis is feasible using crash prediction models or exposure-based crash prediction equations (as given in Appendix A6.5) as follows:
<table>
<tr><th>Is there an crash prediction model or exposure-based crash prediction equation available for the do minimum and project option(s)?</th><th>Then …</th></tr>
<tr><td>Yes</td><td>Go to step 6</td></tr>
</table></td></tr>
</table>

	No	Go to step 9

Step	Action	
6	Where there is not a sufficient crash history and models or exposure equations are available, choose the crash analysis method as follows: Fundamental change is defined earlier in Appendix A6.2.	
	Will there be a fundamental change at the site?	**Where there is insufficient crash history, conduct an crash analysis using**
	Yes	Method C for do-minimum Method B for project option
	No	Method C for do-minimum and project option
7	Where there is a well-established crash history, choose the crash analysis method as follows: Fundamental change is defined earlier in Appendix A6.2.	
	Will the project result in a fundamental change at the site?	**Where there is good crash history information, conduct an crash analysis using**
	Yes	Method A for do-minimum Method B for project option
	No	Method A for do-minimum and project option
8	Where there is no or unreliable crash, use Method B for do-minimum and project option where crash prediction models or exposure-based crash prediction equations are available.	
9	Where a site fails to meet any of the preceding criteria for undertaking an crash analysis, it may be possible to undertake an crash analysis if the following criterion is met:	
	Is the site a rural re-alignment and does a recognised crash investigation specialist consider the site to have significant safety deficiencies?	
	Yes	Conduct a peer reviewed crash by crash analysis (method A)
	No	Go to step 10

Step	Action
10	Where there is insufficient crash history and no crash prediction models or exposure-based crash prediction equations available, contact the NZ Transport Agency.

A6.3 Choosing the type of analysis

Introduction

This section of the manual provides further guidance on the definitions used within the crash analysis procedures and which analysis method to use if there are complications with the particular site.

Site

A site is the specific road infrastructure for which an evaluation is carried out. A site can be a bridge, intersection, mid-block, curve, S-bend, etc, or any combination of these, eg, a mid-block and an intersection. In the case of combinations, a site may have to be broken into parts for the purpose of evaluation.

Remote and near rural roads

Remote rural roads are sites carrying less than 1000 vpd and more than 20 kilometres away from a town with a population of 3,000 or more. Other rural sites are considered to be "near rural".

Crash history

For the purpose of crash analysis, generally a minimum of the past five years (sixty months) of reported crash history is used. This reduces the error caused by regression to the mean.

The principle of regression to the mean states that when an earlier measurement is either extremely high or extremely low, then the expected value of later measurements will be closer to the true mean than the observed value of the first.

The effect of regression to the mean can be reduced by using a longer crash history when investigating crashes at a site, and by ensuring that there is a commonality amongst crashes at the site.

Completeness of crash history data

The latest data available in the Crash Analysis System (CAS) should be used for crash analysis. As there is typically a lag between the time when an crash occurs and when it is entered into CAS, care should be taken to ensure that the data being used is complete.

When establishing the crash history, it is considered good practice to check all the Traffic Crash Reports (TCR) along the length of the site and up to one kilometre either side. Where possible, the location of serious and fatal crashes should be discussed with the local Police to confirm the location, particularly along roads where it is suspected that crashes may have incorrect locations noted in the TCR. At sites with low crash occurrence, the impact of an incorrectly coded crash in the TCR, particularly a serious or fatal crash, can have a major impact on crash benefits (both positive and negative).

Local crash data

The NZ Transport Agency and local authorities have set up systems that involve the collection of local contact crash data (also called 'contractor reported' or 'unreported to police' crashes) from contractors, local residents and network management personnel. The quality of this data varies and caution should be taken when using it in crash analysis.

Local contact crash data can be used in an crash-by-crash analysis (Method A) where the data is supported by sufficient evidence to be audited and a reasoned justification provided as to why it should be used to supplement information from CAS. Evidence might include a second independent report of the crash, confirmation of crashes by the local police or by local network contractors or consultants.

If local contact crash information is used for an analysis then under-reporting factors **must not** be included in the calculations of injury or non-injury crash costs.

Site characteristics

There are four site characteristics which have an impact on the time-span of crash history required and the method used for analysis:

- the traffic volume through the site
- whether or not there has been a major change at the site
- whether or not it is a new site (eg, new road or intersection)
- when there is no crash history

The table below illustrates the adjustment to the crash history requirements or the choice of crash analysis methods resulting from these characteristics.

If…	Then…
the site has an AADT equal to or greater than 1,500 vpd.	use the latest five year crash history for the site being investigated.
the site has an AADT less than 1,500 vpd.	use the latest 10 year crash history in addition to the latest five years to ascertain whether the site under consideration has a crash problem not revealed by the latest five years of data. if a crash problem is reveled in the five-year range, divide the 10 year crash numbers by two to obtain a equivalent five year crash history*.
*At low-volume sites, anomalies can be created where a five year crash history does not reflect the overall patterns. In some cases it may be appropriate to use a longer crash history. Advice should be requested from the NZ Transport Agency.	
a fundamental change has occurred at the site (prior to project implementation) that could be expected to have changed the incidence of crashes.	use the crash history for the period since the change (minimum of 3 years), or adjust the record for the period prior to the change by removing those crashes remedied by the change.
the site is new (eg, a new road or intersection).	use Method B.
there is no obvious crash history at the site.	depending on the reasons for this, crash analysis may not be required. Contact the NZ Transport Agency for further clarification.

Minimum number of crashes required for Method A

The use of method A for crash analysis requires that a minimum number of crashes have occurred at the site, depending on the length of the site as follows:

a. At intersections or sites less than one kilometre in length, within the last five years there have been:

- five or more injury crashes; and/or
- two or more serious or fatal crashes;

b. At sites longer than one kilometre in length, within the last five years there have been:
   - three or more injury crashes per kilometre; and/or
   - one or more serious or fatal crash per kilometre;

Generally, there should be some commonality amongst the crashes that have occurred.

Where a site does not meet these minimal requirements, then method C (weighted crash procedure) should be used. The exception is where no crash prediction equations or exposure based accident equations are available to use in method C. It should be endeavoured to obtain models for an analysis.

Fundamental change in a site

An option results in a fundamental change in a site when the types of crash or the level of crash severity is expected to change significantly. The following list gives examples of site changes that would result in a fundamental change:

- a completely new site is being provided (such as a new road or intersection)
- realignment of a road (other than an isolated curve)
- removal or significant modification of road elements (eg, grade separation of a railway crossing and conversion of a single lane bridge to a two-lane bridge)
- change in intersection form of control
- flush median installed on urban road with multiple accesses.
- adding lanes, including passing lanes.

Options that are not normally regarded as resulting in fundamental changes include:

- upgrade of a single or S-bend to a higher design speed curve or S-bend
- shoulder widening on rural roads (in the absence of road realignment)
- signage and delineation improvements, including lighting
- traffic volume changes (in the absence of other improvements)
- road resurfacing and shape corrections, and
- minor improvement works.

When there is a fundamental change, method B is generally used for analysis of the option, while method C or A can be used for the do-minimum depending on the number of crashes that occur at the site.

Where there is a fundamental change in a site but no crash prediction models or exposure-based crash prediction equations are available for the do-minimum, method A can be used for the do minimum while method B is used for the options, providing that models are available for the options.

Area-wide changes in traffic networks

When considering projects of an area-wide nature, such as the evaluation of an urban traffic network, eg, for transport planning or traffic management studies, it is insufficient to calculate crash costs from changes in global totals of vehicle-kilometres of travel.

Where a new road link is being added to a network, or a network change will result in major redistributions of traffic, analysis is required of the incidence of crashes on the links to which the traffic is being diverted and on the links for which traffic volumes reduce.

For a new link, use method B crash prediction models or exposure-based crash prediction equations appropriate to its intended design, speed limit and intersections along it. On major links that experience significant changes in traffic volumes, crash prediction models are preferred (where available) over exposure-based crash prediction equations. In some situations the use of the site (or route) specific crash rates can be appropriate.

Availability of models and equations

In the absence of an adequate crash history for the site, method B or C may be used for both the do-minimum and the option, provided there is a suitable crash prediction model or exposure-based crash prediction equation available. A summary of the available models and equations is found in Appendix A6.3 while Appendix A6.5 provides the details about them.

Crash prediction models or exposure-based crash prediction equations other than those specified may be used if the robustness of these models or equations can be demonstrated to the NZ Transport Agency and a peer reviewer.

A6.4 Applying the analysis methods

Introduction

This section describes the general process for how to determine future annual crash numbers and costs for the do-minimum and options using the three analysis methods:

- method A: Crash-by-crash analysis
- method B:Crash rate analysis
- method C: Weighted crash procedure.

Worked examples of the methods B and C are provided in Appendix A6.8.

Intersection crashes

Crashes occurring within the area of priority controlled intersections, roundabouts and traffic signals on the primary road network, and up to 50 metres from the influence of the intersection in a 50km/h speed limit area and up to 200 metres in a 80km/h and above area.

Mid-block crashes

Crashes occurring on a road section excluding crashes at major intersections, or 50 metres from the influence of the intersection in a 50km/h speed limit area and up to 200 metres in a 80km/h and above area. Crashes at minor intersection are sometimes included.

Categorisation by speed limit

Crashes are categorised according to the speed limit areas in which they occur:

- 50 km/h speed limit areas (including 30 km/h and 60 km/h areas)
- 70 km/h speed limit areas (including limited speed zones)
- 100 km/h speed limit areas (including 80 km/h and above areas).

Types of crash rate

A crash rate is the average number of injury crashes per year, measured over a period of time (normally five calendar years). Caution is required when using the latest three to six months CAS data as the data set may not be complete.

Site-specific crash rate (A_S)

is the crash rate for a specific site based on reported injury crashes on the record of TCRs prepared by the Police and compiled by the NZ Transport Agency (normally five years of data). These are available from the Crash Analysis System (CAS).

Typical crash rate (A_T)

is the crash rate for a typical or generic site, eg, a bridge, with characteristics similar to the site being evaluated. Typical crash rates are determined using either a crash prediction model or exposure-based crash prediction equation, depending on the type of site, or part of a site, being evaluated.

Weighted crash rate (A_W)

The crash rate produced when using the weighted crash procedure.

Method A: crash-by-crash analysis

Crash-by-crash analysis is based on the crash history of the site and is dependent on the number of reported crashes, as set out in Appendices A6.1 and A6.2. The analysis uses the individual crash severity categories (fatal, serious, minor, non-injury) and these can be further disaggregated by movement category and/or type of vehicle involved.

In the first stage of the analysis, using the worksheets in chapter 5, the do-minimum total estimated number of crashes per annum is calculated. Costs are assigned using the crash costs from tables A6.21(a) to (d) for 50 km/h speed limit areas and from tables A6.21(e) to (h) for 100 km/h speed limit areas.

The number of crashes predicted for a project option is determined from an expected reduction in the do-minimum crash numbers, based on the guidance provided in Appendix A6.6. The forecast percentage crash reductions for the project option can be applied either globally or varied for each crash type and severity (eg, for fatal, serious, minor and non-injury crashes). Costs are taken from tables A6.21(a) to (h) as appropriate to the site. Where the mean speed of traffic for the do-minimum and/or options differs from that provided in table A6.21, an adjustment should be made to the costs using the formula found in Appendix A6.8.

Severity

In method A, crashes are categorised by the most severe injury sustained. The four severity categories are:

- Fatal: when death ensues within 30 days of the crash.
- Serious: injuries requiring medical attention or admission to hospital, including fractures, concussion and severe cuts.
- Minor: injuries other than serious, which require first aid or cause discomfort or pain, including bruising and sprains
- Non-injury: when no injuries occur, sometimes referred to as ‘property damage only’ (PDO) crashes.

The crash reports from police officers recorded in CAS are to be used to classify crash severity in preference to hospital records.

Changes in crash severity

Options, such as crash barriers, can in some cases reduce the crash severity at a site. Use method A, rather than method B or C, when the majority of crash benefits are obtained from a reduction in crash severity.

Redistribution of fatal and serious crash costs

The difference between occurrences of a fatal or serious crash at a site is influenced by random chance. The severity of a crash can be influenced by various factors, including the roadside environment and the location of major hazards like large trees and power poles. Given fatal crashes are rare events that have a high cost, fatal and serious crashes are redistributed in accordance with the fatal to serious ratios in tables A6.19(a) to (c) for each crash type. This method applies for up to two fatal crashes and unlimited serious crashes at each site (up to one kilometre length). The exception is when three or more fatal crashes occur at a site where the crash costs do not need to be redistributed at the site.

Vehicle involvement

In assigning costs to crashes using method A, crashes are classified by ‘vehicle involvement’ according to the highest ranked ‘vehicle’ involved in a crash. The ranking from highest vehicle to lowest vehicle is:

- pedestrian
- bicycle
- motorcycle including moped
- bus
- truck

- cars, light commercial vehicles and any other.

For example, a crash involving a truck and a bicycle is categorised as a ‘cycle crash’.

Adjustment for under-reporting

Only a proportion of non-fatal crashes that occur are recorded on TCR and in CAS. This is referred to as under-reporting. It is generally assumed that all fatal crashes are reported.

To counteract the effect of underreporting when using method A, factors are applied to reported crash numbers (TCR numbers) to estimate the total number of crashes that actually occur. Table A6.20(a) provides factors for converting from reported injury crashes to total injury crashes, while table A6.20(b) provides factors for converting from reported non-injury crashes to total non-injury crashes.

If local contact crash information has been used, then under-reporting factors must not be included in the calculations of injury or non-injury crash costs.

Change in traffic volume

If there is a change in traffic volume for the option compared with the do-minimum, then the crash numbers must be scaled in proportion to this change.

Method B: Crash rate analysis

Crash rate analysis involves determining a typical crash rate per annum as the basis for calculating the crash cost savings for a project. Typical crash rates have been calculated using either a crash prediction model or an exposure-based crash prediction equation from Appendix A6.6, which have been derived using information from similar types of site elsewhere.

In some cases, the models used for the do-minimum and the option already account for the proposed improvement/treatment of the site (eg, an intersection treatment to change from priority or a roundabout to signalised; the construction of a two-lane rural bridge to replace a single lane bridge). In others, it may be necessary to apply a crash reduction factor from Appendix A6.6 to the option model or equation to take account of the site treatment/improvement (eg, various mid-block pedestrian treatments; construction of a cycle lane).

In crash rate analysis, it is not possible to differentiate crashes other than by speed limit category, therefore the crash costs are taken from table A6.22, and are for ‘all vehicles and all movements combined’. Where the mean speed of traffic for the do-minimum and/or options differs from that provided in table A6.22, an adjustment should be made to the costs using the formula found in Appendix A6.8.

Only reported injury crashes are considered when using crash rate analysis because of the inconsistency in non-injury reporting rates from district to district. The crash costs in table A6.22 take into account the typical number of unreported injury crashes, the number of non-injury crashes and proportion of crashes of each severity per reported injury crash.

Refer to the calculation of future crash benefits section below for details on calculating future safety benefits when using crash prediction models. Use either worksheet A6.4(a), A6.4(b) or A6.4(c).

Method C: Weighted crash procedure

The weighted crash procedure uses both historical crash data relating to a particular site, and the typical crash rate for the site, as calculated from the appropriate crash prediction model or exposure-based crash prediction equation (from Appendix A6.6).

The historical data is converted into a site-specific crash rate by dividing the reported crashes by the number of years of data. The site-specific crash rate is then combined with the typical crash rate, resulting in a weighted crash rate for the do-minimum and the option(s).

Crash cost savings for the do minimum and option(s) are calculated using the costs provided in table A6.22. Where the mean speed of traffic for the do-minimum and options differs from that provided in table A6.22, an adjustment should be made to the costs using the formula found in Appendix A6.8.

The weighted crash procedure also allows analysis of sites with no crash history, provided that the site has been in existence for more than three years with no major changes and the site is assessed to have a high crash risk.

Use of site specific crash rates

For existing links, use site-specific crash rates calculated from the crashes that have occurred on the links.

Where there is low crash occurrence due to short link lengths or low traffic volumes, site-specific crash rates can be unrealistic. In this case, crash prediction models, exposure-based crash prediction equations or site-specific crash rates from adjoining links should be used to determine future crash numbers. Intersections and other sites can be similarly analysed if necessary.

Calculation of future crash benefits

In most crash prediction models the relationship between traffic volume and crashes is non-linear. When using crash prediction models a prediction should be produced for every five years through to the end of the analysis period. Intermediate crash costs can be interpolated. If traffic volumes fall above or below the traffic volume ranges specified by the model the predictions must be capped at the lowest or highest flow allowed for analysis purposes. Worksheets A6.5(b) and (c) and A6.6(b) and (c) should be used.

When using the exposure-based crash model, future predictions are not required as the relationship between crash numbers and traffic volumes is linear. In such circumstances, only future traffic volumes need to be checked that they are within any ranges specified for the equations, otherwise the benefits need to be capped. Worksheets A6.5(a) and A6.6(a) should be used.

Weighted crash rate for the do minimum

The do-minimum weighted crash rate is calculated using the following equation:

$$A_{W,dm} = w \times A_T + (1 - w) \times A_S$$

where:

$A_{W,dm}$ is the do-minimum weighted crash rate

A_T is the typical crash rates calculated from the appropriate crash prediction model or exposure-based crash prediction equation (from Appendix A6.5) for the do-minimum

A_S is the site-specific crash rate (from historical crash data)

w is the weighting factor.

Weighting factor (w)	When **w** = 1, the method simplifies to a crash prediction model or equation (method B). When **w** = 0, the method simplifies to a crash-by-crash analysis (method A). **w** is calculated using the following equation if **k** is specified: $\mathbf{w} = \frac{k}{k + A_T(km) \times Y}$ Where: **k** is a dispersion parameter (defined below), and A_T(km) is typical annual crash rate per site or kilometer (for mid-blocks) Y is the number of years of crash records.
Dispersion parameter (k)	**k** is a dispersion parameter of the negative binomial distribution, which is the probability distribution assumed for the crash data. **k** values for different sites are in Appendix A6.6. Generally the higher the value of k the higher the accuracy of a crash prediction model (and vice versa). The accuracy is, however, also relative to the typical crash rate at a site, ie, a low **k** value may be acceptable at a site with a low typical crash rate but unacceptable at a site with a high typical crash rate. For a mid-block, the typical crash rate (A_T) must be divided by the length of the mid-block because the mid-block **k** values provided in Appendix A6.6 are on a per kilometre basis. In all other situations A_T is for the full length of the mid-block section.
Reliability of crash history	An assessment of the reliability of both the site-specific crash rate and the typical crash rate is required for method C. The reliability factor for the site-specific crash rate is α_X and the reliability factor for the typical crash rate is α_M. The main factor influencing the reliability of the site-specific crash rate is whether crashes are correctly coded at the site. Crashes may be missing from the site or may be incorrectly coded within the site. For example, a crash may be incorrectly coded within a series of back-to-back curves, where it is not always easy to accurately locate the exact curve the crash occurred on. When the historical crash data is reliable, α_X should equal 1.0 (this is the default setting). When it is unreliable, α_X should be between 1.0 and 2.0, with 2.0 being very unreliable data.
Reliability factors (α_X, α_M),	The reliability of the typical crash rate information presented in Appendix A6.5 is an issue when a crash prediction model or exposure-based crash prediction equation is used for: • A different type of site, or part of a site, than the model or equation was derived for. For example, a four-arm roundabout model might be used for a three-arm roundabout (the prediction would then be approximately 75% of that given by the model) • A ‘non-standard’ intersection, mid-block or other site or part of a site. An example of a ‘non-standard’ intersection would be one with many traffic signal phases (say 5 or 6) or greater than four approach lanes. In both situations α_M should be increased above 1.0 (the default value). A value of 2.0 would represent poor reliability.
Weighted crash	Method C can only be used for the project option when it does not bring about a fundamental

rate for project option

change in a site. In this case, the site-specific historic crash data is still relevant for the project option. The project option weighted crash rate is calculated by increasing or decreasing the typical crash rate of the project option by the same proportion used to adjust the do minimum typical crash rate to the do minimum weighted crash rate.

$A_{W,opt} = A_{T,opt} \times A_{W,dm} / A_{T,dm}$

where: $A_{W,opt}$ is the weighted crash rate for the option

$A_{W,dm}$ is the weighted crash rate for the do-minimum

$A_{T,opt}$ is the typical crash rate calculated from crash prediction models or exposure-based crash prediction equations for the option. Note that it may be necessary to apply a reduction factor from Appendix A6.6 if the prediction model or equation does not already take the treatment / improvement into account.

$A_{T,dm}$ is the typical crash rate calculated from crash prediction models or exposure-based crash prediction equations for the do-minimum.

A6.5 Crash trends

Introduction

This section provides guidance on the adjustment of crash numbers for general crash trends.

General crash trends

Since 1985, there has been a downward trend in reported traffic crashes. At the same time that crash numbers have decreased, traffic volumes have increased, indicating that crashes rates have decreased more tha crash numbers.

The combination of these two factors means that typical crash rates established from past research and site specific crash numbers need to be adjusted in order to give a realistic estimate of the likely crash situation at the project site in the future.

The adjustment to crash numbers is a two stage procedure, with the first adjustment being to modify the crash numbers at time zero and the second adjustment being to modify the growth rate used for discounting crash benefits to take account of the forecast continued trend after time zero.

There have been marked differences between the crash trends in 50 km/h areas compared with 70 km/h and above areas, and different factors are used to modify the crash numbers for the different posted speed limit areas.

Table A6.1(a) provides factors to convert historic average crash numbers to time zero for method A. For method B, an equation is provided to adjust the rate to time zero.

Table A6.1(b) provides factors to modify the predicted future traffic growth rate when discounting the crash cost savings.

Adjustment to time zero

Crash numbers and rates for project evaluation are to be determined for time zero. This requires adjusting the observed or predicted number of crashes assessed at the mid-point of the analysis period to time zero. The procedure differs if using crash history (crash-by-crash analysis) or crash prediction models or rates (crash rate analysis).

Method A adjustment

This procedure should be followed if using crash-by-crash analysis. From table A6.1(a), select the appropriate adjustment factor for the site based on its traffic growth rate and posted speed limit. For example, for a project where the posted speed limit is 50 km/h and the traffic growth rate is 2% at time zero, the crash numbers will be factored by 0.90 to adjust the crash numbers to time zero.

Table A6.1(a) Crash trend adjustment factors

Speed limit	Traffic growth rate							
	0%	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**
50 and 60 km/h	0.83	0.86	0.90	0.93	0.96	0.99	1.03	1.06
70 km/h and above	0.95	0.98	1.02	1.06	1.10	1.14	1.17	1.21

Method B adjustment

This procedure should be followed if using crash rate analysis. As the prediction models and equations in Appendix A6.5 use historical crash data, the predicted number of crashes needs to be adjusted for crash trends.

$A = A_T \times (1 + f_t (y_z – 2006))$

where:

A is the crash rate adjusted for crash trends

A_T is the typical rate found from models or rates

f_t is the factor for adjusting the typical rate

- -0.03 for sites with speed limits 60km/h and below
- -0.01 for sites with speed limits 70 km/h and above

y_z is year zero of the analysis period

Adjusting traffic growth rate for discounting

When discounting the crash cost savings from time zero forwards the predicted growth rate is adjusted to reflect the predicted continued trend in crashes. Table A6.1(b) provides the adjustments to use for the different speed limit areas.

Using the factors in table A6.1(b) it is possible for the crash growth rate used for discounting to be negative if the predicted traffic growth rate at the site is less than 3% in 50 km/h areas or 1 percent in 70 km/h and above areas. For example, if the site is in a 50 km/h posted speed area and the traffic growth rate for the site is 1.5% then the growth rate to use for discounting crash costs is 1.5 – 3 = –1.5, ie –1.5% is entered in the discounting equation.

Table A6.1(b) Growth rate adjustment factors

	Posted speed limit	
	50 and 60 km/h	**70 km/h and above**
Modification to traffic growth rate	–3%	–1%

A6.6 Typical injury crash rates and prediction models

Introduction

The typical crash rates and prediction models of reported injury crashes presented in this section are the result of studies carried out for the NZ Transport Agency and its former organisations, Transit NZ and Land Transport NZ. Crash prediction models and exposure-based crash prediction equations differ in how they relate crashes to traffic volumes.

The exposure-based crash prediction equations in this section assume that the number of crashes at a site is directly proportional to traffic volume. That is, if the traffic volume doubles then the number of crashes will also double (if everything else remains the same).

However, for the crash prediction models the number of crashes per vehicle varies depending on the traffic volume. Therefore a doubling in traffic volume will not result in a crash rate that is double – in such cases the predicted crash rate can be significantly different from double the number of crashes.

Definition of exposure

Exposure to the risk of having a crash is defined as follows:

- For mid-blocks, exposure is the number of vehicle-kilometres of travel on the mid-block, measured in hundred million vehicle-kilometres per year, ie

$$\text{Exposure} = \frac{L \times AADT \times 365}{10^8}$$

where L is the section length in kilometres, and AADT is the annual average daily traffic.

- For sites, or parts of sites, other than mid-blocks, exposure is the number of vehicles travelling through, measured in hundred million vehicles per year, ie

$$\text{Exposure} = \frac{AADT \times 365}{10^8}$$

Types of terrain

In rural areas, the values for model co-efficients are based on different terrain types, defined as follows:

Terrain type	Definition
Level	Level or gently rolling country, with gradients generally from flat up to 3%, which offers few obstacles to an unrestricted horizontal and vertical alignment.
Rolling	Rolling, hilly, or foothill country with moderate grades generally from 3%to 6% in the main, but where occasional steep slopes may be encountered.
Mountainous	Rugged, hilly, and mountainous country (and river gorges) often involving long, steep grades over 6%, and considerable proportions of the road with limited sight distance.

Definition of movement category

There are movement categories which are groupings of the two letter movement codes used in CAS to categorise crashes. Figure A6.1 shows the CAS movement codes.

Figure A6.1 CAS movement codes (version 2.4 February 2005)

	TYPE	A	B	C	D	E	F	G	O
A	OVERTAKING AND LANE CHANGE	PULLING OUT OR CHANGING LANE TO RIGHT	HEAD ON	CUTTING IN OR CHANGING LANE TO LEFT	LOST CONTROL (OVERTAKING VEHICLE)	SIDE ROAD	LOST CONTROL (OVERTAKEN VEHICLE)	WEAVING IN HEAVY TRAFFIC	OTHER
B	HEAD ON	ON STRAIGHT	CUTTING CORNER	SWINGING WIDE	* BOTH OR UNKNOWN	LOST CONTROL ON STRAIGHT	* LOST CONTROL ON CURVE		OTHER
C	LOST CONTROL OR OFF ROAD (STRAIGHT ROADS)	OUT OF CONTROL ON ROADWAY	OFF ROADWAY TO LEFT	OFF ROADWAY TO RIGHT					OTHER
D	CORNERING	LOST CONTROL TURNING RIGHT	LOST CONTROL TURNING LEFT	MISSED INTERSECTION OR END OF ROAD					OTHER
E	COLLISION WITH OBSTRUCTION	PARKED VEHICLE	CRASH OR BROKEN DOWN	NON VEHICULAR OBSTRUCTIONS (INCLUDING ANIMALS)	WORKMANS VEHICLE	OPENING DOOR			OTHER
F	REAR END	SLOW VEHICLE	CROSS TRAFFIC	PEDESTRIAN	QUEUE	SIGNALS	OTHER		OTHER
G	TURNING VERSUS SAME DIRECTION	REAR OF LEFT TURNING VEHICLE	LEFT TURN SIDE SIDE SWIPE	STOPPED OR TURNING FROM LEFT SIDE	NEAR CENTRE LINE	OVERTAKING VEHICLE	* TWO TURNING		OTHER
H	CROSSING (NO TURNS)	RIGHT ANGLE (70° TO 110°)							OTHER
J	CROSSING (VEHICLE TURNING)	RIGHT TURN RIGHT SIDE	OBSOLETE	TWO TURNING					OTHER
K	MERGING	LEFT TURN IN	RIGHT TURN IN	TWO TURNING					OTHER
L	RIGHT TURN AGAINST	STOPPED WAITING TO TURN	MAKING TURN						OTHER
M	MANOEUVRING	PARKING OR LEAVING	"U" TURN	"U" TURN	DRIVEWAY MANOEUVRE	PARKING OPPOSITE	ENTERING OR LEAVING	REVERSING ALONG ROAD	OTHER
N	PEDESTRIANS CROSSING ROAD	LEFT SIDE	RIGHT SIDE	LEFT TURN LEFT SIDE	RIGHT TURN RIGHT SIDE	LEFT TURN RIGHT SIDE	RIGHT TURN LEFT SIDE	MANOEUVRING VEHICLE	OTHER
P	PEDESTRIANS OTHER	WALKING WITH TRAFFIC	WALKING FACING TRAFFIC	WALKING ON FOOTPATH	CHILD PLAYING (TRICYCLE)	ATTENDING TO VEHICLE	ENTERING OR LEAVING VEHICLE		OTHER
Q	MISCELLANEOUS	FELL WHILE BOARDING OR ALIGHTING	FELL FROM MOVING VEHICLE	TRAIN	PARKED VEHICLE RAN AWAY	EQUESTRIAN	FELL INSIDE VEHICLE	TRAILER OR LOAD	OTHER

* = Movement applies for left and right hand bends, curves or turns

General and conflicting flow models

General models are suitable for most mid-block or intersection types indicated. Where a breakdown of crashes by crash type or road user type is required; or, in the case of intersections, where the proportion of turning vehicles is high compared to through vehicles, then **conflicting flow** models should be used.

Available models and equations

This section contains general and conflicting flow crash prediction models and exposure-based crash prediction equations for:

	General models	Conflict models
Intersections - ≤70 km/h	(1) Urban cross and T intersections, 50-70 km/h - Uncontrolled, priority, traffic signals (2) Urban roundabouts, 50-70 km/h	(3) Urban signalised cross roads (4) Urban roundabouts
Mid-blocks	(5) Urban mid-blocks, 50-70 km/h	(6) Urban mid-block – pedestrians and cyclist facilities
High speed intersections	(7) High speed cross and T intersections, ≥80 km/h – priority and traffic signals	(8) High speed roundabout (9) High speed priority crossroads (10) High speed priority T-junctions
Rural roads	(11) Rural two lane roads, ≥80 km/h (12) Rural two-lane roads: heavy vehicles (13) Motorways & four-lane divided rural roads (15) Rural passing lanes crash reduction factor	(14) Rural isolated curves (≥80 km/h)
Rural bridges	(16) Single lane rural bridges, >80 km/h (17) Two lane rural bridges, >80 km/h	
Railway crossings	(18) Urban and rural railway crossings – half arm barriers; flashing lamps and bells, no control	

Application of models and equations

All crash prediction models and exposure-based crash prediction equations calculate total injury and fatal crashes per year. The models and equations are valid within the flow ranges provided. Analysts should exercise caution when using the models and equations outside these ranges.

The crash prediction models and exposure-based crash prediction equations in this section have been developed for the most common types of site in each category. For example, traffic signal models were developed for two and three phase signals, and are therefore not as accurate for signals with four or more phases, or where there are a lot of phase changes during set periods of the day.

The more unusual a site is from the typical site type, the less appropriate the general models and equations will be for predicting the typical crash rate. In most cases where there is a feature of a site, such as the site's layout, that has a significant effect on the crash rate, the models and equations in this section are not likely to be appropriate.

Models and equations from other sources

Analysts are permitted to use crash prediction models and exposure-based crash prediction equations from other sources, as long as the robustness of these other sources can be demonstrated. These sources need to be referenced (eg, papers, research reports or unpublished material), along with information on sample size, modelling technique and goodness-of-fit statistics.

For intersection and mid-block crash prediction models, analysts are referred to the appropriate research report on crash prediction models. The crash prediction models in these reports are useful for determining the effects of varying traffic demands on particular movements at intersections, mode split and site specific features.

(1) General cross and T urban intersection 50-70 km/h

The ‘general’ model is suitable for most urban cross and T intersection types and uses two-way link volumes where the posted speed limit is 50-70 km/h. Where a breakdown by crash type and road user type is required, or where the proportion of turning vehicles is high compared to through vehicles, then the appropriate conflicting flow models should be used.

For urban intersections on the primary road network (excluding roundabouts), the typical crash rate (reported injury crashes per year) is calculated using:

$A_T = b_0 \times Q_{major}^{b_1} \times Q_{minor/side}^{b_2}$

where:

Q_{major}	the highest two-way link volume (AADT) for cross-roads and the primary road volume for T-junctions
$Q_{minor/side}$	the lowest of the daily two-way link volumes (AADT) for cross-roads and the side road flow for T-junctions

b_0, b_1 and b_2 are given in table A6.2(a).

Table A6.2(b) shows the range of flows over which the crash prediction models should be applied. The k values are for use in the weighted crash procedure.

Caution

Caution should be exercised when using the prediction models for intersections where opposing approach flows (on Q_{major} or Q_{minor}) differ by more than 25 percent. In such cases, conflicting flow models should be used.

Table A6.2(a) Urban intersection injury crash prediction model parameters (2006)

Intersection type	b_0	b_1	b_2
Uncontrolled – T	2.53×10^{-3}	0.19	0.36
Priority – Cross	1.25×10^{-3}	0.51	0.21
Priority – T	5.65×10^{-5}	0.20	0.76
Traffic signals – Cross	3.25×10^{-3}	0.14	0.46
Traffic signals – T	1.52×10^{-1}	0.12	0.04

Table A6.2(b) Urban intersection injury crash flow ranges and k values

Intersection type	Range Q_{major} AADT	Range Q_{minor} AADT	k value

Uncontrolled – T	3,000 – 30,000	500 – 4,000	2.6
Priority – Cross	5,000 – 22,000	1,500 – 7,000	2.3
Priority – T	5,000 – 26,000	1,000 – 5,000	3.8
Traffic signals – Cross	10,000 – 32,000	5,000 – 16,000	4.8
Traffic signals – T	11,000 – 34,000	2,000 – 9,000	4.6

(2) General urban roundabouts, 50-70 km/h

Often roundabouts do not have the roads with the highest or lowest volumes on opposing arms, or if they have three arms these are seldom in a 'T'. Therefore, crashes are calculated for each arm of the roundabout, and the total obtained by adding these together. The typical crash rate (reported injury crashes per approach per year) is calculated using the model:

$A_T = b_0 \times Q_{approach}^{b_1}$

where:

$Q_{approach}$ the two-way link volume (AADT) on the approach being examined.

b_0, and b_1 are given in table A6.3(a).

This model can be applied for roundabouts with three, four or five approaches. Table A6.3(b) shows the range of flows over which the crash prediction model should be applied. The k values are for use in the weighted crash procedure.

Table A6.3(a) Urban roundabout injury crash prediction model parameters (per approach - 2006)

Number of entry lanes per approach	Single		Multiple	
	b_0	b_1	b_0	b_1
Roundabout	5.56×10^{-4}	0.58	9.19×10^{-4}	0.58

Table A6.3(b) Urban roundabout injury crash prediction model flow ranges (per approach) and k values

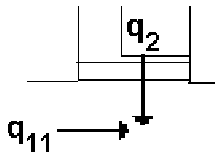
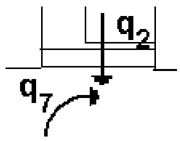
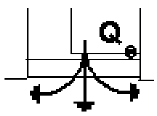
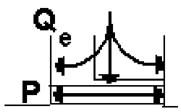
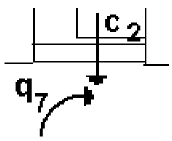
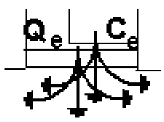
Number of entry lanes per approach	Single		Multiple	
	Flow range AADT	k value	Flow range AADT	k value
Roundabout	170 - 25000	2.2	800 - 42000	2.2

Figure A6.1
< 80 km/h

The conflicting flow models for signalised crossroads are suitable for situations where a breakdown of crashes by crash and road user type is required, or where the proportion of turning vehicles is high compared to through vehicles.

For urban (speed limit < 80 km/h) signalised crossroads on the primary road network the typical crash rates can be calculated for the six crash types (13, 19) in table A6.4(a).

Table A6.4(a) Urban signalised crossroad crash prediction models types

Crash types	Variables		CAS movement categories
Crossing (no turns, motor vehicle only)		$q_{2/11}$ = Through vehicle flows in veh/day	HA
Right turn against (motor-vehicle only)		q2 = Through vehicle flow in veh/day q7 = Right-turning vehicle flow in veh/day	LA, LB
Others (motor-vehicle only)		Qe = Entering vehicle flow in veh/day	-
Pedestrian versus motor vehicle		Qe = Entering vehicle flow in veh/day P = Pedestrian crossing volume in ped/day	NA-NO, PA-PO
Right turn against (cyclist travelling through)		q7 = Right-turning vehicle flow in veh/day c2 = Through cycle flow in cyc/day	LA, LB
Others (cyclist versus motor vehicle)		Qe = Entering vehicle flow in veh/day Ce = Entering cycle flow in cyc/day	-

The number of reported injury crashes per year for each crash type on each approach can be calculated using the models in table A6.4(b). These models calculate the number of crashes per approach and therefore must be used for each approach to the intersection.

Table A6.4(b) Urban signalised crossroad crash prediction models (per approach - 2006)

Crash Types	Model	k value
Crossing (no turns, motor vehicle only)	$A_T = 1.06 \times 10^{-4} \times q_2^{0.36} \times q_{11}^{0.38}$	1.1

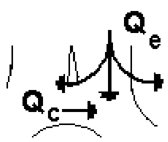
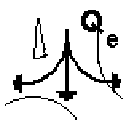
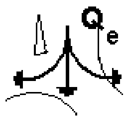
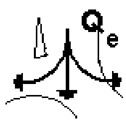
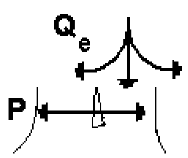
Right turn against (motor-vehicle only)	$A_T = 6.48 \times 10^{-5} \times q_2^{0.49} \times q_7^{0.42}$	1.9
Others (motor-vehicle only)	$A_T = 2.45 \times 10^{-4} \times Q_e^{0.59}$	5.9
Pedestrian versus motor vehicle	$A_T = 3.22 \times 10^{-2} \times Q_e^{-0.05} \times P^{0.03}$	1.4
Right turn against (cyclist travelling through)	$A_T = 3.48 \times 10^{-4} \times q_7^{0.34} \times c_2^{0.20}$	1.3
Others (cyclist versus motor vehicle)	$A_T = 1.42 \times 10^{-3} \times Q_e^{0.28} \times C_e^{0.03}$	1.1

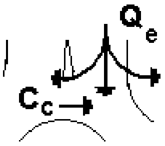
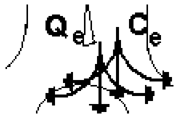
(4) Conflict - urban roundabouts, < 80 km/h

The conflicting flow models for roundabouts are suitable for situations where a breakdown of crashes by crash and road user type is required, such as roundabouts with high proportions of cyclists.

For urban (speed limit < 80 km/h) roundabouts on the primary road network the typical crash rates can be calculated for the seven crash types (15) in table A6.5(a).

Table A6.5(a) Urban roundabout crash prediction models types

Crash types	Variables		CAS movement categories
Entering-vs-circulating (motor-vehicle only)		Q_e = Entering vehicle flow in veh/day Q_c = Circulating vehicle flow in cyc/day S_c = Mean free speed of circulating vehicles	HA, JA-JO KA-KO, LA-LO
Rear-end (motor-vehicle only)		Qe = Entering vehicle flow in veh/day	FA-FO, GA, GD
Loss-of-control (motor-vehicle only)		Qe = Entering vehicle flow in veh/day V10 = Visibility 10 m back from the limit line to vehicles on the approach to the right	CA-CO, DA-DO, AD, AF
Other (motor-vehicle only)		Qe = Entering vehicle flow in veh/day	-
Pedestrian		Qe = Entering vehicle flow in veh/day P = Pedestrian crossing volume in ped/day	NA-NO, PA-PO

Entering-vs-circulating (cyclist circulating)		Qe = Entering vehicle flow in veh/day Cc = Circulating cycle flow in cyc/day Se = Mean free speed of entering vehicles	HA, JA-JO KA-KO, LA-LO
Other (cyclist)		Qe = Entering vehicle flow in veh/day Ce = Entering cycle flow in cyc/day	-

The number of reported injury crashes per year for each crash type on each approach can be calculated using the models in table A6.5 (b). These models calculate the number of crashes per approach and therefore must be applied at all approaches to the roundabout.

Table A6.5(b) Urban roundabout crash prediction models (per approach - 2006)

Crash types	Model	k value
Entering-vs-circulating (motor-vehicle only)	$A_T = 5.57 \times 10^{-8} \times Q_e^{0.47} \times Q_c^{0.26} \times S_c^{2.13}$	1.3
Rear-end (motor-vehicle only)	$A_T = 8.76 \times 10^{-2} \times Q_e^{-0.38} \times e^{0.00024 \times Qe}$	0.7
Loss-of-control (motor-vehicle only)	$A_T = 8.71 \times 10^{-6} \times Q_e^{0.59} \times V_{10}^{0.68}$	3.9
Other (motor-vehicle only)	$A_T = 1.99 \times 10^{-5} \times Q_e^{0.71} \times \Phi_{MEL}$ Φ_{MEL} = 2.66 (if multiple entry lanes) Φ_{MEL} = 1.00 (if single entry lane)	-
Pedestrian	$A_T = 2.93 \times 10^{-4} \times P^{0.60} \times e^{0.00013 \times Qe}$	1.0
Entering-vs-circulating (cyclist circulating)	$A_T = 3.30 \times 10^{-5} \times Q_e^{0.43} \times C_c^{0.38} \times S_e^{0.49}$	1.2
Other (cyclist)	$A_T = 4.24 \times 10^{-7} \times Q_e^{1.04} \times C_e^{0.23}$	-

(5) General urban mid-blocks, 50-70 km/h

The ‘general’ models are suitable for most urban mid-blocks (two to four lane road) types in posted speed limit areas of 50-70 km/h. The typical crash rate (reported injury crashes per year) is dependent on roadside development, and for arterials, the presence of a median. separate pedestrian and cyclist models are available. All reported injury crashes are calculated using the model:

$A_T = b_0 \times Q_T^{b_1} \times L$

where: Q_T is the daily two-way traffic volume (AADT)

L is the length of the mid-block site

b_0 and b_1 are given in table A6.6(a). Use the commercial classification when the majority of roadside development is either commercial or industrial, while 'other' is for residential and all other types.

Table A6.6(b) shows the range of flows and speed limits over which the crash prediction models should be applied. The arterial models can be used for 50 and 60 km/h speed limit areas. The collector and local street models are applicable for 50 km/h speed limit areas only. The k values are for the weighted crash procedure.

Arterials with ≥6 lanes

There is currently no information available for six or more lane arterials. Six-lane roads are likely to have a greater proportion of weaving related crashes, particularly where intersections are closely spaced.

Effect of medians

A reduction of 15% in the crash prediction for arterial and collector mid-blocks should be applied for flush medians. A reduction of 25% in the crash prediction for arterial mid-blocks should be applied for raised medians. Note that raised medians can migrate crashes to adjacent intersections.

Table A6.6(a) Urban mid-block injury crash prediction model parameters (2006)

Land-use	Commercial		Other	
Mid-block road type	**b_0**	**b_1**	**b_0**	**b_1**
Local street	2.53×10^{-4}	0.98	2.53×10^{-4}	0.98
Collector	2.24×10^{-5}	1.08	3.46×10^{-5}	1.08
Arterial (2 and 4 lane)	7.66×10^{-6}	1.20	1.34×10^{-4}	0.88

Table A6.6(b) Urban mid-block injury crash prediction model flow ranges and k values

Mid-block type	Speed limit	Flow range AADT	k value	
			Commercial	**Other**
Local street	50 km/h	< 3,000	0.6	0.6
Collector	50 km/h	2,000 – 8,000	10.0	10.0
Arterial (2 and 4 lane)	50 or 60 km/h	3,000 – 24,000	8.5	10.8

(6) Conflict - urban mid-block – pedestrian and cyclist facilities

The pedestrian or cyclist models are required when using crash rate analysis to assess a new or improved pedestrian or cyclist facility. These rates are for urban (speed limit < 80 km/h) areas and do not include any pedestrian or cyclist crashes that occur at side roads. However, driveway crashes are included. The typical crash rates can be calculated for the crash types in table A6.7(a).

The number of reported injury crashes per year for each crash type is calculated using the models in table A6.7(b).

Table A6.7(a) Urban mid-block pedestrian and cycle crash prediction model types

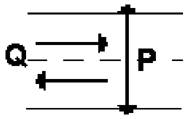
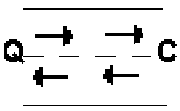
Crash types	Variables		CAS movement categories
All mid-block pedestrian crashes		Q = Two-way vehicle flow in veh/day P = Pedestrian crossing volume per 100 metres in ped/100m/day L = Segment length in km	NA-NO, PA-PO
All mid-block cyclist crashes		Q = Two-way vehicle flow in veh/day C = Two-way cycle flow in veh/day L = Segment length in km	All

Table A6.7(b) Urban mid-block pedestrian and cycle crash prediction models (2006)

Crash types	Model	k value (mid-point)
All mid-block pedestrian crashes	$A_T = 1.47 \times 10^{-4} \times Q^{0.69} \times P^{0.26} \times L$	-
All mid-block cyclist crashes	$A_T = 1.37 \times 10^{-7} \times Q^{1.38} \times C^{0.23} \times L$	-

(7) General high speed cross and T intersections, ≥80 km/h

The ‘general’ model is suitable for most high speed cross and T intersections and use two-way link volumes. Where a breakdown of crashes by crash and road user type is required, or where the proportion of turning vehicles is high compared to through vehicles then conflicting flow models should be used.

For high speed cross and T intersections, the typical crash rate (reported injury crashes per year) is calculated using the model:

$$A_T = b_0 \times Q_{major}^{b_1} \times Q_{minor/side}^{b_2}$$

where:

$Q_{\underline{major}}$	the highest two-way link volume (AADT) for cross-roads and the primary road volume for T-junctions
$Q_{minor/side}$	the lowest of the daily two-way link volumes (AADT) for cross-roads and the side road flow for T-junctions.

b_0, b_1 and b_2 are given in table A6.8(a).

Table A6.8(b) shows the range of flows over which the crash prediction models should be applied. The k values are for use in the weighted crash procedure.

Caution

Caution should be exercised when using the prediction models for intersections where opposing approach flows (on Q_{major} or Q_{minor}) differ by more than 25%. In such cases, conflicting flow models should be used.

Table A6.8(a) High speed intersection injury crash prediction model parameters (2006)

Intersection type	b_0	b_1	b_2
Priority – Cross	4.32×10^{-4}	0.39	0.50
Priority – T	4.07×10^{-4}	0.18	0.57
Traffic signals – Cross	3.64×10^{-4}	0.52	0.19
Traffic signals – T	5.10×10^{-2}	0.37	-0.10

Table A6.8(b) High speed intersection injury crash flow ranges and k values

Intersection type	Range Qmajor AADT	Range Qminor AADT	k value
Priority – Cross	50 - 24000	50 - 3500	2.6
Priority – T	50 - 26000	50 - 9000	4.7
Traffic signals – Cross	19000 - 46000	11000 - 20000	4.7
Traffic signals – T	10000 - 54000	1700 - 17000	2.0

(8) Conflict - high speed roundabout

Often roundabouts do not have the roads with the highest or lowest volumes on opposing arms, or if they have three arms these are seldom in a 'T'. Therefore, crashes are calculated for each arm of the roundabout, and the total obtained by adding these together. The typical crash rate (reported injury crashes per approach per year) is calculated using the model:

$A_T = b_0 \times Q_{approach}^{b1}$

where:

$Q_{approach}$ the two-way link volume (AADT) on the approach being examined.

b_0, and b_1 are given in table A6.9(a).

This model can be applied for roundabouts with three or four approaches. Table A6.9(b) shows the range of flows over which the crash prediction model should be applied. The k values are for use in the weighted crash procedure.

Table A6.9(a) High speed roundabout injury crash prediction model parameters (per approach - 2006)

	b_0	b_1
Roundabout	1.50×10^{-3}	0.53

Table A6.9(b) High speed roundabout injury crash prediction model flow ranges (per approach)

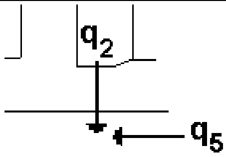
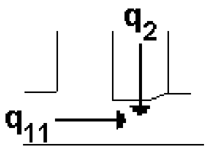
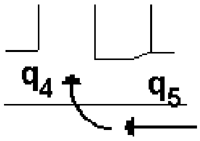
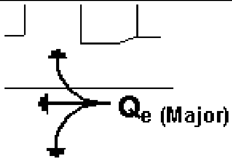
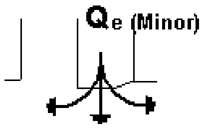
	Flow range AADT	k value
Roundabout	800 - 29000	2.1

(9) Conflict – high speed priority crossroads, > 70 km/h

The conflicting flow models for priority crossroads in high-speed areas are suitable for situations where a breakdown of crashes by crash type is required, or where the proportion of turning vehicles is high compared to through vehicles.

For high speed (speed limit > 70 km/h) priority crossroads on two-lane, two way roads the typical crash rates can be calculated for the five crash types in table A6.10(a).

Table A6.10(a) High speed priority crossroad crash prediction models types

Crash types	Variables		CAS movement categories
Crossing – hit from right (major road approaches only)		$q_{2/5}$ = Through vehicle flows in veh/day	HA
Crossing – hit from right (minor road approaches only)		q2/11 = Through vehicle flows in veh/day	HA
Right turning and following vehicle (major road approaches only)		q5 = Through vehicle flow along major road in veh/day q4 = Right-turning flow from major road in veh/day	GC, GD, GE
Other (major road approaches only)		Qe = Entering vehicle flow on major road in veh/day	-
Other (minor road approaches only)		Qe = Entering vehicle flow on minor road in veh/day	-

The number of reported injury crashes per year for each crash type is calculated table A6.10(b). These models calculate the number of crashes per approach. However, unlike urban roundabout and signalised crossroad models, each model is only applied to two approaches only (not all four). These approaches are specified as either ‘major road’ or ‘minor road’ with the minor road being the road with stop or give way control.

Table A6.10(b) High speed priority crossroad crash prediction models (per approach -2006)

Crash types	Model	k value
Crossing – hit from right (major road approaches only)	$A_T = 1.15 \times 10^{-4} \times q_2^{0.60} \times q_5^{0.40}$	0.9

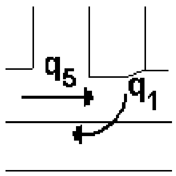
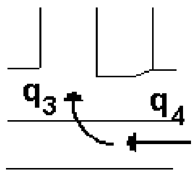
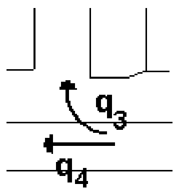
Crossing – hit from right (minor road approaches only)	$A_T = 1.97 \times 10^{-4} \times q_2^{0.40} \times q_{11}^{0.44}$	2.0
Right turning and following vehicle (major road approaches only)	$A_T = 1.04 \times 10^{-6} \times q_4^{0.36} \times q_5^{1.08} \times \Phi_{RTB}$ Φ_{RTB} = 0.22 (if right-turn bay present) Φ_{RTB} = 1.00 (if right-turn bay absent)	2.6
Other (major road approaches only)	$A_T = 1.09 \times 10^{-4} \times Q_{e(Major)}^{0.76}$	1.1
Other (minor road approaches only)	$A_T = 3.30 \times 10^{-3} \times Q_{e(Minor)}^{0.27}$	0.2

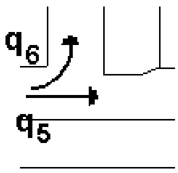
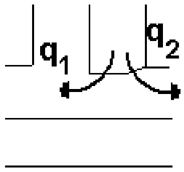
(10) Conflict – high speed priority T-junctions, > 70 km/h

The conflicting flow models for priority T-junctions in high-speed areas are suitable for situations where a breakdown of crashes by crash type is required, where one turning movement from the side road is greater than the other, or where the intersection has a visibility deficiency.

For high speed (speed limit > 70 km/h) priority T-junctions on two lane, two way roads the typical crash rates can be calculated for the five crash types in table A6.11(a).

Table A6.11(a) High speed priority T-junctions crash prediction models types

Crash types	Variables		CAS movement categories
Crossing – vehicle turning (major road approach to right of side road)		q_5 = Through vehicle flow along major road to right of minor road vehicles in veh/day q_1 = Right-turning flow from minor road in veh/day V_D = Sum of visibility deficiency in both directions when compared with Austorads SISD (3)	JA
Right-turning and following vehicle (major road approach to left of side road)		q5 = Through vehicle flow along major road to right of minor road vehicles in veh/day q3 = Right-turning flow from major road in veh/day SL = Mean free speed of vehicles approaching from the left of vehicles minor road	GC, GD, GE
Other (major road approach to right of side road)		q_5 = Through vehicle flow along major road to right of minor road vehicles in veh/day q_3 = Right-turning flow from major road in veh/day	-

Other (major road approach to right of side road)		q_5 = Through vehicle flow along major road to left of minor road vehicles in veh/day q_6 = Left-turning flow from major road in veh/day	-
Other (side road approach)		q_1 = Right-turning flow from minor major road in veh/day q_2 = Left-turning flow from minor road in veh/day	-

The typical crash rate (number of reported injury crashes) per year for each crash type is calculated using table A6.11(b). Unlike models for other intersections, these models are each for a specific approach.

Table A6.11(b) High speed priority T-junction crash prediction models (2006)

Crash types	Model	k value
Crossing – Vehicle turning (major road approach to right of side road)	$A_T = 5.08 \times 10^{-6} \times q_1^{1.33} \times q_5^{0.15} \times V_D^{0.33}$	8.1
Right-turning and following vehicle (major road approach to left of side road)	$A_T = 5.08 \times 10^{-27} \times q_3^{0.46} \times q_4^{0.67} \times S_L^{11}$	0.2
Other (major road approach to right of side road)	$A_T = 1.53 \times 10^{-5} \times (q_5 + q_6)^{0.91}$	1.0
Other (major road approach to right of side road)	$A_T = 2.87 \times 10^{-4} \times (q_3 + q_4)^{0.51}$	3.0
Other (side road approach)	$A_T = 1.41 \times 10^{-2} \times (q_1 + q_2)^{-0.02}$	0.6

(11) Rural two-lane roads, ≥ 80 km/h

For two-lane rural roads in 80 and 100 km/h speed limit areas, the typical crash rate (reported injury crashes per year) is calculated using the exposure-based equation:

$A_T = (b_0 \times S_{adj}) \times X$

where:

S_{adj} is the cross section adjustment factor for seal widths

X is the exposure in 100 million vehicle kilometres per year.

Coefficient b_0 is provided in table A6.12(a). The coefficient b_0 is applicable to a given mean seal width. S_{adj} is found in table A6.13, and varies according to traffic flow, seal shoulder width and lane width.

The terrain type for b_0 can be selected by analysing the route gradient data. The gradient ranges should generally be maintained throughout the road section. Portions of road that are less steep can occur in mountainous sections for short lengths. Provided that the lower gradient length is followed by another mountainous gradient, then the entire section can be classified as mountainous.

Table A6.12(b) shows the k values per kilometre that should be used in the weighted crash procedure.

Table A6.12(a) Rural mid-block equation coefficients (b0) (2006)

AADT	Mean seal width (m)	Coefficients b_0 by terrain type		
		Level (0 to 3 %)	Rolling (>3 to 6 %)	Mountainous (> 6 %)
< 1,000	6.7	16	21	30
1,000 – 4,000	8.2	16	18	26
> 4,000	9.5	11	16	22

Table A6.12(b) Rural mid-block k values per km

AADT	k values per km by terrain type		
	Level terrain (0 to 3%)	Rolling terrain (>3 to 6%)	Mountainous terrain (> 6%)
< 1,000	0.4	0.2	0.5
1,000 – 4,000	0.8	0.2	0.5
> 4,000	0.7	0.7	1.3

Applying the cross-section adjustment factors

Table A6.13 provides adjustment factors for two lane rural crash rates for various combinations of seal widths that differ from the mean seal widths in table A6.12(a).

First, the overall seal width, shoulder width and lane width is determined. Then, look up S_{adj} that corresponds to the traffic volume, shoulder width and lane width in table A6.13. Adjust b_0 by multiplying with the adjustment factor and use this value to calculate the typical crash rate.

In the case of shoulder widening, different adjustment factors must be used for the do-minimum and option.

Effect of crash barriers

In mountainous and rolling terrain the typical crash rates can be reduced by 25% when crash barriers are installed to protect errant vehicles from drop-off areas and other obstacles in the roadside clear zone.

Three to four lane rural roads

For three and four lane rural roads refer to Appendix A6.5 on passing lanes.

Worked example

An example of the use of the cross-section adjustment factors in table A6.13 is provided in Appendix A6.8.

Table A6.13 Cross-section adjustment factors (Sadj)

S_{adj} for traffic flows < 1,000 vpd					
Seal shoulder width	Lane width				
	2.75 m	3.00 m	3.25 m	3.50 m	3.60 m
0 m	1.17	1.10	1.03	0.96	0.93
0.25 m	1.10	1.03	0.96	0.89	0.86
0.50 m	1.03	0.96	0.89	0.82	0.79
0.75 m	0.89	0.82	0.75	0.68	0.66
1.00 m	0.75	0.68	0.61	0.55	0.52
1.50 m	0.61	0.55	0.48	0.41	0.41
2.00 m	0.48	0.41	0.41	0.41	0.41
S_{adj} for traffic flows 1,000 to 4,000 vpd					
Seal shoulder width	Lane width				
	2.75 m	3.00 m	3.25 m	3.50 m	3.60 m
0 m	1.47	1.38	1.30	1.21	1.17
0.25 m	1.38	1.30	1.21	1.12	1.09
0.50 m	1.30	1.21	1.12	1.03	1.00
0.75 m	1.12	1.03	0.95	0.86	0.83
1.00 m	0.95	0.86	0.77	0.69	0.65
1.50 m	0.77	0.69	0.60	0.51	0.51
2.00 m	0.60	0.51	0.51	0.51	0.51
S_{adj} for traffic flows > 4,000 vpd					
Seal shoulder width	Lane width				
	2.75 m	3.00 m	3.25 m	3.50 m	3.60 m
0 m	2.11	2.01	1.90	1.79	1.74
0.25 m	2.01	1.90	1.79	1.67	1.58
0.50 m	1.90	1.79	1.67	1.45	1.36
0.75 m	1.79	1.67	1.45	1.22	1.18
1.00 m	1.67	1.45	1.22	1.11	1.07
1.50 m	1.22	1.11	1.00	0.89	0.85
2.00 m	1.00	0.89	0.78	0.66	0.66

(12) Rural two-lane roads: heavy vehicles, ≥ 80 km/h

For freight transport service proposals, where the road network affected by the proposal are primarily two-lane rural roads in 80 and 100 km/h rural areas, crash rate equations for crashes involving heavy vehicles can be used to estimate the change in freight related crashes.

The typical heavy vehicle crash rate (reported injury crashes involving heavy vehicles per year) is calculated using the exposure-based equation:

$A_H = b_0 X$

where: X is the exposure in 100 million heavy vehicle kilometres per year.

Coefficient b_0 is provided in table A6.14.

Table A6.14 Rural mid-block equation coefficients (b0) for heavy vehicles (2006)

AADT	Coefficients b_0 by terrain type		
	Level terrain (0 to 3 %)	Rolling terrain (> 3 to 6 %)	Mountainous terrain (> 6 %)
≤ 4000	19	40	50
> 4000	19	19	41

(13) Motorways and four-lane divided rural roads

The typical crash rate (reported injury crashes per year) for motorways and four-lane divided rural roads is for a one directional link only and is dependent on the one-way traffic volume.

Motorways

The typical crash rate is calculated using the model:

$A_T = b_0 \times Q_O^{b_1} \times L$

where: Q_O is the daily one-way traffic volume (AADT) on the link, and
L is the length of the motorway link.

b_0 and b_1 are given in table A6.15(a).

Table A6.15(b) shows the range of one-way flows over which the crash prediction models should be applied. The k values are for use in the weighted crash procedure.

4-lane divided rural roads

For four-lane divided rural roads, the same motorway crash prediction model is used. The b_0 coefficient from this model has been increased by 20% to take into account the presence of pedestrians, cyclists and limited access provisions of rural roads compared to motorways.

Table A6.15(a) Urban mid-block injury crash prediction model parameters

	b_0	b_1
Motorway	2.96×10^{-7}	1.45
4-lane divided rural road	3.55×10^{-7}	1.45

Table A6.15(b) Urban mid-block injury crash prediction model flow ranges and k values

	Flow range AADT	k value
Motorway	15,000 – 68,000	10.2
4-lane divided rural road	15,000 – 68,000	10.2

(14) Conflict - rural isolated curves, ≥ 80 km/h

Figure A6.2 and the equation below provide typical crash rates for reported injury loss of control and head-on crashes on rural curves, adjusted for the general trends in crashes. They should be used only for an isolated curve that is replaced with a single curve of a higher design speed.

The data for typical injury crash rates has been based on sealed rural state highways. An underlying assumption is that the road section under consideration is not affected by ice or other adverse factors such as poor visual conditions.

The typical crash rate (reported injury crashes per year, by CAS movement categories B, C and D) for an isolated rural curve is calculated using the equation:

$A_T = b_0 X e^{(b_1 S)}$

where: $b_0 = 4.1$

$b_1 = 2.0$

X is the exposure in 100 million vehicles (in one direction) passing

through the curve, and

$S = 1 - \frac{\text{design speed of curve}}{\text{approach speed to curve}}$

A_T must be calculated for both directions, and S is likely to vary between the two directions. If the design speed is approximately equal to the approach speed then the equation reduces to:

$A_T = b_0 X$

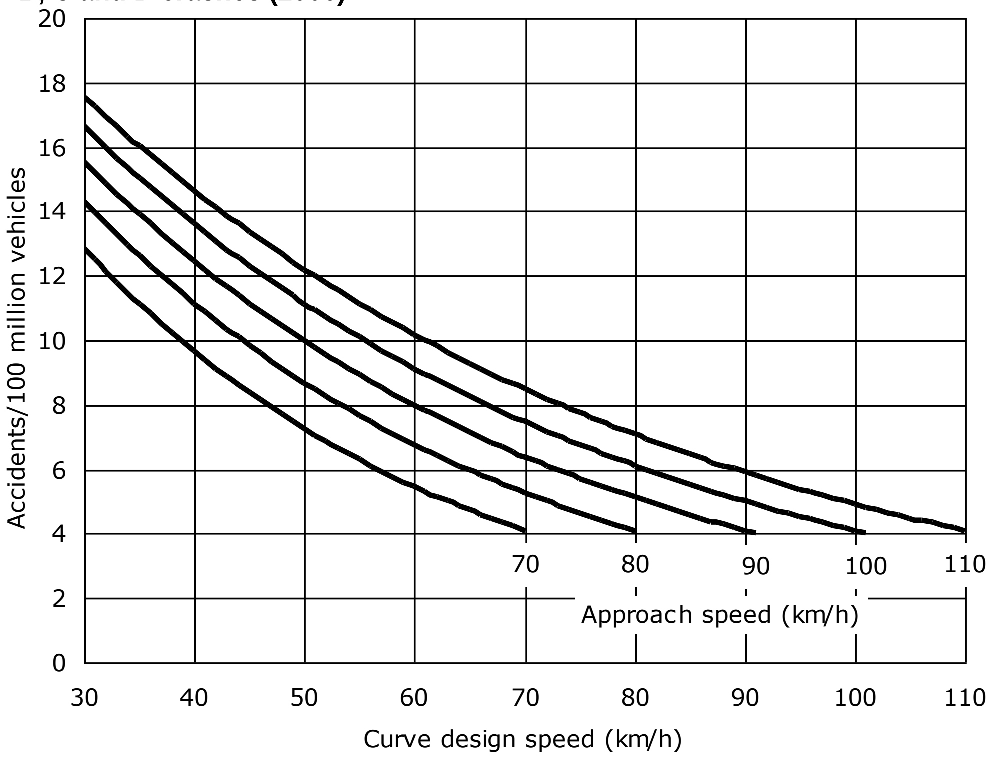
A k value of 1.1 is used in the weighted crash procedure.

Assumptions

The following assumptions apply when using the equation or figure A6.2:

- for figure A6.2 the rate is in terms of injury crashes per 100 million vehicles, and for the equation the rate is in injury crashes per year through the curve
  - the design speed of the curve should be determined from a standard design reference
  - the approach speed to the curve is the estimated 85th percentile speed at a point prior to slowing for the curve (for longer tangents this would approximate to the speed environment).

Figure A6.2 Injury crashes per 100 million vehicles for rural curves in 100 km/h speed limit areas for type B, C and D crashes (2006)



(15) Rural passing lanes crash adjustment factor	The construction of passing lanes on rural roads (posted speed limit ≥80 km/h) has the effect of reducing the typical crash rate calculated using the rural two lane roads model for both the road section and for the road downstream of the passing lane. Where a passing lane is constructed in one direction only, for the road section alongside the passing lane, the reduction in the typical crash rate is 25% for both directions of travel. The reduction in the typical crash rate decreases linearly to zero from the end of the passing lane to either the location where vehicle platooning returns to normal (generally 5 to 10 km downstream), or where another passing lane begins. Where passing lanes are constructed in both directions at the same location, no further crash reduction along the length of the passing lane is permitted. Downstream benefits can be calculated for either side of the section of passing lanes. There are currently no conclusive research findings available on the upstream benefits of installing passing lanes. At this stage, no reduction in the b_0 coefficient is permitted for benefits upstream. If a passing lane is being constructed to address a specific crash type, an appropriate crash reduction factor may be found in Appendix A6.6.
(16) Single lane rural bridges, ≥ 80 km/h	The typical crash rate (reported injury crashes per year) of a single lane bridge on a rural road (≥80 km/h) is determined by the equation: $A_T = b_0 X$

where: X is the exposure in 100 million vehicles crossing the bridge per year

$b_0 = 10.1\,(Q_T)^{0.3}$ (2006 analysis year)

Q_T being the two-way daily traffic volume (AADT).

This equation does not take into account low design speed approach curves (65 km/h advisory speed or less), traffic signal control or adjoining intersections within 200 m of the bridge.

(17) Two lane rural bridges, ≥ 80 km/h

The typical crash rate (reported injury crashes per year) of a two-lane bridge on a rural road (≥80 km/h) is determined by the equation:

$A_T = b_0\,X$

where: X is the exposure in 100 million vehicles crossing the bridge per year

$b_0 = 0.96 \times c \times (0.5 - 0.25\,RW + 0.025\,RW^2)$ (2006 analysis year)

with RW being the difference between the seal width across the bridge and the total sealed lane width in metres (both directions) on the bridge approaches (normally 7 m on State highways). A narrow bridge seal width leads to a negative value for RW. The limits of RW are governed by the limiting width for single lane operation (for the maximum negative value of RW) and 2.5 m (maximum positive value of RW).

The value of c is given by the formula:

$c = e^{(3.5 - Q_T / 7{,}500)}$

where: Q_T is the two-way daily traffic volume (AADT).

This model does not take into account low design speed approach curves (65 km/h advisory speed or less) or adjacent intersections within 200 m of the bridge.

In the weighted crash procedure, use the k-values provided in table A6.16.

Table A6.16 Rural bridge k values

Rural bridge type	k value
Single lane bridge	0.3
Two lane bridge	0.2

(18) Urban and rural railway crossings

For urban and rural railway crossings, the typical crash rate (reported injury hit train and rear-end crashes per year) is calculated using the model:

$A_T = b_0 \times T^{b1} \times Q_T^{b2}$

where:

T is the number of trains per day

Q_T is the daily two-way traffic volume (AADT)

b_0, b_1 and b_2 are given in table A6.17(a)

Table A6.17(b) shows the range of traffic volumes and trains over which the crash prediction models should be applied.

The k values are for use in the weighted crash procedure.

A large number of railway crossings are located in close proximity to low design speed curves. Low design speed approach curves are often caused by the route having to deviate sharply when crossing the railway line. In such circumstances separate predictions of the typical crash rates on these approach curves need to be made using the model for rural isolated curves (≥80 km/h).

Table A6.17(a) Railway crossing crash prediction model parameters (2006)

Control type	b_0	b_1	b_2
Half arm barriers	4.83×10^{-4}	0.27	0.33
Flashing lamps and bells	7.19×10^{-4}	0.61	0.32
No control	1.67×10^{-3}	0.31	0.36

Table A6.17(b) Railway crossing crash prediction model traffic volumes ranges and k values

Control type	Traffic volumes		k value
	Q_T AADT	Trains AADT	
Half arm barriers	< 13,000	< 40	1.8
Flashing lamps and bells	< 6,000	< 30	0.7
No control	< 1,000	< 20	2.7

A6.7 Typical crash reduction factors

Introduction

The following section provides average crash reduction factors for treatments or improvements in urban and rural areas. These reductions can be applied to the crash rate calculated using any of the three crash analysis methods.

In rural areas, crash migration should also be considered.

The reduction factors are only a guide to possible reduction rates and the evaluation documentation will need to substantiate all claimed crash reductions, particularly if they are expected to be greater than indicated here.

Typical crash reductions

The following five tables provide a typical range of injury crash reductions for mid-block and intersection treatments:

- in urban (speed limits of 70 km/h or less);
- in high speed areas (speed limits of 80 km/h or more);
- for cyclist and pedestrian treatments in urban areas.

When determining the crash reduction for implementing more than one measure, it is not appropriate to add all of the reduction factors together, particularly if the measures are treating similar crash types. In these cases judgement should be exercised in determining the likely overall effectiveness.

Sealing unsealed roads

Only a crash by crash analysiscan be conducted when estimating benefits for sealing unsealed roads. Analysis of crash rates before and after sealing shows that there is no statistically significant crash benefit or disbenefit associated with sealing unsealed roads.

Table A6.18(a) Typical crash reductions for mid-block treatments in urban areas

Measure	Typical effectiveness of measure (% reduction)
Flush medians 50 km/h	10% to 25% of all crashes
Raised medians 50/60 km/h	20% to 30% of all crashes. The benefitsare greater on roads with less through roads
Lighting – installation or upgrade	35% of night time crashes that are due to poor lighting
Ban on street parking on both sides of the street	20% of mid-block crashes. There is little research on banning parking on only one side of a street only, but some research indicates that crashes may increase.
Implementation of area wide traffic calming on local streets	25% of all crashes within the traffic calmed area.
Bus lanes (taxis permitted)	No reduction. Research indicates that there may be an increase in crashes for permanentbus lanes and peak period bus lanes
High occupancy vehicle lanes	No reduction, but research indicates that there could be a 60% increase of all crashes for peak period lanes.

Road diet: Four lanes to two lanes plus flush median	30% to 40% reduction odf all crashes
Increase from four to siz traffic lanes	No reduction but research indicates that there could be an increase in all crashes.

Table A6.18(b) Typical crash reductions for intersection treatments in urban areas

Measure	Typical effectiveness of measure (% reduction)
Lighting – installation or upgrade	35% of night time crashes that are due to poor lighting.
Installation of throat or fishtail islands at priority intersections	20% to 40 % of all crashes.
Establishing a right turn phase at traffic signals	10% of crashes involving right-turn-against crashes.

Table A6.18(c) Typical crash reductions for pedestrian and cyclist treatments in urban areas

Pedestrian measure	Typical effectiveness of measure (% reduction)
Kerb extensions to assist pedestrians to cross	35 % of pedestrian (type N) crashes.
Pedestrian refuges to assist pedestrians to cross	15 % of pedestrian (type N) crashes.
Pedestrian refuges and kerb extensions	30 % of pedestrian (type N) crashes.
Zebra crossings	No reduction in general and if located on a multi lane road or at a site with a speed limit of greater than 50 km/h an increase in crashes is possible.
Elevated pedestrian platforms constructed in conjunction with local traffic management or calming schemes	80 % of pedestrian (type N) crashes.
Mid-block traffic signals	45 % of pedestrian (type N) crashes, however an increase in motor-vehicle only crashes is possible if no crossing facility was previously installed.
Grade separated crossing facilities	30% of all crashes or up to 80% of pedestria crashes depending on the extent to which pedestrians are prevented from crossing at grade.
Cyclist measure	**Typical effectiveness of measure (% reduction)**
Cycle lanes	10% of cycle crashes.
Advanced stop lines for cyclists at signalised intersections	10% of cycle crashes at signalised intersections.

Table A6.18(d) Typical crash reductions for mid-block treatments in high speed areas

Measure	Typical effectiveness of measure (% reduction)
Route lighting – installation	30% of night-time crashes that are due to poor lighting.
Passing lanes or crawler lanes (ie, passing lanes on an uphill gradient)	30% of overtaking crashes within passing lane. 40% to 60% of head on crashes within passing lane. 15% of rear-end/obstruction crashes within passing lane. Reduce these percentages linearly to zero for crashes following the passing lane up to five kilometres away. Ensure loss of control crashes do not increase due to design
Shoulder widening	0% to 20% of loss of control and overtaking crashes on straights from shoulder widening alone. 0% to 20% of loss of control, overtaking and head-on crashes on bends from shoulder widening alone. 0% to 40% of loss of control, overtaking and head-on crashes on bends if sight-rails and traffic signs are installed at the same time as shoulder widening.
Guardrailing	Crash reduction in terms of changed severity: 40% reduction in fatal crashes. 30% reduction in serious crashes. 10% reduction in minor crashes.
Resurfacing of curves	Compare injury crash rate at site with typical injury crash rate and injury crash rates at other local sites that are considered satisfactory.
Installation of reflective raised pavement markers	6% of all crashes.
Installation of edge marker posts	30% to 40% of off-road on curve and loss-of control on curve crashes.
Edge lines where none previously existed	8% of all crashes.
Marking no-overtaking lines missing from a section of road where they are deemed necessary	50% to 60% reduction in head-on crashes. 40% to 60% reduction in overtaking crashes.
Marking centrelines where none previously existed	13% of all crashes providing that seal width is sufficient.
Installation of audible edge lines (rumble strip/vibraline)	11% of all crashes.
Implementation of clear zones where there were previously hazards within six metres of the roadway	35% of loss of control and off the road crashes.

Table A6.18(e) Typical crash reductions for intersection treatments in high speed areas

Measure	Typical effectiveness of measure (% reduction)
Intersection lighting – installation or upgrade	30% to 50% of night-time crashes at intersections that are due to poor lighting.
Right turn bays and associated seal widening at priority intersections	75 % of crashes involving vehicles turning right from the main road and those travelling in the same direction.
Installation of throat or fishtail islands at intersections	35 % of intersection crashes.
Installing advance warning of intersections where it is deemed necessary	7% of all intersection crashes.
Conversion of rural cross-road to two rural T-junctions (100 m plus stagger)	Reduction (or increase) depends on traffic flows. Use crash prediction models for two T-junctions to determine the benefits.

Crash migration

Crash migration downstream of the treated site is normally not an issue in the urban road environment (50 km/h to 70 km/h). Crash migration is more prevalent on rural roads and in close proximity to the site being treated. The migration of crashes from the improved site down to the next curve or substandard road element (eg, narrow bridge) is more likely than migration to a similar element 20 km downstream.

To assess the possibility of crash migration, one to two kilometres either side of the study area should be considered. If road elements, such as low design speed curves (75 km/h or less), narrow bridges and railway crossings occur within this one to two kilometres, the analysis should assess whether an increase in travel speeds through the project area will increase crashes at the adjoining road elements. If there is an expected increase in the crash occurrence then either:

1. the negative benefits need to be included in the economic evaluation
2. improvements need to be made to downstream road elements to eliminate or reduce the crash migration
3. a reduced estimate of crash savings should be used in the analysis.

A similar exercise should be undertaken for a longer length, up to five kilometres either side of the study area, if the speed change from the site improvements is expected to influence speeds and driver perception over a wider area. This may be the case for major realignments.

A6.8 Adjusting crash costs to reflect mean speeds

Effect of speed on crash costs

Evidence indicates that injuries per crash and injury severity increase linearly with speed. To account for this in a crash analysis, the crash costs for the do minimum and the option(s) are calculated using mean traffic speeds.

Adjusting crash costs by movement and vehicle involvement

Crash costs by movement and vehicle involvement for use in method A are provided for 50 km/h speed limits and 100 km/h speed limits in table A6.21(a) to (h).

Where the mean speed of the do minimum and/or project options differ from these speeds, the crash costs are adjusted using the following formula:

$C_V = C_{50} + (C_{100} - C_{50})(V - 50)/50$

where: C_V is the cost of crashes for the mean speed V

C_{50} is the cost of crashes in 50 km/h speed limit areas

C_{100} is the cost of crashes in 100 km/h speed limit area

V is the mean speed of traffic in km/h

Adjusting reported injury crash costs

Costs per reported injury crash for use in method B or C are provided for 50, 70 and 100 km/h speed limits in table A6.22.

Where the mean speed of the do-minimum and/or project options differ from these speeds, the crash costs are adjusted using the one of the following formulae:

for $50 < V < 70$ km/h: $C_V = C_{50} + (C_{70} – C_{50})(V - 50)/20$

for $70 < V < 100$ km/h: $C_V = C_{70} + (C_{100} - C_{70})(V - 70)/30$

where: C_V is the cost of crashes for the mean speed V

C_{50} is the cost of crashes in 50 km/h speed limit areas

C_{70} is the cost of crashes in 70 km/h speed limit areas

C_{100} is the cost of crashes in 100 km/h speed limit area

V is the mean speed of traffic in km/h

Calculation of mean speed

If the road section has a design speed based on the 85th percentile speed then to convert the design speed to the mean speed use the approximation of dividing the 85th percentile speed by 1.13 (or multiplying by 0.885) and round the result to the nearest whole kilometre per hour.

Mean speed should be established over a section length of at least one kilometre.

A6.9 Worked example of crash procedures

Introduction

This section provides a worked example using methods B and C.

Do minimum crash costs

A straight and flat 3.3 km section of near rural road in a 100 km/h area is identified as having a high incident of loss of control crashes. This section of road has two 3.5 metre lanes and no sealed shoulder. The AADT is 2,800 with a traffic growth rate of 4%. Nine injury crashes were recorded in CAS for the previous five years. Two of these were serious injury crashes.

The option is to widen the seal to 9 metre in total: two 3.5 metre lanes and one metre wide sealed shoulders. Time zero is 2006.

The weighted crash procedure is used as there are less than three injury crashes, or one serious or fatal crash, per kilometre in the previous five years. Exposure-based crash prediction equations are available for the do minimum and option (Appendix A6.5).

The proposed improvement (seal widening) is not considered a fundamental change, and hence the crash history is still relevant in calculating the site specific crash rate and costs.

Do-minimum

Site specific crash rate A_S

A_S = 9 injury crashes / 5 years for the site history × 1.10

where: 1.10 is the crash trend adjustment factor from table A6.1(a)

A_S = 9 / 5 × 1.10 = 1.98 crashes per year

Typical crash rate A_T

A_T = $(b_0 \times S_{adj}) \times X$ (from Appendix A6.5, rural two lane roads)

where: coefficient b_0 = 16 from table A6.12(a), for a mean seal width of 8.2 m, for 1,000 to 4,000 AADT on level terrain

Exposure (X) = 3.3 km × 2,800 AADT × 365 / 10^8 = 0.034

S_{adj} = 1.21 from table A6.13. This adjusts b_0 upward, because the current seal width of 7 m is narrower than the mean seal width of 8.2 m for a road that carries 1,000 to 4,000 vehicles per day.

$A_{T,dm}$ = 16 × 0.034 × 1.21 = 0.66 crashes per year.

No adjustment is required for time zero as year zero is 2006.

Weighted crash rate A_W for the do-minimum

The weighted crash rate equation from Appendix A6.3 is:

$A_{W,dm}$ = $w \times A_T + (1 - w) \times A_S$

$$w = \frac{k}{k \times A_T \times Y}$$

where k = 0.8 (from table A6.12(b)) and Y=5 (years)

Because k is per kilometre, A_T needs to be divided by the site length(3.3 km), therefore A_T =

0.66 / 3.3 = 0.200

$$w = \frac{0.8}{0.8 + 0.20 \times 5} = 0.44$$

Therefore the weighted crash rate is:

$A_{W,dm}$ = $0.44 \times 0.66 + (1 - 0.44) \times 1.98$

= 1.40 crashes per year

Do-minimum crash costs

= 1.40 × $555,000 (from table A6.22)

= $777,000 per year

Option (a) crash costs: no significant changes at site

Typical crash rate A_T

$A_{T,opt}$ = b_0 × exposure × cross-section adjustment factor

= 16 × 0.034 × 0.69 = 0.38 crashes per year

where:

the cross-section adjustment factor from table A6.13 adjusts b_0 downwards as the proposed seal width of 9 m is wider than the mean seal width of 8.2 m (for a road with 1,000 to 4,000 vehicles per day).

Weighted crash rate A_W for the option

$A_{W,opt}$ = $A_{T,opt} \times A_{W,dm} / A_{T,dm}$ (from Appendix A6.3)

= 0.38 × 1.40 / 0.66 = 0.81 crashes per year

Option (a) crash costs

= 0.81 × $555,000 = $449,550 per year

Option (a) crash benefits= $777,000 - $449,550 = $327,450 per year

Option (b) crash costs: site significantly changed

If the proposed improvement is considered a fundamental change, in this case due to other works such as the protection of steep drop-offs or removal of obstacles in the roadside clear zone, then the site specific crash history used in the weighted crash procedure (method C) is not relevant in the calculation of the option crash rate and costs. When there is a fundamental change the crash costs for the option are calculated using method B.

Typical crash rate A_T for option

$A_{T,opt}$ = b_0 × exposure × cross-section adjustment factor

= 16 × 0.034 × 0.69 = 0.38 crashes per year

Option (b) crash costs = 0.38 × $555,000 = $210,900 per year

Option (b) crash benefits = $777,000 – $210,900 = $566,100 per year.

A6.10 Tables

Introduction

Tables A6.19 to A6.22 are for use in the worksheets provided chapter 5 of this manual. These tables are used for calculating annual crash costs, depending on which of the crash analysis procedures is used.

Tables A6.19 through to A6.21 are for use with method A, crash-by-crash analysis, while table A6.22 is for use with methods B and C, crash rate analysis and the weighted crash procedure.

Table A6.19(a), (b) and (c) – Ratio of fatal to serious crash severities by movement for different speed limits.

Table A6.20(a) – Factors for converting from reported injury crashes to total injury crashes.

Table A6.20(b) – Factors for converting from reported minor injury crashes to total non-injury crashes.

Table A6.21(a), (b), (c) and (d) – Cost per crash by movement and vehicle involvement for fatal, serious, minor and non-injury crashes in 50 km/h speed limit areas.

Table A6.21(e), (f), (g) and (h) – Cost per crash by movement and vehicle involvement for fatal, serious, minor and non-injury crashes in 100 km/h speed limit areas for use with Method A, crash-by-crash analysis.

Table A6.22 – Cost per reported injury crash.

Table A6.19(a) Ratio of fatal to serious crash severities by movement for 50 km/h speed limit areas

Movement category	CAS movement codes	Fatal/ (fatal + serious)	Serious/ (fatal + serious)
Head on	AB,B	0.13	0.87
Hit object	E	0.04	0.96
Lost control off Road	AD,CB,CC,CO,D	0.11	0.89
Lost control on road	CA	0.08	0.92
Miscellaneous	Q	0.17	0.83
Overtaking	AA,AC,AE-AO,GE	0.05	0.95
Pedestrian	N,P	0.10	0.90
Rear end, crossing	FB,FC,GD	0.07	0.93
Rear end, queuing	FD,FE,FF,FO	0.08	0.92
Rear end, slow vehicle	FA,GA-GC,GO	0.06	0.94
Crossing, direct	H	0.07	0.93
Crossing, turning	J,K,L,M	0.03	0.97
All movements		0.08	0.92

Table A6.19(b) Ratio of fatal to serious crash severities by movement for 70 km/h speed limit areas

Movement category	CAS movement codes	Fatal/ (fatal + serious)	Serious/ (fatal + serious)
Head on	AB,B	0.24	0.76
Hit object	E	0.10	0.90
Lost control off road	AD,CB,CC,CO,D	0.20	0.80
Lost control on road	CA	0.14	0.86
Miscellaneous	Q	0.30	0.70
Overtaking	AA,AC,AE-AO,GE	0.12	0.88
Pedestrian	N,P	0.30	0.70
Rear end, crossing	FB,FC,GD	0.16	0.84
Rear end, queuing	FD,FE,FF,FO	0.14	0.86
Rear end, slow vehicle	FA,GA-GC,GO	0.15	0.85
Crossing, direct	H	0.21	0.79
Crossing, turning	J,K,L,M	0.09	0.91
All movements		0.18	0.82

Table A6.19(c) Ratio of fatal to serious crash severities by movement for 100 km/h speed limit areas

Movement category	CAS movement codes	Fatal / (fatal + serious)	Serious / (fatal + serious)
Head on	AB,B	0.33	0.67
Hit object	E	0.11	0.89
Lost control off road	AD,CB,CC,CO,D	0.17	0.83
Lost control on road	CA	0.16	0.84
Miscellaneous	Q	0.34	0.66
Overtaking	AA,AC,AE-AO,GE	0.14	0.86
Pedestrian	N,P	0.45	0.55
Rear end, crossing	FB,FC,GD	0.19	0.81
Rear end, queuing	FD,FE,FF,FO	0.16	0.84
Rear end, slow vehicle	FA,GA-GC,GO	0.17	0.83
Crossing, direct	H	0.25	0.75
Crossing, turning	J,K,L,M	0.15	0.85
All movements		0.21	0.79

Table A6.20(a) Factors for converting from reported injury crashes to total injury crash

		Fatal	Serious	Minor
50, 60 and 70 km/h speed limit	Pedestrian	1.0	1.5	4.5
	Other			2.75
80 and 100 km/h speed limit (excluding motorways)	Pedestrian	1.0	1.9	7.5
	Other			4.5
100 km/h speed limit remote rural area	Pedestrian	1.0	2.3	13.0
	Other			7.5
Motorway	All	1.0	1.9	1.9
All	All	1.0	1.7	3.6

Table A6.20(b) Factor for converting from reported non-injury crashes to total non-injury crashes

Speed limit area	50,60 or 70 km/h	80 or 100 km/h	Motorway
All movements	7	18.5	7

Table A6.21(a) Cost per crash by movement and vehicle involvement for fatal injury crashes in 50 km/h speed limit areas

50 km/h speed limit fatal injury crashes		Total cost per crash ($m July 2006)					
Movement category	CAS movement codes	Cycle	Motor cycle	Bus	Truck	Car, van & other	All vehicles
Head on	AB,B	3.1	3.35	3.1	3.2	4.1	3.75
Hit object	E	3.1	3.35	3.1	3.1	3.4	3.05
Lost control off road	AD,CB,CC,CO,D	3.1	3.35	3.1	3.15	3.6	3.55
Lost control on road	CA	3.1	3.35	3.1	3.15	3.45	3.15
Miscellaneous	Q	3.1	3.35	3.1	3.1	3.05	3.05
Overtaking	AA,AC,AE-AO,GE	3.1	3.35	3.1	3.15	3.45	4.45
Pedestrian	N,P	3.1	3.35	3.1	3.1	3.05	3.05
Rear end, crossing	FB,FC,GD	3.1	3.35	3.1	3.1	3.4	3.35
Rear end, queuing	FD,FE,FF,FO	3.1	3.35	3.1	3.15	3.45	3.35
Rear end, slow vehicle	FA,GA-GC,GO	3.1	3.35	3.1	3.1	3.4	3.05
Crossing, direct	H	3.1	3.35	3.1	3.1	3.4	3.3
Crossing, turning	J,K,L,M	3.1	3.35	3.1	3.2	3.1	3.15
All movements		3.1	3.35	3.1	3.15	3.4	3.35

Table A6.21(b) Cost per crash by movement and vehicle involvement for serious injury crashes in 50 km/h speed limit areas

50 km/h speed limit serious injury crashes		Total cost per crash ($000 July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	325	340	370	410	480	450
Hit object	E	320	335	325	360	360	345
Lost control off road	AD,CB,CC,CO,D	340	335	330	415	385	380
Lost control on road	CA	320	345	325	375	380	355
Miscellaneous	Q	325	335	335	370	360	360
Overtaking	AA,AC,AE-AO,GE	325	320	325	330	410	345
Pedestrian	N,P	330	335	365	335	330	330
Rear end, crossing	FB,FC,GD	325	335	350	340	355	350
Rear end, queuing	FD,FE,FF,FO	325	325	325	385	350	350
Rear end, slow vehicle	FA,GA-GC,GO	325	330	340	370	450	360
Crossing, direct	H	325	335	370	375	395	375
Crossing, turning	J,K,L,M	325	335	330	360	370	345
All movements		325	335	335	370	370	360

Table A6.21(c) Cost per crash by movement and vehicle involvement for minor injury crashes in 50 km/h speed limit areas

50 km/h speed limit minor injury crashes		Total cost per crash ($000 July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	17	16	24	31	25	25
Hit object	E	16	17	20	25	19	19
Lost control off road	AD,CB,CC,CO,D	18	15	16	34	21	21
Lost control on road	CA	15	15	16	41	21	20
Miscellaneous	Q	15	17	15	25	18	19
Overtaking	AA,AC,AE-AO,GE	17	17	18	26	22	20
Pedestrian	N,P	22	18	19	30	18	18
Rear end, crossing	FB,FC,GD	15	18	16	30	21	21
Rear end, queuing	FD,FE,FF,FO	16	17	18	30	22	23
Rear end, slow vehicle	FA,GA-GC,GO	16	16	18	27	21	20
Crossing, direct	H	17	18	21	31	24	23
Crossing, turning	J,K,L,M	16	17	17	30	23	21
All movements		17	18	18	30	21	21

Table A6.21(d) in 50 Cost per crash by movement and vehicle involvement for non-injury crashes km/h speed limit areas

50 km/h speed limit non-injury crashes		Total cost per crash ($000 July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	1	1.1	4.2	5.9	2	2.4
Hit object	E	1	1.1	4.9	5.8	2	2.5
Lost control off road	AD,CB,CC,CO,D	0.9	1.4	2	5.2	1.2	1.3
Lost control on road	CA	0.7	1.1	1.1	5.4	1.5	1.7
Miscellaneous	Q	1	1.1	5.5	5.3	1.6	2.5
Overtaking	AA,AC,AE-AO,GE	1.5	1.3	3.1	5.9	2.1	2.8
Pedestrian	N,P	0.5	1.1	0.2	4.9	1.1	1.2
Rear end, crossing	FB,FC,GD	1.4	1.1	2.5	5.8	2	2.2
Rear end, queuing	FD,FE,FF,FO	1.2	1.1	3.4	5.9	2	2.2
Rear end, slow vehicle	FA,GA-GC,GO	1.1	1.1	3	5.9	2	2.5
Crossing, direct	H	1	1	3.4	5.9	1.9	2.1
Crossing, turning	J,K,L,M	1	1.1	2.4	5.8	2	2.2
All movements		1	1.1	2.8	5.8	1.8	2.1

Table A6.21(e) Cost per crash by movement and vehicle involvement for fatal injury crashes in 100 km/h speed limit areas

100 km/h speed limit fatal injury crashes		Total cost per crash ($m July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	3.1	3.65	3.95	4	4.5	4.3
Hit object	E	3.1	3.55	3.4	3.85	3.7	3.55
Lost control off road	AD,CB,CC,CO,D	3.1	3.55	3.1	3.35	3.6	3.55
Lost control on road	CA	3.1	3.55	3.4	3.85	3.85	4
Miscellaneous	Q	3.1	3.55	3.4	3.75	3.25	3.3
Overtaking	AA,AC,AE-AO,GE	3.1	3.55	3.2	3.1	3.8	3.3
Pedestrian	N,P	3.1	3.55	3.4	3.1	3.1	3.1
Rear end, crossing	FB,FC,GD	3.1	3.55	3.4	3.85	3.85	3.7
Rear end, queuing	FD,FE,FF,FO	3.1	3.55	3.4	3.8	3.85	3.8
Rear end, slow vehicle	FA,GA-GC,GO	3.05	3.55	3.4	3.15	3.85	3.25
Crossing, direct	H	3.1	3.55	3.4	44	3.65	3.9
Crossing, turning	J,K,L,M	3.1	3.55	3.2	4	3.75	375
All movements		3.1	3.55	3.4	3.8	3.85	3.8

Table A6.21(f) Cost per crash by movement and vehicle involvement for serious injury crashes in 100 km/h speed limit areas

100 km/h speed limit serious injury crashes		Total cost per crash ($000 July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	325	405	360	435	535	495
Hit object	E	330	370	320	380	370	360
Lost control off road	AD,CB,CC,CO,D	320	375	335	375	385	375
Lost control on road	CA	330	375	345	390	445	415
Miscellaneous	Q	325	370	345	375	345	355
Overtaking	AA,AC,AE-AO,GE	325	325	370	425	395	390
Pedestrian	N,P	330	370	345	335	350	350
Rear end, crossing	FB,FC,GD	330	370	365	400	435	415
Rear end, queuing	FD,FE,FF,FO	330	370	395	355	385	375
Rear end, slow vehicle	FA,GA-GC,GO	335	370	350	385	420	380
Crossing, direct	H	330	370	330	390	460	435
Crossing, turning	J,K,L,M	325	330	370	400	420	405
All movements		330	370	345	400	415	405

Table A6.21(g) Cost per crash by movement and vehicle involvement for minor injury crashes in 100 km/h speed limit areas

100 km/h speed limit minor injury crashes		Total cost per crash ($000 July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	19	20	21	31	28	28
Hit object	E	18	19	15	30	20	21
Lost control off road	AD,CB,CC,CO,D	18	19	16	34	22	22
Lost control on road	CA	18	19	18	32	25	24
Miscellaneous	Q	18	18	16	22	20	21
Overtaking	AA,AC,AE-AO,GE	17	16	19	27	21	22
Pedestrian	N,P	18	19	18	30	18	19
Rear end, crossing	FB,FC,GD	17	18	20	31	27	27
Rear end, queuing	FD,FE,FF,FO	20	16	18	31	23	23
Rear end, slow vehicle	FA,GA-GC,GO	16	15	22	28	23	24
Crossing, direct	H	18	18	20	31	29	29
Crossing, turning	J,K,L,M	17	17	19	31	27	27
All movements		18	19	18	32	23	24

Table A6.21(h) in 100 Cost per crash by movement and vehicle involvement for non-injury crashes km/h speed limit areas

100 km/h speed limit non-injury crashes		Total cost per crash ($000 July 2006)					
Movement category	**CAS movement codes**	**Cycle**	**Motor cycle**	**Bus**	**Truck**	**Car, van & other**	**All vehicles**
Head on	AB,B	1.2	1.6	4.3	7.7	2.5	3.5
Hit object	E	1.2	1.6	3.2	6.8	1.5	2.4
Lost control off road	AD,CB,CC,CO,D	1.2	1.3	1.1	6.3	1.3	1.6
Lost control on road	CA	1.2	1.3	0.8	6.7	1.7	2.6
Miscellaneous	Q	1.2	1.3	6.7	6.5	1.7	3.7
Overtaking	AA,AC,AE-AO,GE	1.2	1.5	4.1	7.4	2.5	3.9
Pedestrian	N,P	1.2	1.5	2.9	6.7	1.4	2.7
Rear end, crossing	FB,FC,GD	1.2	1.3	5.1	7.7	2.4	3
Rear end, queuing	FD,FE,FF,FO	1.2	1.9	4.4	7.5	2.5	2.9
Rear end, slow vehicle	FA,GA-GC,GO	1.2	1.3	5.2	7.5	2.5	3.3
Crossing, direct	H	1.2	1.5	4.9	7.6	2.5	3.2
Crossing, turning	J,K,L,M	1.2	1.3	3.2	7.5	2.4	3.2
All movements		1.2	1.5	2.9	7.1	1.8	2.4

Table A6.22 Cost per reported injury crash ($000 July 2006)

Crash site/type	Speed limit area			
	50 km/h	70 km/h	100 km/h near rural	100 km/h remote rural
All other sites	200	365	520	795
Mid-block crashes	225	425	555	840
Intersection crashes:				
Uncontrolled T	195	375	500	765
Roundabout	140	180	455	685
Priority T, Y	170	290	465	715
Priority X	170	295	585	880
Signalised T, Y	150	N/A	N/A	N/A
Signalised X	170	N/A	N/A	N/A
Motorway crashes			270	N/A
Railway crossing crashes	N/A	N/A	1,235	1,625
Rural bridge crashes	565	870	610	905
Heavy vehicle crashes	N/A	N/A	700	1,030
Cycle crashes	260	475	565	830
Pedestria crashes	160	270	1.080	1.420

A6.11 References

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A7 Passing lanes

A7.1 Introduction

Introduction

This appendix contains procedures to evaluate the benefits of providing passing lanes, typically through the provision of passing lanes, climbing lanes, slow vehicle bays, and increases in the natural passing opportunities from improved alignments.

Benefits of providing increased passing lanes

A wide range of vehicle types travel on New Zealand highways each day and inevitably some slower vehicles impede other faster vehicles. In order to overtake these slower vehicles on two lane highways, drivers must use the opposing traffic lane. However this is not always possible or safe. Suitable gaps in the opposing traffic may be limited and the road alignment may restrict the forward sight distance. The result is increased travel times as well as increases in driver frustration. Research suggests that the latter may lead to an increase in unsafe passing manoeuvres and crashes (Thrush, 1996).

In this appendix

Passing lanes

Passing lanes (and climbing lanes) provide a relatively safe environment for vehicles to overtake other vehicles, allowing them to travel at their desired speed until such time as the platoons reform. As a consequence the benefits of passing lanes generally extend much farther than the physical length of the passing lane section itself, as shown in figure A7.1 below.

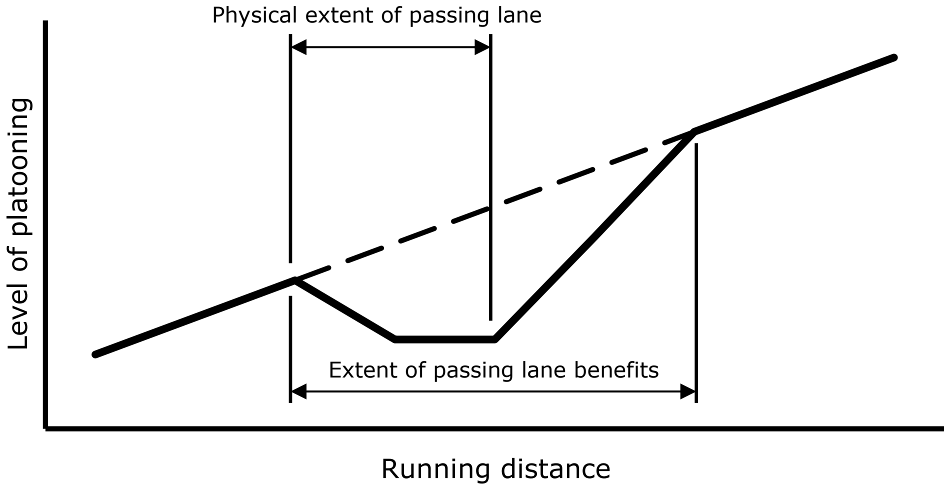


Figure A7.1 Benefit length of installing passing lanes

Passing lanes free impeded vehicles from slow moving platoons and in doing so they improve levels of service, reduce travel times and driver frustration. These benefits will be greatest at locations where road and traffic conditions result in significant passing demand.

Other improvement options

In hilly and mountainous terrain, passing lanes (and climbing lanes) may not be viable, particularly on lower volume roads. In such cases other improvement options such as slow vehicle bays and shoulder widening should be considered. The benefit of full length passing lanes in less severe terrain can also be low, when traffic volumes are low. In such cases improving sight lines through clearance of vegetation and vertical or horizontal realignment may increase the available passing opportunities and generate other safety benefits.

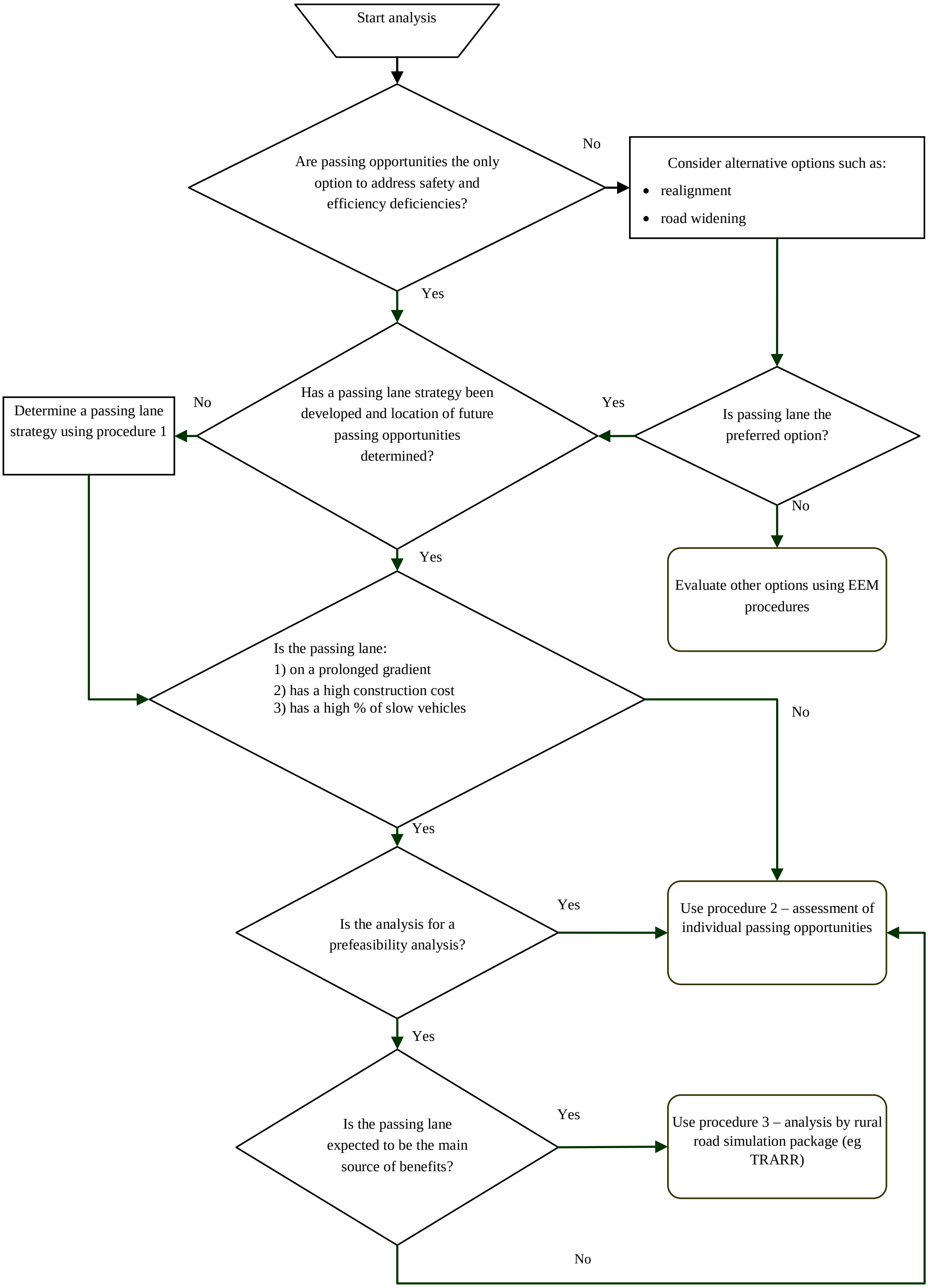
Passing lane evaluation procedures

There are three procedures in this appendix;

1. passing lane strategy for determining the location of individual passing lanes (Appendix A7.3).
2. assessment of individual passing lanes identified as feasible from a passing lane strategy (Appendix A7.4).
3. detailed analysis of passing lane projects using rural traffic simulation software, such as TRARR (Appendix A7.5).

Figure A7.2 should be used to determine the appropriate procedure.

Figure A7.2 Selection of passing lane analysis procedure



A7.2 Background

Travel time and driver frustration savings

Travel time and driver frustration benefits are generated when passing lanes reduce the amount of time drivers spend travelling in platoons. The demand for passing and consequently the benefits, are a function of a number of parameters including:

Traffic variables

- traffic volume
- percentage of HCVs
- initial platooning
- directional split of traffic
- vehicle speed distributions

Road variables

- terrain/alignment
- grades
- available passing lanes (sight distance)
- passing lane lengths and frequency

The downstream distance over which road user benefits accrue reduces as traffic volumes, the proportion of slower vehicles (HCVs), and the speed differential between fast and slow vehicles increases. Features that re-platoon the traffic stream, such as urban areas and major intersections, may limit the available benefits. While passing lanes also have an impact on the passing opportunities available to traffic travelling in the opposite direction (where passing is not prohibited), these impacts are typically quite small and are ignored.

These procedures provide graphs of travel time and driver frustration benefits, which are used or incorporated into graphs of BCR for different input parameters. These graphs were developed from a simulation model, which simulates two traffic streams (fast and slow vehicles) travelling along sections of highway. The simulations are used to determine the demand for passing lanes. The travel time benefits of passing lanes are then assessed using the Unified Passing Model developed by Werner and Morrall (1984). The changes observed in the level of platooning determine the driver frustration benefits, while the reduction in travel time is a benefit in its own right, it is also used to determine the change in mean travel speed and the subsequent change in vehicle operating costs.

Crash rates

A crash rate analysis has been undertaken to produce the crash reduction benefit graphs shown in figures A7.9 to A7.12. The typical crash rate by terrain type is taken from table A6.5(a). The crash rate at the passing lane and downstream of the passing lane is less than the typical rate and varies depending on proximity to the passing lane. The maximum reduction is along the passing lane where the reduction in the typical rate is 25%. The reduction in the crash rate reduces linearly to zero from the end of the passing lane to either the location where vehicle platooning returns to normal (generally 5 to 10 km downstream), or where another passing lane begins.

Table A7.1 shows the crash rate before the installation of a passing site. The typical crash rates for hilly terrain have been interpolated as mid-way between the crash rates for rolling and mountainous terrain.

If the passing lane forms part of a rural realignment or there are five or more injury crashes or two or more serious and fatal crashes in any 1 km section (up to 10 kms downstream of the passing lane) then crash-by crash analysis may be suitable. To determine if such an analysis is appropriate refer to figure A6.1.

For crash by crash analysis, table A6.9(b) provides crash reductions for up to 10 km downstream of the passing lane. In the majority of cases however crash benefits should only be claimed up to 5 km downstream of a passing lane unless a rural simulation analysis indicates that vehicle platooning will not return to normal until more than 5 km downstream. No upstream crash benefits can be included unless international or local research is produced to justify such benefits.

Passing lane length

A standard passing lane length of 1 km is assumed in these procedures. When evaluating passing lanes with a length greater or shorter than 1 km, the appropriate factors in table A7.8 should be applied to the road user benefits.

Table A7.1 Crash rates for rural mid-block locations (/10^8 veh-km)

Terrain type	Typical crash rate – no passing lane
Flat	16
Rolling	20
Hilly	24 (interpolated from rolling and mountainous crash rates)
Mountainous	28

Proportion of heavy traffic

Two traffic streams, ‘cars’ (passenger cars and light commercial vehicles) and ‘trucks’ (medium/heavy commercial vehicles and buses) are assumed. The relative proportions are based on the All periods composition for a rural strategic road, which is 88% light vehicles and 12% heavy vehicles (refer table A2.1). This assumption impacts on both the level of travel time benefits and on the value of these benefits. The adjustment in equation 1 (Appendix A7.4) can be applied when the percentage of heavy vehicles is above or below 12%.

Traffic flow profile

The benefits of passing lanes are a function of the traffic using the road during a particular period (vehicles/hour). To express the benefits of passing lanes as a function of AADT, it is necessary to assume a traffic flow profile and the number of hours per year that this particular level of traffic flow (percentage of AADT) occurs. The traffic flow profile assumed for these procedures is based on that recorded for rural State Highways that do not carry high volumes of seasonal holiday or recreational traffic.

Although it may be expected that additional benefits will accrue to passing lanes on roads that do carry high volumes of recreational traffic, the differences have been found to be insignificant. The exceptional peaks of the roads with high volumes of recreational traffic are offset by a reduction in the proportion of time the road operates at around 7% of AADT (refer table A7.2 below).

The relationship between the benefits and the flow profile is relatively robust. In situations where the traffic flow profile differs significantly from the above, the simplified procedure may not be applicable, and more detailed analysis using ruralsimulation (eg, TRARR) may be required.

Table A7.2 Traffic flow profiles

Hourly flow as % of AADT	Roads with low volumes of recreational traffic			Roads with high volumes of recreational traffic		
	hours/year	% hours	% AADT	hours/yr	% hours	% AADT
0.9	3,979	45.42	9.7%	3,797	43.35	9.3%
3.5	933	10.65	8.9%	2,062	23.54	19.8%
7.0	3,210	36.64	61.6%	1,819	20.76	34.9%
10.5	541	6.18	15.6%	822	9.38	23.6%
14.0	97	1.11	3.7%	96	1.10	3.7%
17.5	10	0.11	0.5%	120	1.37	5.8%
21.0	-	-	-	6	0.07	0.4%
25.0	-	-	-	38	0.43	2.6%
Total	**8,760**	**100%**	**100%**	**8,760**	**100%**	**100%**

Traffic growth

The procedures have been developed using a traffic growth of 2%. Adjustment factors are produced to modify benefit graphs when the traffic growth is 0%, 1%, 3% and 4%. Where the traffic growth does not correspond to these values an appropriate adjustment factor can be calculated using interpolation or extrapolation.

Speed

The variation in traffic speed of individual vehicles within each traffic stream is expressed in terms of the coefficient of variation (standard deviation divided by the mean) of all vehicle speeds. The procedure assumes the coefficient of variation (COV) to be 13.5%for both traffic streams.

In situations where road geometry or terrain type has a significant impact on the speeds of particular vehicle types, it is likely that the coefficient of variation will increase. In such cases the simplified model will under predict the benefits of releasing faster vehicles from platoons. Similarly on long flat straights where there is likely to be less variation in speed the model can be expected to over predict the travel time benefits. The adjustment in equation 2 (Appendix A7.4) can be applied when the COV is above or below 13.5%.

Construction costs

The construction costs presented here, and used in the analysis for determining the appropriate passing lane strategy, are based on the average costs of constructing a 1 km passing lane in each of the terrain categories. These average costs are generally weighted to the lower end of the reported range, as in most instances passing lanes are located to avoid costly items, such as bridges.

Table A7.3 Classification of passing lane costs

Category	Cost/m ($2005)	Typically had some or all of the following features:	Assumed cost/m ($2005)
Easy	$120 to $250	• Flat, straight road and terrain, • Very good ground conditions, • Two orthree3 passing lanes projects in one contract, • Existing road 10 metres seal width, new passing lanes on both sides of road, and • No expensive special features	$170
Average	$250 to $500	• Flat or gently rolling terrain, • Straight or curved alignment, • Good or average ground conditions (soft material encountered on some projects), • Typically one passing lane per contract, and • Some special features on some projects	$320
Difficult	≥ $500	• Poor ground requiring removal and replacement, • Curved or straight alignment, • Awkward or hilly terrain, • Short length of passing lane in one contract, • High traffic count and control costs, and • Often expensive special features such as rehabilitation and intersection improvements	$800 (Estimates in this category were as high as $1,700 per linear metre)

Average construction and maintenance costs have been calculated for each of the terrain types, using real costs from a number of projects and from data collected for passing lane research. The construction costs per linear metre from these projects determined the cost categories shown in table 10.3. Table A7.4 relates each of the four terrain types to the cost categories, together with the unit and total construction costs used in the analysis.

Where the estimated cost of construction differs significantly from that assumed in table A7.4, an adjustment to the BCR could be made using equation 3 (Appendix A7.4):

Be aware that analysis of data from selected passing lane sites indicated that:

- passing lanes generally cost between $120 and $800 per linear metre, but can cost up to $1700 in some cases. Specific cost estimates should be prepared for each site under consideration
- ssignificant savings in both design and construction costs are possible if two or three projects are combined into one contract.

Special features can be very expensive and should be avoided where possible, and local knowledge is important to achieving accurate estimates. Special features include:

- swamps/soft ground
- significant earthworks quantities
- large culvert and/or drain extensions
- intersection improvements
- expensive service relocations

Construction period

The procedures outlined in this appendix assume that the construction of the passing lane is completed within the first year.

Update factors

Update factors for user benefits and constructions costs should be used with these procedures. These can be found in table A12.1 and A12.2. When applying an update factor to the combined travel time and vehicle operating costs, the adjustment factor for travel time costs should be used.

Table A7.4 Passing lane average costs ($2005)

Terrain type	Cost category	Unit cost (per m)	Total cost (for 1 km)
Flat	Easy/average	$250	$250,000
Rolling	Average	$320	$320,000
Hilly	Average/difficult	$500	$500,000
Mountainous	Difficult	$800	$800,000

Note: Construction cost estimates vary widely depending on site-specific factors. Use caution with these costs for other applications. All costs include the end tapers.

A7.3 Passing lane strategies

Introduction

This section provides a procedure for assessing passing lane strategies and is divided into two sections. Firstly a coarse analysis to identify passing lane spacing strategies and when increased passing lane frequency may become economic. The second section is used for determining actual locations for passing lanes and approximate BCRs of individual projects. More detailed guidance on individual passing lanes can be found in Appendix A7.4.

The assumptions made in this procedure are affected by local conditions (refer Appendix A7.2).

Strategy identification procedure

This procedure is required as an initial step to evaluate strategies. It can also be used in isolation as a coarse analysis to identify the approximate BCR for each passing lane within a particular strategy.

This procedure can be used to determine the most appropriate passing lane spacing strategy for sections of strategic rural roads and by doing so identify when increased passing lane frequency may be required.

Step	Action
1	**Break the network into sections,** as specified in the NZ Transport Agency's state highway performance indicators and targets guidelines (or similar for local authority roads). Further classify these traffic sections into sub-sections with consistent traffic volume and terrain type. Sub-sections should start or finish at main urban areas. Sub-sections should not be shorter than: • 10 km for passing lanes at 5 km spacing • 20 km for passing lanes at 10 km spacing. When terrain and traffic volumes change frequently, then smaller sections should be combined and the average traffic volume used in the analysis. The predominant terrain type should also be used in the analysis. Where this procedure does not seem appropriate, such as where there is a steep grade on a route that has typically a rolling or flat alignment, analysts should use a simulation model such as TRARR to calculate the benefits.
2	**Classify the terrain**, terrain can be classified vertically by generalised gradient (sum of the absolute value of rises and falls expressed as m/km) and horizontally by generalised curvature (degrees/km). Combined terrain classifications of vertical and horizontal terrain are shown in table A7.5, and are a result of analysis of 500 metre lengths using a 1500 metre moving average of these parameters. The curvature, or degrees per kilometre specified in table A7.5, is estimated by summing the deviation angles of the horizontal curves from plans or aerial photography, and dividing by the road length. Rise and fall can be obtained from profile drawings or highway information sheets. Alternatively, this profile and curve data can be obtained from surveyed road geometry data.

Step	Action
3	**Determine percentage of road with passing sight distance** (% PSD), for each sub-section. The % PSD is the proportion of the section that has visibility greater than 450m. This can be calculated using surveyed gradient and horizontal curvature data. In the absence of survey data, each sub-section can be classified according to terrain type, based on average gradient and curvature. Terrain type sectioning can then be converted to percentage passing sight distance using table A7.6. Note that this method is not as accurate and may not be sufficient in situations where the benefits are sensitive to % PSD, especially where traffic volumes are higher. In table A7.6 PSD has been calculated as a moving average over 15 km, with the PSD ascribed to the centre 5 km. This is the basis of the BCR graphs and should be observed when applying the method. The curvature can be estimated as in step 2.

Table A7.5 Combined terrain classification

<table>
<tr><td></td><td colspan="4">Horizontal terrain (degrees/km)</td></tr>
<tr><td>Vertical terrain
(rise and fall, m/km)</td><td>Straight
(0-50)</td><td>Curved
(50-150)</td><td>Winding
(150-300)</td><td>Tortuous
(>300)</td></tr>
<tr><td>Flat (0-20)</td><td rowspan="2">Flat</td><td rowspan="2">Rolling</td><td rowspan="3">Hilly</td><td rowspan="4">Mountainous</td></tr>
<tr><td>Rolling (20-45)</td></tr>
<tr><td>Hilly (45-60)</td><td rowspan="2">Rolling</td><td rowspan="2">Hilly</td></tr>
<tr><td>Mountainous (>60)</td><td>Mountainous</td></tr>
</table>

Table A7.6 Terrain relationship to passing sight distance

Measure	Vertical terrain			
	Straight	**Curved**	**Windy**	**Tortuous**
Curvature, degrees per km	0-50	50-150	150-300	>300
Number of curves per km	<1.0	1.0 – 3.0	3.0 – 6.0	>6.0
Average % passing sight distance	35	15	10	5
Percentage of road length with:				
less than 25% sight distance	45	85	95	98
25 to 50% sight distance	30	15	5	2
50 to 75% sight distance	15	-	-	-
over 75% sight distance	-	-	-	-

Strategy identification procedure, continued

Step	Action
4	**Use the analysis year AADT, and % PSD, to calculate a BCR**, using the figures A7.3 to A7.6. If traffic growth is not 2% per year, multiply the BCR by the correction factors in table A7.7. If the traffic growth is not in table A7.7, extrapolate or interpolate to obtain a correction factor. The analysis is carried out in both directions, generally with a stagger between opposing passing lanes where the terrain and available width allows.
5	Repeat step 4 using the predicted AADT for future years in increments of five years from the analysis year, to identify when it may be worthwhile to adopt a strategy that involves more frequent passing lanes.

Table A7.7 Traffic growth correction factors for BCR graphs

AADT	Traffic growth				
	0%	1%	2%	3%	4%
2000	0.80	0.90	1.00	1.10	1.21
3000	0.82	0.91	1.00	1.09	1.18
4000	0.84	0.92	1.00	1.08	1.16
6000	0.84	0.92	1.00	1.08	1.16
8000	0.84	0.92	1.00	1.08	1.15
10000	0.86	0.93	1.00	1.07	1.15

Refinement of strategy

The following steps determine the location of passing lanes before evaluating individual passing lanes (Appendix A7.4).

Step	Action

6	**Identify existing and planned passing lanes** for each section where passing lanes can be justified.
	
	If existing passing lanes spacing ≤ calculated, then
	
	No new passing lanes required
	
	If existing passing lanes spacing > calculated, then
	
	Identify potential new sites at the calculated interval
	
	Older sites are unlikely to be at set intervals (as part of a strategy) and judgement is required in determining whether new sites are justified. Where relevant, identify possible sites for future years.

Step	Action
7	**Identify suitable sites**. Sites should be within 1 km of either side of the calculated spacing. Construction cost, land availability and forward visibility at the exit merge are important factors for site selection. Site spacing or length may be adjusted to balance passing demand and opportunities. For wider spacing it will be necessary to combine each of the sub-sections identified in step 1. Where the strategy results in similar site spacing for each sub-section, this spacing must be maintained over sub-section boundaries. If the optimal spacing for each sub-section results in different desired site spacing for each sub-section, the overall strategy should be based on the largest spacing, ie where the spacing changes from 5 km in sub-section one to 10 km in sub-section two, then the spacing should be increased to the higher values (10 km) over the boundary. Any inbound sites in the vicinity of towns should commence at least 5 km from the urban speed limit, unless reasons for a closer facility can be justified. This normally requires modelling using TRARR. Use the following guidance to maximise passing lane benefits: • select locations where large numbers of vehicles are observed travelling in slow moving platoons • select locations where there is the greatest speed differential between slow and fast vehicles (for example, on steep grades) • locate sites leading away from congestion (such as urban areas) • where possible locate sites on sections with existing no-overtaking lines to maximise the increase in net passing opportunities • avoid significant intersections (particularly right-turn bays) • consider site lengths of between 800m and 1500m in most rural areas – shorter lengths are unlikely to release all platooned vehicles and little benefit is gained from excessively long lengths • do not locate the merge area at the end of the sites where there is limited forward sight distance or where there is a sudden reduction in the desired speed, eg at a tight horizontal curve • the termination of sites in opposing directions should not be adjacent to each other • ensure that sufficient shoulder width and merge space are provided, otherwise an increase in lost-control and merging crashes could occur • avoid costly physical restraints such as narrow bridges and culverts that require widening. Refer to Austroads (2003) ‘Rural road design’ for further information.

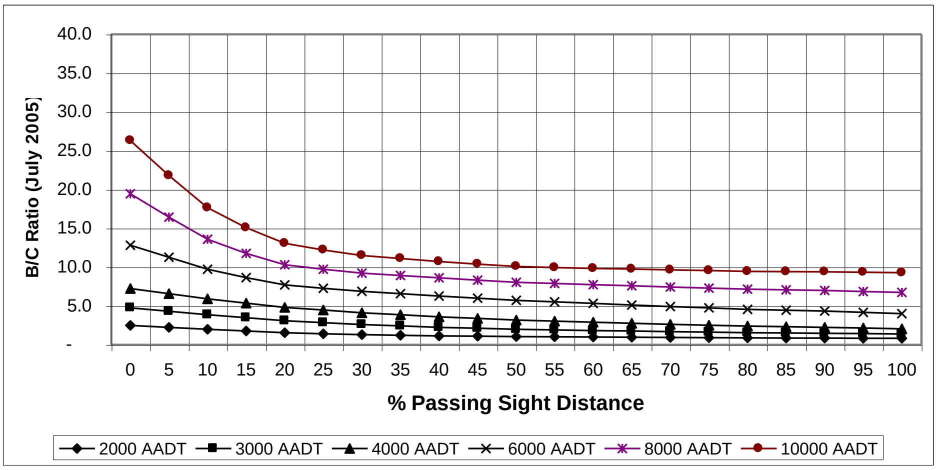
Step	Action
8	**Sections of prolonged gradient should be identified,** as possible opportunities for climbing lanes (or slow vehicle bays) using table A7.8 below, which is adapted from Austroads (2003) 'Rural road design' and considers the length of sustained gradient necessary to reduce the speed of a heavy commercial vehicle to 40 km/h. To assess the benefits of such sites a more detailed analysis is required using rural simulation software (see section A7.5).

Table A7.8 Limiting lengths m for consideration of climbing lanes

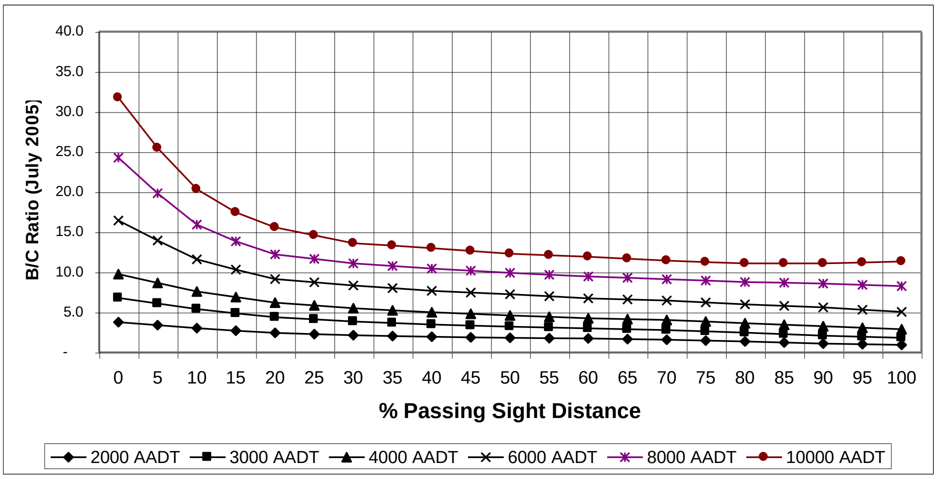
Gradient %	Approach speed (km/h)		
	60	**80**	**100**
10	100	200	450
9	100	250	550
8	100	300	650
7	150	300	800
6	150	350	1000
5	200	450	
4	300	650	

Figure A7.3 Graphs of strategy BCR for flat terrain

Flat terrain - 5 km spacing – 2% traffic growth



Flat terrain - 10 km spacing – 2% traffic growth



Flat terrain - 20 km spacing – 2% traffic growth

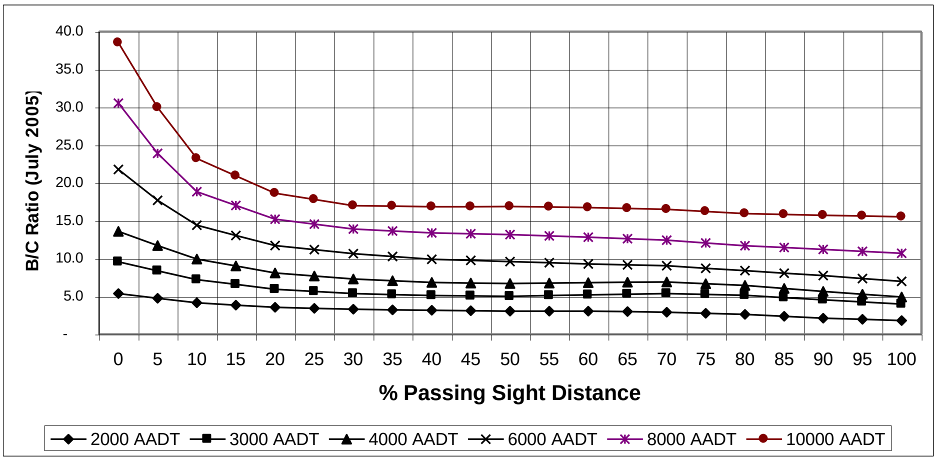
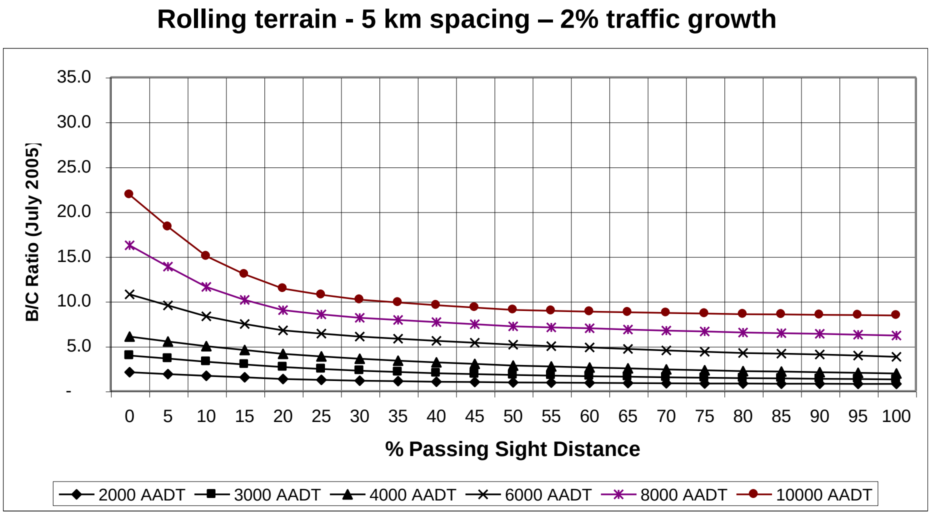
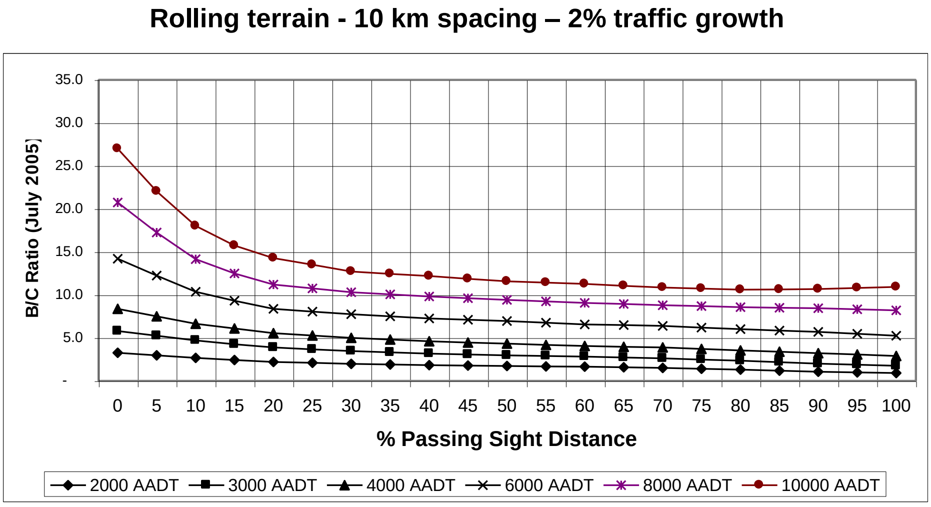


Figure A7.4 Graphs of strategy BCR for rolling terrain





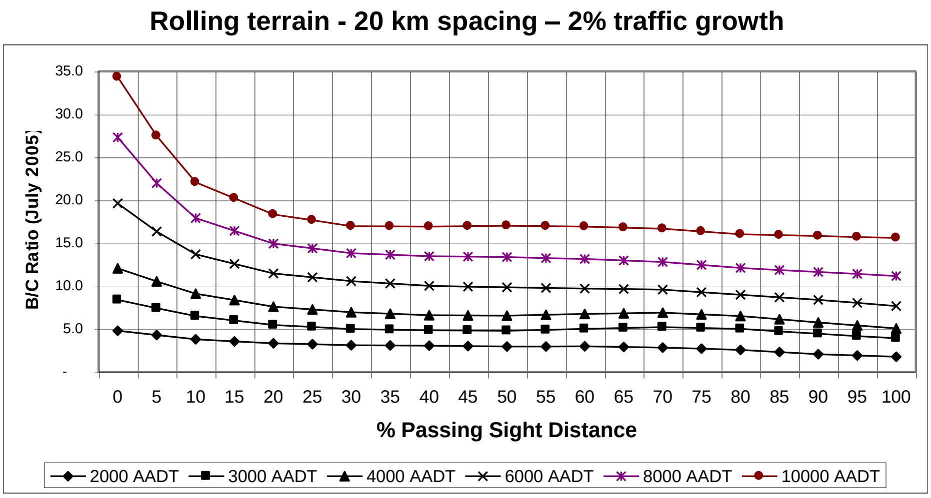
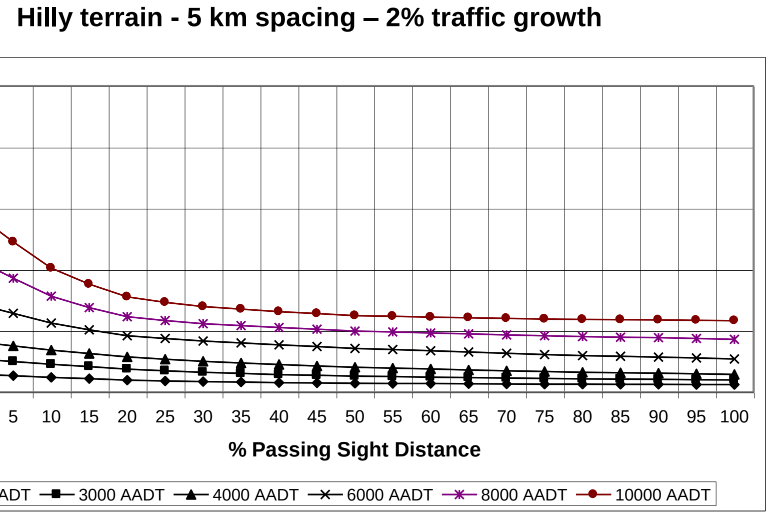
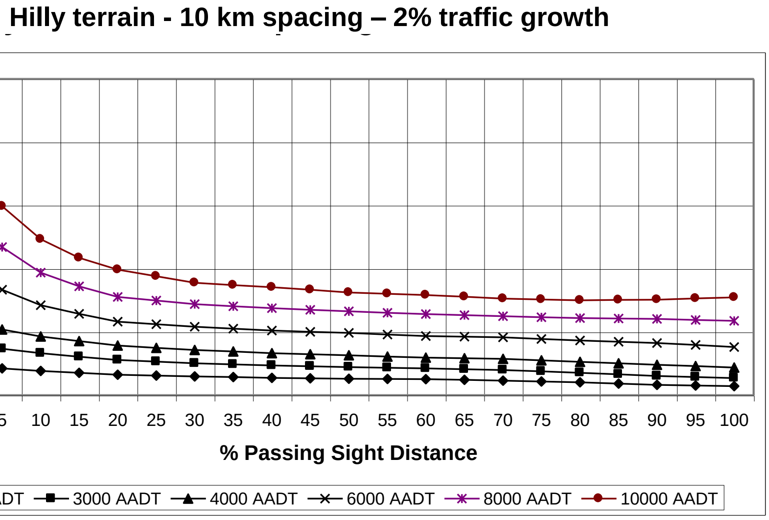


Figure A7.5 Graphs of strategy BCR for hilly terrain





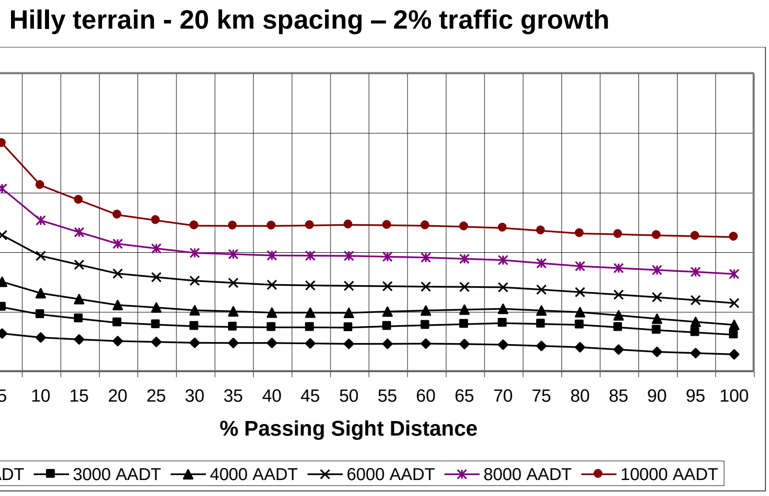
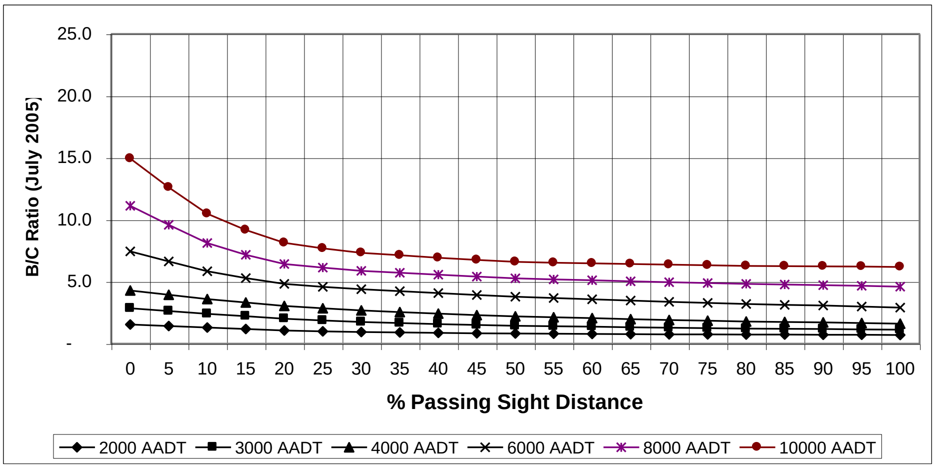
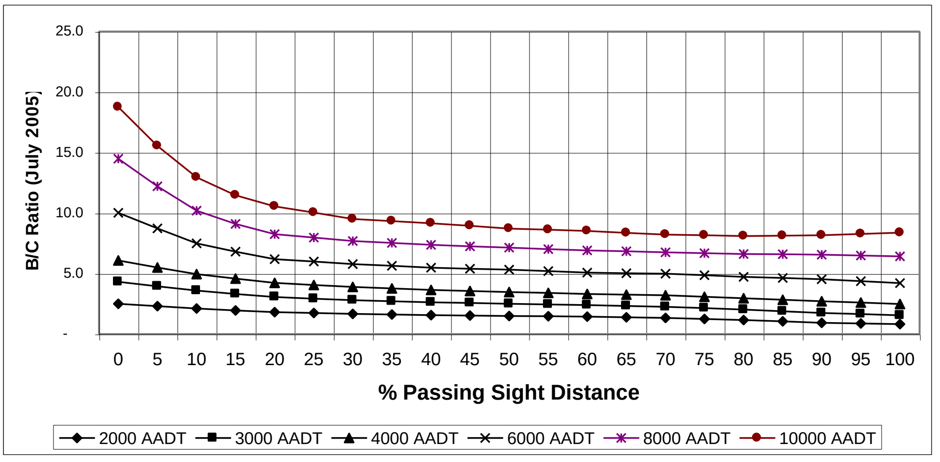


Figure A7.5 Graphs of strategy BCR for mountainous terrain

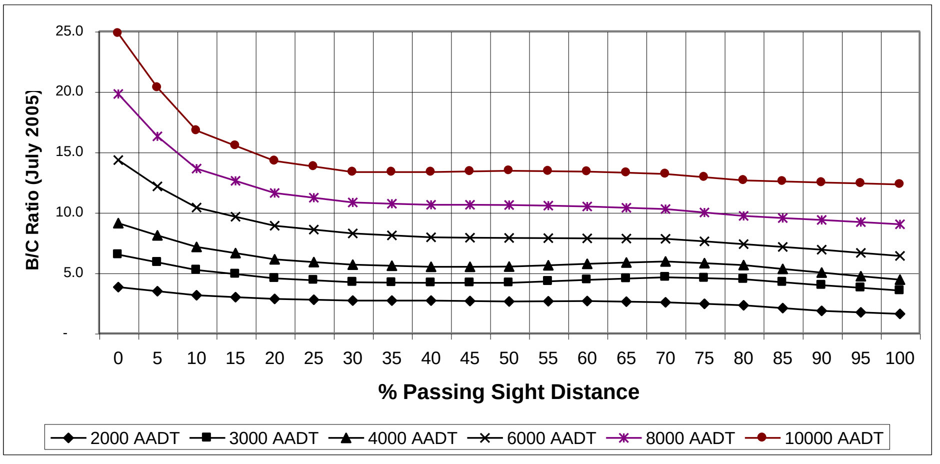
Mountainous terrain - 5 km spacing – 2% traffic growth



Mountainous terrain - 10 km spacing – 2% traffic growth



Mountainous terrain - 20 km spacing – 2% traffic growth



A7.4 Assessment of individual passing lanes

Introduction

This procedure is suitable for establishing the benefits of individual passing lane projects. This method is not suitable for:

- slow vehicle bays and crawling lanes at the indicative business case stage
- locations where there are a large proportion of slow vehicles such as campervans, coaches, or slow heavily loaded commercial vehicles
- passing lanes with significant construction costs or significant construction and preconstruction periods.

For locations where one or more of the above factors apply, a rural traffic simulation model is required to assess the benefits (see Appendix A7.5).

It is assumed that before using this procedure that an appropriate passing lane strategy has been developed using the method in Appendix A7.3 and individual passing lanes are being investigated. This procedure is used to calculate the benefits of passing lanes in one direction only. For dual passing lanes (passing lanes in both directions), the procedure needs to be undertaken for both directions separately.

To use the procedure in this section, the BCR graphs in figures A7.3 to A7.6 are not to be used. Instead, separate graphs for each category of road user benefits are used (figures A7.7 to A7.12), and these can be adjusted where necessary to account for local conditions.

Procedure for individual passing lanes

Step	Action
1	**Calculate the travel time and vehicle operating savings,** using graphs in figure A7.7. If necessary multiply by the traffic growth correction factor in table A7.9 and the travel time update factor in table A12.2. The inputs to the graphs are: • passing lane spacing (either 5, 10 or 20 km - for isolated passing lanes use 20 km spacing) • analysis year AADT • % PSD (to calculate see Appendix A7.3)

Table A7.9 Traffic growth correction factors for travel time and VOC graphs

AADT	Traffic Growth				
	0%	1%	2%	3%	4%
2000	0.66	0.83	1.00	1.18	1.39
3000	0.70	0.85	1.00	1.17	1.34
4000	0.72	0.86	1.00	1.14	1.27
6000	0.80	0.90	1.00	1.10	1.20
8000	0.82	0.91	1.00	1.09	1.18
10000	0.82	0.91	1.00	1.09	1.17

Step	Action
2	**Calculate the driver frustration savings,** using graphs in figure A7.8. If necessary multiply by the traffic growth correction factor in table A7.10 and the driver frustration update factor in table A12.2.
3	**Sum the road user benefits from steps 1 and 2.** These are the road user benefits that need to be adjusted to account for the site specific characteristics such as passing lane length, speed distribution and proportion of heavy traffic.
4	**Adjustment for the passing lane length.** The benefits calculated in the previous steps are based on passing lanes of 1 km in length. Where individual passing lanes are less than 1 km in length, the benefits are reduced because a lesser number of platooned vehicles will be released. Where the proposed passing lane is longer than 1 km, additional benefits may result. The formation of platoons depends on the spacing between passing lanes, therefore an adjustment to the benefits is calculated based on the combined effect of passing lane length and spacing, as provided in tables A7.11a and A7.11b below (intermediate values may be interpolated).

Table A7.10 Traffic growth correction factors for driver frustration graphs

AADT		Traffic growth			
	0%	1%	2%	3%	4%
2000	0.64	0.82	1.00	1.19	1.40
3000	0.70	0.85	1.00	1.15	1.30
4000	0.76	0.88	1.00	1.11	1.22
6000	0.84	0.92	1.00	1.08	1.15
8000	0.86	0.93	1.00	1.07	1.15
10000	0.86	0.93	1.00	1.07	1.15

Table A7.11a. Passing Lane Length Factors for Travel Time Delays & Vehicle Operating Cost Savings

AADT (veh/day)	Passing Lane Length (m, excl tapers)								
	400	600	800	1000	1200	1400	1600	1800	2000
2000	0.39	0.65	0.91	1.00	1.17	1.15	1.13	1.16	1.18
4000	0.30	0.60	0.86	1.00	1.19	1.30	1.40	1.48	1.55
6000	0.08	0.35	0.80	1.00	1.21	1.38	1.54	1.65	1.76
8000	0.04	0.18	0.60	1.00	1.22	1.43	1.63	1.76	1.88
10,000	0.02	0.11	0.38	0.82	1.24	1.47	1.69	1.83	1.96
12,000	0.02	0.08	0.27	0.57	1.06	1.49	1.73	1.88	2.03
14,000	0.01	0.06	0.20	0.43	0.80	1.32	1.76	1.93	2.09
16,000	0.01	0.05	0.16	0.34	0.63	1.04	1.59	1.97	2.14
18,000	0.01	0.04	0.13	0.28	0.51	0.85	1.30	1.81	2.19
20,000	0.01	0.03	0.11	0.23	0.43	0.71	1.09	1.51	2.03
22,000	0.01	0.03	0.09	0.20	0.37	0.60	0.93	1.29	1.73
24,000	0.01	0.02	0.08	0.17	0.32	0.52	0.80	1.11	1.50
26,000	0.00	0.02	0.07	0.15	0.28	0.46	0.70	0.98	1.31

Note: 1) Shaded values show either excluded values 1.6-2 km passing lane with 2,000-4,000 vpd or drop-off in efficiency. 2) The values are for passing lanes on flattish gradient with 110 km/hr overtaking speed. 3) Refer to NZ Transport Agency National Office for passing lanes that lie outside of the above range of values. 4) These factors do not apply to passing lanes in 2+1 layouts (continuous alternating passing lanes). 5) One-way hourly flows were converted to AADT, using a 45%/55% directional split and a peak hourly flow of 7.6% AADT.

Table A7.11b. Passing Lane Length Factors for Frustration Cost Savings

AADT (veh/day)	Passing Lane Length (m, excl tapers)								
	400	600	800	1000	1200	1400	1600	1800	2000
2000	0.17	0.52	0.87	1.00	1.13	1.33	1.52	1.62	1.71
4000	0.13	0.48	0.82	1.00	1.18	1.30	1.41	1.50	1.59
6000	0.03	0.29	0.80	1.00	1.20	1.29	1.37	1.47	1.56
8000	0.02	0.15	0.60	1.00	1.21	1.30	1.38	1.48	1.58
10,000	0.01	0.09	0.38	0.82	1.21	1.31	1.40	1.51	1.61
12,000	0.01	0.07	0.27	0.57	1.03	1.32	1.43	1.55	1.66
14,000	0.01	0.05	0.20	0.43	0.78	1.17	1.47	1.59	1.71
16,000	0.00	0.04	0.16	0.34	0.61	0.92	1.32	1.61	1.73
18,000	0.00	0.03	0.13	0.28	0.50	0.75	1.08	1.47	1.75
20,000	0.00	0.03	0.11	0.23	0.42	0.63	0.90	1.23	1.62
22,000	0.00	0.02	0.09	0.20	0.36	0.53	0.77	1.05	1.38
24,000	0.00	0.02	0.08	0.17	0.31	0.46	0.66	0.91	1.19
26,000	0.00	0.02	0.07	0.15	0.27	0.41	0.58	0.80	1.05

Note: 1) Shaded values show either excluded values 1.6-2 km passing lane with 2,000-4,000 vpd or drop-off in efficiency. 2) The values are for passing lanes on flattish gradient with 110 km/hr overtaking speed. 3) Refer to NZ Transport Agency National Office for passing lanes that lie outside of the above range of values. 4) These factors do not apply to passing lanes in 2+1 layouts (continuous alternating passing lanes). 5) One-way hourly flows were converted to AADT, using a 45%/55% directional split and a peak hourly flow of 7.6% AADT.

Step	Action
5	**Adjustment for the proportion of heavy traffic,** by comparing the medium plus heavy vehicle component of the traffic flow at the site with the component for rural strategic roads identified in Appendix A2. For every percentage above the assumed 12% proportion of heavy vehicles (rural strategic), increase the road user benefits by 1%. Similarly for every percentage point below the assumed 12% of heavy vehicles decrease the road user benefits by 1%. **Equation 1** Road user benefits (adjusted) = Road user benefits (unadjusted) × (1 + [prop heavy vehicles - 0.12])
6	**Adjustment for differences in the speed distribution**. This adjustment of road user benefits (from step 5) is performed if the speed distribution at the site varies from the assumed 13.5%. A current sample of vehicle speeds over the road sections being analysed is required. The adjustment is to increase the road user benefits by 2.5% for each percentage point above the assumed coefficient of variation (COV) of speed of 13.5%. Similarly reduce the road user benefits for a lower COV. **Equation 2** Road user benefits (adjusted) = Road user benefits (unadjusted) × (1 + [COV - 0.135] × 2.5)
7	**Calculate crash costs savings**, using graphs in figures A7.9 to A7.12 (interpolate or extrapolate if necessary) and multiply with the appropriate traffic growth correction factors in table A7.12. If the passing lane forms part of a rural realignment, or there are either five or more injury crashes, or two or more serious and fatal crashes in any 1 km section (up to 10 km downstream of the passing lane) then crash-by crash analysis can be used. To determine if such an analysis is appropriate, refer to figure A6.1

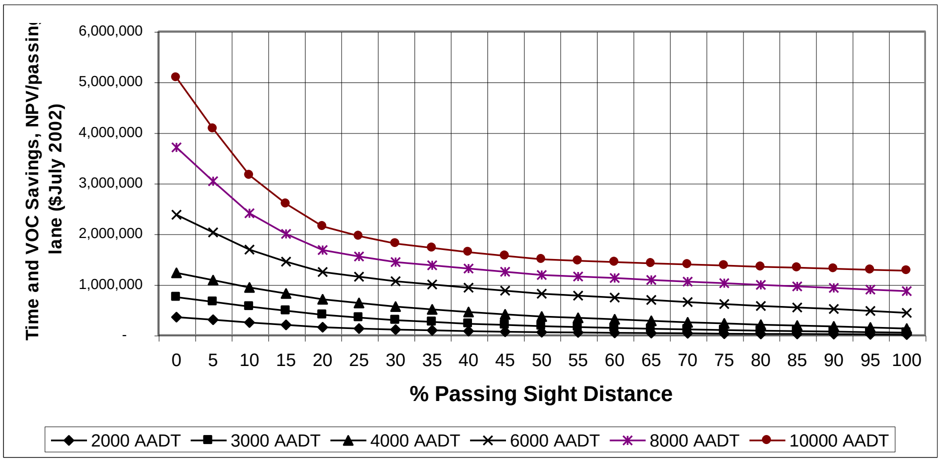
Table A7.12 Traffic growth correction factors for crash savings graphs

AADT		Traffic growth			
	0%	1%	2%	3%	4%
2000	0.84	0.92	1.00	1.08	1.15
3000	0.88	0.94	1.00	1.04	1.07
4000	0.88	0.94	1.00	1.02	1.05
6000	0.88	0.94	1.00	1.06	1.12
8000	0.88	0.94	1.00	1.06	1.12
10000	0.88	0.94	1.00	1.06	1.12

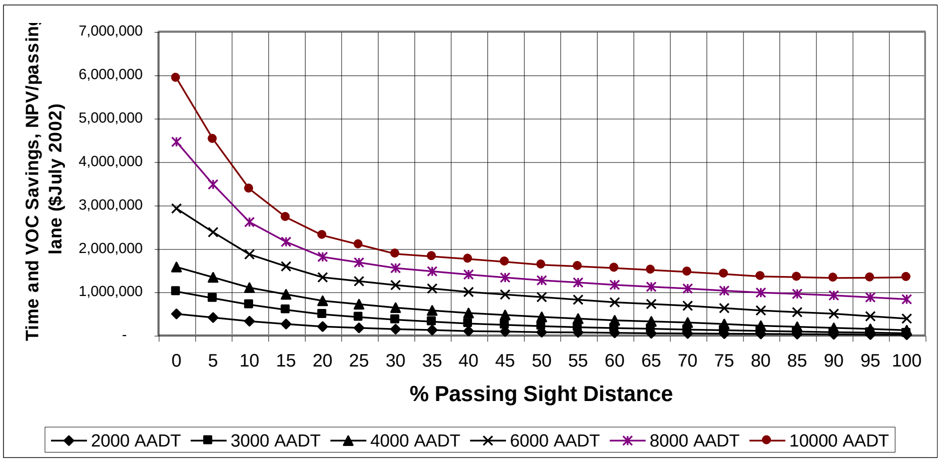
Step	Action
8	**Calculate the BCR,** for the individual passing lanes using the cost estimates for the site and the benefits calculated in the preceding steps. The BCR can be recalculated using the following formula (if the unit costs are taken from table A7.4). **Equation 3** $$\text{BCR (adjusted)} = \frac{\text{BCR (calculated above) x table A7.4 unit cost}}{\text{Local unit cost (per m)}}$$

Figure A7.7 Graphs of vehicle operating cost and delay savings for all terrain

5 km spacing – 2% traffic growth



10 km spacing – 2% traffic growth



20 km spacing – 2% traffic growth

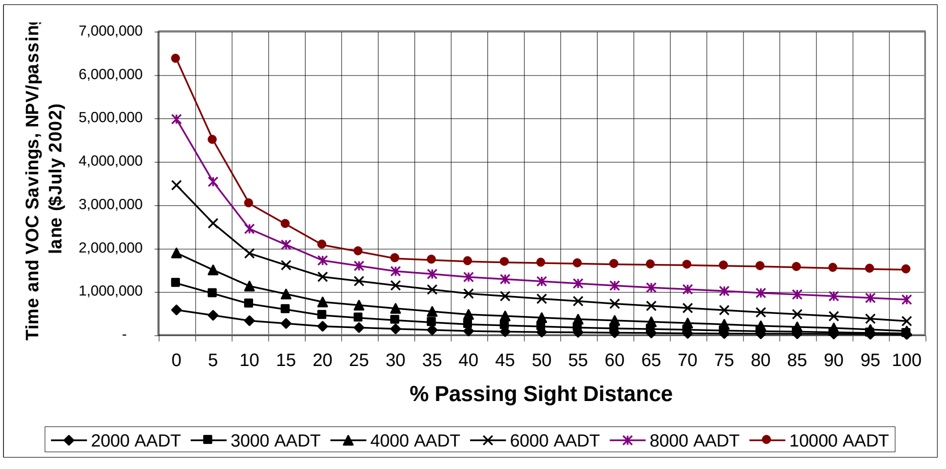
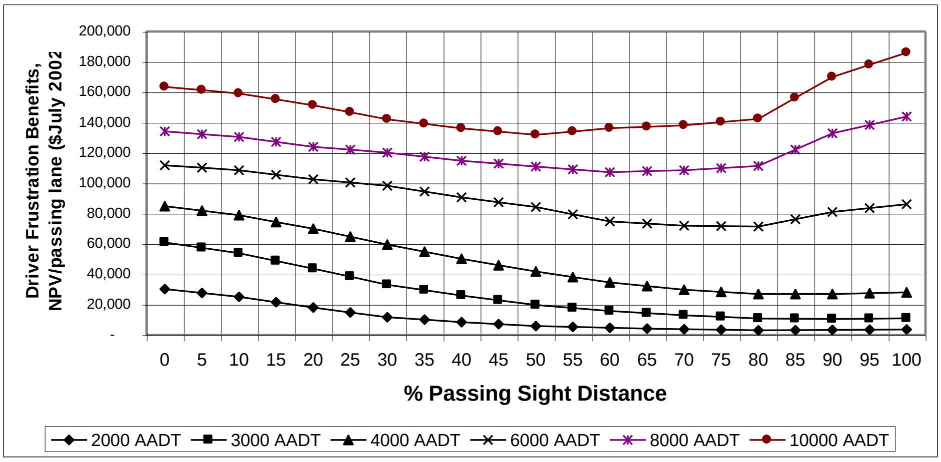
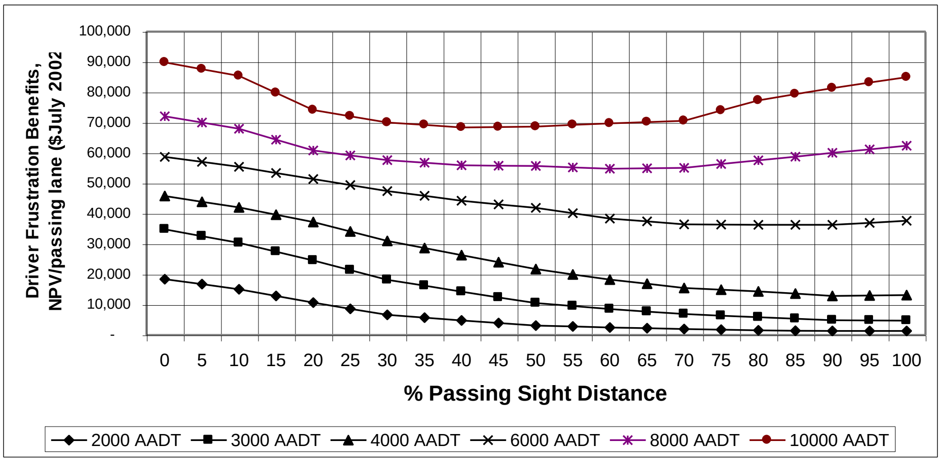


Figure A7.8 Graphs of driver frustration benefits for all terrain

5 km spacing – 2% traffic growth



10 km spacing – 2% traffic growth



20 km spacing – 2% traffic growth

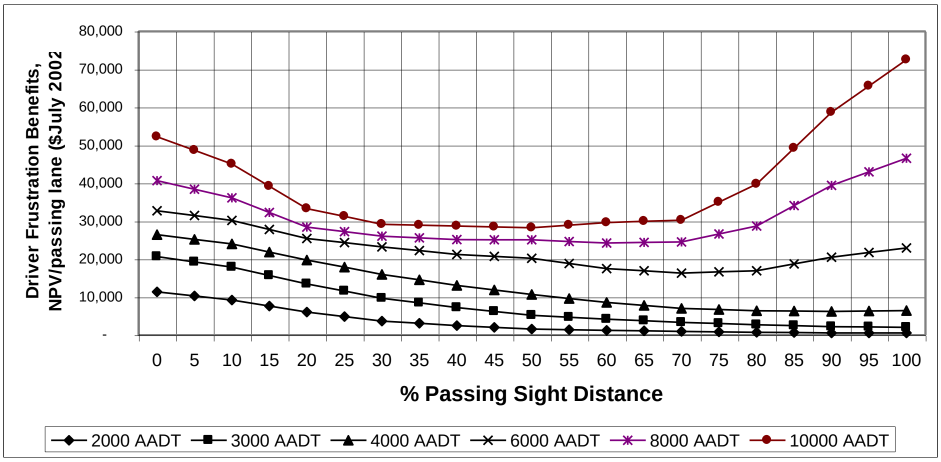
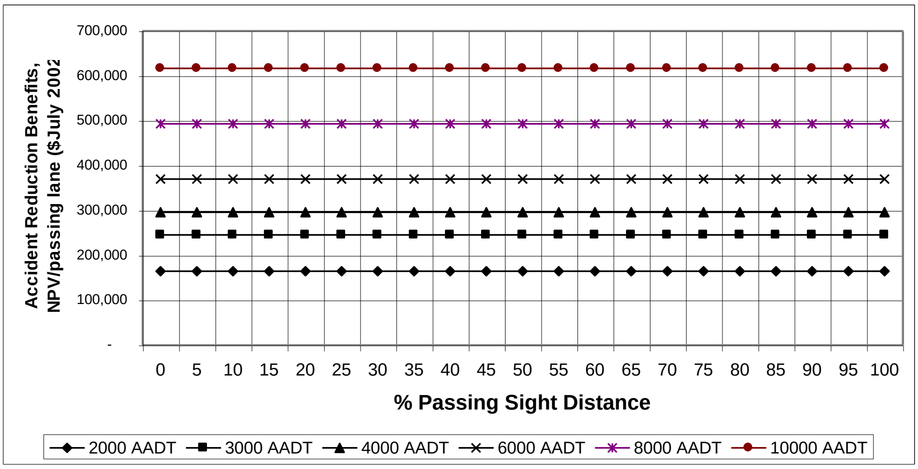
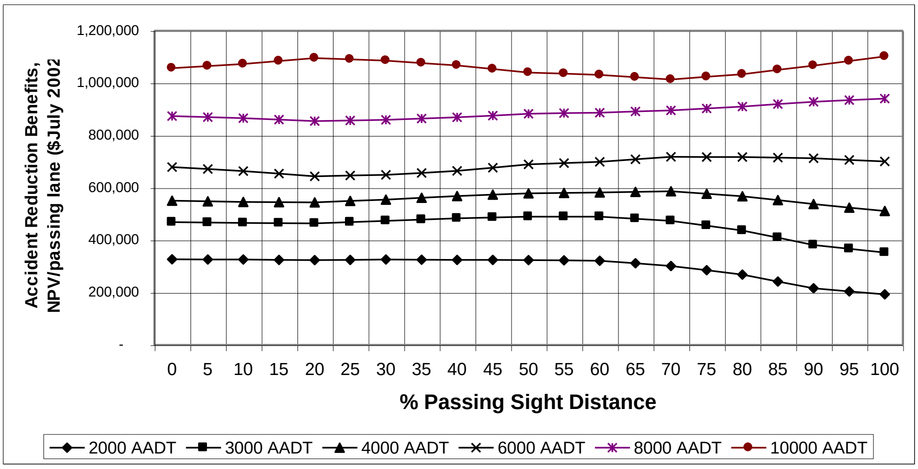


Figure A7.9 Graphs of crash savings for flat terrain

Flat terrain - 5 km spacing – 2% traffic growth



Flat terrain - 10 km spacing – 2% traffic growth



Flat terrain - 20 km spacing – 2% traffic growth

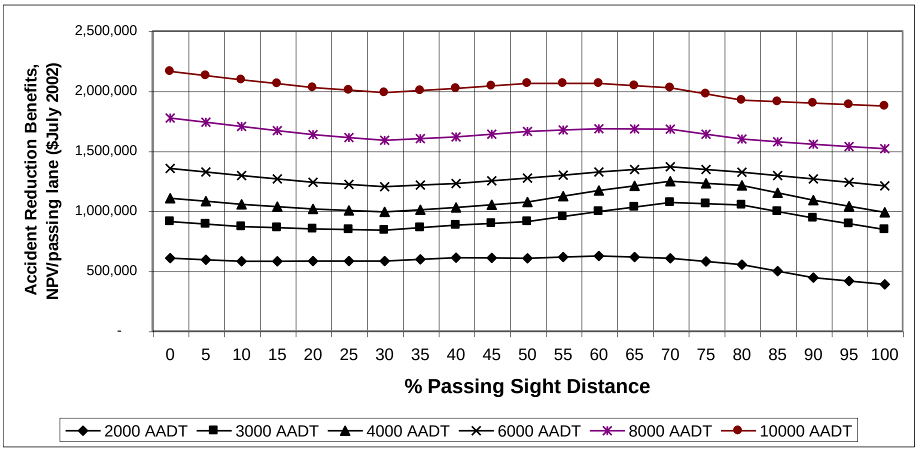
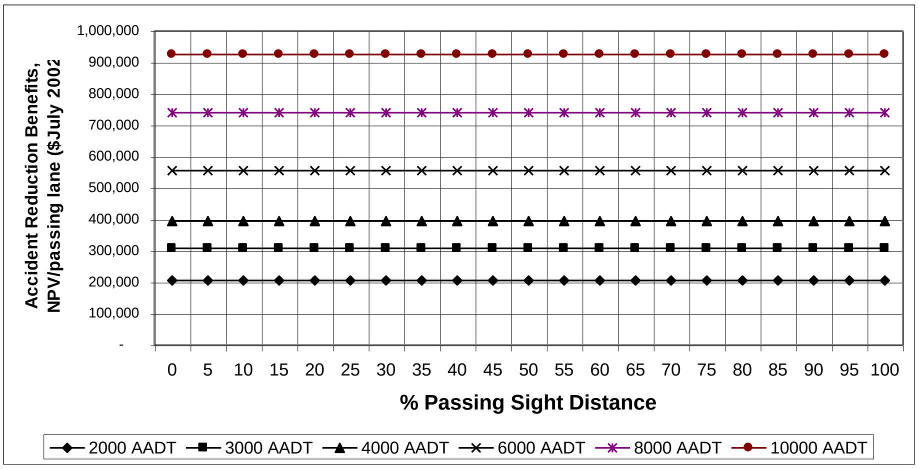
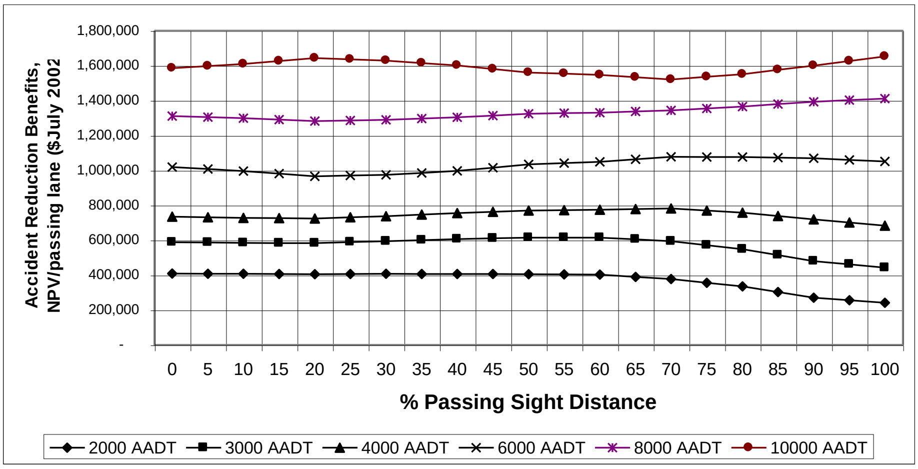


Figure A7.10 Graphs of crash savings for rolling terrain

Rolling terrain - 5 km spacing – 2% traffic growth



Rolling terrain - 10 km spacing – **2% traffic growth**



Rolling terrain - 20 km spacing – 2% traffic growth

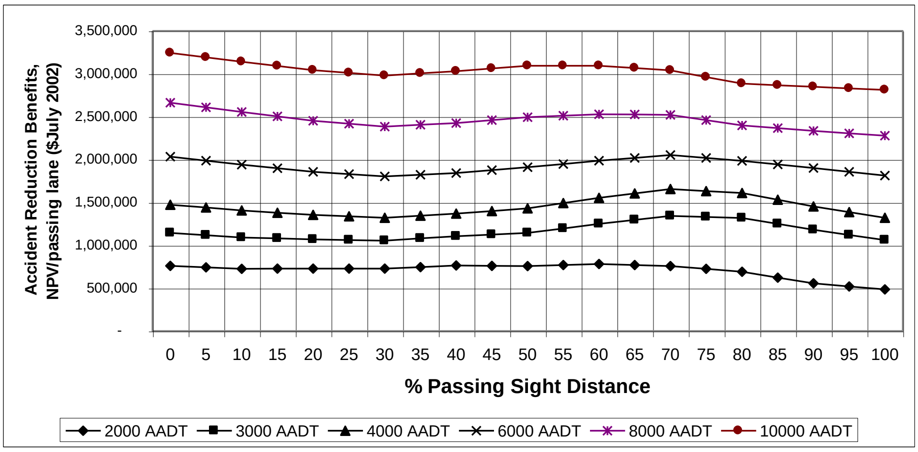
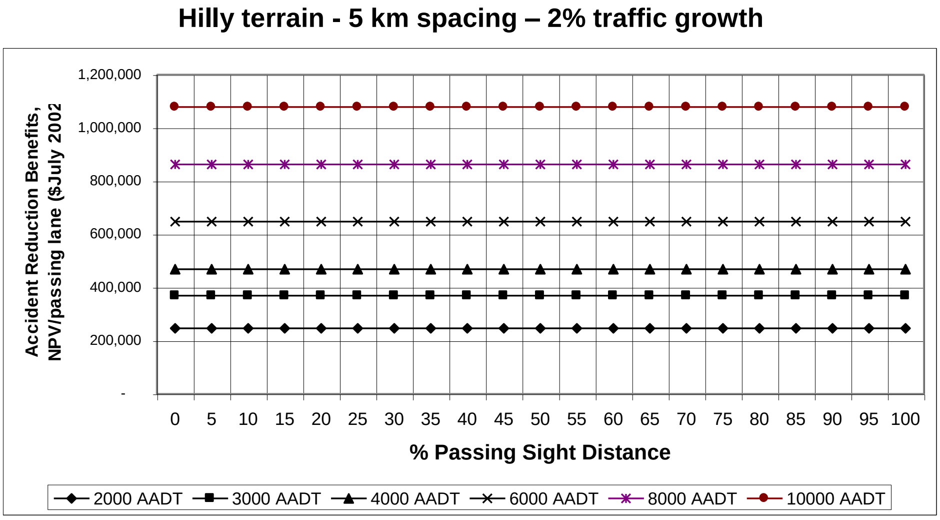
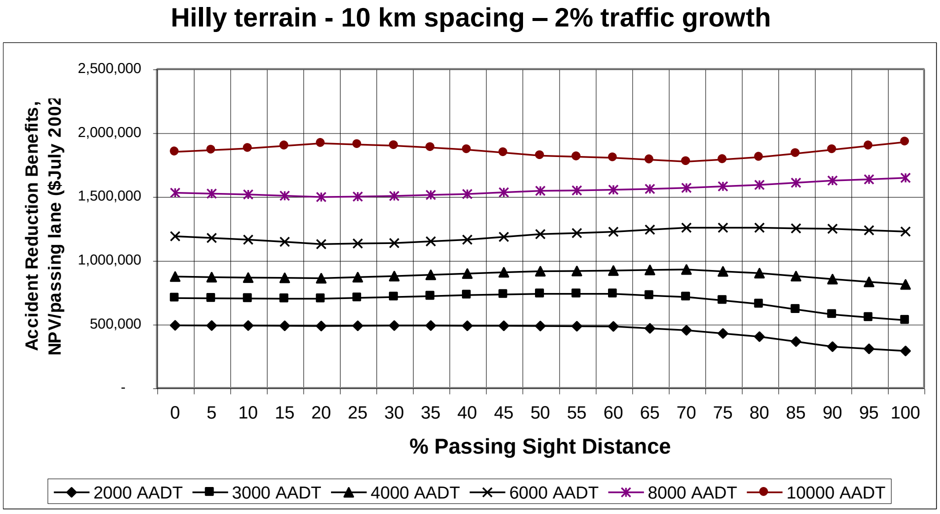


Figure A7.11 Graphs of crash savings for hilly terrain





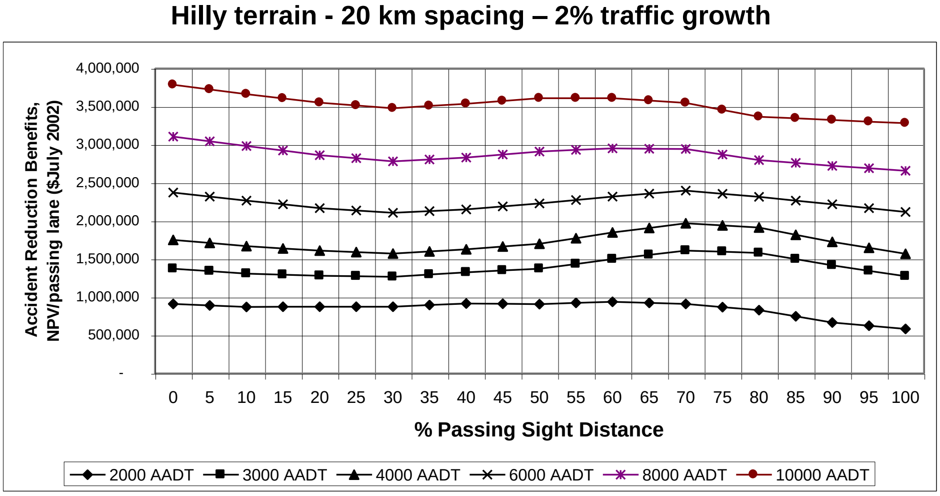
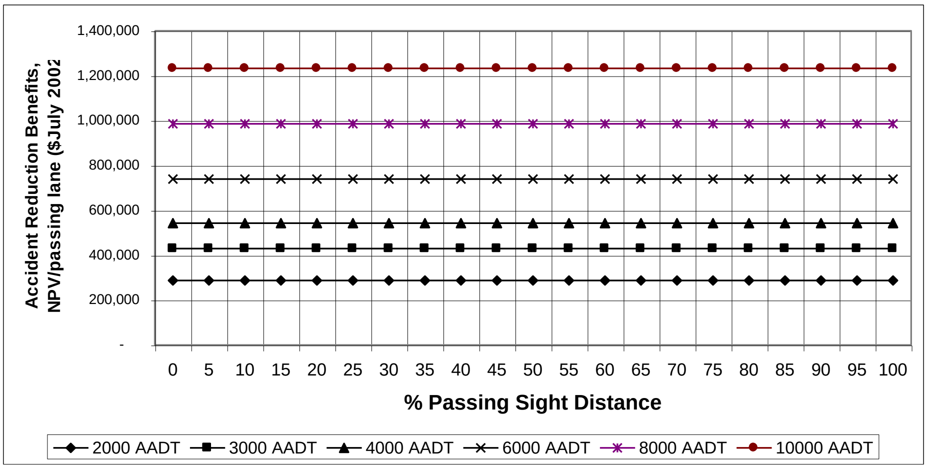
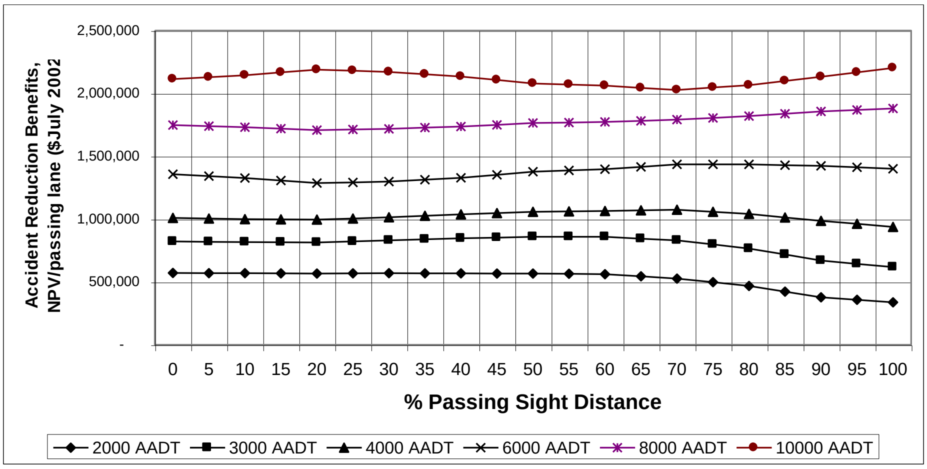


Figure A7.12 Graphs of crash savings for mountainous terrain

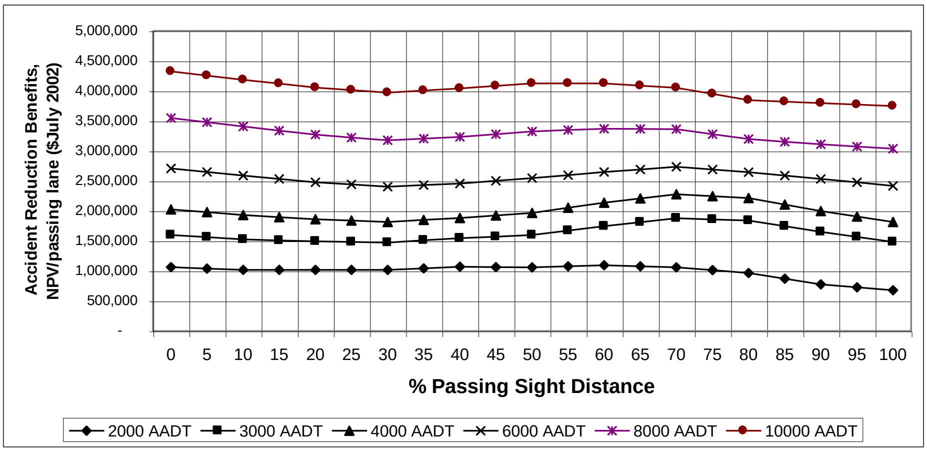
Mountainous terrain - 5 km spacing – 2% traffic growth



Mountainous terrain - 10 km spacing – 2% traffic growth



Mountainous terrain - 20 km spacing – 2% traffic growth



A7.5 Rural simulation for assessing passing lanes

Introduction

Due to the complex nature of vehicle interactions on two lane rural roads, traffic simulation programmes such as TRARR (or TWOPASS) should be used where a more detailed analysis is required or the costs of a passing lane project are very high. Rural road simulation should be used for:

- slow vehicle bays and climbing lanes at the scheme assessment stage
- locations where there are a large proportion of slow vehicles such as campervans, coaches or slow moving heavy vehicles.

Rural simulation can be used to obtain a more precise calculation of travel time and vehicle operating cost benefits resulting from passing lanes, particularly when the sites are constructed as part of road realignments. For strategic assessment of road links, rural simulation can also be used to evaluate the relative benefits of passing lanes at various spacing or where local circumstances suggest that these procedures may not be appropriate or the assumptions have been violated.

TRARR has traditionally been the rural simulation package used for evaluating passing lanes, however, other packages are also available and can be used. Koorey, (2003) discusses some of the advantages and disadvantages of TRARR and other packages. The following sub-sections describe analysis by TRARR as well as model calibration and validation.

Analysis using TRARR

TRARR requires particular care to accurately model traffic flows for both existing and proposed road layouts. The following notes are provided as a guide. Refer to Hoban *et al* (1991) for further details about the TRARR model.

- The modelled road section should include 2 km of road upstream of the actual passing site(s). The modelled road section shall, where appropriate, start and end at points where significant changes in the nature of the traffic stream occur, such as restricted speed zones (as in urban areas) and major intersections. The length of the road modelled downstream of the project end point shall be sufficient to ensure that traffic platooning differences between the do minimum and the passing lane option will have tapered out over this length. Depending upon the traffic volume, terrain and passing lanes downstream of the project section, this may be up to 10 kms.
- A sufficient range of traffic volumes should be modelled to adequately represent all existing and predicted traffic flows. The proportion of trucks to be modelled should be checked from traffic data, as it may vary with time of day or volume. For traffic flows of less than 50 veh/hr the benefits can be assumed to be negligible and not included if desired.
- Select a sufficient settling-down period to enable traffic (including the slowest vehicles) to fully traverse the modelled section.

- A New Zealand-based set of vehicle classes and parameters (as specified in VEHS & TRAF files) should be used for accurate representation of the traffic stream. Refer to Tate (1995) for examples.
- Suitable intermediate observation points should be specified to enable an accurate assessment of vehicle operating costs. The same points should be used for all options (except where realignments preclude this).
- Driver frustration benefits are derived from the ‘Time spent following’ information (given in the TRARR OUT file). Research by Koorey *et al* (1999) established a willingness to pay value for the provision of passing lanes of 3.5 cents per vehicle per kilometre of constructed passing lane (this is in addition to other benefits such as travel time savings). This benefit is applied to all vehicles that are freed from a platoon at the passing lane over the length they remain free from a platoon. The value of 3.5 cents/veh/km shall only apply to vehicles travelling in the direction of the passing site. The vehicle-km to apply the willingness to pay factor to shall be determined by multiplying the traffic volume by the analysis length and the change in time spent following.

  Example: TRARR is used to analyse 12 km of road.

  For a traffic volume of 200 veh/hr, the do minimum option gives 50% of time spent following.

  A passing lane option gives 35% of time spent following. The resulting veh-km to apply the willingness to pay value to, is: 200 □ 12 □ (50% - 35%) =
  360 veh-km/hr
- Crash benefits should be considered up to 10 km downstream of the passing lane depending on where the traffic platooning differences between the do minimum and the option have tapered out.

Calibration/ validation of TRARR

TRARR modelling requires care to ensure that it accurately models the actual rflows. Although Tate (1995) found that the relative changes were typically not as sensitive as the absolute values, it is desirable to match the two where possible. To this end, sufficient field data must be obtained to verify the models.

- The same random traffic generation shall be used for both the do-minimum and project options. Likewise, for each traffic volume, an equal number of vehicles (at least 1000) shall be simulated for each option.
- Field data must be collected on typical travel times along the modelled section, including intermediate points, for both cars and trucks in each direction. These should be used to calibrate the do minimum model, adjusting the TRARR desired vehicle speeds to replicate the observed travel time under the given volume. Overall modelled travel times should match to within 5%, while intermediate times should be within 10%.
- The proportion of bunching at the start and end of the modelled section should be collected, along with any desired intermediate points. This data should be calibrated against the do minimum model for the particular traffic volume by adjusting the TRARR initial bunching parameters and intermediate passing lanes. Modelled bunching values should be within 5% (absolute value) of the field data.
- Once calibrated the models may then be validated by assessing their performance against outputs measured under different traffic conditions. So if for example, calibration data was

collected when the average traffic flow was 100 vehicles per hour, the models may be validated by comparing the model outputs against field measurements taken when traffic volumes were 200 vehicles per hour.

Refer to Section 2.12 for further information on checking traffic models.

A7.6 Definitions

Bunching	The proportion of vehicles travelling behind others in platoons. Calculated as the ratio of following vehicles over total vehicles.
Climbing lane	An additional lane provided on steep grades where large and heavy vehicles travel at reduced speeds.
Desired speed	The speed that drivers would like to travel when not constrained by other traffic. This is largely dependent on the road alignment. Also known as free speed or unimpeded speed.
Following vehicles	Vehicles that are sufficiently close to the vehicle in front to be affected by the speed of the front vehicle. Vehicles with headways of less than 6 seconds are usually considered to be following.
Free vehicles	Vehicles able to travel at their desired speed. This includes vehicles on their own, ie, not part of a multi-vehicle platoon, and leading vehicles. Vehicles with headways of more than six seconds are usually considered to be free.
Headway	The amount of space between successive vehicles. Can be measured either by distance or time. Usually measured from the front of one vehicle to the front of the next.
Leading vehicles	The vehicle at the head of a multi-vehicle platoon. Leading vehicles are able to travel at their desired speed.
Merge area	The zone at the end of the passing lane where the two lanes taper into one.
Overtaking	An equivalent term for passing.
Passing lane	An additional lane, providing two lanes in one direction. A common form of passing lane. Typically 400m to 2km in length. Also known as auxiliary lanes or climbing lanes (on grades). For the purposes of analysis, the length of the passing lane does not include the end tapers.
Passing opportunity	Any measure designed to improve the likelihood of vehicles passing safely. These include passing lanes, slow vehicle bays, shoulder widening, and improved passing sight distance (eg, realignments).
Platoon	A group of vehicles clustered together (ie, small headways) and all travelling at approximately the same speed as the leading vehicle. Also known as queues or bunches. The size of the platoon is defined by the number of vehicles. A vehicle on its own is considered a platoon of size one.
Sight distance	The road distance ahead of the driver that is visible. This enables the driver to assess whether it is safe to pass. Refer to Austroads (2003) 'Rural road design' for further information, especially with regard to object and eye heights.
Slow vehicle	A short section of shoulder marked as a lane for slow vehicles to move over and let other

bay	vehicles pass. Typically up to 400m in length. Slow vehicles have to give way to the main traffic flow at the end of the bay.
TRARR	A rural road simulation package from ARRB transport research in Australia - the latest version is TRARR 4 (Shepherd, 1994). The name ‘TRARR’ is a contraction of ‘TRAffic on Rural Roads’. TRARR uses various vehicle performance models together with terrain data to establish, in detail, the speeds of vehicles at each location along the road. This establishes the demand for passing and determines whether or not passing manoeuvres may be executed. The outputs, mean travel times and journey speeds are used to calculate the benefits of various project options.

A7.7 References

References

1. Austroads, *Rural road design - guide to the geometric design of rural roads,* Sydney, 2003.
2. I Bone, S Turner, *Simplified procedures for passing lanes, Transit New Zealand report and supplementary report simplified procedures for passing lanes – further analysis (draft),* 2001.
3. C J Hoban et al, *A model for simulating traffic on two-lane roads: user guide and manual for TRARR version 3.2, technical manual ATM 10B,* Australian Road Research Board, Victoria, 1991.
4. G F Koorey, P M Farrelly, T J Mitchell, C S Nicholson, *Assessing passing lanes - stage 2,* Transfund NZ research report 146, 1999.
5. G F Koorey, *Assessment of rural road simulation modelling tools,* Transfund NZ research report 245, 2003.
6. R Shepherd, *TRARR 4 User manual,* Australian Road Research Board, Victoria, 1994.
7. F N Tate, *Assessing passing lanes - stage 1,* Transit NZ research project PR3-0097, 1995.
8. M J Thrush, *Assessing passing lanes,* Transit NZ research report 60, 1996.
9. A Werner, J F Morrall, *Unified traffic flow theory model for two-lane rural highways,* Transportation Forum, 1(3), pp.79-87, 1984.

A8 External impacts

A8.1 Introduction

Introduction

This appendix deals with externalities (both monetised and non-monetised), and guidance is given on how these effects may be assessed, quantified and reported.

For some of the external effects, eg, noise, a standard monetary value is provided. These monetary values can be included in the benefit cost ratio as a useful way of comparing projects and project options. The inclusion of any other monetary values for external effects must be clearly set out in the project summary sheet and in any funding application to NZ Transport Agency, and double counting of any benefits must be avoided.

Vehicle emissions impacts including CO_2 are contained in Appendix A9.

In this appendix

This appendix contains the following topics:

	Topic
A8.1	Introduction
A8.2	Road traffic noise
A8.3	Vibration
A8.4	Water quality
A8.5	Special areas
A8.6	Ecological impact
A8.7	Visual impacts
A8.8	Community severance
A8.9	Overshadowing
A8.10	Isolation
A8.11	References

Requirement to consider effects

There are requirements under both the *Resource Management Act 1991* and the *Land Transport Management Act 2003* to consider effects beyond those to the immediate users of transport facilities. The *Resource Management Act* requires a statement of effects of a project on the environment. All effects shall be fully described, including the scale and extent of the effects.

There are a number of evaluation factors against which project performance can be assessed. With respect to environmental sustainability, the evaluation factors can include the impact of a project on:

- air quality
- greenhouse gasses
- noise and vibration
- water environment (quality)
- landscape impacts, etc.

If there are significant effects that need to be taken into account in a project evaluation it is more appropriate for the analyst to use the full procedures rather than the simplified procedures.

The monetised and non-monetised impact summary sheet (worksheet A8.1) shall include all significant impacts identified in this statement of effects. Where there are no significant impacts this should be stated in the project summary sheet.

Extent of investigations required

The work required to describe and quantify monetised and non-monetised impacts will depend both on the likely severity of the effects and the difference between the effects of the existing situation and the effects of the various project options. It is possible that in some cases there will be no significant change to impacts resulting from a project. If this occurs, all that is required is a note to this effect.

If there is a significant difference between the monetised and non-monetised impacts of the project options, either in terms of their total effects or in the distribution of these effects, then these differences shall be described and where practicable quantified.

Where a project generates traffic the environmental effect of such induced traffic shall be assessed. An example may be a project to provide a shorter route. The fuel savings to existing traffic will provide environmental benefits (less emissions), but the shorter route may generate additional traffic, which in turn may have a negative environmental effect.

Wherever practicable, the scale of impact shall be measured in natural units, and the extent of the effects shall be quantified, eg, the number of persons affected.

In many cases, monetised and non-monetised impacts are not amenable to quantitative description. Accordingly, verbal qualitative descriptions shall also be presented, covering such issues as:

- historical background
- community attitudes
- characteristics of the area affected
- effects of the project.

Specialists in the appropriate disciplines may be required for the evaluation of significant monetised and non-monetised impacts. Public consultation and opinion surveys shall be undertaken for major projects.

Incremental analysis of additional project costs

Incremental analysis shall be undertaken to determine if the additional costs of higher cost options are justified by the additional benefits gained (refer to Section 2.8). This approach shall be used to assess the cost effectiveness of any features of projects included to mitigate monetised and non-monetised impacts. It is not appropriate to arbitrarily include a range of mitigation features as part of the basic project if these features are not essential to the project.

A8.2 Road traffic noise

Road traffic noise

Noise is a disturbing or otherwise unwelcome sound, which is transmitted as a longitudinal pressure wave through the air or other medium as the result of the physical vibration of a source. Noise propagation is affected by wind and intervening absorbing and reflecting surfaces, and is attenuated with distance.

Road traffic noise sources include:

- engine and transmission vibration
- exhaust systems
- bodywork and load rattle
- air brake and friction brakes
- tyre/road surface contact
- horns, doors slamming, car audio systems
- aerodynamic noise

Impacts of road traffic noise

Road traffic noise is generally continuous, and long term exposure can have significant adverse effects. These can be categorised as disruptive impacts, such as sleep disturbance and speech interference, and psychological impacts such as annoyance reaction and other behavioural impacts. While there is no evidence of permanent hearing loss from road traffic noise, there is a great deal of evidence to show that noise can cause adverse health effects in people due mainly to stress-related factors.

While the untrained ear will generally only detect noise level differences of three decibels (dB) or more, smaller increases will still affect people's wellbeing. To increase the noise level by 3 dB requires a doubling of traffic volume.

Design guidelines for road traffic noise

Design guidelines for the management of road traffic noise on state highways are given in *Transit New Zealand's Guidelines for the management of road traffic noise - state highway improvements*. These guidelines apply to noise-sensitive facilities adjacent to either new state highway alignments or to any other State Highway improvements, which require a new designation.

The assessment point at which the design criteria apply is one metre in front of the most exposed point on the façades of existing residential buildings or educational facilities. An exception is in the case of noise buffer strips where the assessment point is the outer limit of the buffer strip.

The two criteria in the guidelines, both of which apply, are:

- Average noise design criteria

  The average noise design levels for residential buildings and educational facilities at the assessment point are set out in table A8.1.

  If it is not practicable or cost effective to meet the average design noise criterion at the assessment point given in table A8.1, then the guidelines specify internal noise design criteria. These criteria apply to all living rooms (including kitchens) and bedrooms in residential buildings, or teaching areas in educational facilities, with windows closed on the exposed walls.

The internal noise level criterion for residential buildings is either the level given in table A8.1 minus 20 dB(A), or 40 dB(A) Leq (24 hour), and for educational facilities the internal noise level criterion is either the level given in table A8.1 minus 20 dB(A), or 42 dB(A) Leq (24 hour), in each case whichever is the higher.

Table A8.1 Average noise design levels (leq (24 hour))

Noise area	Ambient noise level (dB(A))	Average noise design level (dB(A))
Low Areas with ambient noise levels of less than 50 dB(A) Leq (24 hour)	Less than 43	55
	43-50	Ambient + 12
Medium Areas with ambient noise levels of 50 to 59 dB(A) Leq (24 hour)	50-59	62
	59-67	Ambient + 3
High Areas with ambient noise levels of more than 59 dB(A) Leq (24 hour)	67-70	70
	more than 70	Ambient

- Single noise event design criterion

A single noise event is the maximum noise level emitted by a single vehicle passing the assessment point.

Where the assessment point for residential buildings and educational facilities is less than 12 metres from the nearside edge of the traffic lane, the *Transit Guidelines for the measurement of road traffic noise - state highway improvements* require noise reduction measures to reduce noise by at least 3 dB(A). This is designed to provide a level of protection to properties from the noise effects of single vehicles.

Mitigation of road traffic noise impacts

There are various options for reducing the effects of road traffic noise. These include realignment to increase the distance between the roadway and the assessment points, noise buffer strips, barriers, alternative road surfaces (Dravitzki et al 2002 and 2004) and building insulation.

Where project optimisation requires noise mitigation measures, the cost of such measures will be identified and included in the project cost as discussed in Section 2.4.

Measurement and prediction of road traffic noise impacts

Traffic volumes used for noise predictions shall be based on forecasts of traffic flow 10 years after the completion of the project.

Equipment and methods for the measurement of noise shall comply with *NZS 6801: 1991 Measurement of sound*. Prediction of road traffic noise shall be carried out using the *United Kingdom Calculation of road traffic noise (1988)* method, calibrated to New Zealand conditions (refer to *Transit NZ Research report 28, Traffic noise from uninterrupted traffic flow (1994))* and converted to the appropriate Leq index.

The conversion formulae to calculate Leq values from the L10 values derived from the *UK Calculation of road traffic noise (1988)* method are:

Leq (24 hour)	=	L10 (18 hour) - 3 dB(A)
Leq (1 hour)	=	L10 (1 hour) - 3 dB(A)

Valuation of road traffic noise impacts

There have been no specific studies carried out in New Zealand to determine the cost of road traffic noise however there is evidence to suggest that road traffic noise levels of 53 to 62 dBA do encourage people to move out of an area more quickly (Dravitzki et al, 2001).

A British survey (1995) of international (predominantly hedonic price) valuations suggests that the costs of noise are approximately 0.7% of affected property values per dB. A Canadian survey (Bein 1996) found that hedonic pricing revealed typical costs of 0.6% of affected property prices per dB, and the OECD recommends noise valuation based on 0.5% per dB. Bein argues that the total costs of noise are much higher than the change in property values because:

- consumers may not consider the full effects at time of purchase (supported by a German study which showed increased willingness to pay with increased understanding of noise);
- effects on other travellers and on occupants of commercial or institutional buildings are not captured;
- hedonic studies typically consider values of homes which experience noise above and below certain levels (a German study shows increasing willingness to pay as base noise rises).

A reasonable figure for New Zealand is suggested as being 1.2% of value of properties affected per dB of noise increase, (0.6% multiplied by a factor of two to take into account the factors mentioned by Bein). Using average values for urban property of $450,000 and occupancy of 2.9 persons, this suggests a PV cost of $5,400 per dB per property and $1,860 per dB per resident affected ($350 per household or $120 per person per year). This figure should be applied in all areas, since there is no reason to suppose that noise is less annoying to those in areas with low house prices. It is arguable as to what range of noise increase the cost should be applied to, but a conservative approach would be to apply it to any increase above existing ambient noise. This reflects a belief that most people dislike noise increases, even if the resulting noise is less than 50 dB.

Costs of road noise shall be incorporated into the external impact valuation (worksheet A8.1) and valued at:

$350 per year x dB change x number of households affected.

Where noise affects schools, hospitals, high concentrations of pedestrians and other sensitive situations an analysis may be required to determine the cost of noise that is site specific. The methodology for undertaking a valuation of noise at sensitive sites should be appropriate to the site (ie, willingness to pay surveys may be appropriate for sites with high concentrations of pedestrians and inappropriate for hospital sites).

Reporting of road traffic noise impacts

The number of residential dwellings and the educational facilities affected by a change in road traffic noise exposure shall be reported in terms of:

- the predicted change from the ambient noise level
- the difference between the predicted noise level and average noise design levels given in table A8.1.

Predicted noise levels, which exceed the design guidelines given in *NZ Transport Agency's Guidelines for the management of road traffic noise - State Highway improvements*, shall be reported on the worksheet A8.3.

Where noise is a significant issue, plans shall be prepared distinguishing each type of land use. These plans shall show:

- contours of noise exposure in the do-minimum and for each project option, and changes in noise exposure in bands of 3 dB(A), ie, 0 to 3 dB(A), > 3 to 6 dB(A), > 6 to 9 dB(A)
- the number of residents in each band
- where the predicted noise level is above the average noise design levels given in table A8.1 or where the single event criterion should apply.

Where projects incorporate measures to mitigate noise, the incremental costs and benefits of these measures shall be reported. If appropriate these costs and benefits shall be reported for various levels of noise mitigation.

A8.3 Vibration

Vibration

Two types of vibration are evident alongside traffic routes; ground-borne vibrations and low frequency sound which can result in building vibrations.

The primary cause of ground-borne vibrations is the variation in contact forces between vehicle wheels and the road surface. The interaction between vehicle tyres and road surface irregularity can result in the release of significant energy. Therefore, roads with surface irregularities generate more vibrations than new, smooth roads. Once produced, ground conditions markedly affect the way in which ground-borne pressure waves are propagated. Also, distances between the road and dwelling locations will determine how much vibration energy actually reaches nearby properties.

Air-borne low frequency sound below 100 Hz can also induce building vibration. The primary cause of these vibrations is low-frequency vehicle-produced sound, which enters the building and can excite the building structure and/or the contents. This excitation at the natural frequency of the structure being excited is highly dependent upon the type of building structure, and its proximity to the road. In general, air-borne vibration is taken into account in the assessment of noise effects, ie, locations likely to experience significant air-borne traffic-induced vibrations are likely to have been assessed as high noise areas and the impact determined according to Appendix A8.2.

Traffic induced vibrations are evident in many parts of New Zealand and variations occur because of sub-soil geological factors such as high water tables, light volcanic sub-soil, or peaty soils. Generally the levels of vibration perceived will be a function of vehicle size, speed, proximity to the road, sub-soil geology, building characteristics, and sensitivity at the receiver location.

Impacts of vibration

The mechanism of vibration disturbance for persons inside a building is a complex combination involving structural vibration and low frequency sound which may be either heard or felt as a body vibration. Both forms of traffic-induced vibration may produce resonance, which is perceived as sound (eg, rattling of windows), or perceived as a body vibration. Such factors as the direction of the vibration, the frequency distribution of the vibrations, and the time history of the vibrations should be taken into account for a comprehensive assessment.

Two main attributes are used to assess vibration, these are peak particle velocity and acceleration. For particle velocity it is generally sufficient to assess the impact of traffic-induced vibrations. This is based on the premise that traffic-induced vibrations are ‘event based’ and not generally continuous in nature. Where traffic-induced vibrations are of a continuous nature detailed procedures for measurement and assessment are contained in such documents as *BS 6472:1992 Guide to evaluation of human exposure to vibration in buildings*.

Assessment criteria

The following two criteria are designed for the assessment of traffic-induced vibration for sporadic traffic events such as the passing of heavy vehicles in proximity to vibration sensitive locations (eg, residential housing, schools, hospitals, etc.) If the criteria for level one are met, then this shall be reported and no further assessment is required. If the criteria for level one are not met, a level two assessment is required which will involve a more detailed investigation.

Level one criteria

Traffic induced vibration is assessed as not likely to cause adverse reaction if all the following criteria are met:

- The minimum site-back distance between the building location and the nearside edge of the traffic lane conforms to the minimum distance of 12 metres specified in Appendix A8.2.
- The road surface is reasonably smooth and meets a set minimum NAASRA count level. In 100 km/h posted speed limit areas a minimum roughness guide is 100 NAASRA counts (3.8 IRI) and in lower than 100 km/h posted speed limit areas a minimum roughness guide is 120 NAASRA counts (4.5 IRI). A check should be made of local road surface conditions in the vicinity of residential areas (or other land uses likely to be sensitive to vibration, eg hospitals). Features such as poorly fitted manhole covers, slumped bridge abutments, or road surface repairs not vertically aligned with the true road surface level (eg by more than 20 mm or more) shall be noted, and a level two assessment carried out.
- The site is in an area not commonly known to experience traffic-induced vibrations. This will require a subjective judgement based on local knowledge. For example, it is known that the light volcanic soils of the central North Island volcanic plateau and the peaty soils (with a high water table) in low lying areas of Christchurch city cause vibration impacts.

Level two criteria

For sites that do not meet the level one criteria a more detailed assessment is required as follows:

- Vibration levels shall be measured to determine the level of effect. Vibration measurement equipment usually consists of a transducer or pick-up, an amplifying device, and an amplitude or level indicator or recorder.
- Vibration levels shall be measured at a representative position on the floor level of interest in a room that is normally occupied in a dwelling, or other building in which an assessment is required (eg hospital).
- The peak particle velocity shall be measured during normal traffic conditions, especially during the passage of heavy vehicles past the site. Several recordings shall be made, and the highest particle velocities recorded.

The following guideline levels shall be used in the assessment of vibration effects:

- minor impact 2 to 5 mm/sec
- major impact 5 mm/sec or greater

During measurements an inspection of the building for cracks and other building damage likely to have been caused by traffic-induced vibrations shall be noted and reported.

Mitigation of vibration impacts

There are a limited number of options for reducing the effects of vibration. These include:

- structurally isolating houses from concrete driveways;
- the use of effective noise reducing fence designs;
- smoothing the road surface to mitigate wheel bounce and body pitch
- road realignment to increase the distance between the roadway and the building; and
- re-routing heavy vehicles to less sensitive roads or reducing the speed of heavy vehicles.

Reporting of

In New Zealand it is anticipated that the quantifiable disbenefits of vibration will be very much

vibration	site specific and apply in situations such as roads near historic buildings and to road construction in densely populated urban areas. In general, the number of buildings exposed to significant vibration (and an estimate of the numbers of people affected) shall be identified and recorded on maps. For a level one assessment the report should include the locations assessed and an explanation of the reasons why the level one criteria has been met. For a level two assessment the report shall contain a summary of the method, locations, and measurement results together with an assessment of whether either of the minor or major impact levels have been exceeded. Measurement results for one or two locations can be used to interpret the likely impact for other buildings of similar construction, and at similar distances from the nearside edge of the traffic lane.

A8.4 Water quality

Water quality

Water quality is affected by:

- short term impacts during construction such as modifications of river channels, and lake or sea beds causing interruption or change to natural flows and the release of sediment downstream caused by disturbances from engineering works
- permanent modifications of river channels, and lake or sea beds, caused by engineering works, and modifications in ground water levels caused by aquifer penetration and changes in permeability or the shape of the ground surface
- increased discharges resulting from modifications of natural flows caused by faster rates of run-off from paved surfaces and the use of storm water drains and channels
- pollution of surface water and ground water.

Impacts on water quality

Potential impacts include the following:

- surface water pollution from surface run-off or spray. Potential pollutants include suspended solids, lead and other heavy metals, organic materials (such as rubber, bitumen and oil), salt and herbicides or pesticides (from roadside maintenance)
- surface water pollution from accidental spillage which is potentially very damaging
- ground water pollution from either soakaways which discharge directly into ground water or surface waters which find their way into aquifers. Pollution of ground water can also occur when road construction disturbs contaminated ground
- changes to water flows or levels which can increase the risk of flooding, interfere with aquifers, and affect the ecology of surrounding areas.

Mitigation of impacts on water quality

Avoidance and mitigation of some effects is possible through a wide variety of measures including bunding, vacuuming and filtering during construction; stormwater run-off management using marginal strips along roads that provide for infiltration; and emergency management such as sealing of drains and collection of clean-up materials. For more detailed guidance on erosion and sediment control of earthworks refer to the *Auckland Regional Council publication Erosion and sediment control guidelines for earthworks, 1992*.

The assistance of regional councils shall be sought where appropriate on the water quality and the hydrological regime within the road corridor, and to obtain further advice on the mitigation of impacts.

Measurement of impacts on water quality

All water effects are directly measurable through clarity and volume measurements (sediment), chemical analysis (water pollution), flow measurements (change in run-off rates), physical observation (some surface pollutants), and ground water level measurements. Appropriate measurement techniques are well established, and should be applied to determine the effects of road projects (Kingett, Mitchell and Associates 1992).

Prediction of impacts on water quality

If the impacts on water quality are significant reference shall be made to an appropriate design manual, eg, *UK Manual Design manual for roads and bridges, volume 11, Environmental assessment, part 10 - Water quality and drainage* or an equivalent.

Reporting of impacts on water quality

The expected short term construction effects and permanent effects of projects on water quality shall be reported. This reporting shall include effects on ground water and natural water courses and levels, and the pollution effects of surface water run-off and potential accidental spillage.

Where projects incorporate measures to mitigate the effects on water quality, the incremental costs and benefits of these measures shall be reported.

A8.5 Special areas

Special areas

Projects may affect special areas either physically or by their proximity to such areas. These areas include:

- sites of cultural, spiritual, historic, aesthetic and amenity value including sites with historically, culturally or architecturally significant buildings, or sites of former buildings, and their environs
- archaeological sites, waahi tapu (sacred sites) and other sites of special importance to tangata whenua (people who hold customary authority over a particular area), including places at which significant events took place or are commemorated
- sites of special ecological, botanical, geological, geomorphological, or other scientific values, including rare landforms, either natural or modified, of special scientific or archaeological interest or cultural association. (For special ecological areas refer to Appendix A8.6)
- important recreational areas including wilderness areas which derive special value through being little modified by human intervention.

Projects that affect these features either physically or by their proximity shall include consideration of such effects in the evaluation. These considerations will often involve Maori values, which have a special place in New Zealand law and custom.

Sources of information

The principal sources of information on special areas are:

- Regional and District Planning Schemes, which identify areas with special community values under such headings as ‘listed buildings’, ‘identified sites’, ‘protected trees’, and ‘protected ecological areas’
- the Department of Conservation, which maintains a database of sites of archaeological and cultural significance
- the Historic Places Trust, which keeps a record of historic sites, including sites with and without legal protection.

There are sites and areas which can only be recognised through local knowledge. Examples are locally important recreational areas.

Waahi tapu are a special group. It may not be possible to readily identify the exact site or locality affected but consultation with those who hold mana whenua (customary authority) in the area will advise on the presence of waahi tapu. For guidance on consultation with tangata whenua refer to your regional NZ Transport Agency representative.

Impacts of land transport projects on special areas

The impact of road projects on special areas can be direct, completely or partially destroying the site; or indirect, detracting from the values for which the site is considered special. Examples would include removal of a historic building from its original location and disturbance of waahi tapu.

Assessment of impacts on special areas

The value that a community places on a particular site will be specific to the site. This value can only be determined by experts who have knowledge of the site features. The value may be reflected by legal protection or planning classification, or through writings and traditions of the community and its institutions, but these sources cannot be relied upon alone.

Assessments of the value of special areas shall also include a process of public consultation. It is important to establish the relative importance that people place on different aspects of the project's impact on special sites and features.

Reporting of special areas

Any special areas affected shall be identified, described and, if appropriate, mapped. The expected impacts shall be described and community attitudes to these impacts on special areas shall be reported. The sources of information on special areas shall be indicated.

Where projects have been modified to protect or enhance special areas, the incremental benefits and costs of these measures shall be reported.

A8.6 Ecological impact

Ecological impact

The direct effects of roads on the human ecosystem are dealt with under noise, air pollution, visual impact and other sections of this appendix. This section is to give additional guidance on handling wider ecological impacts.

Ecology is the scientific study of interactions between and connections between organisms and their environment. Ecological studies are concerned with processes in ecosystems and with the interactions that determine the distribution and abundance of organisms. In ecology, many levels of organization are recognized and these include: ecosystems, biological communities, habitats, species and populations. A population is a group of organisms of the same kind (species) living in the same location (the habitat); for example, beech tree populations and earthworm populations. A habitat is the locality or site occupied by organisms and the term is sometimes used in connection with populations. A biological community is a group of populations of various species living and interacting together in a given place. Communities may be classified according to the dominant plant groups or most noticeable features: thus wetland communities, forest communities, pond communities, and rotting wood communities.

An ecosystem is the combination of biological communities, the physical environment (soil, water, air) and the processes contained therein. They consist of biological entities (animals, plant and other organisms) and most importantly the processes (energy flow, water, CO_2, mineral cycles). At a Department of Conservation workshop (27-28 April 1995) it was generally agreed that ecosystems could not be mapped because they have no boundaries. The use of 'ecosystem' is sometimes confused or equated with 'biological community' (which can be mapped).

Ecological impacts of land transport systems

Different ecological impacts may occur during the construction phase and the operational phase. The impacts will not be constrained within the boundaries of the operations or the finished product. The following is not comprehensive but could be used as a guide to identifying the types of ecological impacts.

Effects within the operation and use area;

a. Direct habitat loss

   Populations, habitats and biological communities may be damaged, reduced in extent and completely lost. Organisms will be lost and some entire populations or even species may become extinct.

b. Fragmentation and isolation

   Equally important is fragmentation and isolation. That is, a transport system may divide and separate a population or a biological community. Populations and communities may also be wholly or partially isolated. Direct physical and chemical effects caused by the transport system.

c. Change in microclimate (light, moisture wind)

   Will cause extinction of some populations. New organisms will colonise the new conditions.

Effects beyond the operation and use area:

- Facilitation of dispersal (along the transport route), of organisms which do not naturally occur in the area of the project. A road provides new conduits for dispersal of organisms not normally found in the area; these may include invasive, exotic species, which may impact on the local biological community. Similarly, vehicles and people travelling along transport systems may inadvertently help to disperse organisms (including invasive and pest species) along new projects.

- Any alterations to the land will affect the soil, local climate and local physical and chemical conditions. Pollution from land transport systems may include sediments, hydrocarbons, metals, salt and nutrients and microbial organisms. Noise, dust, heavy metals and organic material may penetrate nearby biological communities and may also be transported along water systems. This in turn will affect individual organisms and biological communities beyond the transport system.

Increased accessibility to regions resulting in impacts from humans and activities.

Process for identifying impacts

The geographical extent of the impacts

Impacts may have direct and indirect ecological effects beyond the transport system. It is advised therefore that the geographical boundary for identifying ecological impacts be stated. It may also be important to state the time scale over which ecological effects are to be considered and how significant the effects are likely to be.

Designated, protected areas and protected species

These should be identified. Similarly, any indigenous species, biological community or any other aspects of an ecosystem of 'significance' (locally, regionally, internationally) should be identified. 'Significance' could be interpreted as being defined in law or it could be defined in terms of local community perceptions of what is significant.

Determining what is present in the area of the project

Information on what is present has to be obtained before the nature of ecological impacts can be considered. Information about what is present (species, communities etc) may come from direct surveys or existing information. It is not practical to obtain information about all organisms and all aspects of the ecology of the area (because of the limited time scales and because of the range and variety of different levels of biological diversity within an ecosystem or biological community). Therefore expert advice should be obtained about which organisms (groups or taxa) or aspects of ecology should be noted. This information might relate to a specific indigenous species or to a particular ecological process such as nutrient cycling within forest communities.

Quantifying and qualifying the impacts

It is not practical to assess all impacts within the stated geographical boundaries and time scales. It is also not possible to fully quantify all impacts because of lack of knowledge of how impacts affect species, habitats, communities or ecosystems. Therefore, the record of impacts will include general as well as specific information.

Mitigation and ecological restoration

Measures that can be introduced to limit the effects or restore components of ecosystems once the project is in place, and the cost of such measures are to be calculated.

Reporting ecological

Potential sources of information should be identified. These may include government departments, regional and territorial authorities, environmental agencies, centres of education

impacts

and local groups and experts.

The following should be reported:

- designated areas, protected areas and protected species should be identified. Similarly, any species, biological community or any other aspects of an ecosystem of significance (locally, regionally, internationally) should be identified
- geographical boundary, time scale and how significant the impacts are should be stated
- biological communities should be identified (using agreed ecological classification methods) and mapped
- any statutory requirements to liaise with certain groups or agencies.

Ecological surveys should be based on standard ecological field methods. The results should include an assessment of the limitations of the methods. It is impractical to survey all organisms and all components of ecosystems, therefore a selection has to be made and the rationale for that selection should be stated. It is also not practical to assess all impacts on all components of all ecosystems, therefore a selection has to be made and the rational for that selection should be made clear.

Estimates should be made of the likelihood of components of ecosystems recovering (following construction of roads and other infrastructure) and the time scale for recovery. Where projects have been modified to protect or enhance components of ecosystems, the incremental costs and benefits shall be reported.

A8.7 Visual impacts

Visual impacts

Landscape values are very subjective and the appearance of man-made structures in a natural setting may be pleasing to some and displeasing to others.

Roads that conform to the contours of the land are generally less intrusive than those through cuttings or on embankments.

In the urban landscape, the roadway is more than just a route for road vehicles; it is a public area for pedestrian movement and social intercourse, it allows light and air between buildings, and permits a view of the surroundings. Landscape elements such as proportion, exposure and enclosure, contrasts, long and short views, colour and lighting, hardness and softness of line, and architectural style all mix together to create the overall visual impact.

The negative visual amenity from living close to a traffic stream includes loss of privacy, night time glare from streetlights and passing vehicle headlights.

Visual impacts of roads

Visual impacts may be conceptually divided into:

- visual obstruction
- visual intrusion
- view from the road.

The visual impacts of roads and structures can be described as obstructive, in so far as they block the view, or intrusive when their appearance jars with the surroundings. Obstruction is more likely to be encountered in an urban setting.

In some cases a route may pass through an intrinsically attractive area and here the view from the road would be a consideration. The aesthetic appearance of urban and rural roads to road users should also be considered.

Mitigation of unattractive visual impacts

For projects which will significantly change the landscape, any aesthetic treatments based on impact assessments should be incorporated within the planning and design stages. Direct input of community values should be sought, given that visual impacts have a significant cultural component.

Assessment of visual impacts,

Visual impacts shall be assessed as follows:

a. Visual obstruction

   The magnitude of the visual impact caused by an obstruction depends on:

   - size of the obstruction in relation to the viewing point
   - quality of the view being obstructed
   - visual quality of the obstruction
   - numbers of people or properties affected by the obstruction.

   The size of an obstruction can be dealt with by physical measurement. This requires the identification of viewpoints and a measure of the degree of obstruction received.

b. Visual intrusion

This relates to the appearance of the landscape and is a broader concept than visual obstruction. Numerical predictive methods of measuring visual intrusion have so far not achieved general acceptance. Therefore, the appraisal of visual intrusion shall be based on subjective assessments of the appearance of the different options.

The existing scene can be observed but the proposed scene can only be imagined or represented either as artist's impressions, photomontage or physical modelling. Photomontage can now be generated quite realistically by computer image processing.

Perceived loss of amenity by persons located close to a road and its traffic, and loss of privacy, night-time glare from streetlights and vehicle headlights also constitute visual intrusion.

c. View from the road

The types of scenery and the extent to which travellers are able to view the scenery need to be considered. Many New Zealand roads pass through scenic areas but, having numerous sharp curves, create a conflict for the driver between viewing the landscape and concentrating on safe driving. Changes resulting from the project can be presented either as artist's impressions or photomontage.

Reporting of visual impact

The visual obstruction and intrusion of projects shall be reported including, where appropriate, artist's impressions of the project and the numbers of people affected. The view from the road shall be reported in terms of the quality of scenery visible from the road and the types of people expected to benefit. Where artist's impressions or photomontage are used to assist description, care shall be exercised to give a realistic impression of the project.

Where projects have been modified to protect or enhance their visual impact, the incremental costs and benefits of these measures shall be reported.

A8.8 Community severance

Community severance

Community severance is the dislocation and alienation a community feels as a result of roads which sever communities or hinder access. It includes the effect of traffic on security and mobility of people, particularly pedestrians and cyclists and the consequential effects on their movement patterns and interaction.

Impacts of severance

The effects of severance are initially experienced as increased travel times, and difficulty and anxiety in crossing or travelling alongside the road. The results of severance in the longer term are diversion of movements to other, possibly longer routes, and to alternative and possibly less favoured destinations, and the suppression of trips altogether. The degree of effect varies with a person's age, being more severe for children and the elderly. Also the effects of severance can become worse over time as a result of traffic growth on a route.

Assessment of severance impacts

The effects that need to be identified are the suppression of trips, the choice of less favoured destinations, the general feeling of dissatisfaction as a result of severance including the effects on pedestrians and cyclists by proximity to traffic, and changes to neighbourhood and community structures. To quantify these effects requires information on existing patterns of land use and community structures and interactions, particularly in relation to community facilities such as school, neighbourhood shops, outdoor recreation areas, public transport stops and places of work. Some changes in severance effect can be evaluated in a similar way to road traffic by calculating changes in travel times for pedestrians and cyclists and applying the travel time values given in this manual.

For existing traffic routes, severance impacts can be considered on the basis of increased or reduced costs to existing pedestrians crossing the road. The analysis should take account of any additional distance required to walk to a controlled intersection, the time spent waiting to cross and the crossing time. The extreme case of severance is a motorway with fenced reserves, which poses considerable barriers to vehicular traffic as well as pedestrian and cycle traffic. The degree of severance experienced will depend on the number and location of vehicular and pedestrian crossing points.

Reporting of severance effects

Any areas affected by severance shall be identified, described and, if appropriate, mapped. The location of community facilities and the effects of the project on the accessibility of these facilities, particularly for pedestrians and cyclists shall be reported. Travel time changes for cyclists and pedestrians should be included with other road user costs in the economic evaluation.

Main crossing points shall be marked and the numbers of crossing movements indicated. In the case of projects, such as motorways, which create major barriers, their effects on overall community structures shall be reported. Where projects have incorporated features to reduce community severance, the incremental costs and benefits of these measures shall be reported. The benefits of reduced travel times, particularly for pedestrians and cyclists, and crash savings, shall be quantified to determine incremental BCRs of these factors.

A8.9 Overshadowing

Overshadowing	Overshadowing refers to the shadows cast onto adjoining properties. It is analogous to the overshadowing effects of buildings, which are covered by the rules in district plans through daylight admission controls restricting the height and location of building development on individual sites. The overshadowing effect is also analogous to the overshadowing effects of trees on neighbours, where enjoyment of property and personal health is protected by the provisions of the *Property Law Amendment Act (1984)*.
Impacts of overshadowing	Where a structure, such as an embankment or overhead bridge, reduces the amount of direct sunlight on an occupied property, overshadowing has a negative impact. Positive benefits due to an increase in direct sunlight on occupied properties may accrue from the removal of buildings or structures.
Measurement of overshadowing	The changes in shadows cast by a structure shall be calculated from azimuth and altitude data for the sun during the year at the site's particular location. This shall be expressed in contours of sunshine hours lost or gained per year. An adjustment would be necessary to compensate for the average amount of cloud cover in a year, which will reduce the hours of direct sunlight.
Reporting of overshadowing	The properties affected by overshadowing shall be identified, with a description of these properties and the predicted extent and effects of overshadowing. Where projects have been modified to mitigate the effects of overshadowing, the incremental benefits and costs of these measures shall be reported.

A8.10 Isolation

Isolation

Isolation occurs when people are unable to access normal community facilities or where there are long distances to travel to these facilities. Isolation may arise because:

- roads are unreliable
- people live in remote areas.

Impacts of isolation

The impacts of the above two aspects of isolation are as follows:

- Areas may be isolated by road closures caused by flooding, slips, collapses of bridge structures, etc. Areas served by only one road are particularly vulnerable to road closures but potentially access to and from major towns and cities can also be disrupted by events such as flooding and major earthquakes. The impacts of these road closures are firstly that people and businesses are unable to undertake normal activities and secondly there is the potential of being unable to deal with emergencies. In situations where road closures occur frequently, the threat of road closures may also create a sense of insecurity.
- In the case of remote areas, people generally live there by preference. Thus the only case where a valid benefit for isolation shall be claimed is where an existing link has been cut, eg where an existing bridge gets washed away. In this case the project to replace the bridge would produce benefits in terms of reducing unwanted isolation.

Reporting of isolation

In the case of unreliable roads, isolation shall be reported in terms of:

- the number of residents affected by road closures
- frequency and duration of road closures
- availability of alternative routes, particularly for emergencies
- degree of disruption caused by road closures, eg to commerce and to commuters and school children.

In the case of remote areas threatened with isolation, isolation shall be reported in terms of:

- number of residents in the remote area
- additional distance to community facilities by alternative routes
- visitor and tourist potential of the area.

Where projects reduce isolation or the threat of isolation, the benefits shall be quantified, where possible.

A8.11 References

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A9 Vehicle emissions

A9.1 Introduction

Introduction

This appendix gives guidance on calculating vehicle emissions such as carbon dioxide and small particulates and the impacts for the do minimum and project options.

Carbon dioxide emissions are linked to fuel consumption through vehicle operating costs, while other emissions can be calculated using the procedure provided in this appendix.

In this appendix

This appendix contains the following topics:

A9.2 Vehicle emissions

Vehicle emissions

Vehicles with internal combustion motors emit gases and particles into the environment. These pollutants include:

- carbon dioxide (CO_2)
- carbon monoxide (CO)
- oxides of nitrogen (NOx)
- unburnt hydrocarbons (HC)
- lead compounds
- particles such as smoke, tyre and brake wear products.

Air pollution from vehicle emissions may be significant if one or more of the following conditions apply:

- still weather conditions, in which pollutants do not readily disperse
- bright sunlight and temperature inversion which lead to photochemical smog
- high traffic densities and stop/start operations
- confined urban streets with activities such as retail developments in close proximity.

New Zealand cities do not suffer from air pollution to the extent of some overseas cities but temperature inversion and still weather conditions can combine to cause noticeable pollution.

Impacts of air pollution

The effects of air pollutants vary. Some are toxic in high concentration, some aesthetically disagreeable and the persistent gaseous products gradually change atmospheric composition.

Carbon monoxide is dangerous in high doses and can be responsible for chronic effects such as loss of concentration, impairment, tiredness and headaches. However, small doses are removed from the bloodstream when the person affected moves to a cleaner environment. Photochemical oxidants, including nitrogen dioxide can be irritating to the eyes and respiratory system. Unburnt hydrocarbons, particularly benzene ring aromatic compounds that occur in diesel engine emissions, are believed to be carcinogenic. Smoke particles and odours can be offensive but of lesser health significance.

Some pollutants such as lead persist in the environment whereas others like carbon monoxide disperse and undergo chemical change.

Small particles (those less than 10 microns in diameter) from fuel, tyres, exhaust gases, dust, etc, remain airborne for up to 10 days and even in relatively calm conditions will disperse widely through a city. These particles are strongly implicated in respiratory and other infections and as a result there have been suggestions that the public health costs of this pollution are higher than most other traffic-related environmental costs in urban areas.

Design guidelines

The Ministry for the Environment (MfE) in 2002 published ‘ambient air quality guidelines’ which are consistent with World Health Organisation goals. A summary of the guideline values relevant to motor vehicle emissions is shown in table A9.1. The guidelines can be seen as levels, which are consistent with an ‘acceptable’ public health cost, but simply to meet these guidelines does not imply zero public health cost. Also regional councils may set secondary guidelines to deal with other air quality effects, such as visibility.

Note: The air quality guidelines also consider higher concentrations for shorter periods.

Table A9.1 Guidelines for motor vehicle emissions

Pollutant	Period of exposure	Mean concentration mg/m^3
Carbon monoxide (CO)	8 hour	10
	1 hour	30
Nitrogen oxides (NO_x)	24 hour	300
	1 hour	100
Lead	90 days	0.2
Particulates (PM_{10})	1 year	20
	24 hour	50
Sulphur dioxide	1 year	350
	24 hour	120
Ozone	8 hour	100
	1 hour	150

Mitigation of air pollution

Pollution control is best tackled by reducing vehicle exhaust emissions. Elimination of leaded petrol in New Zealand has been completed. Therefore, long-term exposure to lead will diminish. The focus is now turning towards improved vehicle emissions standards for new vehicles and vehicle screening. Potential mitigation measures available to road designers include increased separation distances between road and receptors, land-use controls, careful placement of intersections, and traffic management techniques aimed at maintaining free flow speeds (Transit NZ 2003).

If the concentration of toxic pollutants resulting mainly from motor vehicles exceeds the levels shown in the table A9.1, then there is a strong prima facie case for remedial action. Even where concentrations are lower than in table A9.1, there are likely to be benefits of pollution reduction. The practical application of this may mean reducing traffic volumes and stop/start conditions, or improving the ventilation of affected areas.

Assessment of air pollution

An indication of pollution levels can be obtained from one of several pollution prediction methods. These allow the concentration of pollutants to be estimated from traffic volume and speed, and the distance from the roadway to the point of measurement based on the characteristics of the New Zealand vehicle fleet (Ministry of Transport, 1998).

Recommendations on the most appropriate form of assessment in particular circumstances are currently being prepared (SKM, 2003) and recently good practice guidelines have been issued by the Ministry for Environment covering, the preparation of emissions inventories (MfE, 2001), atmospheric dispersion modelling (MfE 2004) and air quality monitoring (MfE, 2000). Contacting the appropriate regional council may be useful as they sometimes carry out air pollution analysis, eg, using emission inventory techniques.

A9.3 Vehicle emissions procedure

Calculating ambient air emission loads

This procedure has been developed from the Ministry of Transport vehicle fleet emission model and can be used when ambient air quality emission calculations are required. It provides emission estimates for carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM10) and volatile organic compounds (VOC). Procedures for CO_2 emissions are provided in appendix A9.7. Follow the emission procedure below to calculate the emission loads for each road link and time period.

Emission procedure

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td>1</td><td colspan="2">Determine the:
• Traffic composition (Appendix A2.2)
• Time period total average travel time per vehicle (Appendix A3.26)</td></tr>
<tr><td rowspan="4">2</td><td colspan="2">Convert the traffic composition vehicle classes into emission classes:</td></tr>
<tr><td>Emission class</td><td>Vehicle classes (Appendix A2.2)</td></tr>
<tr><td>Light
(vehicles less than 3.5 tonnes)</td><td>Passenger Cars
Light Commercial Vehicles</td></tr>
<tr><td>Heavy
(vehicles greater than 3.5 tonnes)</td><td>Medium Commercial Vehicle (MCV)
Heavy Commercial Vehicle I (HCVI)
Heavy Commercial Vehicle II (HCVII)
Buses</td></tr>
<tr><td>3</td><td colspan="2">Calculate average speed on link road:
Speed (km/h) = 60 x length / TT
where:
length = road link length (km)
TT = time period total average travel time per vehicle (Appendix A3.26)</td></tr>
</table>

Step	Action
4	Calculate the emission rates for light and heavy vehicle types: Emission (g/vkt) = $A \times Speed^2 + B \times Speed + C$ where: Speed = average speed on link road from step 3 A, B, C = coefficients from table A9.2 below

Emission	Vehicle	A	B	C
CO	Light	3.6×10^{-3}	-0.545	25.5
	Heavy	6.47×10^{-4}	-0.11	7.31
NOx	Light	2.46×10^{-4}	-0.0287	1.67
	Heavy	2.04×10^{-3}	-0.275	17.4
PM10	Light	2.45×10^{-5}	-0.00342	0.153
	Heavy	3.82×10^{-4}	-0.0455	2.65
VOC	Light	5.53×10^{-4}	-0.081	3.55
	Heavy	3.07×10^{-4}	-0.0584	3.30

Step	Action
5	Weight the calculated emission rates by vehicle flow composition (g/vkt): = % light vehicles x light emission rate + % heavy vehicles x heavy emission rate
6	Multiply the weighted emission rates by the time period's total vehicle volume and the road's length to give the emission load (g).

Example

For a 1 km road with 1000 vehicles travelling along it with a calculated travel time of 2.371 min/veh and a vehicle flow composition of 95% light and 5% heavy.

Speed	=	1 x 60 / 2.371 = 25.3 km/hr
Light CO	=	$3.6 \times 10^{-3} \times (25.3)^2 - 0.545 \times (25.3) + 25.5$
	=	14.0 g/vkt
Heavy CO	=	$6.47 \times 10^{-4} \times (25.3)^2 - 0.11 \times (25.3) + 7.31$
	=	4.9 g/vkt
Weighted CO emission rate	=	95% x 14.0 + 5% x 4.9
	=	13.5 g/vkt
CO emission load	=	weighted CO emission rate x vkt
	=	13.5 x (1 km x 1000 vehicles) = 13500 g

A9.4 Valuation of emissions

Valuation of emissions

Mortality costs have been estimated as a 0.101% increase in daily death rates for a 1 microgram per m^3 increase in PM10. Based on UK costs (assuming similar death rates and adjusting for New Zealand costs of life), the annual mortality costs in New Zealand are $30 per person exposed per year per microgram/m^3 increase in PM10. This figure can be increased by 30% (based on US and French contingent valuation studies) to take account of poorer health amongst those who do not die, to give a total annual cost of $40 per person per year per microgram/m^3. By contrast, health costs of ground level ozone are believed to be an order of magnitude less.

There are major problems in assessing the meaning and usefulness of these values in the New Zealand environment. Firstly, the death rates do not increase linearly with pollution, and most parts of New Zealand are likely to have far lower rates of pollution than Europe. Secondly, the impacts will be highly site-specific.

Figures for New Zealand need to be based on specific locations. The cost shall be calculated as:

0.001 x △PM10 concentration x population exposed x normal death rate x value of life.

Where: △PM10 concentration is the change in average concentration for the period analysed.

Other research (Bein) suggests that a light vehicle travelling at 40 km/h has particulate costs of approximately NZ1.0 cents per km (C$0.006 mortality + morbidity costs). A heavy vehicle has costs of approximately NZ20 cents per km (C$0.14 + morbidity). Note that the high heavy vehicles cost is for diesel engines and petrol engines impose only 20% of the cost. These per km costs should be used in assessing the negative effects of generated traffic in urban areas. In particular they should be used for studies of major changes to urban traffic networks which increase traffic into urban areas or which reduce traffic by increasing public transport.

Particulate effects are likely to be of most significance in comparing alternative urban transport proposals, and in modelling the effects of motorways where these increase traffic (and hence fuel use) in urban areas.

A9.5 Emissions reporting

Reporting of emissions

Expected effects of projects on air pollution shall be reported. These effects may take the form of reductions in air pollution on confined urban streets or major urban arterial as a result, for example, of a new by-pass, or increases in air pollution in the vicinity, for example, of a new arterial route.

If the effects of the project on air pollution are significant, predictions of air pollution shall be reported against the design guidelines in table A9.1 and where the project includes measures to mitigate air pollution, the incremental costs and benefits of these measures shall also be reported.

In evaluating and reporting expected effects of air pollution, it is important to refer to regional and local authority planning documents. These may provide guidance to the assessment methodology appropriate to the area in question. Also, the *Resource Management Act* does allow regional and territorial authorities to set regionally specific air quality guidelines and standards. Where these exist, predictions should be reported against those criteria rather than the design guidelines in table A9.1. It is also important to recognise other potential sources of air pollution in the vicinity of any proposed development and incorporate these effects into the overall assessment (eg, domestic fires in high density urban areas). The design guidelines in table A9.1 are intended to be applied to the cumulative effects of all activities.

A9.6 Carbon dioxide emissions

Carbon dioxide emissions

The greenhouse effect is the trapping of heat in the lower atmosphere by greenhouse gases, particularly carbon dioxide and water vapour. These gases let energy from the sun travel down to the earth relatively freely, but then trap some of the heat radiated by the earth.

Impacts of carbon dioxide

While carbon dioxide occurs naturally, in the last 200 years the concentration of carbon dioxide in the Earth's atmosphere has increased by 25%. As these extra amounts of carbon dioxide are added to the atmosphere they trap more heat causing the Earth to warm. This extra warming is called the enhanced greenhouse effect and is predicted to significantly after the Earth's climate.

Carbon dioxide makes up about half of the extra greenhouse gases and a significant proportion of this extra carbon dioxide is emitted by motor vehicles.

Valuation of carbon dioxide emissions

There has been considerable debate as to the cost of carbon dioxide emissions and proposed values cover a wide range. The variation reflects uncertainty about the levels and timing of damage as well as an appropriate discount rate. The *Land Transport Pricing Study (1996)* determined an average cost of carbon dioxide emissions of $30 per tonne, which is updated to $40 per tonne (2004 values) and which equates to 12 cents per litre of fuel which is approximately 5% of total vehicle operating costs. These values shall be used in project evaluations.

The monetary value adopted to reflect the damage costs of carbon dioxide emissions in project evaluations has no relationship to the level of carbon tax that the government might consider as a policy instrument to restrain carbon dioxide emissions.

A9.7 Assessment of carbon dioxide emissions

Assessment of carbon dioxide emissions	There is a direct relationship between carbon dioxide emissions and fuel consumption and emissions can be calculated using different procedures for road inks and for intersections.
Road links	For road links vehicle operating costs (2008 base date VOC) are calculated by summing running costs and roughness costs. The fuel cost component of running costs is approximately 50%, while for roughness costs the fuel cost component is negligible. The following formulae can be used to determine carbon dioxide emissions: Light CO_2 (in tonnes) = VOC($) x 0.0009 Heavy CO_2 (in tonnes) = VOC($) x 0.0016 Where VOC includes values due to speed and gradient (tables A5.1 – A5.11) and congestion (tables A5.16 – A5.23), ie VOC due to roughness is excluded (tables A5.12 – A5.15). For shape correction projects the VOC benefits are due mainly to reduced roughness costs and no change in carbon dioxide emissions shall be reported.
Intersections	Where computer-based models, such as SIDRA, INTANAL and SCATES, are used to analyse intersection improvements, then fuel consumption, which is an output of these models, can be used to determine carbon dioxide emissions by applying the following formulae: Light CO_2 (in tonnes) = Fuel consumption (in litres) x 0.0022 Heavy CO_2 (in tonnes) = Fuel consumption (in litres) x 0.0025 These formulae can also be used for activities evaluated using computer-based models.
Generated traffic	For generated traffic, the total VOC or carbon dioxide generated by the additional trips shall be estimated, and the resulting values calculated.
Reporting of carbon dioxide emissions	The predicted value change in carbon dioxide emissions shall be calculated as $40 per tonne of carbon dioxide or 4% of the VOC changes, and shall be included in the BCR. Carbon dioxide impacts shall also be quantified in tonnes and reported in the project summary sheet.

A9.8 References

1. Ministry for the Environment, *Good-practice guide for air quality monitoring and data management,* Wellington, 2000. http://www.mfe.govt.nz/publications/
2. Ministry for the Environment, *Good practice guide for preparing emission inventories,* Wellington, 2001. http://www.mfe.govt.nz/publications/
3. Ministry for the Environment, *Ambient air quality guidelines,* Wellington, 2002. http://www.mfe.govt.nz/publications/
4. Ministry for the Environment, *Good practice guide for atmospheric dispersion modelling,* Wellington, 2004. http://www.mfe.govt.nz/publications/
5. Ministry of Transport, *Vehicle fleet emissions model: New Zealand vehicle fleet database and model development,* Wellington, December 1998
6. Sinclair Knight Merz, *Guidelines for assessing the effects of discharges to air from Land Transport (draft),* report for Auckland Regional Council, 2003.

A10 National strategic factors

A10.1 Introduction

Introduction

This appendix details the procedures to use when considering national strategic factors. The appendix:

- sets out criteria that must be met for the inclusion of national strategic factors in the economic evaluation of activities
- describes national strategic factors that may be included in an economic evaluation.

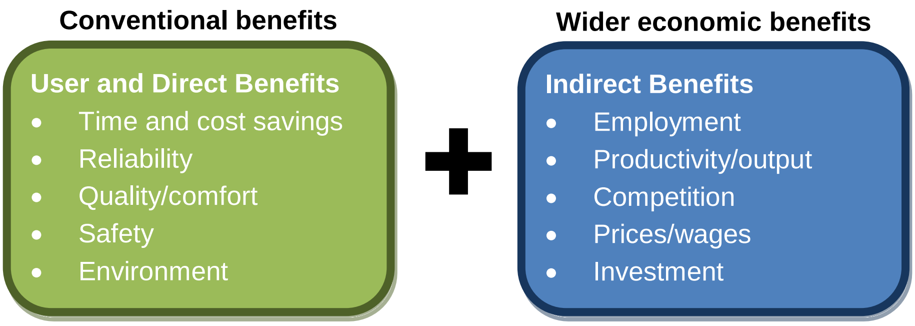
In this appendix

A10.2 Agglomeration economies and transport investment

Introduction

Wider economic benefits are impacts that can result from transport investment that have been used internationally to improve transport cost benefit analysis. They can be thought of as impacts that are additional to the conventional benefits to transport users (illustrated in the following diagram).

Wider economic benefits are additional to conventional benefits



Great care is required to ensure that the estimates for wider economic benefits are truly additional to conventional benefits to avoid double counting. As an example, business travel time savings can result in productivity and output increases. These are a direct user benefit and any wider economic benefits for increased productivity have to be additional to these direct user benefits.

Indirect impacts outside of the transport sector

In addition to, or in some cases as a consequence of direct impacts, there can be indirect impacts on the economy. These may cause a redistribution or reallocation of resources or may cause the entry or exit of firms. These are wider economic impacts and can include:

- Economies of scale from improved transport that can encourage agglomeration or specialisation of economic activity.
- Mitigating existing market failures by improving accessibility and therefore competition between spatial markets.
- Increased output in imperfectly competitive markets by diminishing persistent externalities.
- Technology and knowledge transfer by connecting people and places and increasing the interaction between economic actors.

Types of wider economic benefits

The following wider economic benefits are applicable in the New Zealand context:

- Agglomeration where firms and workers cluster for some activities that are more efficient when spatially concentrated.
- Imperfect competition where a transport improvement causes output to increase in sectors where there are price cost margins.
- Increased labour supply where a reduction in commuting costs removes a barrier for new workers accessing areas of employment.

A10.3 Measurement and estimation of agglomeration

Criteria for considering agglomeration

The required spatial concentration of economic activity for realising agglomeration benefits is only likely to occur in the major industrial and urban centres of New Zealand. It is only the large and complex urban transport activities that will provide the relevant conditions that justify an analysis of agglomeration benefits.

Agglomeration elasticities

Table A10.1 presents weighted average agglomeration elasticities from New Zealand based empirical research.

Table A10.1: Weighted average agglomeration elasticities for New Zealand by industry

ANZSIC 2006	Industry	Agglomeration elasticity (ε)
A	Agriculture, forestry and fishing	0.032
B	Mining	0.035
D	Electricity, gas, water and waste services	
C	Manufacturing	0.061
E	Construction	0.056
F	Wholesale trade	0.086
G	Retail trade	0.086
H	Accommodation and food services	0.056
I	Transport, postal and warehousing	0.057
J	Information media and telecommunications	0.068
K	Finance and insurance services	0.087
M	Professional, scientific and technical services	
N	Administrative and support services	
O	Public administration and safety	
L	Rental, hiring and real estate services	0.079
P	Education and training	0.076
Q	Health care and social assistance	0.083
R	Arts and recreation services	0.053
	All industries	0.065

A10.4 Agglomeration benefits

Introduction

This section sets out a step by step process for estimating agglomeration benefits of transport investment.

The method requires transport modelling data for the urban area of influence. Generally this will be extracted to a spreadsheet from a regional or subregional strategic transport network model, using the model zoning system or an aggregation of zones appropriate to the activity (more detailed zoning in the urban centre and around the locality of the activity, and coarser zoning for peripheral areas). The selected zones should give a reasonable compromise between detail and practicality.

Step A: Define spatial zoning system

Capturing this requires a spatial zoning system to be defined for the purpose of assessing agglomeration economies. The main criteria for a spatial zoning system are:

- full coverage of the study area and as large a geographic area as possible
- a reasonable level of detail (for instance by area units)
- ability to be tied to a set of boundaries for which one can extract detailed statistical information on employment and output.

Since much of the data needed for the assessment will come from one or more transport models, the model zoning system(s) should be the starting point. Transport models tend to have a high degree of geographical detail in the study area and much less detail for external zones. It is usually not possible or desirable to disaggregate model zones in a sensible way so in practice a zoning system needs to use the transport model zones as building blocks.

Step B: Gather economic data

Step B sets out in detail the economic data that is required for the analysis.

B1: Employment data

Zonal employment data (full time equivalent employees) is required for the year or years for which the assessment is being made. Ideally separate employment projections for the do-minimum and option scenarios would be used, but it is most likely only that a fixed land use and employment projections will be available and will be acceptable.

B2: Economic output data

An estimate of gross domestic product (GDP) per zone is obtained by distributing the regional GDP for the assessment year in proportion to zonal employment. Regional GDP estimates can be derived from Statistics New Zealand data. Sector disaggregation by Australian and New Zealand Standard Industrial Classification (ANZSIC) should be used for the analysis and be undertaken individually for each industrial sector.

Table A10.2: Data requirements

Data	Variable	Disaggregation	Source
Demand	D	Origin – destination (OD) pair, do-minimum, option, mode, purpose, year	Transport model
Generalised cost	GC	OD pair, do-minimum, option mode, purpose, year	Transport model
Base year employment	–	Zone, full time equivalents ANZSIC	Statistics New Zealand
Future year employment	E	Zone (option)	Transport model/other
Agglomeration elasticities	ε	ANZSIC	Table A10.1
Output	GDP	Zone/ANZSIC	Statistics New Zealand

B3: Agglomeration elasticities by zone

Current estimates for the relationship between density and productivity are shown in table A10.1 which lists elasticities by sector.

An intermediate step is to calculate the agglomeration elasticities for each study zone using evidence of each zone's sector composition of employment. This is done by calculating the weighted average of the elasticities using employment proportion of each sector for each zone as weights.

$$\varepsilon_i = \frac{\sum_S (\varepsilon_i^S \times E_i^S)}{\sum_S E_i^S}$$

Where:

ε = agglomeration elasticity

E = employment

This operation requires data on base year workplace based employment by study zone (i) for each of the sectors for which agglomeration elasticities are provided, as well as total employment (for the remainder of the economic sectors a zero elasticity is assumed). Employment growth forecasts and output forecasts are required by sector for each assessment year.

B4: Transport model outputs

The transport model data required is OD matrices of demand and generalised cost for:

- each modelled transport mode
- the following journey purposes/user segments:
  - work travel purpose (including freight)
  - commuting to and from work
  - non-work travel purposes
- the do-minimum or option scenarios
- one or more future assessment years.

A typical scenario could include two variables for public transport and car modes, three purposes, two scenarios and one future year produces 24 OD matrices. When gathering and preparing the transport data, there are a number of things to bear in mind:

a. Coverage of all major modes

   Although the transport activity under consideration may only affect one mode, all travel modes need to be included in the analysis, as it is the relative change in travel costs that drives agglomeration benefits.

   If the transport model only represents a single mode, it will be necessary to make assumptions on journey costs for other modes and the proportion of demand by mode.

b. Separately identified user groups

   If the demand and cost data is not available separately for the required journey purposes/user segments, they will need to be estimated. This could be done by adjusting the time-cost element of generalised cost for differences in values of time between user groups.

c. Complete cost matrices

   For the analysis the cost matrices need to contain cost information for all OD movements where there is travel demand. This is to avoid weight being given to OD pairs where the costs are set arbitrarily high or low (transport model matrices frequently contain zeros or very high cost on pairs where there is no cost information). This includes intra-zonal movements. There should be no zeros or empty cells.

Where the available data does not cover all modes or there are missing cells, the matrices should be complemented with evidence from other sources. Possible sources include:

- time, cost or demand data from other transport models
- distance and/or journey time data from geographical information system or journey planning tools
- assumptions on average time/cost per km

- census travel to work data
- travel surveys.

Step C: Calculate weighted average costs for in-work and travel to work across all modes

The relevant measure of journey costs for the purpose of assessing agglomeration impacts is the weighted average generalised cost for work travel purposes (including freight where relevant) and commuting to and from work, across all modes.

Demand should be used as weights. So for a given OD pair, the relevant generalised cost for the do-minimum or option S:

$$AGC_{ij}^{S} = \frac{\sum_{m,p} D_{i,j}^{*,m,p} GC_{i,j}^{S,m,p}}{\sum_{m,p} D_{i,j}^{*,m,p}}$$

Where:

AGC	=	average generalised cost
D	=	demand
GC	=	generalised cost
S	=	do-minimum or option
m	=	mode
p	=	purpose
i	=	origin
j	=	destination

The superscript * on demand reflects that these weights need to be identical for both the do-minimum and option, eg the sum of the do-minimum and option demands.

Step D: Calculate effective density by zones for each scenario

The effective density of employment is calculated for each scenario and assessment year using the AGC from step C and the total employment by zone gathered in step B, using the following relationship:

$$ED_i^S = \sum_j \frac{E_j^S}{AGC_{ij}^S}$$

Where:

ED	=	effective density
E	=	employment

Step E: Calculate productivity gains by zone

The productivity gains from agglomeration are calculated for each zone by applying the agglomeration elasticities to the change in density in each zone:

$$\delta PR_i = \left(\frac{ED_i^{OPT}}{ED_i^{DM}}\right)^{\varepsilon_i} - 1$$

Where:

δPR	=	relative increase in productivity
OPT	=	option
DM	=	do-minimum
ε	=	agglomeration elasticity
i	=	zone

The absolute increase in productivity by zone is then obtained by multiplying the percentage increase with the output by zones:

$$dPR_i = \delta PR_i \times GDP_i$$

Where

dPR_i	=	absolute increase in productivity in dollars
GDP_i	=	total output for each zone

If the agglomeration analysis is undertaken by industrial sectors, this step will have to be repeated for each of the sectors where there is agglomeration evidence (in other words there will be another subscript for all variables in the two equations, except for the effective densities since these are always calculated based on total employment by sector).

Step F: Sum output increases across all zones in the study area

The final step is to sum the agglomeration gains across the study zones:

$$Aggl = \sum_i dPR_i$$

i

Where *Aggl* is total agglomeration benefits from the interventions.

Step G: Profiling and calculation of net present values

Standard guidance on profiling impacts over the analysis period is to interpolate between the base year and the analysis years and to extrapolate from the last year of the analysis period. Whilst the interpolation can be done by linear annual increments, the extrapolation is done by assuming all variables remain constant from the last analysis year, ie demand and employment, but allowing productivity to grow annually. Benefits must be based on constant dollars.

The extrapolation of agglomeration gains is straightforward. The benefits for the last modelled year are assumed to grow by the rate of productivity growth until the last year of the evaluation period. The full stream of agglomeration benefits is then discounted to the base year and summed to derive the net present value.

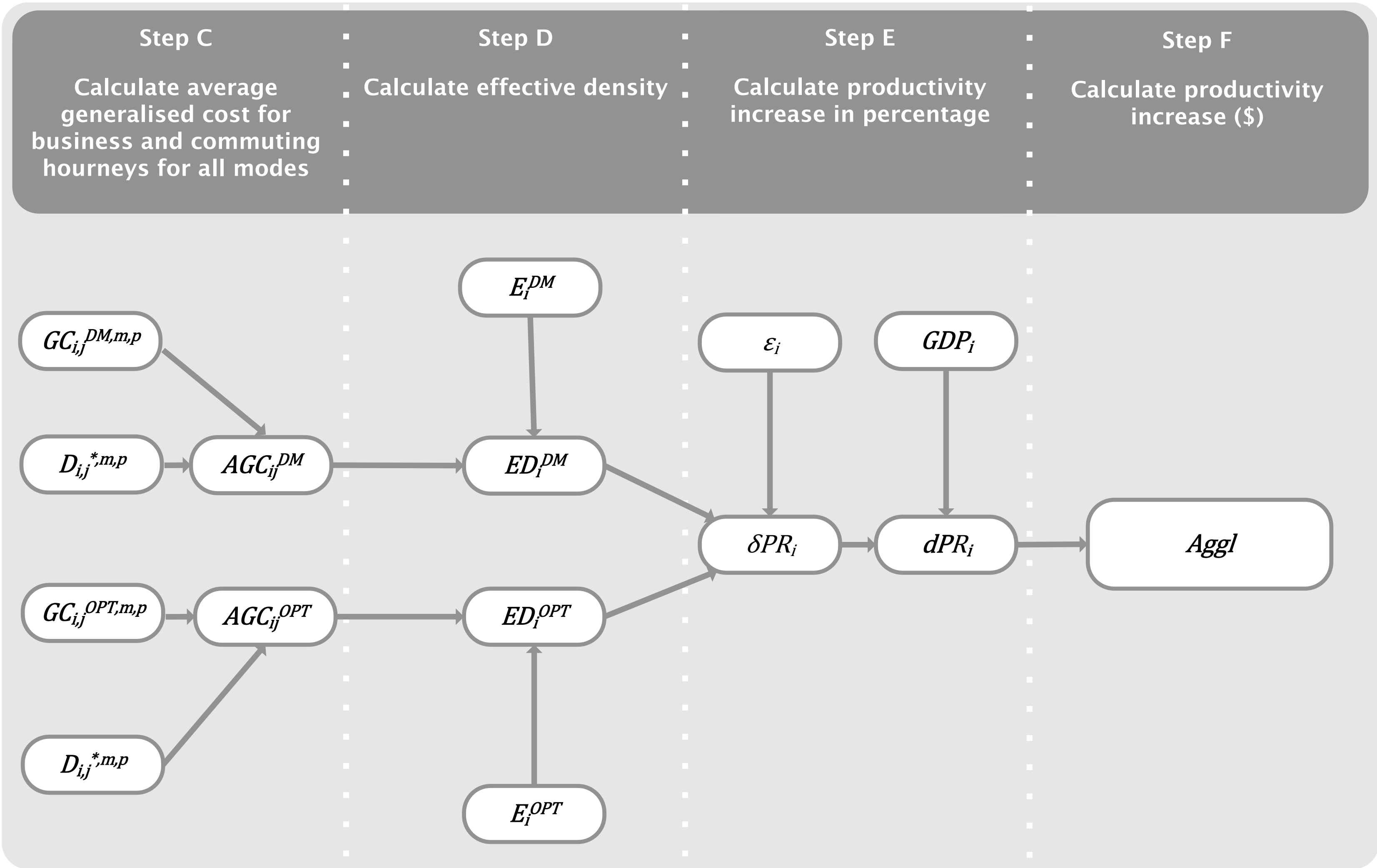
Step H: Interpretation and presentation

The main output of the assessment is total productivity gains from agglomeration as the total net present value of benefits. The results can also be presented in several other ways: as a proportion of conventionally measured evaluation benefits, productivity gains per worker, or productivity gains for a future year.

It can also be useful to demonstrate how the agglomeration benefits are distributed across the study area. This is an indication only, as it will only ever represent the location of the first round of impacts and not their final incidence. There is therefore a clear trade-off between the level of spatial disaggregation and robustness. For New Zealand an appropriate balance between the two may be to present findings at the level of territorial units.

Finally, if the analysis has been undertaken at an industry sector level, the impact on different parts of the economy could be illustrated.

Figure A10.1: Step by step guidance for agglomeration benefits



A10.5 Imperfect competition

Imperfect competition

Conventional transport economics assumes all transport-using sectors operate in perfect competition, where price equals marginal costs. The value of the additional production is identical to the gross marginal labour cost of the additional hour worked. Conventional economics therefore measures the value of the travel time saving as a saving in gross labour cost.

However, if price cost margins exist, they cause a wedge between gross labour costs and the market value of what is produced. Hence, where there are price cost margins, a transport-induced increase in output will cause a wider economic impact identical to the size of this wedge.

Imperfect competition parameters

The average price cost margin in the New Zealand economy is 20%. Together with evidence on how the economy responds to a reduction in transport costs at an aggregate demand elasticity of -0.6 gives an estimated wider economic benefit from increased competition of 10.7% of business user benefits.

Table A10.3: Imperfect competition parameters

Parameter	Description	Value
εad	Aggregate demand elasticity	-0.6
pcm	Price cost margin	20%
τ	Imperfect competition uplift to business user benefits	0.107

Estimating imperfect competition benefits

$$Imperfect\ competition\ impact = \sum_f \tau \times Business\ user\ benefits^f$$

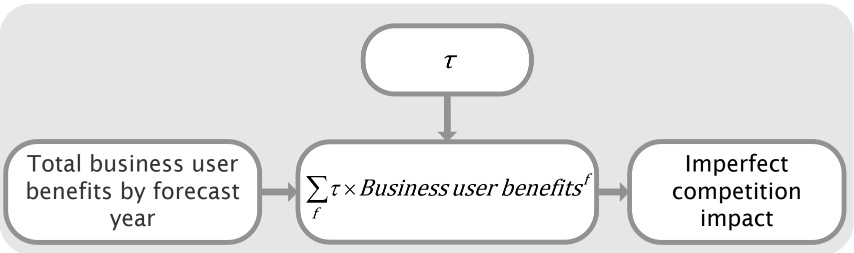
Where

Business user benefits = Total conventional business user benefits from travel time and vehicle operating cost savings

f = Forecast year

τ = Imperfect competition uplift factor

Figure A10.2: Imperfect competition benefits



This can typically add up to an additional 5% of wider economic benefits over conventional benefits.

A10.6 Increased labour supply

Step 1: Calculate commuting costs

The first step requires an estimate of the change in commuting costs for workers living in zone i and working in zone j. Calculate for the do-minimum and option the total annual commuting costs for each origin-destination pair (ie home to work from i to j and work to home from j to i), averaged across all modes.

$$G_{ij}^{OPT,c,f} = \frac{\sum_m \left(g_{ij}^{OPT,m,c,f} + g_{ji}^{OPT,m,c,f}\right) \times T_{ij}^{DM,m,c,f}}{\sum_m T_{ij}^{DM,m,c,f}}$$

The total annual commuting cost savings for workers living in zone i is calculated by multiplying the change in commuting cost for each destination by the number of commuters and summing.

$$dG_i^f = \sum_j W_{ij}^{OPT,f}\left(G_{ij}^{OPT,c,f} - G_{ij}^{DM,c,f}\right)$$

Step 2: Labour supply response

The labour supply response can now be calculated by assessing the magnitude of the commuting cost changes in relation to workers' net wage for each area and multiplying by the labour supply elasticity.

$$dE_i = \varepsilon^{ls} \frac{1}{y_i(1-\tau_l)} dG_i^f$$

Step 3: Gross labour supply impact

The increased output from the increased labour supply impact is estimated using the product of the increased labour supply and the net productivity per worker for new entrants.

$$Labour\ supply\ impact = \sum_i dE_i \eta m_i$$

Step 4: Net labour supply impact

The wider economic impact from increased labour supply is the proportion of the additional output taken in taxation.

$$\begin{aligned} &Wider\ economic\ impact\ from\ increased\ labour\ supply \\ &= Labour\ supply\ impact\ \times \tau^{ls} \end{aligned}$$

This can add up to an additional 10% of wider economic benefits over conventional benefits.

A10.7 Defining national strategic factors

National strategic factors

National strategic factors are defined as national benefits that are valued by road users or communities, but which are not captured elsewhere in the activity evaluation.

When considering large infrastructure investments, particularly land transport investments, it is often difficult to capture in an evaluation process all the benefits (positive or negative). Road investments have impacts over long timeframes, and over large areas. These wider impacts are taken into account in robust strategic planning processes, but it can be difficult to include such considerations in activity evaluation procedures.

It is important that rigorous analysis be applied to national strategic factors that are to be included in an evaluation. Roading activities, particularly large ones, are sometimes inappropriately described as 'strategic' if they cannot be justified by the road user benefits and intangible effects described elsewhere in this manual.

National strategic factors should only be included in the evaluation of an activity where it can be shown that they are national benefits and not transfers and that the factors have not already been counted in the economic analysis. To be included in the analysis, national strategic factors will need to meet the criteria set out below.

National strategic factors may be incorporated as benefits in the evaluation of an activity where they:

- have a material impact on an activity's importance (given the time and costs associated with identifying, quantifying and where appropriate valuing national strategic factors, they should only be considered where they are likely to have a significant impact on the benefits of an activity)
- comprise national economic benefits (not transfers of benefits between different localities)
- have not been counted in the core analysis (many benefits called 'strategic' can be shown to be included in the NZ Transport Agency's current procedures, and are already taken into account through growth in traffic volumes, etc)
- would be valued by land transport users and the wider community (that is, road users and the community would be willing to pay for them, were they able to do so, for example, insure against earthquake damage).

Two categories of national strategic factors that meet these criteria have been identified:

- providing for security of access
- providing for investment option values – including building in extra capacity or flexibility today to enable easier expansion in the future.

Additional national strategic factors

National strategic factors other than security of access and investment option values may be accepted, provided the activity promoters can clearly show that the national strategic factors claimed meet the criteria set out above.

A10.8 Security of access

Security of access

Security of access is an important consideration where there are few (or no) reasonable alternatives to a particular route. There are benefits in providing a greater assurance to road users and communities that they will be able to depend on a particular route (such benefits can be expressed in a survey of road users' willingness to pay).

In other sectors, through insurance markets, people are willing to pay to insure against loss and/or disruption (eg holiday insurance). Incorporating security of access as a national strategic factor enables the willingness of road users to pay to avoid disruption to be incorporated, where appropriate, for road investments.

Examples of this factor include:

- earthquake strengthening of a vulnerable bridge on an important route
- slip prevention work on a busy inter-regional highway
- improvement of alternatives to a busy route that is prone to closure.

Appendix A13.10 outlines a procedure for calculating the benefits associated with reducing risk of loss of access by, for instance, replacing a bridge that would be destroyed by an earthquake. That procedure takes account of the probable road user costs if the bridge was to be destroyed, but not the willingness of road users to pay to avoid the disruption. In assessing the value of the national strategic factor benefit associated with providing greater security of access, the value ascribed to road users' willingness to pay to retain access should be compared to the analysis of the disruption costs, as a benchmark. Care will need to be taken to avoid any double counting. A unit cost (eg dollars per vehicle trip) should be calculated.

A10.9 Investment option values

Land transport investments are often characterised by a difficulty (and usually inability) to easily increase capacity or change routes if circumstances (such as general traffic demand or the location of a traffic generator) change. They are also characterised by uncertainty in estimating capacity requirements for the long term (10 years or more). For these reasons, in certain situations there may be benefits in spending more on an activity now, to provide the option, ability and/or flexibility to easily increase capacity in the future. This becomes particularly important where there may be additional constraints on adding capacity in the future (eg because of planning constraints or significant increases in the cost of land).

Examples of providing for the future in this way include:

- new road construction in an important corridor could include allowance for wide medians – this would potentially facilitate the widening of the road at a later date to accommodate traffic growth, or the introduction of demand management options in the corridor (eg bus priority lanes)
- bridge design enabling the easy addition of extra lanes in the future (eg the Auckland Harbour Bridge)
- when undertaking major earthworks for a two-lane highway (eg when cutting through a steep hillside) providing for a wider corridor (for four lanes) if there is sufficient uncertainty surrounding traffic forecasts or the future availability of land to warrant ‘hedging’ against having to undertake expensive retro-construction costs.

In cases where activity promoters have reasonable confidence in their traffic growth forecasts (and are certain about land use and other relevant trends) it will be relatively straightforward to assess the value of providing for greater capacity or flexibility now, rather than in the future.

In many instances traffic growth, land use and other trends are likely to be uncertain. In these cases, assessment of investment option values will be more subjective, and the assessment of unit cost (eg dollars per vehicle) of the additional expenditure will assume greater importance as a benchmark of the appropriateness of the value ascribed to the national strategic factors. Also, valuation of the benefits of providing flexibility for future investments should be predicated on robust strategic planning processes. Clearly, the greater the quality of strategic planning processes, the greater the confidence in the value ascribed to providing for ease of expansion in the future

A10.10 Procedures for national strategic factors

Procedures

The analysis of national strategic factors involves, where practical, estimating monetary values for each national strategic factor and including these as benefits (or in unusual circumstances disbenefits) in the benefit cost ratio. The monetary values of national strategic factors are often estimates of society's willingness to pay for these factors (such as, certainty of access).

Given the uncertain nature of national strategic factors, it is likely there may be a number of different valuation procedures that are appropriate. It is recommended that advice be sought from the NZ Transport Agency before embarking on any significant exercise to value these factors.

Additional information on the strategic context of activities is provided in the Planning and Investment Knowledgebase. If information on strategic context for the activity in question is not robust, do not include national strategic factors in the evaluation of the activity.

A10.11 References

5. Graham DJ and Mare DC (2009) *Agglomeration elasticities in New Zealand*. NZ Transport Agency research report 376.

6. Statistics New Zealand (2007) *Regional GDP Concepts, Sources and Methods.*

7. Kernohan D and Rognlien L (2011) *Wider economic impacts of transport investments in New Zealand.* NZ Transport Agency research report 448.

A11 Congested networks and induced traffic

A11.1 Introduction

Introduction

This appendix provides guidance on the evaluation of congested networks and induced traffic effects

In this appendix

This appendix contains the following topics:

	Topic
A11.1	Introduction
A11.2	Applying growth constraint techniques
A11.3	Applying peak spreading
A11.4	Applying the matrix scaling method
A11.5	Applying the incremental matrix capping method
A11.6	Applying the shadow network method
A11.7	Applying elasticity methods (FTM)
A11.8	Applying demand models (FTM)
A11.9	Applying variable trip matrix techniques
A11.10	Applying elasticity methods (VTM)
A11.11	Applying project demand models (VTM)
A11.12	Conducting cost benefit analyses using variable matrix methods
A11.13	Checking growth constraint or variable matrix methods

A11.2 Applying growth constraint techniques

When to use

Growth constraint techniques are to be considered where high levels of congestion apply in the do-minimum network and/or where a stable network representation in which supply and demand are in broad equilibrium cannot be achieved.

Growth constraint techniques constrain traffic growth in peak period matrices in highly congested conditions. With fixed trip matrix methods, the adjusted matrix is used for both the do-minimum and project option.

General guidance

Any one of the procedures listed below are available for traffic growth constraint, however it is advised that the shadow network technique be used with caution.

Peak spreading may be used on its own, or with any of the other procedures detailed here.

Procedure

Having decided that there is insufficient capacity in the do-minimum to carry the forecast travel demands, and that a realistic forecast of the future scenario requires the use of a matrix growth constraint technique, follow the steps below to apply growth constraint to the trip matrix.

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td>1</td><td colspan="2">Determine whether to consider peak spreading (Appendix A3.20). If so, apply peak spreading to modify the matrix and peak period (Appendix A11.3).

If the matrix results in a realistic assignment to the do-minimum network, no further capping need be considered. Otherwise go to step 2.</td></tr>
<tr><td rowspan="8">2</td><td colspan="2">Select an appropriate method to cap the matrix:</td></tr>
<tr><td>Selected method</td><td>Go to</td></tr>
<tr><td>Matrix scaling</td><td>Appendix A11.4</td></tr>
<tr><td>Incremental matrix capping</td><td>Appendix A11.5</td></tr>
<tr><td>Shadow network</td><td>Appendix A11.6</td></tr>
<tr><td>Elasticity methods (FTM)</td><td>Appendix A11.7</td></tr>
<tr><td>Demand models (FTM)</td><td>Appendix A11.8</td></tr>
<tr><td colspan="2">Automated growth constraint methods, such as the ME2 matrix capping technique contained in the SATURN modelling package, may also be used.</td></tr>
</table>

A11.3 Applying peak spreading

When to use

Peak spreading procedures may be used to spread traffic from the busiest part of the peak period to the peak shoulders.

General guidance

At present, there are no universally established procedures for peak spreading. Discretion is recommended in developing a peak spreading method, but ensure that the resulting retiming of trips is reasonable.

As a general guide, the following points should be kept in mind:

- Decide whether to apply peak spreading uniformly or only to specific parts of the trip matrix. This decision will largely depend on the extent of congestion in the network.
- Unless evidence suggests otherwise, it is recommended that the transfer of trips from the peak to interpeak or off-peak periods be not more than 5% of the total peak period traffic.
- If appropriate, the traffic profile during the peak period may be adjusted, but it is advisable that the reduction of the peak traffic intensity be no more than 10%.
- It is recommended that information on local traffic profiles and trends in traffic growth for different time periods, such as peak shoulder and business periods, be sought to support assumptions.

Checking reasonableness

Checks for the reasonableness of peak spreading outcomes are given in Appendix A11.13.

A11.4 Applying the matrix scaling method

When to use

Matrix scaling procedures may be used to constrain growth in the trip matrix. If congestion is widespread, the entire matrix may be scaled or, if congestion is confined to a particular area, only the corresponding sections of the matrix need be scaled.

General guidance

The final levels of congestion in the network due to the capped matrix should be sensible. When capping the matrix with this procedure only cap the matrix as much as needed. Excess capping will reduce computed project benefits unnecessarily.

Procedure

Follow the steps below to apply matrix scaling.

Step	Action
1	Choose a scaling factor to reduce congestion to acceptable levels in affected parts of the do-minimum network. As a general guide, link saturation ratios should be less than 1.1 after the new matrix is assigned. Unless evidence suggests otherwise, the scaling factor would typically be between 0.95 and 1.0 for scaling of the entire matrix, or between 0.9 and 1.0 for scaling of selected sections of the matrix. See also: Computing the volume to capacity ratio in Appendix A3.17.
2	Multiply the chosen elements of the matrix by the scaling factor. This matrix will be used with the do-minimum and project options.
3	Assign the matrix to the network

A11.5 Applying the incremental matrix capping method

When to use

The incremental matrix capping method may be used to constrain growth in selected cells of the matrix. This method is also known as the 'incremental loading' method, but should not be confused with incremental assignment techniques

Summary of method

In the incremental matrix capping method, choose a series of forecast year matrices and assign these to the do-minimum network in chronological order. Once an assignment results in average journey speeds dropping below acceptable limits for a matrix cell (or group of cells), further traffic growth is prevented in the affected cells as later matrices are applied.

This process effectively restricts the growth rate in selected matrix cells to levels corresponding to some earlier year (at which an acceptably realistic traffic assignment could be obtained).

Procedure

Follow the steps below to apply incremental matrix capping.

Step	Action
1	Choose a series of forecast years (say, at 5 year intervals) and generate initial forecast matrices for each of these years.
2	Select minimum allowable overall journey speeds for each origin-destination pair. As a guide, minimum speeds will be in the range 15–25 km/h, depending on the quality of the route and the trip length.
3	Assign the first forecast-year matrix to the do minimum network.
4	Update each matrix cell for the next future year, except those where the speed for the origin-destination pair (obtained from the assignment run) has fallen below the minimum allowable speed. Assign the new matrix to the do-minimum network.
5	Repeat step 4 until all future years have been assigned.

A11.6 Applying the shadow network method

When to use

The shadow network method may be used to provide location-specific capping for a trip matrix.

General guidance

The shadow network technique should be used with care. It may take more effort to implement and may risk counter-intuitive results (for example, negative growth in some parts of the matrix).

Procedure

Follow the steps below to apply the shadow network technique.

Step	Action
1	Construct a duplicate 'shadow' network and connect it to the 'real' network at the zone centroids.
2	Select minimum allowable speeds for the links of the shadow network. The choice of this speed will affect the number of trips that are suppressed. As a general guide, minimum speeds will be in the vicinity of 15 km/h for links of average length (On very short road links, junction delays may realistically lead to very low overall link speeds), but this limit may be varied to suit the particular network context.
3	Assign the matrix to the dual network.
4	Check the results and readjust the shadow network speeds if the results are unreasonable. If the speeds are changed, repeat steps 3 and 4.
5	The real network will now contain normal trips and the shadow network trips considered to be suppressed. To obtain a matrix for economic evaluation, cordon off the matrix assigned to the real network.

A11.7 Applying elasticity methods (FTM)

When to use

Fixed trip matrix (FTM) elasticity methods may be used to constrain growth in the trip matrix. As with other fixed trip methods, the matrix produced by an FTM elasticity approach will be used for the do-minimum and project options.

Description

Elasticity methods are based on the principle that the demand for travel between two zones varies according to the cost of travel between the zones. An elasticity method iteratively adjusts the trip matrix by assigning it to the network, measuring the change in costs between the assignment and a reference case, then adjusting the demand according to the cost change.

The inputs to an elasticity approach are:

- A pivot travel cost matrix from which changes in cost are measured. This is derived by assigning the appropriate trip matrix to the network.
- An initial estimate of the do-minimum matrix for the forecast year. This will usually be derived either using a growth factor applied to a base matrix or from an external strategic model.
- An elasticity parameter that specifies the sensitivity of travel demand with respect to travel cost.
- An elasticity formulation that expresses the necessary adjustment to the trip matrix as a result of cost changes.

The pivot matrix and network will commonly be those for the base year. But it would be equally appropriate to use the project opening year (if the network was expected to be relatively uncongested at that time) as a pivot for forecasting trip matrices for later years in the project's economic life.

Procedure

Follow the steps below to apply elasticity methods:

Step	Action
1	Assign the trip matrix from the base year to the base network. Obtain a pivot travel cost matrix from the assignment results (c_{ij}^{P}).
2	Take an initial estimate (using suitable prediction methods) of the forecast year matrix T_{ij}^{F} and assign it to the appropriate do-minimum network. Obtain an initial cost matrix c_{ij}^{1} from the assignment results.

Step	Action
3	Derive a new matrix T_{ij}^{1} by adjusting each cell in the matrix T_{ij}^{F} according to an elasticity formulation. The power formula is advised for this purpose as follows: $T_{ij}^{1} = T_{ij}^{F}\left(\frac{c_{ij}^{1}}{c_{ij}^{P}}\right)^{E}$ Where: T_{ij}^{1} = adjusted number of trips between origin *i* and destination *j* T_{ij}^{F} = initial estimate of the number of trips between *i* and *j* c_{ij}^{1} = forecast journey cost (or time) between *i* and *j* c_{ij}^{P} = pivot journey cost (or time) between *i* and *j* *E* = elasticity of demand with respect to journey cost (or time). Note that the elasticity, *E*, will be negative. Convergence may be assisted by using a damping process, and taking the average of the matrices produced by the two previous iterations: ie, replace T_{ij}^{1} by $\frac{1}{2}\left(T_{ij}^{F} + T_{ij}^{1}\right)$
4	Assign the new matrix T_{ij}^{1} to the network, producing a new cost c_{ij}^{2} matrix. Ensure that the assignment converges satisfactorily.
5	Using the power formula, compute a new trip matrix T_{ij}^{2} equal to: $T_{ij}^{2} = T_{ij}^{F}\left(\frac{c_{ij}^{2}}{c_{ij}^{P}}\right)^{E}$ Damp as required, by replacing T_{ij}^{2} by $\frac{1}{2}\left(T_{ij}^{1} + T_{ij}^{2}\right)$.
6	Repeat steps 4 and 5 until the process converges, that is, trip and cost matrices produced on successive iterations are sufficiently similar.

The final matrix produced by the elasticity formulation must reasonably represent the demand. It may be appropriate to exclude some matrix cells from the elasticity adjustments - for example, those that exhibit negative growth (generally it is undesirable to have cases where traffic volumes between an origin and destination pair decrease between successive forecast years), unreasonably high growth or those that represent external trips.

Elasticities

Elasticities used with an elasticity method must be consistent with the travel costs used in the elasticity formula. For example, if C_{ij}^{n} and C_{ij}^{P} are expressed as journey times, then the elasticity, *E*, should be specified with respect to journey time.

The successful application of elasticity methods depends on elasticities being available for the model's study area and the transport model being able to model travel costs realistically. Values below, derived from UK research may be used.

Period	Journey time elasticity
Peak period	-0.20
Peak hour	-0.33 (includes peak spreading)
Off peak	-0.24

The suggested elasticities correspond to the long-run low modal competition values derived from UK research. In part, they derive from data on the effects of fuel prices on traffic levels, for which there is some evidence of comparability between the UK and New Zealand contexts.

These elasticities could be increased by 25% in corridors to major city central business districts where public transport has a significant modal share.

If it is more convenient to use generalised costs extracted from the model than journey times, then an equivalent generalised cost elasticity can be calculated. If the model assigns on the basis of a generalised cost of $t + k.d$ then the equivalent generalised cost elasticity is obtained by multiplying the journey time elasticities by the factor $(1 + k.v)$, where v is average study area journey speed (in units of kilometres per minute).

If the model generalised cost is $t + k.c$, where c is some perceived operating cost, then the equivalent generalised cost elasticity is obtained by multiplying the journey time elasticities by $(1 + k.p)$ where p is the average perceived operating cost per minute for the study area.

A11.8 Applying demand models (FTM)

When to use	Demand models are commonly used to derive matrices or matrix growth factors that are sensitive to road network journey times.
Description	Demand models refer to one or more of the standard generation, distribution and mode split models handled by most proprietary transport modelling packages or custom-built spreadsheet models. In Auckland, Wellington and Christchurch, demand models are commonly used to generate matrices within more general strategic models. Some project models are also capable of modelling variable travel demands (for example by using trip distribution models).
Procedure	The forecast matrices derived from city strategic models are modified appropriately for the local project model and used in standard FTM project evaluation procedures. Project demand models can be applied in a similar way to elasticity methods (see Appendix A11.7) using the demand model to adjust the trip matrix, rather than an elasticity formulation. In both options, the resulting matrix should be a reasonable representation of demand, and the demand models should be properly validated (see worksheet 8.5).

A11.9 Applying variable trip matrix techniques

When to use

Variable trip matrix (VTM) techniques may be used to model the effects of induced traffic where high levels of congestion are expected in both the do-minimum and project option networks. Variable matrix methods differ from conventional fixed trip matrix techniques in that demand in the project option matrix is generally higher than that in the do-minimum matrix for a given forecast year. VTM methods also require more complex procedures to evaluate net project benefits than fixed matrix methods.

VTM methods may not be necessary if induced traffic is expected to have similar effects on the economic performance of each project option being compared. If this exceptional case is considered to apply, advice should be sought from the NZ Transport Agency as to whether VTM methods should be used.

General guidance

The purpose of variable matrix methods is to provide estimates of the effects of a project on travel patterns (that is, the difference between the do-minimum and project option matrices) and on the benefits of the scheme. Because these effects may be small and the estimates should be unbiased, methods relying heavily on professional judgement (such as many of the growth constraint techniques) are inappropriate. Two variable matrix methods based on analytical techniques are recommended: elasticity methods and demand models.

The options are:

a. using these methods consistently for both the do-minimum and project option matrices or

b. using growth constraint methods to establish the do-minimum matrix and variable matrix methods for estimating the effect of the project option on the trip matrix (as an adjustment to the do-minimum).

For demand modelling approaches, where the source of data is a strategic city model, it may be considered unlikely that the strategic model will have sufficient sensitivity to measure the impact on the trip matrix of a single scheme, and the use of such models will therefore generally not be feasible. Elasticity methods are therefore likely to be needed to supplement the strategic model.

For project demand models, it is likely that these would generally be applied consistently for the do-minimum and project option matrices.

Whatever method is applied, its results should be verified by comparison with an FTM evaluation based on the do-minimum trip matrix.

Procedure

Having decided that congestion will be significant in both the do minimum and project option for a forecast year, follow the steps below to apply variable matrix methods.

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td rowspan="6">1</td><td colspan="3">Select an appropriate method to adjust the do-minimum and project option matrices:</td></tr>
<tr><th>Method</th><th>Description</th><th>Go to</th></tr>
<tr><td>A</td><td>Use elasticity methods for both the do-minimum and project option matrices.</td><td>Appendix A11.10</td></tr>
<tr><td>B</td><td>Use other growth constraint techniques (appendix A11.2) for the do minimum matrix and elasticity techniques to estimate the effects of the project option on the trip matrix.</td><td>Appendix A11.10</td></tr>
<tr><td>C</td><td>Use the project demand model for both the do-minimum and project option matrices.</td><td>Appendix A11.11</td></tr>
<tr><td colspan="3">Alternatively, use a fixed matrix approach, then apply a predetermined correction factor to adjust benefits for variable matrix effects.

Note that project benefits will need to be calculated using a consumer surplus evaluation and reported in worksheet 3.</td></tr>
<tr><td>2</td><td colspan="3">Conduct a fixed matrix analysis (see Appendix A11.2) and compare the results with those obtained from the variable matrix analysis.</td></tr>
</table>

A11.10 Applying elasticity methods (VTM)

When to use

Variable trip matrix (VTM) elasticity methods are referenced in Appendix A11.9 (methods A and B). The two recommended applications are:

a. where the do-minimum and project option matrices are both estimated using elasticity methods; or

b. where the do-minimum matrix is first established using growth constraint techniques and elasticity methods are used to estimate the effect on this matrix of the project option.

Description

Elasticity methods are based on the principle that the demand for travel between two zones varies according to the cost of travel between the zones. An elasticity method iteratively adjusts a trip matrix by assigning it to the network, measuring the change in costs between the assignment and a reference case, then adjusting the demand according to the cost change.

The inputs to an elasticity approach are:

- A pivot travel cost matrix from which changes in cost are measured. This is generally derived by assigning the appropriate matrix to the network;
- An initial estimate of the trip matrix for the forecast year;
- An elasticity parameter that specifies the sensitivity of travel demand with respect to travel cost.
- An elasticity formulation that expresses the necessary adjustment to the trip matrix as a result of cost changes.

In Appendix A11.7 there is a full description of elasticity methods, emphasising the estimation of the do minimum matrix. The process is illustrated using the base matrix and network as the pivot point, and the unconstrained forecast matrix (produced by growth factor techniques or an external model) as the initial matrix estimate.

Method A procedure

For method A, the processes described in Appendix A11.7 are applied separately but consistently for the do-minimum and project option matrices. For example, if the method is pivoted on the base year matrices, then steps 1-6 in procedure A11.7 are applied first using the do-minimum network (in step 2 for c_{ij}^1 and subsequent steps) and then repeated using the project option network (in step 2 for c_{ij}^1 and subsequent steps).

Method B procedure

Step	Action
1	Assign the do minimum matrix to the do-minimum network for the relevant forecast year. Obtain a pivot travel cost matrix from the assignment results (C^P_{ij}).
2	Use the do-minimum matrix as the initial estimate of the forecast year matrix T^F_{ij} and assign it to the project option network. Obtain an initial cost matrix c^1_{ij} from the assignment results.
3	Derive a new matrix T^1_{ij} by adjusting each cell in the matrix T^F_{ij} according to an elasticity formulation. The power formula is advised for this purpose as follows: $$T^1_{ij} = T^F_{ij}\left(\frac{c^1_{ij}}{c^P_{ij}}\right)^E$$ where: T^1_{ij} = adjusted number of trips between origin *i* and destination *j* T^F_{ij} = initial estimate of the number of trips between *i* and *j* c^1_{ij} = forecast journey cost (or time) between *i* and *j* c^P_{ij} = pivot journey cost (or time) between *i* and *j* *E* = elasticity of demand with respect to journey cost (or time). Note that the elasticity, *E*, will be negative. Convergence may be assisted by using a damping process, and taking the average of the matrices produced by the two previous iterations: ie replace T^1_{ij} by $\frac{1}{2}\left(T^F_{ij} + T^1_{ij}\right)$.
4	Assign the new matrix T^1_{ij} to the project option network, producing a new cost matrix c^2_{ij}. Ensure the assignment converges satisfactorily.
5	Using the power formula, compute a new trip matrix equal to: $$T^2_{ij} = T^F_{ij}\left(\frac{c^2_{ij}}{c^P_{ij}}\right)^E$$ Damp as required, by replacing T^2_{ij} by $\frac{1}{2}\left(T^1_{ij} + T^2_{ij}\right)$.

Method B procedure, continued

Automated application of elasticity methods (for example SATURN's elastic assignment) may be used as an alternative to the manual method given above.

For method B, the do-minimum matrix may be determined using any of the growth constraint techniques in Appendix A11.2.

As for FTM elasticity methods, the final matrix produced by the elasticity formulation (in either methods A or B) should be a reasonable representation of demand. It may be appropriate to exclude some matrix cells from the elasticity adjustments - for example, those that exhibit negative growth, unreasonably high growth or those that represent external trips. The convergence requirements for VTM methods are, however, significantly more onerous: the stability and convergence requirements of the combined VTM/assignment procedures are the same as for the simpler FTM assignment-only procedures (see worksheet 8.4, part D).

Elasticities

Refer to Appendix A11.7 for a discussion of suggested elasticities.

A11.11 Applying project demand models (VTM)

When to use	Variable trip matrix (VTM) project demand models may be used to estimate trip matrices differentiated between the do-minimum and project option. As with other VTM approaches, these guidelines should be used only when high levels of congestion exist in both the do-minimum and project options.
General guidance	Project demand models would usually be limited to trip distribution methods. Where considered appropriate, these models may be used to forecast scheme-induced traffic by estimating separate do-minimum and project option matrices. In determining appropriateness, it would be necessary to demonstrate that the model could be reliably applied to the appraisal of individual schemes In such cases variable trip matrix (VTM) evaluation procedures would be used. The stability and convergence requirements are the same as for VTM elasticity methods (Appendix A11.10). The validation of such models is discussed in FP Worksheet 8.5 part C.

A11.12 Conducting cost benefit analyses using variable matrix methods

When to use

Where significant amounts of induced traffic are expected as the result of a project, variable trip matrix (VTM) methods (refer Appendix A11.9) may need to be applied. Variable matrix methods require more complex economic calculations than fixed trip matrix (FTM) methods in order to determine project benefits. This appendix gives advice on the calculations required, and shall be used as a guide to summarising the net benefits and costs of the project options in worksheet A11.3.

Background

For fixed matrix evaluations, the benefits are the change in resource costs between the do-minimum network and the option. Where variable matrices are involved, the benefits of the additional journeys must be included. Since the decision to make additional journeys is based on the costs perceived by car users, the measure of the benefits is also based on perceived user costs, and is usually computed as the change in road user surplus. It is also necessary to include a correction term to compute the total social benefits, since road users do not take full account of the effects of their decisions on resource consumption. This additional term is often referred to as the resource cost correction.

The resulting formula for the net project benefit is computed for each cell of the matrix individually (for a given time period) and is:

$$\text{Benefit} = \underbrace{\tfrac{1}{2}(T_{OPT} + T_{DM}) \times (U_{DM} - U_{OPT})}_{\text{'change in road user surplus'}} + \underbrace{T_{OPT}(U_{OPT} - R_{OPT})}_{\text{'resource cost correction'}} -$$

or, rearranging terms:

$$\text{Benefit} \quad \underbrace{(R_{DM}T_{DM} -}_{\text{'change in resource costs'}} \qquad \underbrace{\tfrac{1}{2}(U_{DM} + U_{OPT}) \times (T_{OPT} -}_{\text{'adjustment for variable trip matrix'}}$$

Where:

T_{DM} = Number of trips in the do minimum.

T_{OPT} = Number of trips in the project option.

U_{DM} = User cost of travel in the do minimum.

U_{OPT} = User cost of travel in the project option.

R_{DM} = Resource cost of travel in the do minimum.

R_{OPT} = Resource cost of travel in the project option.

The implied subscripts *i* and *j* have been omitted for clarity.

For a fixed matrix evaluation when T_{DM} equals T_{OPT}, the second term is zero and this formula becomes the simple difference in resource costs (the first term in the formula). While this first term can be computed using matrix manipulations, it is standard practice to accumulate the resource costs over the network links and use network statistics to estimate total network-wide resource costs in both the do-minimum (the term R_{DM} T_{DM}) and option (the term R_{OPT} T_{OPT}). This is termed a link-based evaluation.

The values of time and vehicle costs given in the appendices are resource costs (which are the actual costs of travel excluding taxation and other non-resource costs). Estimate user costs directly from resource costs according to the table A11.1.

Table A11.1 Guidelines for estimating user time and vehicle operating costs

Cost component	Obtain resource costs from …	To derive the user cost …
Value of time (working)	Tables A4.1 – A4.4	User cost = resource cost
Value of time (non-working)	Tables A4.1 – A4.4	User cost = resource cost x 1.15
Vehicle operating cost (in urban networks):		
Tables and graphs of cost by average speed and gradient	Tables and figures A5.1 – A5.11	User cost = resource cost x 1.2
Tables and graphs of additional costs for roughness	Tables and figures A5.12 – A5.15	User cost = resource cost x 1.125
Tables of fuel costs due to bottleneck delay	Tables A5.16 – A5.23	User cost = resource cost x 2.0
Graphs of additional costs for speed change cycles	Figures A5.24 - A5.43	User cost = resource cost x 1.9

Matrix-based computation

For a variable matrix evaluation, adopt either of the following two methods to accumulate the net benefits of project options:

(a) a matrix-based analysis, where an average cost is computed for each origin-destination pair; or

(b) a link-based analysis, where costs are computed separately for each link (or groups of links).

Choose the most convenient method for the software used.

Create the matrices of trips and costs required to compute the benefits as itemised in table A11.2.

Using matrix manipulations, compute the benefit matrix (for a single time period) using the formula:

For each *i,j* pair,

$$B_{ij} = \left[R_{ij}^{DM} T_{ij}^{DM} - R_{ij}^{OPT} T_{ij}^{OPT}\right] + \tfrac{1}{2}\left[U_{ij}^{DM} + U_{ij}^{OPT}\right] \times \left[T_{ij}^{OPT} - T_{ij}^{DM}\right]$$

The total project benefit B is then given by the matrix total ($\sum_{ij} B_{ij}$) summed over all matrix cells. For use with this procedure, the formula should be applied to travel time and vehicle operating costs only.

Table A11.2 Required cost and trip matrices

Data	Symbol	Comment
Trip matrices	T_{ij}^{DM}, T_{ij}^{OPT}	Available from the model
Resource and user cost matrices	R_{ij}^{DM}, R_{ij}^{OPT} U_{ij}^{DM}, U_{ij}^{OPT}	The constituent times and distances by link type are skimmed from the networks and the costs subsequently computed. The same paths (and link speeds) should be used for both resource and user costs. If in this process the precision of the representation of vehicle operating costs is much reduced, the link based method may be preferred.

Link-based computation

Link-based computation of project benefits is currently standard practice with the change in resource costs determined by summing link benefits over the network but, as may be seen from the benefit formula, to the standard calculation of the change in resource costs should be added a variable matrix term. This can be calculated from overall network statistics, but requires some additional network processing, as follows.

First, the extra term can be expanded to four terms to read:

$$\frac{1}{2}\left(\underbrace{U_{OPT}T_{OPT}}_{\text{'I'}} - \underbrace{U_{DM}T_{DM}}_{\text{'II'}} + \underbrace{U_{DM}T_{OPT}}_{\text{'III'}} - \underbrace{U_{OPT}T_{DM}}_{\text{'IV'}}\right)$$

where each of these four terms (I-IV) may be computed from network statistics.

'I' This is the total user cost for the option network, and may be calculated in the same manner as the resource costs but using the cost weights in table A11.1.

'II' This is the total user cost for the do-minimum network, and may be calculated in the same manner as the resource costs but using the cost weights in table A11.1.

Terms III and IV are unusual and require a particular network/assignment procedure called a 'crossload':

'III' This term uses the do-minimum network, but the user costs must be weighted by the trips in the project option matrix; this is achieved by loading the project option matrix on the do-minimum network keeping the paths and link speeds unchanged (that is, there are no speed or path-building iterations and the paths and speeds are those determined from assigning the do-minimum matrix); network statistics are then extracted and processed using standard techniques.

'IV' this term uses the project option network, but the user costs must be weighted by the trips in the do-minimum matrix; this is achieved by loading the do-minimum matrix on the project option network keeping the paths and speeds unchanged; network statistics are then extracted and processed using standard techniques.

For the computation of variable matrix benefits using link-based evaluation, assignment software must be able to handle 'crossloads'.

Having summed items I - IV and halved the result to obtain the 'adjustment for variable trip matrix', then add the change in resource costs, $(R_{DM}T_{DM} - R_{OPT}T_{OPT})$ as described in the above. The result should be entered into item 5 on the worksheet. Note that for use with this procedure, the road user surplus and resource cost formulas should be applied to travel time and vehicle operating costs only (other benefits are assumed to be unaffected by road user surplus issues). The remaining resource costs associated with crashes and vehicle emissions will be entered separately in items 6 and 7 on FP Worksheet 3.

A11.13 Checking growth constraint or variable matrix methods

When to use

These checks are related to the procedures in Appendix A3.3 and may be used to check the appropriateness of growth constraint or variable matrix methods for dealing with suppressed and induced traffic. The checks supplement the general model validation guidelines given in FP Worksheet 8.

Suggested checks

Suggested checks include.

Method used	Suggested information
The capacity of the do-minimum network was upgraded	• demonstration that the capital cost of do-minimum improvements is less than 10-15% of the project option cost • indication of adequate capacity (see below).
A growth suppression technique was used (eg, matrix scaling, incremental matrix capping, shadow network, elasticity method on the do-minimum)	• indication of adequate capacity (see below) • details on the size and location of the suppressed travel • evidence, where feasible, of network performance before and after growth suppression • details of the methodology applied.
Peak spreading was used	• evidence of current variations in peak proportions: a. within the study area, in the base year and historically b. between cities or across New Zealand. • based on this evidence, an indication that current traffic profiles in the study area are relatively peaked • forecasts of a decline in peak period speeds relative to the interpeak (because peak spreading is more likely to occur when peak speeds deteriorate faster than interpeak speeds).
A variable matrix technique was used (eg elasticity method on both the do-minimum and project option)	• indication of adequate capacity • differences between the do-minimum and project option matrices • evidence of the convergence of the method (ie stable estimates of costs and matrices), or other evidence to justify reliance on forecasts (see FP Worksheet 8.4, part D) • details of the methodology applied.

Checking capacity in the do-minimum and project option

To check the do-minimum and project option capacity, the following performance indices may be used. If the indices suggest congestion over large or significant parts of the network, judged on the basis of at least one hour of flow, then the network should be considered as congested. If, however, the congestion occurs only in the later years of the economic life of the scheme (which contribute very little to the BCR), these effects may be ignored where reasonable.

Performance indices	Indicator of significant congestion
Level of service.	Level of service E or F*.
Matrix feasibility.	Network model is unable to achieve a stable realistic assignment.
Plots of link volume to capacity ratios or manual calculation of the ratio (see Appendix A3.17).	Ratios consistently higher than 1.0.
Link speed plots.	Speeds consistently below realistic values (15-25 km/h) for links of average length.
Junction delay statistics.	Delays consistently longer than five minutes per junction or queues ‘blocking back’ to upstream links.

* Level of service E occurs when traffic volumes are at or close to capacity, and there is virtually no freedom to select desired speeds or to manoeuvre within the traffic stream. Level of service F is in the zone of forced flow where the amount of traffic passing a point exceeds that which can pass it. Queuing, delays and flow breakdown occur at these flow levels. (Source: Austroads).

A12 Update factors and incremental BCR

A12.1 Introduction

Introduction

This appendix contains update factors for benefits and costs. Target incremental BCR ratios are also contained in this appendix.

In this appendix

	Topic
A12.1	Introduction
A12.2	Update factors for construction and maintenance costs
A12.3	Update factors for benefits
A12.4	Target incremental BCR

A12.2 Update factors for construction and maintenance costs

Cost update factors

The factors for updating construction and maintenance cost estimate prepared in earlier years are:

Table A12.1: Cost update factors

Calendar year in which estimate prepare	Factor to adjust to July 2013
2009	1.08
2010	1.06
2011	1.02
2012	1.00

A12.3 Update factors for benefits

Cost update factors

The factors for updating the benefit values in this manual are:

Table A12.2: Benefit update factors

Variable	Base date	Factor to adjust to July 2013
Travel time cost savings[TT]	July 2002	1.40
Vehicle operating cost savings[VOC]	July 2008	1.06
Crash cost savings[ACC]	July 2006	1.22
Comfort benefits[CB]	July 2002	1.40
Driver frustration[DF]	July 2002	1.40
Passenger transport user benefits[PT]	July 2008	1.12
Walking and cycling beneftis[WCB]	July 2008	1.12
Travel behaviour change benefits[TBhC]	July 2008	1.12

A12.4 Target incremental BCR

Target incremental BCR

The analyst shall choose and report the target incremental BCR used when undertaking incremental analysis of project options. Where the selected target incremental ratio differs to the guidance below, the analyst must provide a detailed explanation supporting the chosen value. The following guidance is provided:

a. The minimum incremental BCR shall be 1.0, in order to ensure that the additional spending to invest in a higher cost project option rather than a lower cost option is economically efficient.

b. Where the BCR of the preferred option is greater than 2.0 but less than 4.0, the target incremental BCR shall be 2.0.

c. Where the BCR of the preferred option is greater than or equal to 4.0, the target incremental BCR shall be 4.0.

A13 Risk analysis

A13.1 Introduction

Introduction

This appendix follows the principles set out in the Australian/New Zealand Standard AS/NZS 4360 on risk management. These principles are set out below and the analysis covers all these principles with the exception of treatment:

- Establish the strategic, organisational and risk management context in which the process will take place.
- Identify what, why and how risks can arise as the basis for analysis.
- Analyse risks in terms of their consequences and likelihood within the context of any existing controls. Consequence and likelihood can be combined to produce an estimate of risk.
- Evaluate risks by comparing estimated levels of risk against pre-established criteria. This enables the identification of management priorities.
- Treat risks. This should involve the acceptance and monitoring of low-priority risks and the development and implementation of risk management plans for higher priority risks.
- Communicate and consult with all stakeholders at each stage of the risk management process. The process is often iterative.
- Monitor and review the performance of the risk management system (plan) and any changes that may affect it.

In this appendix

A13.2 Risk

Overview

The purpose of considering risk is to develop ways of minimising, mitigating and managing it. Risk analysis and risk management are continuous processes that start at the project inception stage and proceed through to project completion and ideally should involve all the relevant parties.

The extent of risk analysis needs to be appropriate to the stages of project development. The critical project stages are from the rough order cost (ROC) stage through to preliminary assessed cost (PAC) stage and then to final estimate of cost (FEC) stage. It is intended that the scope and extent of analysis will progress according to the stage of project development and be most comprehensive at the FEC stage. The risk identified and evaluated in these various stages needs to be monitored and managed, particularly in the final construction stage.

Risk management process

Risk definition and planning →	**Implementation and monitoring** →	**Review and recommendations**
Start of project stage:	During the project stage:	At end of project stage:
Identify risks	Implement preferred strategy	Report on outcomes of strategy (one aspect of the reporting would be that contained in worksheets A13.1-A13.3)
Assess risk management strategies (reduction, mitigation, avoidance, quantification through date collection etc.)		Assess implications for next stage of project*
Choose preferred strategy *		

* The types of choices which may be addressed at these decision points are illustrated in Appendix A13.4.

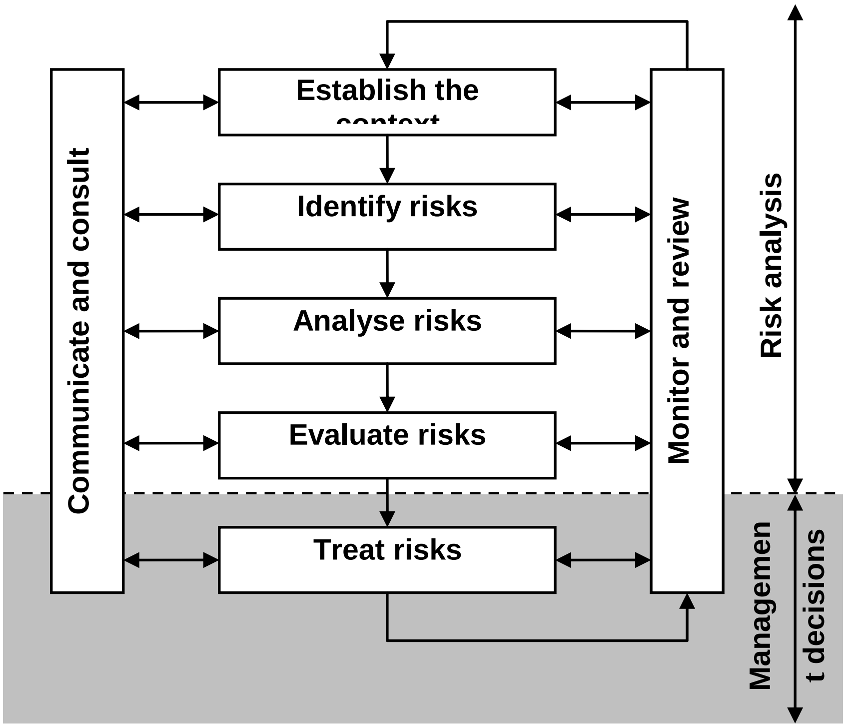
A13.3 Risk management

Risk management options example

Risk	Examples of alternative actions	No action, accept risk	Do more work on issue in:		Purpose of investment is to:		Defer
			this phase	later phase	quantify risk	reduce risk	
Base matrix	Short term emphasis on matrix estimation, validation and additional validation data collection	X	X	X	-	X	-
	Medium term model improvement/ updating	X	-	X	-	X	X
	Longer term data collection	X	-	-	-	-	X
Growth forecasts	Ensure that planning estimates are reliably based on best practice procedures	X	X	X	-	X	X
Assignment	Collect more validation data	X	X	X	X	-	-
	Improve model	X	X	X	-	X	X
Crashes	Collect more crash data	X	X	X	-	X	-
	Defer project until crash rates can be determined with greater confidence	X	-	-	-	X	X
Services	Surveys	X	X	X	X	X	-
	Relocation of services	X	-	X	-	X	-
	Alternative road design	X	X	-	-	X	X
Geotechnical	Surveys; increase sampling density	X	X	X	X	X	-
Environment and planning	Scheme selection	X	X	-	-	X	X
	Redesign/extend consultation procedure	X	X	X	-	X	-
	Natural hazard	X	X	X	X	X	-
Base engineering	Alternative design	X	X	-	-	X	X
	Can more be done to reduce complexity risks?	X	X	X	-	X	-
Land and property	Scheme selection	X	X	-	-	X	X
	Early acquisition	X	X	X	-	X	-

A13.4 Risk analysis

Risk analysis steps



Risk analysis structure

The analysis contain three separate worksheets A13.1 to A13.3:

Worksheet A13.1

Used for both an abbreviated summary of risks for projects that are at the preliminary ROC stage of evaluation and for detailed reporting of risks for projects that are past the ROC stage

Worksheet A13.2

Provides additional detailed information on the high risks identified in worksheet A13.1 plus an indication of the projects relative risk to a typical project

Worksheet A13.3

Provides a summary of the project cost contingencies.

The risk analysis is not intended to be limiting and organisations are welcome to use more advanced techniques such as Monte Carlo analysis if they consider this appropriate. These guidelines do not cover every eventuality.

Use of worksheets A13.1 to A13.3 in risk management

Some of the key features of a risk management process are illustrated in Appendix A13.2, the risk management process where risks are identified at the start of a project stage and risk management strategies (or treatments) developed and implemented through the project. On completion, the outcomes are reviewed and their implications for the next stage established.

At the end of a project stage, depending on the nature of the risks, there are a number of strategic decisions available: accept the risk or, otherwise, reduce its likelihood or its consequences, or transfer or avoid the risk. These decision may in turn lead to the following actions:

- abandon the project (this should normally be limited to the PFR stage)
- reformulate the project to capture the majority of the benefits at reduced cost
- conduct further investigation to reduce one or more of the identified uncertainties (either physical investigations of more detailed assessment of risks)
- defer further processing of the project until information comes available that assists in reducing the uncertainties
- defer further processing of the project until the FYRR increases to the required cut-off level
- proceed to the next stage of processing, or to tender.

In most cases, there are likely to be investigations or other actions which would enable the risks, once identified, to be quantified or reduced. Examples of such actions are illustrated in Appendix A13.3 risk management options.

Worksheets A13.1 to A13.3 shall be used to indicate areas of especially high or low risk in the project evaluation. Risks which are common to most projects (for example, the effects of national economic growth on traffic levels or inflation in the unit costs of construction) should not be included in the analysis. The worksheet instructions give guidance on how high and low risks may be distinguished from such common (‘medium’) risks. Only risks which are expected to have such significant effects on project benefits or costs that they will be material to decisions on the development of the project should be reported in detail. Risks that are expected not to be material to such decisions should be listed, and the reason for them considered not to be material must be outlined..

The procedures described in this worksheet are not reliant on quantitative methods of risk analysis such as Monte-Carlo but, where these detailed and comprehensive methods have been applied, in discussion with NZ Transport Agency those results may be used in place of or as a supplement to these worksheets.

The projects for which risk analysis is required are specified in Section 2.10.

Summary of risk

Worksheet A13.1 shall be used to indicate areas of high or low risk in projects. In this worksheet nine overall categories of risk are defined, within each of which a number of risk sub-categories have been identified as being potentially material. For each item in the worksheet, the analyst should assess the risk according to the suggested criteria (discussed below) and indicate whether any risks fall into the low or high categories. In some cases, additional sensitivity tests may be required to determine the level of risk, and these are included in the instructions below. The list may not be exhaustive and space is allowed for identifying other material risks in the worksheet.

Although it will generally be appropriate to report on the risks for the detailed sub-categories, in those circumstances where only broad risk information is available, such as in early project stages, it would be acceptable to be report on the risks for each category as a whole, and the worksheet is structured to permit this.

The criteria which are used to distinguish high and low risks in the guidance which follows are based on professional experience of the key factors which affect level of risk. Where there is any doubt as to the appropriate classification, the general rule is that the risk should be classified as high if there is a 5% chance that the effect on overall benefits or costs could be outside the range ±5% for costs and ±10% for benefits (that is that the 95% confidence limits are in the region of ±5% for costs and ±10% for benefits).

In cases of doubt, specific sensitivity tests are proposed, but these may be amended if, in the analyst's judgement, there are more appropriate tests.

A13.5 Benefit risks –road activities

Benefit risks

As a general principle, if there is at least a 5% risk that any of the following categories could account for a variation in TOTAL project benefits of more than ±10% then it should be classified as 'High risk'.

Benefit risks – base travel demand

1	**Base travel demand**	Base demand data sources may be counts, intercept surveys or a strategic model usually based on household surveys. References to counts below are concerned with models derived solely from this source.	
1.1	Age of data source	Low risk:	Intercept survey or traffic counts less than one year old. Strategic model: household travel survey less than five years old.
		High risk:	Intercept survey or traffic counts greater than three years old. Strategic model: household travel survey greater than 10 years old.
1.2	Data scope	Low risk:	Count and intercept sites in project corridor. Strategic model has been reviewed and approved.
		High risk:	Count and intercept sites not in close vicinity of project and thus not encompassing most (>80%) of the relevant traffic. No independent review of strategic model.
1.3	Data quantity and statistical reliability	Low risk:	five or more years continuous count data. Intercept data. Strategic model: one-day household travel diary with either a sampling rate greater than 3% of population or a sample of at least 5,000 households.
		High risk:	Counts: a few weeks count data in context of seasonal traffic patterns, such that the 95% confidence level for annual traffic exceeds ±10%. Strategic model: one-day household travel diary with either a sampling rate less than 1.5% of population or a sample of less than 2,500 households.
1.4	Travel demand validation to counts	Low risk:	Very comprehensive count programme with close fit of demand matrix to counts.
		High risk:	Just adequate fit of the demand matrix to limited set of count screenlines.
1.5	Traffic composition (model based on counts alone)	Low risk:	Derived from classified vehicle counts for an adequate sample of annual traffic.
		High risk:	EEM standard values used without local validation,

				such that the HCV proportion of traffic flow could vary by more than ±50%.
Benefit risks – growth forecasts	**2**	**Growth forecasts**	The sensitivity tests proposed below may be varied if alternative ranges can be justified.	
	2.1	High city population	Low risk:	Projected growth less than 0.5% per annum growth.
			High risk:	Projected growth greater than 1.5% per annum. In this case the analyst should conduct sensitivity tests allowing for the growth rate to vary by ±50%. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
	2.2	Development-related traffic as proportion of scheme traffic	Low risk:	Development-related traffic is less than 5% of traffic using the project.
			High risk:	Development-related traffic is greater than 15% of traffic using the project. In this case the analyst should conduct sensitivity tests allowing for the development size to vary by ±50%. If project benefits affected by more than 10%, classify as high risk, otherwise classify as medium risk.
	2.3	Time series projection (for a model based on counts alone)	Low risk:	Analysis based on more than 10 years count data.
			High risk:	Analysis based on less than five years data, or on less than 10 years data where the historic trend is irregular, such that the annual average growth rate cannot be established within a 95% confidence limit of ±1% per annum.
Benefit risks – assignment	**3**	**Assignment**	The sensitivity tests proposed below may be varied if alternative ranges can be justified.	
	3.1	Other future projects	Low risk:	No planned or potential future projects will affect the project.
			High risk:	Future projects will significantly affect the project's traffic flows (greater than 10%). In this case the analyst should conduct sensitivity tests to determine possible future project effects. If project benefits are likely to be affected by more than 10% (allowing for the likelihood of the project proceeding), classify as high risk, otherwise classify as medium risk.
	3.2	Path derivation method	The path derivation method will include the assignment procedures used to load trips onto the network and select vehicle routes.	
			Low risk:	Assignment procedure not used or the project is a simple improvement in a single corridor with no competing routes.
			High risk:	There are a number of closely competing alternative routes. In this case, the analyst should conduct an appropriate sensitivity test. Typical tests would include varying the parameters of the path derivation process, for example by changing the number of iterations used in assignment. The analyst should also ensure the model

				specification is peer reviewed. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
	3.3	Routeing parameters	The routeing parameters control the relative effects of time and distance (and any other factors) on the choice of route.	
			Low risk:	Assignment procedure not used or the project is of a similar standard and length to existing routes.
			High risk:	The project is longer and of a much higher standard than existing routes. In this case, the analyst should conduct sensitivity tests allowing the nominal parameter value to vary by ±50% or some equivalent increment. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
	3.4	Supply relationships	Supply relationships will generally include link capacities, free flow speeds and speed-flow relationships (in the context of a traffic assignment).	
			Low risk:	Assignment procedure not used or the network is uncongested.
			High risk:	Parts of the network are very congested. In this case the analyst should conduct sensitivity tests allowing for a uniform matrix change of ±5% or a uniform change in all saturated junction and link capacities of ±5%. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
	3.5	Convergence	Low risk:	Assignment procedure not used or assignment convergence is substantially better than validation requirement (refer FP Worksheet 8.4).
			High risk:	Assignment does not meet validation requirement.
Benefit risks – crashes	4	**Crashes**	Only consider 4.2 & 4.3 if 4.1 is judged to be high risk.	
	4.1	Proportion of benefits accounted for by crashes	Low risk:	Less than 10% of benefits accounted for by crashes (or crash analysis not used).
			High risk:	More than 20% of benefits accounted for by crashes.
	4.2	Observed crash sample size	Low risk:	Historical crash record includes at least 100 crashes.
			High risk:	Historical crash record contains less than 40 crashes.
	4.3	Judgemental crash reduction risk	Low risk:	Crash analysis not used.
			High risk:	Crash-by-crash analysis used for the project options.

A13.6 Benefit risks – transport services activities

Procedure

As a general principle, if there is at least a 5% risk that any of the following categories or subcategories could account for a variation in total activity benefits of more than ±10% then it should be classified as 'high risk'.

Base travel demand

Age of data source	As for roading. Refer to Appendix A13.5.	
Data scope		
Data quality and statistical reliability	Low risk	Boarding/alighting counts. Intercept data. Census data of recent origin may provide a reliable source of commuting patronage matrices.
	High risk	Screenline counts. Typically based on relatively unreliable observation methods and limited in geographic scope. Strategic model. Because such models may be based on small public transport trip samples, they would usually provide an unreliable, high-risk basis for an activity trip matrix. Convincing evidence that this was not the case would be required in order to reduce the risk classification.
Travel demand validation to counts	As for roading. Refer to Appendix A13.5	
Travel composition	For models based only on count data, reliable passenger composition estimates may be required for choosing elasticities or other modelling factors. In general, the variations in the passenger mix are not believed to be so large as to make assumptions of this nature a particular risk issue. Classify as low risk unless effects of uncertainties on benefits exceed five percent.	

Growth forecasts

The growth scenario	Public transport patronage growth trends are affected by: • population • age structure • employment • vehicle ownership • economic factors • policy measures • other factors.
High city population growth	As for roading. Refer to Appendix A13.5.
Development-related traffic as proportion of scheme traffic	
Other scenario factors	If activity benefits are affected by more than 10% classify as high risk, if less than 5% classify as low risk.

Other scenario factors continued	Public transport patronage trends are more sensitive to economic, strategic and policy factors (eg the past impacts of reduced costs of vehicle ownership in New Zealand), which may not be explicitly represented in forecasting methodologies. In general, this would imply that this aspect of the forecast should be classified as medium or high risk, depending on: a. the evidence of stability in past growth trends b. the extent to which the modelling methods encompass the major scenario factors c. views on the sensitivity of future growth trends.
Effects of public transport activities on overall public transport patronage	Public transport improvements will cause diversion of trips from other transport modes (vehicle, walk and cycle), redistribution of travel demand and induced patronage. If such diversions are a significant part of patronage, the patronage risks are likely to be higher. These risks will be further increased if there is uncertainty regarding the extent of public transport capacity to be provided as part of the activity (such as might be the case if the required service frequencies were subject to uncertainty).
Diversion from private vehicle	Modal change benefits can be a significant element of a public transport service proposal, walking and cycling package or travel behaviour change (TBhC) proposal. These benefits are difficult to estimate with precision, being sensitive to the assumed elasticities and/or model coefficients. Stable iterative modelling processes are required, linked to assignment procedures able to measure accurately the impacts of small traffic changes. Consequently, the risk associated with diversion from vehicle and the associated benefits should be classified as high, unless it can be convincingly demonstrated that these risks are reduced by the particular modelling processes adopted.
Diversion to public transport from walk and cycle; redistributed and induced public transport patronage	In general, these are likely to have a small effect on the overall level of public transport service benefits. Providing it is demonstrated through sensitivity tests that their effects on benefits are less than 5% of the total, these factors can be considered low risk.
Other sources of patronage and benefits	Some activities may have attributes, which, it may be argued, attract additional patronage or bring additional benefits. These may particularly relate to quality improvements to public transport. The risks associated with these sources should be assessed where they account for more than five percent of the benefits.

Assignment and the choice between alternative public transport modes (eg bus, light rail, heavy rail and ferry)

Other future activities	As for roading. Refer to Appendix A13.5
Path derivation method	
Generalised cost (routeing parameters)	In some circumstances, forecasts will be sensitive to the definition of generalised cost in the models (for example, to the size of the assignment boarding and interchange penalties) and sensitivity tests will be needed to demonstrate the extent of the risk.
Supply relationships	Not generally relevant.

Crashes

Proportion of benefits accounted for by crashes	The proportion of benefits accounted for by road crash savings will normally be less than 10% and should therefore be classified as low risk. In exceptional circumstances (for example, the provision of grade separation to replace a level crossing) this may not be the case, and a specific risk assessment should be made. If the proportion of benefits exceeds 20% classify as high risk.

Environment and planning

Proportion of benefits accounted for by environment and planning factors	The proportion of benefits accounted for by environment and planning factors will normally be less than 10% and should therefore be classified as low risk. If the proportion of benefits exceeds 20% classify as high risk.

A13.7 Cost risks – road projects

Cost risks

As a general principle if, there is at least a 5% risk that any of the following categories could account for a variation in TOTAL project cost of more than ± 5% then it should be classified as 'High risk'.

Cost risks – environmental and planning

5	**Environmental and planning**	Concerning each of the issues, the tests of risks are the same, and concern issue identification, tractability and sensitivity, and consultation.		
5.1	Tangata whenua issues	Low risk:	Identification: all issues well defined and understood.	
5.2	Emissions		Tractability: all issues have obvious solutions; few conflicts; low cost impacts.	
5.3	Landscape and visual		Sensitivity of project to issues: more than one affordable solution to issues.	
5.4	Ecological effects		Consultation: is expected to proceed smoothly and effectively.	
5.5	Archaeological and historic sites		Parties involved: previous consultative relationship, parties experienced in consultation process.	
5.6	Social networks and severance		Within designation and/or all resource consents have been obtained.	
5.7	Economic/amenity impacts on land users	High risk:	Identification: no environmental surveys or little consultation.	
5.8	Natural hazards		Tractability: contentious issues with conflicting requirements.	
			Sensitivity of project to issues: issues have very costly impacts on the project and are likely to affect its viability.	
			Consultation: significant consultation is required, but its extent cannot be predicted.	
			Parties involved: no prior contact and parties have no prior experience in consultation process.	
			New or changed designation and/or resource consents to be applied for.	

Cost risks – land and property

6.1	Property acquisition	Low risk:	All property is owned by road controlling authority.
		High risk:	Property still to be acquired from several owners with opposition expected.
6.2	Property economic value	Low risk:	Recent market valuations on a block by block basis; land use unlikely to change in future.
		High risk:	No recent market valuation; approximate valuation established on an area basis by zoning; land where change of use is possible in short to medium term (such as rural land on urban periphery)

Cost risks – earthworks	7.1	Knowledge of ground conditions	Low risk:	High density of sampling; variety of techniques and data available; good exposure of conditions; data interpreted by two parties (peer review).
			High risk:	No or very little subsurface investigation or site exposure.
	7.2	Complex/ unpredictable conditions	Low risk:	Previously engineered ground, non-plastic materials easy to excavate and not moisture sensitive; low water table.
			High risk:	Swamps, marine sediments, rock masses with steeply dipping clay-filled seams, or moisture sensitive clays; high water table or pressurised aquifers.
	7.3	Road design form	Low risk:	Low earthwork heights, no bridges or low bearing pressure structures.
			High risk:	High cuts/fills, tunnels, bridges or viaducts.
	7.4	Extent of topographical data	Low risk:	Flat terrain and comprehensive mapping.
			High risk:	Hilly, mountainous terrain, heavily vegetated and little topographical data.
	7.5	Source and disposal of material	Low risk:	Requirements can conveniently be satisfied locally
			High risk:	High volume requirements, uncertain sourcing and resource consent ramifications.
Cost risks – other engineering costs	8.1	Engineering complexity	Low risk:	Simple engineering using long established principles and approaches.
			High risk:	Complex solutions to difficult engineering issues.
Cost risks – services	**9**	**Services**	Underground and overhead services may include (but not be limited to) telecommunications cables, electricity cables, gas mains, water mains and sewers.	
	9.1	Existence, location and condition	Low risk:	Complete certainty of the services that are present in the area, and a high degree of confidence in their location, construction details and condition.
			High risk:	Service authorities not contacted, or services data unreliable, engineering details and condition unknown or poorly defined.
	9.2	Site flexibility	Low risk:	Wide reservation with few constraints to accommodate last minute service changes.
			High risk:	Constrained (normally urban) corridor with few options to accommodate changes.
	9.3	Cooperation of utilities	Low risk:	Single authority with an excellent track record of prompt attention to relocations
			High risk:	Several authorities to be coordinated in the same work area and/or poorly resourced and organised authority, or an authority in a state of major organisational change.

A13.8 Cost risks – transport services activities

Procedure

As a general principle, if there is at least a 5% risk that any of the following categories or subcategories could account for a variation in total cost of more than ±10% then it should be classified as 'high risk'.

Most of the cost risks are comparable with roading activity cost risks although there may be differences in their precise description and nature,.

Land and property

Property acquisition	As for roading. Refer to Appendix A13.7.
Property economic value	

Earthworks

Knowledge of ground conditions	As for roading. Refer to Appendix A13.7.
Complex/unpredictable conditions	
Design form	
Extent of topographical data	
Source and disposal of material	

Other costs

Engineering complexity	As for roading. Refer to Appendix A13.7.
Signalling and communications	Signalling and communications infrastructure should generally be considered a high risk element of engineering costs.
Transport service operating surplus/deficit	Unless a transport service operating surplus/deficit (the balance of revenue and operating costs) forms a large part of total costs, it would normally be classified as low risk.

Service

Existence, location and condition	As for roading. Refer to Appendix A13.7.
Site flexibility	
Cooperation of utilities	

A13.9 High risks

Identified high risks

There are two parts to treatment of identified high risks in worksheets A13.2(a) and (b). In worksheet A13.2(a), additional information should be supplied on the nature of the high risks identified in each of the main risk categories, and their implications for project decisions. Where possible and appropriate, courses of action for treating the risks should also be proposed and the costs of these actions estimated; a brief discussion of courses of action is given at the end of this section.

In respect of 'high' risk categories identified in worksheet A13.1, additional information should be supplied under the following five headings.

1. Risk category: (base travel demand, growth forecasts etc); only those categories where high risks have been identified need be covered; if it is judged that the identified low and high risks in any particular category are such that, overall, the category risk is not material, this should be stated and justified, and no further information is required.
2. Description: the risks should be described.
3. Estimated impacts on benefits/cost (as appropriate): the analyst's judgement as to the potential size of the risks, in terms of the percentage impact on either benefits or costs should be provided where feasible[4]. It is however accepted that it is the nature of some risks that reliable estimation of their potential impacts is impossible.
4. Description of implications for option selection and/or project timing: risks may impact on decisions on either option selection (where the risks are not common to all options) or project timing (where, for example, the risks of a non-qualifying BCR may be so high as to suggest a delay in project implementation).
5. Recommended actions and estimated costs of those actions (where relevant): the NZ Transport Agency will wish to consider the appropriate treatment for each risk (the generic options are: accept, avoid or transfer risks, reduce likelihood or reduce consequences of risks), and recommendations are sought on specific actions and their potential costs.

[4] This estimate should broadly correspond to a 95% confidence limit.

A13.10 Relative risk

Relative risk indicators

The risk summary table in worksheet A13.2(b) should be completed for the identified high risks. The risk categories are labelled R_1 to R_{17}. Leave a risk category blank if it is not high risk. If it is high risk, but the impact cannot be quantified, simply tick the relevant box. Where the risk impact can be broadly quantified, insert the expected percentage impact[5] on benefits, costs or the anticipated programme delay in the relevant box[6].

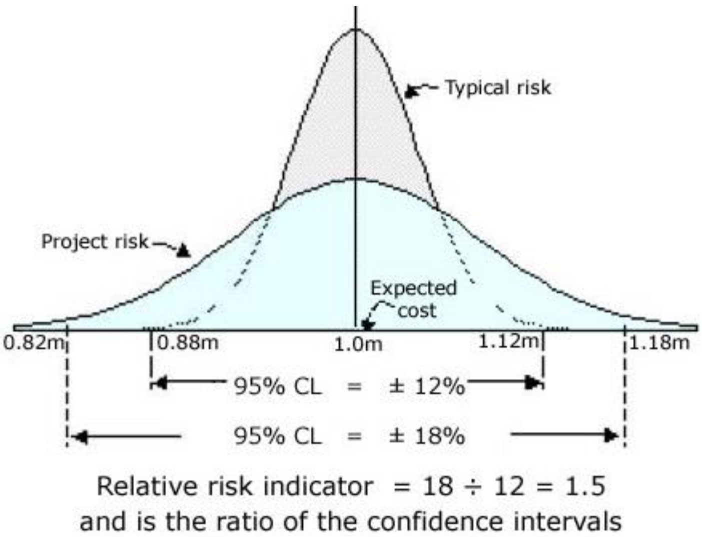
Worksheet A13.2 also provides a means of combining the identified and quantified high benefit and cost risks to give an indication of the impact of these high risks on the overall level of project risk relative to what might normally be expected for a typical project at a late stage in project development.

In order to compute the overall project risk, it is necessary to account for the typical risks to be expected in the other risk categories (the 'medium' or 'baseline' risks). Therefore, for the purpose of this worksheet, a broad judgement has been made on the expected levels of benefit, cost and BCR risks associated with a typical medium risk project in the later stages of development.

These measures of risk have been called 'relative risk indicators'; there are three, RB, RC and RBCR, for benefit, cost and BCR risks respectively. They combine the particularly high risks identified in the table with the expected medium risk levels in other categories to give an overall indication of the impact on project risk. The relative risk indicators measure the project risk relative to the baseline overall risk of a typical project.

The figure below illustrates the concept. If, for example, we estimate the baseline cost risk of a typical project to be $1m ±12% (95% confidence limits) and the risk for a specific project is higher at ±18%, then the relative risk indicator is 1.5, the ratio of the two values. Thus the 'high' risks identified for this project increase the overall risk by 50% over what would normally be expected.

An illustration of the relative risk indicator for project costs:



[5] For very asymmetric risk distributions, base the quantified risk on that part of the distribution corresponding to a decrease in benefits or an increase in costs.
[6] This estimate should broadly correspond to a 95% confidence limit.

Because the calculation takes no account of identified 'low' risk categories, the risk indicator is not a comprehensive measure of the overall project risk – it is partly for this reason that it is termed an 'indicator'. Until knowledge is gained of the performance of this indicator as a measure of risk and the degree to which it varies from project to project, it will not be a factor in funding decisions.

The relative risk indicators labelled RC and RB should be computed using the formulae:

$RB = [1 + (1/0.03) * \sum_i (V_i – 0.0056)]^{0.5}$; where $V_i = (R_i/100)^2$ and the summation is only for R_i values in the table.

$RC = [1 + (1/0.015) * \sum_i (V_i – 0.0025)]^{0.5}$; where $V_i = (R_i/100)^2$ and the summation is only for R_i values in the table

[That is, the benefit risk is computed from values R_1 to R_4 and R_{11} provided in the table and the cost risk from R_5 to R_{10}, where the risks are converted from percentage, eg, 30%, to a fraction, eg 0.3.]

The relative risk indicators RB and RC thus calculated are combined to give the overall BCR relative risk indicator RBCR as follows.

$RBCR = [0.35 * RC^2 + 0.65* RB^2]^{0.5}$

Example of relative risk indicator calculation

The notes below illustrate the calculation of the relative risk indicators, using the example above.

Relative cost risk indicator:

$RC = \{1 + (1/0.015) \times [(R_5^2 - 0.0025) + (R_8^2 - 0.0025)]\}^{0.5} = 2.52$

That is, the estimated cost confidence limit (95%) risk is 152% larger than the nominal value.

Relative benefit risk indicator:

$RB = [1 + (1/0.03) \times (R_2^2 – 0.0056)]^{0.5} = 1.07$

That is, the estimated benefit confidence limit (95%) risk is 7% larger than the nominal value.

Relative BCR risk indicator:

$RBCR = [0.35 \times RC^2 + 0.65 \times RB^2]^{0.5} = 1.72$

That is, the estimated BCR confidence limit (95%) risk is 72% larger than the nominal value.

Example of relative risk indicator table

Estimated 95% confidence limits on quantifiable risk category (expressed as a % of the impact on TOTAL costs or TOTAL benefits)

Risk category	Benefit risk	Cost risk	Programming risk
1			
2	(R_2 =) 10%		
3			
4			
5		(R_5 =) 15%	
6			
7			(R_{14}=) 6 months
8		(R_8 =) 25%	
9			
10		(R_{10} =) ✓	
Overall relative risk indicators	(RB =) 1.07	(RC =) 2.52	(RBCR=) 1.72

A13.11 Contingencies

Contingencies

Significant cost risks which cannot be realistically reduced by other means are covered by contingencies in the cost estimate. These contingencies reduce the likelihood of a cost over-run. Worksheet A13.3 should be used to specify identifiable specific contingencies against the 'high' risks identified in worksheet A13.1(a) (and, if appropriate, any other smaller risks). The overall contingency allocated should be specified and an indication given of the confidence attached to the contingency, in terms of the likelihood of a cost over-run greater than the contingency.

Concerning the relevant contingencies, if the following six types are distinguished:

1. changes in scope definition arising from omissions
2. changes in scope definition arising from client instruction
3. estimating inaccuracy
4. identified risks which are not managed
5. known but undefined risks
6. unknown risks

Then generally we can expect the contingency table to focus on items 4 to 6, while for most projects items 1 and 3 would be allowed for in uniform factors on costs; item 2 is excluded.

A13.12 Example of risk analysis

Introduction

The following example illustrates the application of these risk analysis.

In this example, a minor bridge structure has been assessed to have a limited residual life and has been tentatively programmed for replacement after five years. However, the design of the bridge pre-dates modern earthquake design codes and the bridge would be damaged to an extent requiring replacement in an earthquake of return period of 200 years or more.

Calculating probability of risk

The annual probability of the bridge being destroyed by earthquake in any one year, denoted as p, is 1/200 = 0.005. The probability of the bridge surviving for five years and then being replaced as programmed, is calculated as follows:

a. The probability of an earthquake in the first year = p = 1/200 = 0.005.

b. The probability of the bridge surviving for one year is therefore (1 - p) = 0.995.

c. The probability of the bridge being destroyed in year two is the probability of it surviving through year one multiplied by the probability of an earthquake in year two = p(1 - p) = 0.005 × 0.995 = 0.004975 and so on for five years.

In the general case, the probabilities of the bridge being destroyed in each year are:

year 1	p
year 2	$p\ (1 - p)$
year 3	$p\ (1 - p)^2$
…year n	$p\ (1 - p)^{n-1}$

and the probability of the bridge surviving to n years and then being replaced is therefore:

$$1 - p - p\ (1 - p) - p\ (1 - p)^2 - \ldots - p\ (1 - p)^{(n-1)} = (1 - p)^n$$

The probability of survival to the end of year five is therefore:

$$(1 - 0.005)^5 = 0.97525$$

In the event of earthquake damage, a temporary Bailey Bridge would have to be erected while a new permanent structure was being built. This would impose an additional cost on the road controlling authority which would not occur in the case of a planned replacement. There would also be disruption to traffic at the time of the earthquake.

Calculating costs if risk occurs

Assume that the bridge replacement cost is $2.5 million over two years. Making the assumption that an earthquake, if it occurred, would on average occur mid-year, it is then assumed that these costs are distributed $1.5 million in the first year, and $1.0 million in the next year.

Assume that the cost of erecting a temporary Bailey Bridge is $0.2 million spread over six months, the disruption cost during planned replacement of the bridge is zero (the old bridge remains open), and the disruption cost of unplanned delays while the Bailey is being constructed is $0.5 million and disruption during Bailey use (during the two years it takes to construct the new bridge) is $0.2 million per year.

If the bridge is destroyed before planned replacement, then the costs at the start of the year in which the earthquake occurs are:

Roading costs:	$million	
Bailey bridge	$0.1 × 0.9713	(SPPWF yr 0.5)
	$0.1 × 0.9433	(SPPWF yr 1.0)
Permanent replacement bridge	$1.5 × 0.9433	(SPPWF yr 1.0)
	$1.0 × 0.8900	(SPPWF yr 2.0)
total	$2.496 million	
Road user costs:		
Initial disruption costs	$0.5 × 0.9713	(SPPWF yr 0.5)
	$0.2 × 0.5 × 0.9433	(SPPWF yr 1.0)
Ongoing disruption costs	$0.2 × 0.9163	(SPPWF yr 1.5)
	$0.2 × 0.5 × 0.8900	(SPPWF yr 2.0)
total	$0.663 million	

where: SPPWF is the single payment present worth factor.

Calculating expected values

The probability of the bridge being destroyed by an earthquake in each of years one, two three and four are then multiplied by the above costs and benefits to give expected values in each year. The same is done in year five for the costs of planned replacement of the bridge. The expected values of costs and benefits in each year are then as follows:

Year	Probability	Costs	Benefits	Expected value (costs)	Expected value (benefits)
1	0.005000	2,496,000	-663,000	12,480	-3,315
2	0.004975	2,496,000	-663,000	12,418	-3,298
3	0.004950	2,496,000	-663,000	12,355	-3,282
4	0.004925	2,496,000	-663,000	12,293	-3,265
5	0.004901	2,496,000	-663,000	12,233	-3,249
Year 5 replacement	0.975250	2,305,000		2,248,000	

Remaining calculations

The above costs and benefits are effectively discounted to the start of each year and each must be further discounted by the SPPWF factor for (year - 1).

The example does not take account of any benefits that may arise from bridge replacement such as a reduction in annual maintenance costs, road user benefits from improved alignment or reduction in bridge loading restrictions. These should be dealt with in a similar way, by discounting future costs and benefits to the start of each year one to five and then multiplying by the probability of loss of earthquake occurrence to give expected values, which should then be further discounted to time zero.

A14 Travel demand elasticities

A14.1 Introduction

Introduction

This appendix provides a sample of travel demand elasticises gathered from international literature reviews.

The demand elasticity values provided are intended to provide a guide to the elasticities for use in the demand estimates.

In this appendix

	Topic
A14.1	Introduction
A14.2	Elasticities
A14.3	References

14.2 Elasticities

Price elasticity estimates for rail freight commodities

The elasticities in the table below apply to road/rail modal choice.

Table A14.1: Elasticities for freight commodities

Commodity	Range
Food and kindred products	-1.04 to –2.58
Lumber and wood products	-0.05 to –1.97
Paper products	-0.17 to –1.85
Machinery	-0.16 to –2.27

Elasticity depends on the level of inter-modal competition. The values in the table above are indicative only and represent the percentage change in rail volume with respect to the percentage change in rail to road price.

Transit time (generally used as a proxy for distance) appears to be a significant determinant of mode choice. The greater the distance, the less likely truck transport will be chosen.

In New Zealand, where inter-modal competition is likely to be significant, it is considered that freight price elasticities would more likely be at the higher end of the ranges identified above. However, it should be noted that other factors may influence a shipper's decision.

Fares elasticity for public transport

The recommended elasticity for 'real' fare changes is -0.2 to –0.3 for peak periods in the short term, with a range up to –0.6 in the long term.

It is suggested that, in the absence if any local data, a standard fares elasticity of -0.25 is applied to assess the shorter term effect of fare changes on patronage and revenue in peak periods. Other factors mitigating the use of this elasticity value should be noted.

Service elasticity for public transport

The recommended 'standard' elasticity for service changes (generally measured by public transport vehicle kilometres) is 0.25 for peak periods in the short term (0.5 for off-peak periods). However this varies with initial levels of service (service frequency): it is lower for high frequency services, and vice versa. Long term values are about twice these short-term values.

Public transport cross-modal effects

A New Zealand study completed in 2003 suggested the following effects on public transport patronage in response to changes in private vehicle travel costs (eg through changes in fuel prices):

- Peak: 0.4 extra person public transport trips for each private vehicle trip suppressed.
- Off-peak: 0.2 extra public transport trips for each private vehicle trip suppressed.

Elasticities summaries

Summaries of fare elasticities and cross-elasticities drawn from New Zealand and international literature surveys may be obtained on request from the NZ Transport Agency.

14.2 References

1. Wallis I (2003) *Review of passenger transport demand elasticities*. Transfund New Zealand research report 248.

A15 Bus operating cost

A15.1 Introduction

Introduction

This appendix provides guidance on the estimation of bus operating costs (excluding infrastructure) and offers indicative New Zealand bus unit operating cost rates.

In this appendix

A15.2 Costing variables and categories

Operating cost variables

Bus operating costs can be expressed as a function of the following three variables, which are summarised in Table A16.1:

- The time that the vehicle is in operation – bus hours
- The distance travelled in operation – bus kilometres
- The number of vehicles required to meet peak requirements – buses.

Table A15.1 Operating cost variables

	In-service operations	Total operations
Bus hours	• Total time that buses are engaged in service operations • In addition to terminus-terminus time, includes short breaks (up to 15 mins between trips (waiting at termini, etc) • May be derived from analysis of vehicle/ driver schedules.	• All time running between depot and start/end of route, and between routes. • Any extended periods on the road (with driver in charge) additional to in-service operations.
Bus kilometres	• Total distance run by buses in service operations. • May be derived from number of timetabled trips and route lengths.	• All distance running between depot and start/end of route, and between routes. • Any other non-service running (eg to replace broken down buses, driver training, etc).
Buses	• Maximum number of buses required in use at any one time on a normal weekday in order to operate the scheduled services. • May be derived from analysis of vehicle/driver schedules.	• Additional ('spare') buses required in fleet to allow for operational requirements (breakdowns, etc) and maintenance requirements.

Cost categories

A range of unit costs can be applied to each operating cost variable to determine the gross operational costs associated with providing the service. These are exclusive of any regional council/territorial local authority direct costs for administration and system-wide facilities (e.g. passenger information and enquiry services).

A description of the main bus unit cost categories and their associated variables are set out in table A15.2.

Table A15.2 Unit cost categories and allocation

Unit cost category	Cost items included	Variable
A Operating costs – time	Drivers – wages and direct on costs	Bus hours (total)
B Operating costs – distance: fuel	Fuel Oil, lubricants	Bus kilometres (total) – by vehicle category
C Operating costs – distance: other	Repairs and maintenance – wages and direct on-costs – parts, materials and external services Road user charges Tyres and tubes	Bus kilometres (total) – by vehicle category
D Operating costs – vehicles	Bus comprehensive insurance Bus registration, licensing Bus cleaning, fuelling Depot rental and rates	Buses (total) – by vehicle category
E Operating costs – overheads	Overhead labour – wages/ salaries and direct on –costs Overheads non-labour Minor assets (capital charges)	percentage mark-up on categories A–D
F Profit margin	Profit margin or management fee	percentage mark-up on categories A–E.
G Capital charges – vehicles	Bus assets	Buses (total) – by vehicle category

A15.3 Unit cost values

Unit cost rates

Table A15.3 provides a set of representative unit urban bus operating cost rates, for 'standard' size diesel bus operations. The costs relate to 2009/10 average price levels.

The unit costs given in table A15.3 should be regarded as indicative only: it is preferable to use local unit costs in each region where these are known. These estimates should also address cost differences: 1) between diesel buses and trolley buses; and 2) for diesel buses of 'non-standard' sizes.

Table A15.3 Unit cost rates, 2009/10 prices (standard diesel bus)

Cost category	Units	Cost rate	Notes, comments
A Operating costs – time	$/bus hour	22.00	
B Operating costs – distance: fuel	$/bus km	0.425	Based on typical diesel consumption of 37 litres/ 100km and price of $1.15/litre.
C Operating costs – distance: other	$/bus km	0.452	Includes 0.152 for RUC (Type 2 vehicles, 2/11 tonnes GVW rating); 0.300 for bus R&M, tyres and tubes.
D Operating costs – vehicles	$/bus pa	5000	
E Operating costs – overheads	% mark-up on items A–D	10%	
F Profit margin	% mark-up on items A–E	5%	Typical of profit margins on competitive urban bus contracts in Australia.
G Capital charges – vehicles	$/bus pa	36,000	Based on typical new diesel bus price of $375,000, life 18 years, depreciation rate 12.0% pa (DV), interest rate 7.5% pa (real).

A15.4 References

1. Wallis I and Schneiders D (2012) *New Zealand Bus Policy Model*. NZ Transport Agency research report 472.

A16 Funding Gap Analysis

A16.1 Introduction

Introduction

This appendix provides guidance on the application of funding gap analysis to be used in the evaluation of transport service activities. The funding gap is the level of investment required to ensure that a service operator can a reasonable level of return on their investment in providing transport services.

In this appendix

	Topic
A16.1	Introduction
A16.2	Service provider costs
A16.3	Service provider revenue
A16.4	Cash flow analysis
A16.5	Funding gap
A16.6	Sensitivity testing of the funding gap

A16.2 Service provider costs

Basis

Service provider costs are calculated either from industry standard unit costs, or from cost estimates from service providers. The costs include maintenance and operating costs for the new or increased service.

If costs can be obtained, either from industry standard unit costs or other sources (eg service provider) then undertake a full analysis of service provider costs. If the service provider will only disclose a ‘price’, net of user revenue, for providing the transport service then it can be assumed that the service provider costs are equal to the ‘price’ plus user revenue for use in the economic efficiency evaluation.

Appendix 15 provides guidance on the estimation of bus operating costs and offers indicative New Zealand bus industry standard unit operating cost rates.

Rules

Service provider costs must be calculated for the do-minimum and all activity options.

All costs should be presented both graphically and as a table, showing where the costs occur over the life of the proposal.

All costs must be exclusive of good and services tax (GST).

Indicative quotes

Indicative quotes may be used when activity costs cannot be calculated, for example if service providers will not divulge costs.

Indicative quotes are most likely to be used when there is a sole service provider. An indicative quote should only be sought after user charges have been fully defined (see Section 4.9.3). Care is required not to form a contract when seeking quotes.

Activity costs

Activity costs include:

- activity design and supervision costs
- capital costs
- disruption costs during construction/implementation
- operating and maintenance costs
- costs of decommissioning.

In some cases, costs may be offset by the salvage value of capital assets. Each of these costs is described below in more detail.

Capital costs

Capital costs are split into two types:

- physical infrastructure costs
- vehicle, vessel or rolling stock costs.

Physical infrastructure costs

Physical infrastructure costs include:

- land acquisition
- design
- construction
- environmental mitigation costs
- a contingency allowance for the total physical infrastructure costs.

In the case of the do-minimum, these costs may include essential rehabilitation.

	Where expenditure on an activity has already been incurred, it must still be included in the evaluation if the item has a market value which can be realised. Land is an example. Costs irrevocably committed which have no salvage or realisable value, are termed sunk costs and must not be included in the evaluation, eg investigation, research and design costs already incurred.
Vehicle, vessel or rolling stock costs	Include any capital costs relating to service vehicles or rolling stock. Include a contingency allowance for the total vehicle, vessel or rolling stock costs where the price is not absolutely fixed at the outset.
Disruption costs	Include disruption costs to the service provider during construction/ implementation. Disruption costs may include revenue loss, where services are disrupted to accommodate construction or cost increases such as providing alternative services during the construction period.
Operating and maintenance costs	Estimate operating and maintenance costs for the service over the analysis period. Maintenance costs shall include routine and periodic maintenance costs as well as refurbishment and replacement costs occurring in the analysis period.
Treatment of depreciation	Depreciation is a non-cash item and shall not be included separately in the cash flows used in the financial analysis to estimate the NPV of a proposal. Only actual cash flows associated with maintenance and asset replacement, (which effectively fully account for depreciation of capital assets), are to be included in the analysis.
Treatment of interest	Interest expenses associated with activity financing often represent an actual cash cost outflow. Despite this, interest charges should not be included in the annual cash flow as the required rate of return used in the cash flow analysis already takes account of debt-financing interest. If interest payments were included in discounted cash flows, the interest charges would be double counted and the proposal's funding gap would be overstated and the benefit cost ratio (BCR) understated.
Salvage value of capital assets	In some instances, assets will have a longer life than the analysis period. The salvage value of capital assets should be evaluated where: • items have a market value • there is an alternative use (for example, a bus can provide urban passenger services or could be used for school services or tours, but a road can usually only be a road) • there is a scrap demand for items. Any costs involved in decommissioning assets must be included in the evaluation. **Note:** Salvage values are quite distinct from book values of assets.

A16.3 Service provider revenue

Basis

This section describes the revenue information to be included in a financial analysis where an activity generates revenue. The process for calculating revenue of an improved service is different from that for a new service. The processes are given below.

GST

All revenue shall be exclusive of GST.

Existing public transport services

Where there is an existing public transport service, it is the increase in service provider revenue that is used in calculating the funding gap, as the funding assistance requested will be to facilitate the improved service rather than to fund the existing service.

Using the demand estimate information generated in Section 4.9, calculate the change in service provider revenue:

$$\text{Change in service provider revenue} = (Q_{new} \times P_{new}) - (Q_1 \times P_1)$$

Where:

P_1 = base average user charge.

P_{new} = proposed average user charge.

Q_1 = current annual patronage.

Q_{new} = projected annual patronage.

New public transport services

For a new public transport service, the projected number of new users is multiplied by the proposed average user charge to give the expected annual service provider revenue from a new service.

Using the demand estimate information generated in Section 4.9, calculate the annual service provider revenue.

$$\text{Annual service provider revenue} = (Q_{new} \times P_{new})$$

Where:

P_{new} = proposed average user charge.

Q_{new} = projected annual patronage.

Application for freight services

The above concepts for a public transport service apply to an improved or new freight transport service except that the projected new freight volume will be determined by the intended (or contracted) use by a limited number of freight consignors at a given or average freight rate (usually $ per tonne)

A16.4 Cash flow analysis

Introduction	A new or improved transport service will usually involve some initial capital expenditure and then ongoing annual operating and maintenance costs and annual revenue. Analysis of this cash flow is used to determine the financial viability of the proposed service.
Net cash flow	For each year, the net cash flow is calculated as: annual net cash flow = (revenue + funding gap) – (capital costs + operating and maintenance costs)
Service provider required rate of return	The annual net cash flows are discounted at the service provider's desired rate of return. The weighted average cost of capital (WACC) can be used to estimate the service provider's desired rate of return. WACC is the weighted average of the desired return on equity and the (interest) cost of any debt financing. The service provider's WACC should reflect the appropriate risk and norms associated with the industry.
Post-tax rate of return	Evaluators should use a post-tax rate of return. Care must be taken that service provider revenues and costs are calculated accordingly.
Period of financial analysis	The period of this financial analysis should, if possible, be sufficient to allow projected revenue to offset the initial capital cost but should not be unrealistically long taking account of uncertainties in demand for the proposed service.

A16.5 Funding gap

Funding gap

The funding gap is the deficit in cash flow that needs to be funded by local and central government if the activity is to be financially viable from the service provider's point of view, based on the best estimate of service provider revenue and the service provider's desired rate of return.

The funding gap can be defined in a number of different ways:

- as a contribution to the capital cost of the activity (spread over the construction period or paid at the end of construction)
- spread over the first few operating years of the proposal
- a combination of these.

Where the funding gap is zero or negative, the activity is commercially viable and no funding assistance should be required from government.

A positive funding gap does not mean that funding assistance is justified from the government (public policy) point of view.

Method

The funding gap is determined by trying different values of funding gap until the sum of the PV of the annual net cash flows is zero. The simplest method of determining the value of the funding gap is to use a computer spreadsheet program, such as the 'goal seek' function in the Microsoft Excel.

Example calculation

In this example of improvement(s) to an existing service, a 12% service provider's required rate of return is used. Different activities may justify lower or higher rates of return.

The period of analysis for this particular activity is 40 years. The revenue flow is the increase or change, in revenue from the base case (pre-existing service levels). The revenue for a new service would be equivalent to the number of users multiplied by the proposed user charge.

The funding gap is included in the table as a payment spread over year's two to nine of the proposal.

Different values were inserted for the funding gap until the sum of the last column equalled zero.

As the funding gap is positive, the activity is not commercial and funding assistance is required to make it viable. The value of the funding gap is $1,064,809 per year spread over year's two to nine. The PV of the funding gap is $4,722,845, which does not change irrespective of how the funding gap is defined. However, this PV is at the service provider's desired rate of return, not the discount rate used in economic evaluation.

The cumulative amount of the funding gap is $8,518,471. This depends on how the funding gap is defined. It is smallest when funding for the gap is provided all at the start of the proposal, eg $5,924,337 if all paid in year two.

Year	Capital cost	O&M cost	Revenue	Funding gap	Annual total	SPPWF	Net PV
1	-$2,500,000				-$2,500,000	0.8929	-$2,232,143
2	-$2,500,000	-$484,600	$346,000	$1,064,809	-$1,573,791	0.7972	-$1,254,617
3		-$484,600	$356,380	$1,064,809	$936,589	0.7118	$666,645
4		-$484,600	$367,071	$1,064,809	$947,280	0.6355	$602,014
5		-$484,600	$378,084	$1,064,809	$958,292	0.5674	$543,761
6		-$484,600	$389,426	$1,064,809	$969,635	0.5066	$491,247
7		-$484,600	$401,109	$1,064,809	$981,318	0.4523	$443,898
8		-$484,600	$413,142	$1,064,809	$993,351	0.4039	$401,198
9		-$484,600	$425,536	$1,064,809	$1,005,745	0.3606	$362,682
10		-$484,600	$438,302		-$46,298	0.3220	-$14,907
11		-$484,600	$451,452		-$33,148	0.2875	-$9,529
12		-$484,600	$464,995		-$19,605	0.2567	-$5,032
13		-$484,600	$478,945		-$5,655	0.2292	-$1,296
14		-$484,600	$493,313		$8,713	0.2046	$1,783
15		-$484,600	$508,113		$23,513	0.1827	$4,296
16		-$484,600	$523,356		$38,756	0.1631	-
17		-$484,600	$539,057		$54,457	0.1456	-
18		-$484,600	$555,228		$70,628	0.1300	-
19		-$484,600	$571,885		$87,285	0.1161	-
20		-$484,600	$589,042		$104,442	0.1037	-
21		-$484,600	$606,713		$122,113	0.0926	-
22		-$484,600	$624,914		$140,314	0.0826	-
			PV =	**$4,722,845**		**Sum of Net PV =**	**$0**

A16.6 Sensitivity testing of the funding gap

The financial analysis will involve making assumptions and estimates, which may involve uncertainty or be subjective in nature. Assessments of the sensitivity of the funding gap to critical assumptions must be undertaken on the preferred activity option.

Required sensitivity tests

There are three sensitivity tests that should be performed on the funding gap analysis:

- varying the service provider's required rate of return
- varying the timing of capital expenditure
- varying the length of the analysis period.

Each of these is described below.

Service provider required rate of return

An upper and lower bound of the service provider's required rate of return shall be indicated along with its effect on the PV of the funding gap of the proposal.

Timing of capital expenditure

Where significant capital expenditure is a feature of the proposal, sensitivity testing shall include the effect on the PV of the funding gap of varying the timing of such expenditure.

Period of analysis

The effect of varying the length of the period of analysis on the PV of the funding gap shall be presented.

A17 Equity Impacts and External Impacts

Equity impacts

The cost benefit analysis methods described in this manual do not directly deal with the incidence of benefits and costs on different sections of the public. Cost benefit analysis only indicates those projects with the largest resource gains per dollars of expenditure, irrespective of whether benefits and costs are evenly distributed or whether costs fall more heavily on some sections of society while benefits accrue mainly to others.

Equity refers to how the benefits and costs of transport projects are distributed across population groups. There are four types of equity related to transport:

- egalitarianism – treating everybody the same, regardless of who they are
- horizontal equity – whether benefits, disbenefits, (including externalities) and costs are applied equally to people and groups in comparable condition
- vertical equity with respect to income – whether lower–income people bear a larger portion of the impacts
- vertical equity with regard to mobility needs and abilities – whether transport systems adequately serve people who are transport disadvantaged.

Methods to disaggregate impacts among socioeconomic groups or geographical areas include:

- spatially based analysis that uses spatial units, such as traffic–analysis zones or census tracts that can be classified by characteristic (income, predominate minority, etc)
- spatial disaggregation, where a geographical information system raster module is used to disaggregate socioeconomic data and impact data to grid cells
- micro–simulation that uses a set of actual or synthetic individuals or households that represent the population.

An analysis of the distribution of benefits and costs among different groups of people is not required for the economic efficiency evaluation of the project. However, reporting of the distribution of benefits and costs, particularly where they relate to the needs of the transport disadvantaged, is part of the funding allocation process.

External Impacts

External impacts are benefits or disbenefits stemming from a project that do not reside with the responsible government agencies, approved organisations or transport users. Because cost benefit analysis takes the national viewpoint, external impacts must also be considered.

Environmental impacts

Environmental impacts are an important subset of external impacts.

The, *Land Transport Management Act* and *Resource Management Act* impose a duty when preparing projects to assess the effect of the project on the environment and environmental sustainability. The emphasis is to 'avoiding to the extent reasonable in the circumstances, adverse effects on the environment[7]' by:

- reducing the negative impacts of the transport system on land, air, water, communities and ecosystems
- the transport system is actively moving towards reducing the use of non–renewable resources and their replacement with renewable resources[8].

Quantifying and valuing external impacts

Most of the potential external impacts are discussed in Appendix A8, which contains techniques for quantifying and, in some cases, valuing the impact. Benefits from sealing roads are addressed in simplified procedure SP4.

Where impacts are valued, they should be included as benefits or disbenefits in the economic efficiency evaluation. Non–monetised impacts should be quantified, where possible, and reported as part of the funding allocation process.

Mitigation of external impacts

Where a design feature to avoid, remedy or mitigate adverse external impacts is included in a project and the feature significantly increases the project cost, it shall be treated in the following way. If the feature is:

a. required by the consenting authority in order to conform with the *Resource Management Act* or other legislation, then the cost of the feature shall be treated as an integral part of the project cost;

b. not required by the consenting authority in order to conform with the *Resource Management Act* or other legislation, then the feature shall be described and evaluated in terms of benefits and costs, and the results reported in worksheet A8.2.

The costs of the preferred mitigation measure shall be included in the project cost.

Transferred external impacts

External impacts are not included in the economic evaluation when these merely represent a transfer of impact from one person to another, eg, a change of traffic flow may benefit one service station at the expense of another. Although this may be a significant impact locally, from a national economic viewpoint the two impacts are likely to cancel each other out.

Also refer to Equity impacts in Section 2.3.

[7] *Land Transport Management Act*, section 96(1)(a)
[8] *New Zealand Transport Strategy*, page 85

A18 Public transport user benefits

A18.1 Introduction

Introduction

This appendix provides guidance on the calculation of benefits to public transport users, arising from activities that change the attributes of public transport services or infrastructure.

In this appendix

Reliability improvement benefits for public transport

Reliability relates to the uncertainty in the time taken to travel from the start to the end of a person's journey. For a public transport journey, reliability can affect users in two ways:

- as a delay when picking up the passenger, and
- as a delay when the passenger is on the service

Unreliable services cause adjustments in an individual's desired trip-making behaviour for example, by catching earlier services to get to their destination on time. And therefore an improvement in reliability generates a benefit to users in time savings. It may also impact demand for the service.

The number of passengers affected for the calculation of departure benefits is the number of passengers boarding, and the number of passengers affected when calculating in vehicle travel benefits is the number of passengers already on the service. Generally, just the number of passengers boarding can be used for simplified use.

Services running greater than 10 minutes late should be treated as 10 minutes late.

The total reliability benefit cannot exceed any travel time saving.

The following table contains the minute late ratios for each minute the service is late.

Table A18.1: Equivalent time to a minute late ratios

Segment	Departure	In vehicle travel	Combined
All	5.0	2.8	3.9
Train	3.9	2.4	3.1
Bus	6.4	3.2	4.8
Work	5.5	2.8	4.1
Education	3.0	3.8	3.4
Other	5.4	2.0	3.7

Note: The combined value assumes a 50:50 split between departure and in vehicle time delay en route

Calculate the user reliability benefits using the formula below:

Reliability benefit = EL × (VTT($/h)/60) × AML × NPT

Where:

EL = equivalent time to a minute late ratio from table A18.1

VTT = vehicle travel time ($/h) from table A4.2 in Appendix A4

AML = reduction in average minutes late (minutes)

NPT = number of passengers affected

Price change benefits for public transport

The calculation of transport service user benefits for a price change on an existing service is based on the difference between the existing average user charge and the proposed average user charge.

Calculate the price change transport service user benefits using the information in Section 4.9 to give the projected new patronage level, as follows:

Change in net total benefits for existing transport service users:

$Bp_{existing} = (P_1 - P_{new}) \times Q_1$

Net total benefits for new transport service users:

$Bp_{new} = (P_1 - P_{new}) \times (Q_{new} - Q_1) \times ½$ (rule of half)

Total price change benefits:

$Bp_{total} = Bp_{existing} + Bp_{new}$

Where:

P_{new} = proposed average user charge

P_1 = existing average user charge

Q_1 = existing number of passengers (patronage)

Q_{new} = projected new number of passengers

Increased service frequency benefits for public transport

Increased service frequency may also be described as decreased waiting time, headway reduction, or less queuing time. The benefit of the headway reduction depends on the existing frequency of the service.

Calculate the service frequency transport service user benefits using the information in Section 4.9 to give the projected new patronage level, as follows:

Frequency benefit per transport service user:

$FB = WTf \times 2 \times VOT$

Change in net total benefits for existing transport service users:

$Bf_{existing} = FB \times Q_1$

Apply the rule of half for the total benefits for new transport service users:

$Bf_{new} = FB \times (Q_{new} - Q_1) \times ½$

Total service frequency benefits:

$Bf_{total} = Bf_{existing} + Bf_{new}$

Where:

Q_1 = existing number of passengers (patronage)

Q_{new} = projected new number of passengers

WTf = wait time benefit (in minutes) from table A18.2

VOT = value of vehicle occupant time ($/minute) for by trip purpose from table A4.1(b) in Appendix A4.

Using the existing headway/service frequency (minutes), and the appropriate trip purpose from the table below, identify the benefit in minutes of wait time for improving service frequency. If the proposed new headway/service frequency is significantly less than the existing (ie 20 minutes compared with 40 minutes) an average of the wait time benefit for the two frequencies should be used.

Table A18.2: Increased service frequency benefit

Existing headway (minutes)	Wait time benefit (minutes)		
	Commute	Other	Combined
5.0	2.4	3.2	2.5
10.0	3.3	4.0	3.3
15.0	4.1	4.8	4.2
20.0	5.0	5.6	5.1
30.0	6.6	7.2	6.8
45.0	9.8	10.6	10.1
60.0	11.7	12.3	11.9

Interchange reduction benefits for public transport

In addition to the wait and/or walk time to transfer time that applies to service frequency benefits, there is a five minute IVT 'interchange penalty'.

Calculate the interchange reduction transport service user benefits for public transport using the information in Section 4.9 to give the projected new patronage level, as follows:

Interchange reduction benefit per public transport service user:

$IB = (WTi \times 2 + 5) \times VOT$

Change in net total benefits for existing public transport service users:

$Bi_{existing} = IB \times Q_1$

Apply the rule of half for the total benefits for new public transport service users:

$Bi_{new} = IB \times (Q_{new} - Q_1) \times ½$

Total interchange reduction benefits:

$Bi_{total} = Bi_{existing} + Bi_{new}$

Where:

Q_1 = existing number of passengers.

Q_{new} = projected new number of passengers.

WTi = existing wait and/or walking time to transfer between public transport services (minutes).

VOT = value of vehicle occupant time ($/minute) by trip purpose from table A4.1(b) in Appendix A4.

Other public transport service user benefits

The value of public transport service user benefits (other than fare change benefits, increased service frequency benefits and interchange reduction benefits), eg improved comfort, is usually based on a willingness to pay (WTP) value derived from a stated preference (SP) survey or on values derived for similar service improvements in other areas.

Calculate the other transport service user benefits using the information in Section 4.9 to give the projected new patronage level, as follows:

Change in net total benefits for existing transport service users:

$Bo_{existing} = (P_{max} – P_{new}) \times Q_1$

Apply the rule of half for the total benefits for new transport service users:

$Bo_{new} = (P_{max} – P_{new}) \times (Q_{new} - Q_1) \times ½$

Total other benefits:

$Bo_{total} = Bo_{existing} + Bo_{new}$

Where:

P_{new} = proposed average user charge (this may be different from the existing user charge).

P_{max} = maximum charge users are WTP for improved service.

Q_1 = existing number of passengers.

Q_{new} = projected new number of passengers.

Infrastructure and vehicle features for public transport

Users value infrastructure and vehicle features. Typical user valuations expressed in terms of in vehicle time are provided in tables A18.3, A18.4 and A18.5. These may be converted to generalised costs by multiplying by the value of time given in table A4.1(b) in Appendix A4. All values represent the difference between the do-minimum and an improvement. These values have been drawn from SP surveys and are the perceived benefits of an individual feature.

Vehicle features

Table A18.3: Vehicle feature values for rail public transport services

Rail			
Attribute	**Sub-attribute**	**Valuation (IVT minutes)**	**Comment**
Driver/staff	Train attendant	1.6	
	Ride	1.2	Quiet and smooth
Facilities	CCTV	2.0	
	On-board toilets	0.6	
Information	Interior	1.1	Frequent and audible train announcements
Seating	Comfortable	1.5	
	Layout	0.7	Facing travel direction
	Maintained	1.5	Clean and well maintained
Comfort	Ventilation	1.5	Air conditioning

Table A18.4: Vehicle feature values for bus services

Bus			
Attribute	**Sub-attribute**	**Valuation (IVT minutes)**	**Comment**
Boarding	No steps	0.1	Difference between two steps up and no steps
	No show pass	0.1	Two stream boarding, 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 and etchings
	Graffiti	0.2	No graffiti compared to 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

Table A18.4: Vehicle feature values for bus services continued

Bus			
Attribute	**Sub-attribute**	**Valuation (IVT minutes)**	**Comment**
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 on 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 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

Infrastructure features for public transport

Table A18.5: Infrastructure features values

Bus			
Attribute	**Sub-attribute**	**Valuation (IVT minutes)**	**Comment**
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-sized
	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

Table A18.5: Infrastructure features values continued

Bus			
Attribute	**Sub-attribute**	**Valuation (IVT minutes)**	**Comment**
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/Real time	0.8	Up to the minute arrival times/disruptions, plus audio compared

	information		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 at info desk, central electronic sign giving departure times, snack bar, cash-point, newsagent, landscaping, block paving and photo-booths

Benefits from multiple features

Experience from other SP surveys indicates that the perceived benefits of multiple features are less than the sum of individual components. When multiple features are combined, the values should be divided by two to adjust for any overestimation.

Demand change impact on existing public transport users

If there is a significant detrimental effect of the new level of demand on existing transport service users then the disbenefits to existing users should be subtracted from the total user benefits.

Possible negative effects of demand change on existing transport service users include:

- the proportion of standing passengers is increased
- the probability of being left behind has increased.

Example: Assume that the probability of being left behind has increased by 50%. Calculate the potential increased waiting time and multiply it by the appropriate value of vehicle occupant time value from table A4.1(b) in Appendix A4. Multiply by the probability (50%) of having to wait, times the total number of existing users.

Service demand disbenefit = (increased waiting time × VOT) × 0.5 × total number of existing users.

A19 Incremental cost benefit analysis example

Introduction

Where project alternatives and options are mutually exclusive (section 2.13), incremental cost benefit analysis of the alternatives and options shall be used to identify the optimal economic solution.

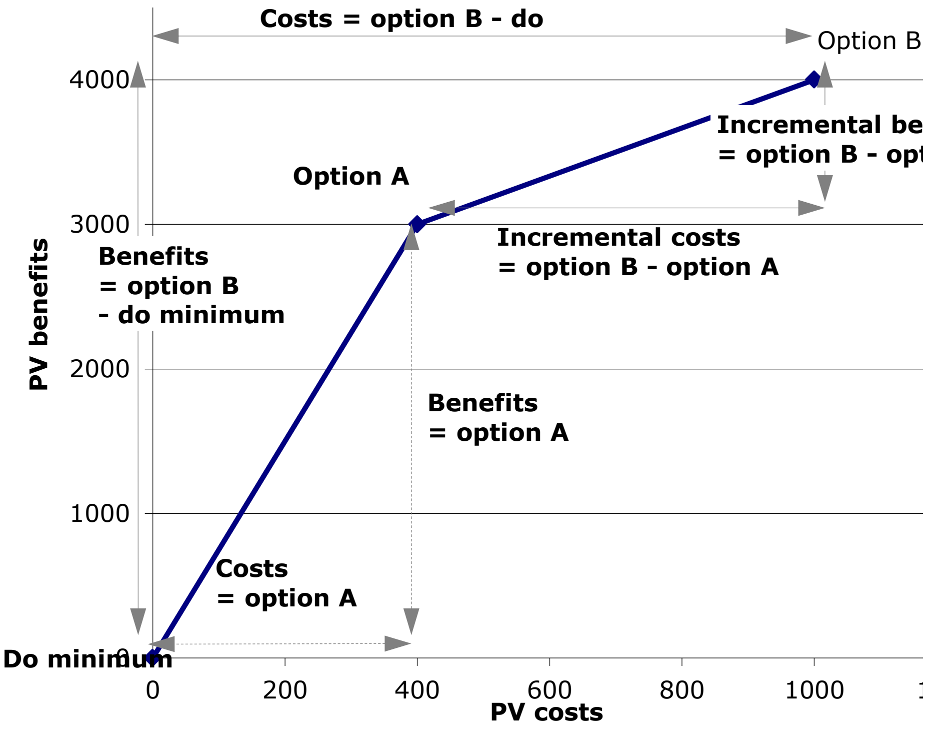
The incremental BCR indicates whether the incremental cost of higher–cost project alternatives and options is justified by the incremental benefits gained (all other factors being equal). Conversely, incremental analysis will identify whether a lower–cost alternative or option that realises proportionally more benefits is a more optimal solution.

$$\text{Incremental BCR} = \frac{\text{Incremental benefits}}{\text{Incremental costs}}$$

Example

The concept of incremental cost benefit analysis is illustrated in the figure below, which considers two options – A and B.

The BCR for option B is 4.0 (4000/1000). Such a value would usually result in the project receiving a *High* rating for the economic efficiency criteria considered under NZTA's funding allocation process. The less–costly option A, with a BCR of 7.5 (3000/400), would receive the same *High* rating. However, incremental cost benefit analysis demonstrates that the incremental benefits gained by supporting option B ahead of option A represent only a small return on the additional cost, as the incremental BCR is 1.7 ((4000–3000)/(1000–400))



Procedure for calculating incremental BCR

The following procedure shall be used to calculate the incremental BCR of mutually exclusive options:

a. Rank the options in order of increasing cost.

b. Starting at the lowest–cost option, consider the next higher–cost option and calculate the incremental BCR of the PV of the incremental benefits to the PV of the incremental costs.

c. If the incremental BCR is equal to or greater than the target incremental BCR, discard the lower–cost option and use the higher–cost option as the comparison basis with the next higher–cost option.

d. If the incremental BCR is less than the target incremental BCR, discard the higher–cost option and use the lower–cost option as the basis for comparison with the next higher–cost option.

e. Repeat the procedure in (b), (c) and (d) until all options have been analysed.

Select the option with the highest cost which has an incremental BCR equal to or greater than the target incremental BCR.

Target incremental BCR

The method for choosing a target incremental BCR for testing project options is provided in Appendix A12.4.

Sensitivity testing of incremental analysis

The results of the incremental BCR analysis should be sensitivity tested using a target incremental BCR that is 1.0 higher than the chosen target incremental BCR. If this affects the choice of preferred project alternative or option, the results of this sensitivity test must be described and included in the project report. For example, if the target incremental ratio is 2.0, the choice of project alternative or option should also be tested by using a target incremental ratio of 3.0 and reporting how this affects the choice of option.

Example of incremental analysis

To analyse five mutually exclusive project options against a target incremental BCR of 4.0, first rank the options in order of increasing cost as follows:

Option	Benefits	Costs	BCR
A	110	15	7.3
B	140	30	4.7
C	260	45	5.8
D	345	65	5.3
E	420	100	4.2

Next, calculate the incremental BCR of each higher cost option, discarding those below the target incremental BCR as follows:

Next higher cost option	Calculation	Incremental BCR	Above/below the target incremental BCR	Current Preferred Option
B	(140–110)/(30–15)	2.0	Below	A
C	(260–110)/(45–15)	5.0	Above	C
D	(345–260)/(65–45)	4.3	Above	D
E	(420–345)/(100–65)	2.1	Below	D

Finally select the option that has the highest cost *and* an incremental BCR greater than the target incremental BCR, which in this example is option D.

A20 Cycle demand analysis

A20.1 Introduction

Introduction

This appendix provides guidance on the calculation of demand and benefits of new or improved walking and cycling facilities.

In this appendix

	Topic
A20.1	Introduction
A20.2	Prediction of demand
A20.3	Benefits of walking and cycling investment

A20.2 Prediction of demand

Factors influencing demand

Factors influencing demand for walking and cycling include:

- availability of facilities
- type and quality of facility including cycle parking, signage and safety of use
- location, route length and connectivity of walking and cycling paths or lanes
- population served by the facilities
- education, promotion and marketing.

Studies have shown that there is a positive correlation between the number and quality of facilities that are provided and the percentage of people that use cycling for commuting purposes. It has also been observed that, in addition to having walking and cycling facilities, they must connect appropriate origins and destinations, and use of the facilities must be promoted to encourage walking and cycling as alternative commuting modes.

Demand estimate

Evaluators are required to make realistic estimates of the demand for a new or improved walking or cycling facility, particularly the number of new pedestrians or cyclists. Worksheet A20.1 can be used to estimate the demand for cyclists. Worksheet A20.1 calculates the population within areas surrounding the facility, and applies a probability of new cyclists using the facility by considering the distance from the facility and the existing commuting mode share of cycling.

Cycling mode shares for commuting in individual local authorities, derived from the 2006 census, are contained in table A20.1. As data from subsequent census years becomes available table A20.1 will be updated.

Education, promotion and marketing are the prime drivers for generating demand for walking and cycling (and change from use of private motor vehicles). The methodology for estimating travel impacts in Section 4.3 should be used to estimate the number of private vehicle trips diverted to new or improved walking and cycling facilities where this is part of a package including travel behaviour change (TBhC) activities.

Where a new or improved walking or cycling facility provides a significantly improved quality of service, trips in addition to those diverted from private vehicles may be generated. The total demand for the facility may be estimated using the procedures in Section 4.3.

Worksheet A20.1 Cycle demand worksheet

New and existing cyclists					
	Buffers (km)	<0.4	0.4 to <0.8	0.8 to ≤1.6	
1	Area (km^2)				
2	Density per square kilometre				
3	Population in each buffer **(3)** = **(1)** × **(2)**				
4	Total population in all buffers (Sum of **(3)**)				
5	Commute share (single value for all)				%
6	Likelihood of new cyclist multiplier	1.04	0.54	0.21	
7	Row **(7)** = **(3)** x **(6)**				
8	Sum of row **(7)**				
9	Cyclist rate **(9)** = (**(5)** x 0.96) + 0.32%				%
10	Total existing daily cyclists **(10)** = **(4)** × **(9)**				
11	Total new daily cyclists **(11)** = **(8)** x **(9)**				

Table A20.1: Cycle demand indicators

Territory authority area	Commute share 2006 (%)	Annual growth (2001 – 2006)	Territory authority area	Commute share 2006 (%)	Annual growth (2001 – 2006)
Far North District	0.7%	-11%	Manawatu District	2.1%	-7%
Whangarei District	1.4%	-4%	Palmerston North City	5.4%	-6%
Kaipara District	1.0%	-9%	Tararua District	1.5%	-10%
Rodney District	0.5%	-5%	Horowhenua District	2.6%	-9%
North Shore City	0.8%	-3%	Kapiti Coast District	1.7%	-5%
Waitakere City	0.9%	-4%	Porirua City	0.6%	-4%
Auckland City	1.5%	-1%	Upper Hutt City	1.7%	-7%
Manukau City	0.6%	-7%	Lower Hutt City	1.5%	-6%
Papakura District	0.8%	-7%	Wellington City	2.5%	0%
Franklin District	0.5%	-9%	Masterton District	3.5%	-8%
Thames-Coromandel District	3.0%	-2%	Carterton District	1.8%	-9%
Hauraki District	1.5%	-11%	South Wairarapa District	1.5%	-12%
Waikato District	1.1%	-7%	Tasman District	5.1%	0%
Matamata-Piako District	1.8%	-8%	Nelson City	6.8%	-1%
Hamilton City	3.2%	-8%	Marlborough District	4.6%	-5%
Waipa District	1.3%	-8%	Buller District	3.9%	8%
Otorohanga District	0.9%	-12%	Grey District	2.0%	-13%
South Waikato District	2.4%	-10%	Westland District	3.9%	-10%
Waitomo District	0.8%	-13%	Kaikoura District	4.5%	-7%
Taupo District	1.7%	-7%	Hurunui District	1.9%	1%
Western Bay of Plenty District	0.9%	-6%	Waimakariri District	1.9%	-4%
Tauranga City	2.5%	-6%	Christchurch City	6.1%	-3%
Rotorua District	2.2%	-6%	Selwyn District	2.7%	-5%
Whakatane District	2.9%	-7%	Ashburton District	3.9%	-5%
Kawerau District	3.4%	-10%	Timaru District	3.3%	-7%
Opotiki District	1.5%	-6%	Mackenzie District	3.7%	-7%
Gisborne District	3.4%	-4%	Waimate District	2.2%	-8%
Wairoa District	2.3%	-2%	Chatham Islands Territory	1.1%	-
Hastings District	3.3%	-6%	Waitaki District	2.4%	-4%
Napier City	3.7%	-2%	Central Otago District	3.4%	-6%
Central Hawke's Bay District	0.9%	-8%	Queenstown-Lakes District	2.3%	-5%
New Plymouth District	2.5%	-4%	Dunedin City	1.8%	-9%
Stratford District	1.0%	-9%	Clutha District	1.1%	-9%
South Taranaki District	3.0%	-7%	Southland District	1.5%	-6%
Ruapehu District	2.4%	-11%	Gore District	1.9%	-7%
Wanganui District	3.9%	-8%	Invercargill City	2.2%	-10%
Rangitikei District	1.9%	-9%			

Demand and use of benefits for different types of facility

Where a quality improvement (amenity, comfort or security) is proposed to existing walking and cycling facilities or new walking and cycling facilities is proposed, the value of different levels of quality must be assessed. The valuation should be based on a stated preference (SP) survey or information from similar improvements to facilities in other areas.

Reference 4 describes a SP methodology and study to identify preferences for different types of cycling facilities. The study determined the additional time that cyclists would spend travelling on each type of facility (the incremental attractiveness of that type of facility) compared with a base case of 20 minutes of travel in-traffic with road-side parking. The study gave the values in table A20.2.

Table A20.2: Relative benefit for different types of cycle facilities

Type of cycle facility	Relative benefit
On-street with parking (no marked cycle lane)	1.0
On-street with parking (marked cycle lane)	1.8
On-street without parking (marked cycle lane)	1.9
Off-street cycle path	2.0

The relative benefit values should be used in an incremental analysis.

Walking distances

Activities that involve mode change need to be careful not to claim unrealistic walking distances. Statistics on walking used in this manual are based on the 1997/98 New Zealand Travel Survey. The average pedestrian trip length is estimated at one km.

Cycling distances

Statistics on cycling provided are based on the 1997/98 New Zealand Travel Survey. The current average cycle trip length is estimated at three km. This applies equally to new and existing users.

A20.3 Walking and Cycling Benefits

Introduction	Walking and cycling project benefits can include the road traffic reduction and health benefits from mode change, and travel time cost, quality, and safety benefits for existing users.
Travel time cost savings	Differences in travel time (and hence travel time cost) between modes for people that change modes is deemed to be included in the perceived benefits of changing modes. The travel time cost differences for mode changers are therefore included in the benefits calculated in Section 4.3. Where a proposed walking or cycling facility improvement reduces the existing walk or cycle travel time, eg by adding a pedestrian or cyclist priority phase at a signalised crossing, there will be travel time cost savings to existing pedestrians or cyclists and to new pedestrians or cyclists other than those covered by the procedures in Section 4.3 The standard values of time given in table A4.1(b) in Appendix A4 may be used to calculate these benefits. These benefits may, however, be offset by increased delays to motor vehicles, which may also be taken into account depending on the road and community context.
Walking and cycling costs	Cycle operating costs and walking costs are assumed to be included in the perceived costs of changing to, and using these modes.
Crash cost savings	There is evidence that the crash rate per cyclist or per pedestrian reduces significantly as the number of cyclists or pedestrians increases, and that the overall number of crashes (motor vehicles, cyclists and pedestrians) does not change substantially when private vehicle trips are diverted to cycling or walking. This means that, in most cases, there are no significant negative crash costs associated with diverting private vehicle trips to walking and cycling trips. Some new or improved walking and cycling facilities effectively eliminate hazards along an established route used by pedestrians or cyclists, eg provision of over bridges, underpasses bridge widening and intersection improvements. In these cases a more detailed analysis of the changes in crash types, numbers and costs should be completed using the procedures in Appendix A6. Reduction or elimination of hazards on a walking or cycling route is likely to be a factor in attracting new users or additional use of the facility. The evaluation should quantify (by surveys/research) the extent to which the hazards are an impediment to new users or additional use and provide supporting information on pedestrian or cycle numbers.
Health benefits	Health benefits of walking and cycling benefits relate to people that change modes, eg from private vehicles to walking or cycling (being inactive to being active) and are included in the composite benefit values given in Appendix A20.3
User benefits for new facility	The calculation of net benefits for users of a new walking or cycling facility is based on the maximum benefit value to a potential user. The result is then divided in half, based on the rule of half. Calculate net user benefits for users of a new walking and cycling facility using the procedure in Appendix A20 to determine the projected number of new service users. Net user benefits = $P_{max} \times Q_{new} \times ½$ Where:

P_{max} = WTP value for new facility.

Q_{new} = projected number of new users.

User benefits for improved facility

The value of walking or cycling facility user benefits (other than time saving benefits), eg improved quality, comfort or security, is usually based on a WTP value derived from a SP survey or on values derived for similar facility improvements in other areas.

Calculate the facility user benefits to give the projected new use level, as follows:

Change in net total benefits for existing users:

$Bf_{existing} = P_{max} \times Q_1$

Apply the rule of half for the total benefits for new users:

$Bf_{new} = P_{max} \times (Q_{new} - Q_1) \times ½$

Total facility benefits:

$Bf_{total} = Bf_{existing} + Bf_{new}$

Where:

P_{max} = WTP value for improvement of facility.

Q_1 = existing number of users.

Q_{new} = projected total number of users.

Composite benefits for footpaths and other pedestrian structures

A composite benefit of $2.70 per pedestrian per kilometre of new facility may be applied to pedestrians using a new facility. The composition of the benefit is shown in table A20.3.

Table A20.3: New pedestrian facility benefits ($/pedestrian km – 2008)

Benefit	**Benefit per pedestrian (km)**
Health	2.60
Safety	0.00
Road traffic reduction	0.10
Composite benefit	**2.70**

Where a new facility eliminates or improves a site that is an impediment to safe walking, a benefit of $2.70 may be ascribed to pedestrians using the facility. The benefit is irrespective of the length of work. It uses the average pedestrian trip length of one km times the composite benefit given above.

Composite benefits for cycle lanes, cycleways or increased road shoulder

A composite benefit of $1.45 per cyclist per kilometre of new facility may be used for cyclists using the facility. The composition of this benefit is shown in table A20.4.

Table A20.4: New cycle facility benefits ($/cyclist km - 2008)

Benefit	**Benefit per cyclist (km)**
Health	1.30
Safety	0.05
Road traffic reduction	0.10

widths

Composite benefit	**1.45**

It is assumed that provision of facilities that enhance the cycling environment will encourage existing cyclists to continue using that mode of transport.

Where a new facility eliminates or improves a site that is an impediment to safe cycling, a benefit of $4.35 may be ascribed to cyclists using the facility. The benefit is irrespective of the length of work. It uses the average cycle trip length of three kilometres times the composite benefit given above.

Combined modes

Activities that combine walking and cycling may claim benefits for both modes but safety issues arising from pedestrian/cycle conflicts must be addressed and if there are additional crashes these must be accounted for in the evaluation.

Disruption costs to existing users of walking and cycling facilities during the implementation of new or improved facilities shall be included in the evaluation as a disbenefit (negative benefit). Possible disbenefits include:

- increased travel time
- travel discomfort.

A21 Workplace Travel Plans

A21.1 Introduction

Introduction

This appendix provides guidance on the evaluation of workplace, school and household/community-based travel plans. Analysis is based on the reduction in private car travel resulting from travel plans being initiated.

In this appendix

A21.2 Diversion Rates

Workplace travel plans

There are two sets of diversion rates for workplace travel plans:

- standard – where no public transport improvements are proposed, and
- alternative – where there are proposed public transport improvements.

Within these two sets of diversion rates, a scoring system is used to select the appropriate profile for a given workplace travel plan. The score, out of six, is assigned based on the responses to the questions in the table below.

	Yes	No
Is parking availability constrained at the workplace?	1	0
Does the proposed workplace travel plan include:		
One or more parking management strategies?	1	0
Improvements to cycling/walking facilities?	1	0
Ridesharing matching service?	1	0
Public transport service improvements or company transport?	1	0
Public transport subsidies?	1	0
Total score:		

*Strategies for managing parking demand include activities such as parking charges, reduced supply of parking spaces, parking 'cash-out' scheme, etc. Use the total score from above in table A21.1. First, obtain the reduction in the target population of car drivers assigned across the other modes of transport.

Table A21.1: Workplace diversion rates

Reduction in target population				Mode share of the mode change			
	Score	Reduction in car as driver		Car as passenger	Public transport	Cycling	Walking
Standard – without public transport measures							
Low	1 or 2	0.0%		0%	0%	0%	0%
Medium	3 or 4	-5.0%		26%	26%	12%	36%
Alternative – with public transport/company measures or improvements							
Low	1 or 2	0.0%		0%	0%	0%	0%
Medium	3 or 4	-5.0%		26%	52%	6%	26%
High	5 or 6	-12.9%		26%	57%	8%	26%

The standard diversion rate values are applicable in most situations where no significant public transport measures are included in the workplace travel plan. The alternative 'with public transport service improvements' diversion rate values are applicable when significant public transport service improvements (including company provided transport), subsidy schemes, or other similar measures (covered by the last two questions in the scoring table) are part of the workplace travel plan.

School travel plans

There are two default diversion rate profiles for schools, one for primary and another for intermediate and secondary schools. Assign the change in car passengers across public transport, cycling and walking.

Table A21.2: School diversion rates

Reduction in target population			**Mode share of the mode change**		
School type	Car as driver	Car as passenger	Public transport	Cycling	Walking
Primary	0.0%	-9.0%	0%	17%	83%
Secondary/ intermediate	0.0%	-9.0%	55%	6%	39%

Household and community-based activities

The standard diversion rate value is applicable for most activities.

The low diversion rate is applicable in situations where:

- the activity will implement fewer measures than ‘usual’ household based programmes, eg a community travel awareness campaign on its own would not achieve the standard diversion rate
- public transport services and cycling/walking facilities in the area are poor and no significant changes to these are envisaged as part of the travel behaviour change (TBhC) proposal.

Assign the changes in car drivers and car passengers across public transport, cycling and walking.

Table A21.3: House hold and community diversion rates

Reduction in target population			**Mode share of the mode change**		
	Car as driver	Car as passenger	Public transport	Cycling	Walking
Low	-1.0%	-0.2%	42%	25%	33%
Standard	-3.1%	-0.5%	39%	25%	36%

A21.3 Travel Plan Benefits

Composite benefit values

Composite benefit values have been derived for a range of TBhC activity types and situations. The composite benefit values include benefits to the persons changing their travel behaviour as well as benefits to remaining road users and the general community, such as reduced health costs and accident cost savings, vehicle operating cost (VOC) savings and environmental benefits. Composite benefit values are the average annual benefit for all people in the workforce, school or community targeted by the TBhC activity (and take account of the proportion that do not participate or change their travel behaviour).

The composite benefits also incorporate the default diversion rate assumptions for each TBhC activity type as well as the average trip length for each mode affected by the proposal. If evaluators consider they have strong reasons why a different diversion rate is more appropriate for the situation they can interpolate a composite benefit value (based on the values given below and the particular situation compared with the default diversion rates) for workplace travel plans, or use a computer spreadsheet programme (available from the NZ Transport Agency) to forecast a diversion rate and calculate a composite benefit value for any TBhC proposal.

Table A21.4: Workplace travel plan benefit ($/employee/year - 2008)

Location	Workplace	CBD			Non-CBD		
	Diversion	Low	Medium	High	Low	Medium	High
Auckland	Standard	0.00	188.51		0.00	165.51	
	Alternative	0.00	214.47	616.23	0.00	191.47	556.89
Wellington	Standard	0.00	170.88		0.00	147.88	
	Alternative	0.00	191.97	554.77	0.00	168.97	495.43
Christchurch/ other	Standard	0.00	61.97		0.00	61.97	
	Alternative	0.00	58.21	196.51	0.00	58.21	196.51

Based on 100% of changed trips being in peak period.

Standard = without public transport improvements or subsidies.

Alternative = with public transport improvements or subsidies.

School travel plan benefits

Table A21.5: School travel plan benefit ($/student/year – 2008)

Location	School type	
	Primary	Secondary/intermediate
Auckland	85.35	141.74
Wellington	82.70	121.17
Christchurch/ other	74.83	77.97

Based on 55% of changed trips being in peak period

Household/ community-based activity benefits

Table A21.6: Household and community-based activity benefits ($/capita/year - 2008)

Location	Level of diversion	
	Standard	Low
Auckland	139.11	42.57
Wellington	158.72	49.25
Christchurch/ other	129.45	39.19

Based on 15% of changed trips being in peak period