Monetised benefits and costs manual

NZ TRANSPORT AGENCY
WAKA KOTAHI

Te Kāwanatanga o Aotearoa
New Zealand Government

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More information

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Introduction

Purpose of this manual

The *Monetised benefits and costs manual* (MBCM) is NZ Transport Agency Waka Kotahi (NZTA) standardised guidance for assessing the monetised benefits and costs of proposed investments in land transport (activities). The main purpose of this manual is to establish consistency, transparency and comparability between activities to aid with the calculation of their economic efficiency.

The MBCM is focused on economic costs and economic benefits (including disbenefits), and it is the primary tool available in New Zealand for assessing the economic efficiency of transport activities.

The MBCM includes guidance for assessing the 12 monetised benefits of the 25 benefits within the benefits framework. It is designed to be read in conjunction with the *Land Transport Benefits Framework measures manual* and the Benefits management guidance on our website, as together these will provide all the information necessary for preparing an AST.

Who this manual is for

The information contained within this manual is designed to assist three primary types of user.

Proposal submitters

The cost–benefit analysis and appraisal concepts at the start of this manual should be used to guide the development of investment proposals and options. They are references that will help ensure that proposals have been correctly scoped.

Additionally, the summaries of monetised benefits will encourage the systematic identification of a proposal's benefits and disbenefits.

Transport analysts

The procedures, values and worksheets in this manual have been designed to assist analysts in developing fit-for-purpose economic analyses of transport activities. The material in this manual enables activities to be assessed using standardised approaches, however, professional judgement and supporting evidence can be utilised for bespoke analyses.

Decision makers

Decision makers use benefit–cost ratios, an output of the monetised components of cost–benefit analysis as a decision support tool. By standardising the methods of analysis, this manual is able to assist decision makers when proposals are compared or put forward for funding decisions.

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1. Concepts

1.1 Social cost–benefit analysis

Social cost–benefit analysis, generally referred to as economic cost–benefit analysis or CBA, differs from financial analysis by incorporating social, economic, environmental and cultural impacts. A CBA measures costs and benefits at a national level and is a systematic method of organising information about the costs and benefits of a proposed activity.

CBA is primarily a decision support tool and so the level of effort put into measuring impacts should reflect the scale, scope and complexity of the decision that needs to be made. This manual sets out standardised guidance for measuring impacts and monetising them, but a CBA can include non-monetised costs and benefits.

Benefit–cost ratios, or BCRs, are often confused with CBA. BCRs are an indicator of economic efficiency in the CBA framework, but they focus solely on monetised benefits and costs. NZTA uses BCRs as one measure of efficiency, but decisions are further supported by the impacts captured in the appraisal summary table (AST), including non-monetised benefits.

> The appraisal summary table is a structured way to show the monetised and non-monetised benefits and costs of short-listed options and the preferred solution. This tool plays a key role in demonstrating how a preferred solution contributes to outcomes and also enables NZTA to track benefits.

BCRs indicate whether activities will generate more benefits than they cost, make it possible to compare activities, and enable prioritisation of activities under funding constraints – all within a well-defined framework. For this reason, they remain the primary measure of economic efficiency used by NZTA when assessing an activity from a purely monetised point of view.

Refer to the NZTA Planning and Investment Knowledge Base for information on when a BCR is required to support a funding application.

The process for preparing an analysis of an activity is detailed step by step throughout this section of the manual and specific information about BCRs, and other appraisal tools, is discussed in section 1.10.

> For a more in-depth discussion of social cost–benefit analysis in a New Zealand context, please refer to Treasury's *Guide to social cost benefit analysis*

1.2 Equity or distributional effects of land transport initiatives

The term equity is normally used to refer to the ethical desirability of distributional effects among groups of individuals. Equity impacts of transport service activities should be quantified wherever possible and reported as part of the evaluation (separately from the economic efficiency calculation). The potential benefits related to distributional issues and implications have been also included in the description of benefits in *the* Land Transport Benefits Framework.

> While an analysis of the distribution of benefits and costs among different groups of people is not required for economic efficiency analysis, evaluations of an activity should report the distribution of benefits and costs, particularly where they relate to the needs of transport disadvantaged populations. This reporting forms a part of the funding allocation process.
>
> When it is required, distributional effects should be reported separately from, but alongside, the CBA results.

1.3 Steps in BCR calculation

Options

- Do-minimum
- Improvement alternatives and options
- Consider whether the improvement(s) should be part of a package and/or programme of activities

Demand forecast

- Collect data
- Use of transport models and calibration

Benefits estimates

- Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options

Costs estimates

- Investigation and design
- Property
- Construction, including preconstruction and supervision
- Maintenance, renewal and operation
- Risk management and mitigation of external impacts
- Residual values

Risk analysis

- Undertake risk analysis when there are significant unpredictable events that may affect or be affected by the improvement activity

Discounting

- Discount the monetised benefits and costs over the analysis period to obtain present values

BCR calculation

- Determine the benefit–cost ratios (BCR) of the preferred option

Incremental analysis

- Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options

Sensitivity analysis

- Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the evaluation outcome

1.4 Counterfactuals and the do-minimum

A counterfactual is a future in which a proposed activity does not occur. Typically, a CBA will analyse counterfactuals known as the 'do-nothing' and the 'do-minimum'.

There should be careful consideration of what the counterfactual is, as this is what the activity will be measured against. Overstating or understating the counterfactual can have an adverse effect on the CBA. Effort should therefore be applied early in the development of the analysis to define the future state if an activity did not proceed in order to establish a realistic baseline that options can be assessed against.

The analysis of the counterfactual should match the analysis period applied to the CBA (see section 1.6). The do-nothing and do-minimum will usually involve a multi-year forecast, as opposed to a point-in-time estimate. Such forecasts should estimate the costs and benefits likely to occur in the absence of further intervention. A common example is increased congestion in response to population growth. In the case of greenhouse gas (GHG) emissions, the counterfactual should reflect baseline emissions forecasts for the relevant network or region, using data and tools described in section 3.4.

In some cases it is possible that through a comprehensive CBA it is determined that the counterfactual is the preferred option. This could occur if the expected costs of alternative options are very high relative to their expected benefits.

Do-nothing

Most forms of activity analysis 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. However, this is often not practical as usually there is a minimum level of expenditure required to keep a facility or service functioning.

Do-minimum

For many transport activities, it is often not practical to do nothing. A certain minimum level of expenditure or activity may be required to maintain a minimum level of service. This minimum level of expenditure or activity and the resultant performance is known as the do-minimum, and should be used as the basis for analysis, rather than the do-nothing. It is important not to overstate the scope of the do-minimum.

The do-minimum may include maintaining the status quo and should account for committed and funded transport activities. For the purposes of this manual, the do-minimum is defined as the least cost option that provides a minimum 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.

If an activity's preferred option results in present value cost savings compared with the developed do-minimum, then the option becomes the new do-minimum that all other options should be assessed against. If all options result in economic cost savings (i.e. the option economic costs minus the do minimum economic costs is negative), or the net economic benefits are negligible, this may suggest the activity is better assessed financially rather than economically (refer to section 1.12 Economic assessment vs financial assessment for more information).

Note that there can be situations where there is a legal requirement to implement a minimum standard of facility or level of improvement, particularly in respect to physical assets, such as when a specific safety standard has to legally be met. In these situations, it is not possible to consider a do-nothing option, and the do-minimum option has to meet the minimum legal requirements for the site in question.

Do-minimum for safety activities

For safety activities where reducing the speed limit is a potential option, the do-nothing scenario is the existing baseline conditions of the network, based on the existing speed limit, operating speed, infrastructure and services.

Where a road controlling authority decides to introduce one or more interventions to address unacceptable levels of collective and/or personal risk, to re-set the speed limit, and/or to manage speeds on a particular piece of road, the do minimum can include benefits and costs of implementing a new safe and appropriate operating speed.

In such situations the do-minimum should be compared to both the do-nothing and the other activity options in order to determine whether the do-minimum is the preferred option (ie the optimal solution), or whether additional improvements are justified over and above the do-minimum, and if these additional improvements are therefore the preferred option.

When undertaking safety interventions addressing speed the following information should be referenced:

- Land Transport Rule: Setting of Speed Limits
- the NZTA *Speed management guide*, and
- the NZTA MegaMaps tool that is used with the *Speed management guide*.

1.5 Alternatives and options

Rigorous consideration of alternatives and options is a key component of the NZTA investment process and a requirement of the Land Transport Management Act 2003 (LTMA).

Alternatives

Alternatives are different means of achieving the same objective as a proposed activity. Alternatives should, amongst other things, try to consider whether non-transport solutions, such as changes to existing policy, are suitable responses to an identified problem and can achieve the outcomes sought.

An alternative can be a response to a problem or opportunity by applying a whole-of-system approach (this can include corridor or network planning). For example, exploring the potential for different land-use arrangements or encouraging greater use of other modes to address projected growth in network demand. Alternatives may have been identified as part of development strategies and spatial plans but may also be developed as part of the business case development process. In developing alternatives, it is important to consider the intervention hierarchy, which addresses:

- demand – for example, ways in which the need for travel can be reduced
- productivity – for example, by making sure the current system is optimised
- supply – for example, provision of new services or infrastructure.

Options

Options are variants of a proposed activity. Activity options may differ in scale, scope, or even alignment, and all realistic options for addressing the problem must be evaluated.

It is a common mistake for evaluations to concentrate on a single preferred option. Typically, this is caused by a failure to understand the problem that needs to be addressed, by overstating the do-minimum, or from narrowing the scope of analysis too early.

Some options may be classed as being mutually exclusive. Mutually exclusive options occur when proceeding with a specific option would preclude another option from being progressed. For example, when choosing between two different alignments for a road, the choice of one alignment precludes the choice of the other alignment. The two alignment options are therefore mutually exclusive.

The concept of mutually exclusive options is important for incremental assessment.

Multi-modal options

When considering the possible options to solve a problem, the solutions should not be constrained to a specific mode. Solutions to problems can come from different modes and can even be combinations of interventions targeting multiple modes. These options should be considered in the analysis.

1.6 Period of analysis

The procedures outlined in this manual are time dependent. It is important to set appropriate critical times and analysis periods. These periods should be applied consistently to all options, including the do-minimum or do-nothing. There are three critical times to be set up for the analysis process which are described in more detail below.

Time zero

Time zero is the date that all future cost and benefit streams are discounted to. Time zero for all proposed activities is standardised to 1 July of the financial year in which the analysis is submitted.

Time zero is independent of the construction date of a proposed activity and therefore all options being assessed must use the same time zero.

Base date

The base date is used to standardise the valuation of all monetised impacts to a common year. The base date for all proposed activities is standardised to 1 July of the financial year in which the analysis is prepared.

The base date does not need to coincide with time zero. It is common for the base date to be one year earlier than time zero.

This manual contains factors for converting the value of monetised impacts from earlier base years to the current financial year.

Analysis period

The analysis period, starting from time zero, is the period for which all costs and benefits are included in the BCR calculations.

The time period used in economic analyses must be sufficient to cover all costs and benefits that are significant in present value terms.

The standard analysis period is 40 years using a 4% discount rate.

An increase of the analysis period to 60 years is permitted where appropriate for the activity under consideration and where the benefits and costs can reliably be forecast for up to 60 years, in order to ensure that the whole-of-life costs and benefits of long-lived infrastructure activities are captured. An extension of the analysis period increases the importance of demand forecasting. Emphasis should be placed on developing a range of options and scenarios, and on reporting uncertainty in the business case and economic evaluation, when the analysis period is extended. Examples of where it can be appropriate to use a 60-year analysis period are for major infrastructure projects that have an expected life of least 60 years and potentially much longer, such as an additional Waitematā Harbour crossing or a new railway line to a major urban area.

Note that public transport services should not be forecast to have a life greater than 40 years, unless they are part of an assessment of public transport infrastructure which has been determined to have a known and proven life beyond 40 years. In such cases, the costs and benefits of the infrastructure improvement can be forecast for longer than 40 years and an assumption can be made that the transport services will operate on this infrastructure for longer than 40 years. This is the only situation where transport services should be forecast to operate for a period longer than 40 years.

The appropriate period of analysis may also be less than the standard 40 years. It is important to consider the useful lifespan of an activity and adjust the analysis period accordingly. For activities with short-lived assets, or activities where benefits dissipate quickly, it may only be necessary to assess the activity over a 5- to 10-year period. In these circumstances changes to the analysis period should be used as a sensitivity test.

1.7 Benefits

Benefits are any positive or negative impacts that are attributable to an activity. The benefits within this manual have been named impacts to explicitly account for the generation of both positive benefits and negative benefits (disbenefits).

> The NZTA policy is that any expenditure on delivery, maintenance operations and renewal is treated as a cost while all the negative impacts are treated as disbenefits.

The impacts of transport activities may affect individuals outside of the transport system. Externalities – the impacts that affect individuals outside the transport system – must be considered in the BCR calculation, as the analysis is conducted from a national viewpoint.

As a rule, only changes to real resources should be considered an impact in the analysis. Where there is a transfer of resources between parties, such as a road user paying a toll, this should be left out of the BCR. Similarly, any change in resources that is not attributable to the activity should be left out of the BCR.

If there is no change in resources between the do-minimum and the activity scenario then there can be no impact.

This manual provides standardised methodologies for monetising a range of impacts generated by transport activities.

Transfers

Care must be taken to ensure that a change in real resources for one set of individuals is not offset by a change of real resources in the opposite direction for another set of individuals. Where this transfer occurs, there is no net effect on national resources and therefore these transfer payments must be excluded from the BCR calculation.

Specifically, tolls, which are a cost to transport system users, simultaneously benefit transport operators and are excluded from the BCR. It is important, however, that tolls are considered during demand estimation.

Similarly, any changes to business or retail profitability as a result of a transport activity are also considered transfers and must be excluded from the BCR unless there are economy-wide efficiencies from increased competition. The wider economic benefit procedures for calculating the output change in imperfectly competitive markets, contained within section 3.12 of this manual, must be followed.

Double counting

The 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 an improved level of service and accessibility, but these impacts must be excluded from the BCR calculation. The capitalisation of reduced travel costs leads to an increase in the underlying land value, but including this in the BCR would be double counting as direct travel-cost benefits and wider economic benefits should already have been calculated using the benefits in this manual.

Wider economic benefits

In some instances, second order impacts may be generated by transport activities of significant scale and scope. These are termed wider economic benefits as they can alter the distribution of economic activity generated by firms, households and workers. Note that these benefits can be both positive and negative.

Wider economic benefits are additional to conventional transport system benefits, but care must be taken to ensure that they are not already captured within the analysis to avoid double counting.

Excluded benefits

Unlawful behaviours, such as travelling in excess of a post speed limit, are not considered beneficial, and as such unlawfully obtained benefits should be excluded from the economic calculations.

Level of data collection and analysis

The primary impacts of transport activities and the monetised parameter values associated with these impacts need to be included in the BCR calculations. This manual contains defined parameter values and assessment procedures to estimate the economic costs and benefits of transport activities.

The level of work associated with collecting information on parameters (and their associated values), and the data needed for economic analysis, should be commensurate with the likely impact of those parameters on the analysis together with the decision-making needs of both the activity proponents and NZTA.

This manual also contains both full procedures (extensive) and simplified procedures for the BCR calculations. The simplified procedures contain standardised default assumptions, which can be used to assess the majority of transport activities, and they match the level of effort to the appropriate level of complexity of the activity. In many cases the full procedures analysis will be proceeded by a simplified analysis to indicate whether the BCR will be sufficiently viable to continue with a fuller and more expensive analysis. Activities should be considered on a case-by-case basis to determine the appropriate level of data collection and analysis to apply.

Monetisation

After benefits have been quantified they should be monetised, where possible. Chapter 3 of this manual contains all impacts ascribed standardised monetary values for transport appraisal in New Zealand. Section 3.15 contains advice on approaches for monetising impacts not contained in this manual, while the *Land Transport Benefits Framework measures manual* contains information on non-monetised measures, namely quantitative and qualitative measures, for all of the benefits included in the benefits framework.

Types of monetised benefits

There are two broad types of monetised benefits.

The first type of benefit, market benefits, have values that can be directly derived from real world goods and services. For example, vehicle operating cost benefits are comprised of changes in the costs of fuel, tyres, repairs and maintenance, oil, and depreciation, all of which have market values, and therefore vehicle operating cost benefits are a market value.

Non-market benefits form the second type of benefit. While non-market benefits have standardised monetised values, the benefits are not based on traded goods and services, and therefore they do not have directly observable values. The valuation must instead be established through research, typically via surveys or indirect valuation methodologies.

While market and non-market benefits can be compared, in many instances the market prices for goods and services do not equal their resource cost due to taxes or market imperfections. It is necessary in those situations to substitute the market price with a shadow price that is adjusted to equate the market benefit with its true resource cost. All the benefits in this manual take into account any differences between market prices and resource costs, and therefore they do not require any further adjustment.

Rule of a half

The rule of a half is a simplifying assumption used to calculate the benefits that accrue to transport system users who change their travel behaviour, such as by switching their mode of travel, as a result of changes to the cost or quality of travel.

In the do-minimum, users experience benefits from their existing travel behaviour. If they choose to change their travel behaviour in response to a new or improved activity, then it must be the case that they experience a higher level of benefits as a result of the activity. However, upon changing their travel behaviour, the users must also forgo the benefits of their previous travel behaviour in the do-minimum, which offsets the increase in benefits after the change. Therefore, the transport system users who change their travel behaviour receive only an incremental increase in benefits between the do-minimum and activity scenarios.

The rule of a half assumes that, on average, transport system users will receive half of the incremental benefits after changing their travel behaviour.

In the case of transport system users who change their mode of travel, some new users may have been almost indifferent between the two modes in the do-minimum. After changing their behaviour in response to an improvement in the activity scenario, they receive the full value of the incremental benefits. Other new users may only be marginally better off in the activity scenario compared with the do-minimum, and they receive almost zero benefit from the improvement. If it is assumed that new users are evenly distributed along the demand curve, then the average new user gains one half of the maximum incremental benefits. The sum of new user benefits can then be approximated by multiplying half of the maximum incremental benefit by the number of new users. This is also known as a consumer surplus calculation.

Without this assumption extensive surveys of potential travel behaviour change would be required to establish the willingness to pay of any improvements, which is not realistically feasible for the majority of activities.

A worked example of consumer surplus and the rule of half is provided in Appendix 8: Worked examples.

1.8 Costs

The costs taken into account in a BCR calculation include all costs necessary for the planning and investigation, delivery, maintenance, operation and renewal of a transport activity. These whole-of-life costs cover all resource costs incurred at any time during the analysis period including indirect and administration costs incurred by the approved organisation or by NZTA.

Indirect costs

Indirect costs are costs that are not directly attributable to a specific activity. They are indirectly applied, typically by way of a separate allocation, for example overheads. Indirect costs may be either fixed or variable, and include administration and personnel costs.

Administration costs

Administration costs are an overhead cost incurred in the delivery of activities. They are not integral to the delivery of an activity but must be provided to support the delivery of the activity.

Expected cost

The costs included in the BCR calculation should be expected costs, which are the 50th percentile, or p50, costs.

The expected cost is based on probability and risk theory. That is, if the activity was theoretically delivered 100 times, in 50 instances the total cost of delivery would be below the expected cost and the total cost of delivery for the remaining 50 instances would be above the expected cost. Full information on estimating expected costs is contained within the NZTA *Cost estimation manual* (SM014).

The expected cost must include any contingency that has been allowed for in the cost estimate.

In some instances, it may be appropriate to use 95th percentile, or p95, costs as a sensitivity test of the cost risks of an activity.

Sunk costs

Sunk costs are costs that have been irrevocably committed and which have no realisable value through resale or salvage.

Sunk costs that have already been incurred, such as prior investigation or design costs, must not be included in the BCR calculation. If a pre-committed cost has a market value that could be realised in the future, such as land, then this must continue to be included in the BCR calculation.

Avoided costs and cost savings

An activity may prevent costs in the do-minimum from being incurred. These avoided costs must be included in the BCR calculation as a cost saving.

Typically avoided costs relate to reductions in ongoing maintenance or operation costs, but can include cost savings from deferring future physical infrastructure. For technology projects there may be cost savings as a result of corporate efficiencies or reduced staffing costs. These avoided costs must be considered where they are applicable.

Costs to include in BCR

The cost of a preferred option needs to be compared with the costs of an alternative (counterfactual). For example, a do-minimum scenario may encompass projects that are either committed or already completed. In these instances, it is appropriate to evaluate a baseline level of expenditure, which may include maintenance and operation costs directly related to the do-minimum scenario. The denominator in the BCR calculation should be the present value of option costs minus the present value of the do-minimum (or, if appropriate, do-nothing) costs.

Interest costs

Interest payments are generally excluded from BCR calculations irrespective of any arrangements to finance an activity by way of loans. Interest is excluded as it forms part of the cost of capital and is accounted for in the discount rate. In the analysis, capital costs should be included as cash flows in future years according to when the costs are incurred.

An exception to the interest payment rule applies only when NZTA borrows to fund its share of an activity, whether this is through a traditional loan or alternative funding arrangements such as public private partnerships (PPPs). In this instance the costs are treated as cash flows from the National Land Transport Fund (NLTF) in the future years that actual payment is predicted to occur.

Escalation

Costs must be measured in real terms and reported in constant present-day dollars using the base date year. In practical terms, this means that escalation is not applied to future costs and that all costs must be calculated according to the prices of inputs in the financial year that the analysis is prepared.

Inflation and escalation are often confused. Inflation is defined as an increase in general prices throughout the full economy. Escalation refers to an increase in the cost of inputs relevant to an activity. The rate of escalation can be different to the inflation rate, and the rate of escalation may even differ between inputs. Full information on cost estimation and escalation is available in the *Cost estimation manual* (SM014).

No adjustments to the discount rate should be made to account for future inflation or escalation, as the discount rates in this manual are real discount rates.

Funding gap

All BCR calculation procedures in this manual use economic costs based on changes to real resources. This differs from financial analysis, which does include the effects of transfer payments between parties.

The simplified and full procedures for public transport services require an additional step that includes financial analysis of the expected funding gap between future revenue and cost of operating a service.

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 public transport 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 service provider costs can be compared with the predicted revenue or increase in revenue if there is a pre-existing service, using a net present value methodology to determine whether or not the activity is viable in a financial sense.

Full information on conducting funding gap analysis for public transport services is contained within section 4.4 of this manual.

1.9 Discounting

There is a trade-off between consuming resources now and in the future. In most instances people demonstrate a preference in favour of immediate consumption rather than delaying consumption to future years. This preference is the time preference or, alternatively, the time value of money.

Over a 40-year analysis period, activities will have a profile of costs and benefits that are generated over time. Furthermore, different activities will generate, often quite substantially, different profiles of costs and benefits. However, due to the time value of money, costs and benefits in one period cannot be treated with the same weighting as costs and benefits in another period. To ensure that costs and benefits that occur in the future are given less weight than those incurred today, and to ensure that costs and benefits from different years and different activities can be compared in a common unit, they must be discounted.

Discount rate

The discount rate serves two purposes. Firstly, the discount rate represents the rate at which society is willing to trade off present benefits and costs against future benefits and costs, thus capturing the time value of money. In this instance, a high discount rate indicates a high degree of impatience in the time value of money or more simply a greater preference towards immediate consumption of resources.

Secondly, as resources committed to one activity preclude those resources being committed to another purpose, the discount rate reflects the opportunity costs of resource expenditure. Here a high discount rate indicates that the committed resources may have a higher return if put to an alternative use.

In either case a high discount rate means costs and benefits incurred in future years are given much less weight than those occurring immediately or in the near term. Therefore, particular care must be taken when allocating cost and benefit flows to the first five years of the analysis period as this can have a large impact on an activity's economic efficiency compared with costs and benefits occurring in future years.

NZTA has revised the discount rate from 6% to 4%. This is based on the social opportunity cost of resources methodology.

Further information on the methodology used to calculate and revise the discount rate can be found in Heerdegen (2013) and NZTA (2019a).

Present value

The discount rate is used to calculate discount factors for future years according to the formula:

$$\frac{1}{(1+i)^n}$$

where: n is time in years after time zero; and
i is the discount rate expressed as a decimal, ie for 4% i = 0.04.

The discount factor for each year is then applied to the costs and benefits that occur in that year, yielding a present value of costs and benefits.

The present value of a future benefit or cost is therefore its value discounted back to the present day or, more commonly for transport activities, to the base date.

As an activity will have a series of benefits occurring over the analysis period, the present value of net benefits is found by summing the discounted benefits from all years in the analysis period. Similarly, the present value of net costs is found by summing the discounted costs. It is these present values of net costs and benefits that enable activities to be compared with the do-minimum and other activities, despite their different cost and benefit profiles.

Chapter 5 of this manual contains the formulas used to calculate discount factors, while Appendix 6: Discount factors contains tables of discount factors for 3%, 4% and 6% discount rates to assist in calculating the present value of costs and benefits.

1.10 Benefit–cost ratios and other appraisal tools

The primary purpose of conducting a CBA is to support decision making. The CBA indicates to decision makers whether the benefits of proceeding with an activity outweigh its costs, indicates the optimal timing for delivering an activity, or, when comparing activities, indicates activity is the most economically efficient.

BCRs are the primary measure of economic efficiency with the CBA framework used by NZTA when assessing an activity from a purely monetised point of view. A BCR must be developed for any activity submitted for funding from the NLTF, and it is expected that BCRs will be reported for all shortlisted options assessed. Additionally, further information on an activity’s net present value and first year rate of return may be required.

Benefit–cost ratios

The benefit–cost ratio (BCR) of an activity is calculated by dividing the present value of net benefits by the present value of net costs.

A BCR greater than 1.0 indicates that an activity generates benefits in excess of its costs, while a BCR less than 1.0 indicates that the costs are greater than its benefits.

Additionally, it is possible for an activity to have a negative BCR. This can occur when an activity generates net disbenefits when evaluated against the do-minimum. If an option is of lower cost than the do-minimum, then the option is treated as the new do-minimum.

BCRs are used as an aid for prioritising project and programme options against other options. An option with a higher BCR than another option indicates that the option with the higher BCR delivers greater benefits per dollar of cost (to the extent that all costs and benefits can be monetised).

There are two types of BCR in this manual, the national benefit–cost ratio (BCR_N) and the government benefit–cost ratio (BCR_G). The procedures for estimating these BCRs are included in Chapter 6. The generic term BCR is used in this guidance for BCR_N, which is a measure of economic efficiency from a national perspective. A national benefit–cost ratio must be calculated for all the shortlisted options. The BCR_G is not an alternative to the BCR_N. Rather the BCR_G is additional information that is helpful when considering the business case and the financing for an activity or a programme of activities.

Net present value

The net present value (NPV) of an activity is simply the present value of net benefits less the present value of net costs.

A positive NPV indicates that an activity generates more benefits than it costs, while a negative NPV indicates that the costs of the activity outweigh its benefits.

The conceptual simplicity of an NPV is useful for communicating to decision makers whether an activity is economically efficient, however, unlike BCRs, NPV should not be used to rank activities when funding is constrained, as is the case of activities funded from the NLTF.

First year rate of return

First year rate of return (FYRR) helps indicate the optimal start date of an activity.

FYRR, expressed as a percentage, is calculated by dividing the present value of benefits in the first full year following completion of construction by the activity's full present value of net costs. The formula for FYRR is given by:

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

The FYRR is useful for sequencing activities when funding is constrained, but it should not be used to evaluate whether an activity is economically efficient. The FYRR indicates the extent to which the benefits of an activity arise immediately, or are dependent on future growth, but the overall economic efficiency cannot be evaluated on the basis of the activity's benefits in the first year of operation.

It is a requirement that the FYRR is reported for the preferred option of any activity submitted for funding from the NLTF. Ideally, the FYRR should be calculated and reported for a range of possible implementation start dates. This allows changes in the FYRR over time to inform the optimal timing of investment.

Back to 1.1 Social cost–benefit analysis >>

1.11 Sensitivity analysis

Conducting a CBA requires making assumptions and predictions about the future. Moreover, it requires not only predicting what the future looks like if an activity went ahead, but also what the future would look like in a situation where the activity doesn't proceed. As the future is unknowable, it is entirely possible, indeed even likely, that these futures do not come to pass.

Due to the inherent uncertainty involved in predicting the future it is important to test the sensitivity of the assumptions and predictions that underlie the analysis.

Chapter 7 of this manual details the methodologies that should be followed to undertake sensitivity and risk analysis. It is important, however, to record the assumptions and predictions that have been made during the development of a proposal, and keep in mind at all times the risks and uncertainties that could have a material impact on the analysis.

Risk and uncertainty

The terms risk and uncertainty are often confused with each other or used interchangeably. References to risk and uncertainty in this manual are established upon formal definitions of risk and uncertainty based on probability theory.

A risk has known objective probabilities of outcomes occurring. The simplest example of a risk is calling a coin toss. There is a 50% risk of the coin landing on heads when tails have been called.

Uncertainties arise when it is impossible to define all possible outcomes or when the objective probabilities of outcomes occurring are unknown. Future population growth is classed as an uncertainty because it is both impossible to define all possible outcomes, and it is impossible to define the probability of those outcomes occurring.

Care needs to be taken when assessing risks and uncertainties to ensure that uncertainties are not misclassified as risks by relying on subjective probabilities. A subjective probability is a best guess estimate of the probability of outcomes occurring that combines probability data with personal judgements about the probability distribution.

Scenario testing

One of the most powerful sensitivity analysis tools available is scenario testing. Scenarios are plausible states of the future and are developed by changing key assumptions such as population and employment growth rates, future land use patterns and future travel behaviour.

Before defining the do-minimum or developing alternatives and options, consideration should be given to how sensitive the problem being addressed is to changes in the assumptions being made about the future. If the nature or scale of the problem is likely to change substantially based on changes in the assumptions, then multiple do-minimums and scenarios should be developed. Doing so early will ensure that an appropriate range of alternatives and options are developed that are adaptable to forecasting uncertainties.

Sensitivity testing

Sensitivity testing is a simple method of checking the sensitivity of a BCR to changes in assumptions and uncertain input variables. The most basic method of sensitivity testing involves manipulating a single variable, such as an activity's cost, for a range of values to produce a BCR range. A more robust method, which can highlight interactions between assumptions, is to manipulate multiple variables at the same time. This should be used as a precursor to full risk analysis.

Sensitivity testing is useful for quickly testing the veracity of the analysis and demonstrating to decision makers the robustness of the BCR to often extreme changes in key assumptions. It should be noted, however, that sensitivity testing is unable to provide information on the probability of outcomes occurring, and the choice of variables tested can greatly impact on the credibility of the analysis.

When conducting sensitivity testing focus should be given to variables that have the highest impact and are uncertain.

Risk analysis

Risk analysis is a more detailed type of sensitivity testing 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 benefits and costs arising from each of the possible outcomes and their probability of occurrence have to be estimated. Risk analysis can support the development of methods for minimising, mitigating, and managing uncertainties.

Adaptive decision-making

Adaptive decision-making involves considering all possible outcomes when selecting options for further investigation where there is deep uncertainty. It provides the analyst with additional analysis options and methods during the assessment process. For further information on adaptive decision-making refer to section 7.6.

1.12 Economic analysis vs financial analysis

Economic and financial analyses have similar features of costs and benefits. However, economic analysis compares the benefits and costs of an activity to society and the economy as a whole, while financial analysis compares only the financial revenue and costs of the activity. It should be noted that while these two analysis methods are different, they are also complementary.

Financial analysis focuses on the financial and monetary impacts (dollar amounts, flows and financial changes) over the life of the activity.

The following provides more detailed explanation of economic analysis and financial analysis.

Economic analysis

Economic analysis uses economic prices that are either converted from market prices by excluding tax, profit, subsidy, etc., or by calculating shadow prices for non-market goods (e.g. CO2) and using these to measure the overall benefit of implementing a project, while financial analysis uses market prices to check the balance of investments and sustainability of projects.

Economic prices reflect the cost and value to the economy of goods and services after adjustment for the effects of government intervention and distortions in the market structure through shadow pricing of the financial prices. In such analyses, depreciation charges, sunk costs and expected changes in the general price are not included.

Economic analysis of investment options calculates the difference between the present value (PV) user costs of the chosen option and the PV user costs of the do minimum. These benefits are included in the numerator of the BCR. In relation to an infrastructure activity, the economic costs are the PV costs of planning, construction, operation, and maintenance, etc. of the option minus the equivalent PV costs of the do minimum. These costs are included in the denominator of the BCR. Economic analysis does not include the impacts of inflation in this calculation.

Economic benefits: the primary economic benefits are the monetised values for vehicle operating costs, injury costs, travel time costs, harmful emissions, CO_2, etc. Note that these benefits can be positive or negative, and some are tangible such as the vehicle operating costs, and some are non-tangible but have been given monetary values, such as the pain, grief and suffering captured in the injury costs, and the environmental impacts captured in the emission costs. Also, some of these parameters have been given values using "shadow pricing" as they do not have market prices, such as CO_2, and these shadow prices are based on various sources of information, in the case of CO_2 the shadow price is determined by the NZ Treasury.

Economic costs: these are the costs required to enable an activity to proceed, such as the planning costs, construction costs, maintenance costs, operating costs, etc. The net economic costs in the denominator are the difference between the PV of total costs of the chosen option and the PV of total costs of the agreed do minimum, as usually it is not possible to do nothing. All these costs are excluding taxes.

The calculation of a BCR reflects with the net societal impacts to New Zealand as a whole. To understand the distribution of impacts (i.e. to understand the level of impact on different segments of society), further analysis would be required.

Economic analysis does not include any financial transfers where money is going from one sector of the economy to another sector, as there is a zero-sum gain to the economy. An example of a transfer is a toll road payment, which is not a cost in economic terms, but it is a transfer from one sector (the users) to another (the operators/owners).

Financial analysis

In the context of appraising transport activities, financial analysis focuses on the revenue generated from the activity and financial costs to implement, maintain, renew, and operate a facility or service. Revenue may also include funding contributions from users or third parties in relation to the activity.

Financial prices are market prices of goods and services that include the effects of government intervention and distortions in the market structure.

Financial benefits: revenue (tolling, taxes), value capture from implementing activities, reductions in users' financial costs, etc.

Financial costs: the total expenditure on project costs, including planning costs, construction costs, maintenance costs, operating costs, etc.

Financial analysis includes the impacts of escalation of costs that are recorded in current day dollars but are expected to be incurred in future years.

Financial analysis may include analysis of financial transfers, where money is going from one sector of the economy to another sector.

Examples

The distinction between economic and financial analysis can be highlighted in the different treatment of transfers, where money moves from one group to another, without a good or service being produced in response. Transfers are excluded from the CBA and the BCR. For example, tolls represent a benefit to one party (e.g. Government) but an equal cost to another party (road users) and hence are zero-sum and not included in the national BCR (BCRN). However, information about transfers is still useful for decision makers, and as such should be considered as part of the government BCR (BCRG) and as part of the financial component of the business case (refer to section 1.10 for more information on benefit cost ratios).

Some activities may have small or negligible economic impacts, be they user benefits, non-user benefits, or externalities. However, such activities despite having small economic impacts may have significant financial implications. For example, a large investment in new buses may reduce expected maintenance costs over the lifetime of the physical assets, without materially impacting transport users. This means there are potentially only small economic benefits as a result of the new buses, but they will result in potentially large whole of life financial cost savings to the operator. In such a scenario the proposed investment could produce a marginal or even negative BCR (note this refers to the National BCRN not the Government BCRG), despite being financially worthwhile. There are two possible approaches in situations like these: a) focus on the financial case and present value costs, as the nature of the proposal is fundamentally not centred on the economics related to societal impacts, or b) treat the bus maintenance cost-saving option as the do-minimum in the economic case.

2. Demand estimation and mode share

This chapter brings together the different elements of travel demand estimation, which play a more significant role in economic assessments. It provides information and some guidance to assist with a systematic and balanced approach to demand estimation carried out as part of an economic assessment.

2.1 Demand estimates and importance to economics

A demand estimate is a prediction of the use of a transport facility, service or travel mode. The term 'demand estimate' can be applied to the production of any representation of trip-making in an area or location, including both base-year (existing/current) and future-year trip-making levels.

The term 'forecasting' is generally used in reference to the production of future-year trip-making levels.

How demand estimates will be developed for the assessment of a transport activity will vary depending on such factors as the type, significance, and location of the activity. For example, different approaches are likely to be deployed for a rural intersection upgrade in Southland compared to a large-scale public transport project in Auckland.

Demand estimates are important in most economic assessments because the amount of predicted use of the facility, service, or mode is often a key, if not critical, driver of the potential benefits.

Demand estimation covers a wide range of information, factors and aspects related to transport trip-making. For example, mode choice is just one of many components that make up a potential demand estimate – this starts from whether an individual person has a desire/need to make a trip, where they start from, the purpose of the trip, where they wish to go, the modes available to get there (or to other destinations related to the same purpose), down to details such as the departure time and route chosen.

This chapter broadly covers the following areas:

- high-level principles of demand estimation and key concepts related to it
- clarification of important definitions and linkages noted with key industry guidelines
- key considerations around inputs that are likely to affect demand estimates and forecasts
- broad description of key elements in the New Zealand context, for example, the availability of transport models
- the influence demand estimates and particularly forecasts can play on economic assessments, and key considerations such as optimism bias
- broad considerations related to the application of different methods for estimating demands, including transport modelling aspects
- considerations relating to fixed and variable trip matrix approaches.
- aspects of uncertainty in demand estimation and forecasts.

Sensitivity and risk analysis of demand estimation is included in Chapter 7: Sensitivity and risk analysis. Further considerations and high-level guidance can be found in these sections on carrying out sensitivity and risk assessment relating to demand estimates.

Appendix 1: Demand estimation methods and guidance contains more detailed information, some specific technical information and guidance on applying certain methodologies, and key factors such as elasticity parameters.

2.2 Key concepts

This section provides a definition of key terms and concepts related to demand estimation.

The following definitions are specifically and directly related to demand estimation.

Travel demand

The representation of movements (vehicles, persons, etc) across the area spatially and over time. Commonly in the form of origin–destination (OD) trip matrices and the profile of demand or proportions through the time period modelled. (*Transport model development guidelines* (NZ Transport Agency 2019)).

Trips

A trip is a journey made between a start and end point for a specific reason or purpose. A trip can involve multiple modes, for example, a trip to work could involve walking from home to a bus stop, catching the bus, getting off the bus at the bus stop and then scootering to the office – all of which is one home-to-work trip. A trip chain is a series of linked trips made from point A to B, and then from point B to point C, etc. Traditional regional transport models model trips rather than trip chains, which are from a start point to an end point for an associated travel purpose. For example, a home-to-recreation trip.

Demand estimation

The estimation of travel, including trip numbers, destination choices, mode choices, time choices, route choices, etc. Demand estimation encompasses multiple and different types of analyses. One example is developing vehicle trip origin–destination matrices representing base or future years. Another example is estimating future-year cycle link volumes or pedestrian crossing volumes at a particular location.

Mode share

The percentage split of demand using a particular travel mode, typically related to person travel demand. Typically assessed travel modes are: private vehicle/car (sometimes differentiated by driver and passenger), public transport (bus, rail, ferry, etc), walking, and cycling. Freight (for example, commercial vehicle trips) is usually considered separately and is not considered a travel mode.

Elasticities

Elasticity is a general term for the relative rate of change of demand when compared to a causal variable. Economists refer to elasticities as the percentage change in consumption/use of a ‘good’ caused by a 1% change in its price or other characteristic. In transport demand estimation, elasticities typically describe a percentage change associated with a demand response linked or related to a change in the transport system or environment. For example, public transport elasticities are defined as the percentage change in patronage resulting from a 1% change in the relevant transport service attribute, for example, fare level or service frequency.

Elasticities are one of many methods that may be used to develop future demand and mode choice estimations.

Rule of half

The rule of half is applied in situations where there is a difference in the travel demand (number of trips between any origin and destination) in the study area between the do-minimum scenario and the activity scenario for the same analysis year. When estimating demands and carrying out economic assessments, it is important to distinguish situations where the rule of half is and isn’t applied; in other words what constitutes a ‘real’ difference in trip numbers between the do-minimum and what does not. This is important for how economic benefits are calculated from the demands used in these assessments. (Refer to 'Rule of half' in Chapter 1 for more information.)

The following elements of potential changes relating to travel may produce variable trip matrices in the activity scenario and may have the rule of half applied. The four elements listed below may be collectively described as 'demand responses', particularly with reference to changes in travel between the do-minimum and activity scenarios.

Pure induced demand/supressed demand

Pure induced travel demand relates to entirely new trips that would not have been made without the activity or supply. For example, if an activity (or collection of activities) improves access to a shopping location, a person who in the do-minimum scenario would make an average of one trip to the shop per week may make an average of two trips to the shop.

Supressed demand is effectively the opposite of induced demand. It is when people would like to undertake trips but the travel impedance is too great for the trip to occur. It is also when people who previously made a trip decide to no longer undertake that trip because travel impedance increased (for example, congestion increases).

Re-distributed trips

A trip where the destination is changed due to the transport or land use activity causing the impedance on travel to move around different areas of the network, making another destination more attractive. For example, a home-to-shop trip, where the shopping destination alters as a particular retail location has become easier to travel to or provides greater opportunities with the activity in place.

Mode-shifted trips

A trip which switches from one travel mode to an alternative mode due to changes in the transport system and/or land use bought about by the activity. For example, when a home-to-work trip previously made by car changes to being made on public transport due to transport system changes associated with the activity.

Macro-time shifted trips (from one discrete time period to another)

A trip which shifts from one discrete time period to be made in another period. For example, if the morning commuter period is assessed as 7am to 9am, a trip which no longer occurs within this time period and instead is made in the inter-peak (after 9am, and before the start of the afternoon or evening period).

The following elements of potential changes relating to travel do not typically have the rule of half applied.

Micro-time shifted trips (within discrete time periods)

A trip that has its departure time altered within a discrete time period. For example, a vehicle trip which leaves 10 minutes later in the morning peak due to an activity reducing the travel time to reach a destination. This also may be called 'peak spreading', in reference to increasing travel delays and people leaving earlier or later to account for longer trip times.

Re-assigned (re-routed) trips

A trip which continues to travel from A to B in the same time period and by the same mode, but takes a different route to get there. For example, a home-to-work car trip which travels on Road X in the do-minimum, but which switches to Road Y with the activity in place due to changed conditions on the road network.

The study area for an economic assessment should be defined such that any potentially significant reassignment effects associated with changes due to the activity are captured within the study area. Where origin–destination demand matrices are used in transport economic analyses and assessment, the OD trip volumes in the do-minimum and activity scenarios should not differ due to reassignment (re-routeing).

The following general terms and concepts have important links with demand estimation.

Land use

Land use is used in transport assessments to describe the data and characteristics relating to the use of land parcels (often zones in a transport model, developed from census area units, statistical areas or meshblocks) which is used as input to estimating travel demand. Typically includes information such as the population, households, education roll numbers, employment numbers by type, and further information relating to family units (for example, numbers of vehicles available, income, age band, number of school-aged children, number of working aged adults, etc).

Generalised cost and generalised time

Broadly, generalised cost/time is the sum of monetary and non-monetary components of a trip across all modes. For generalised cost, the non-monetary elements (for example, travel time or wait time) are converted to monetary units using value of time. Generalised time is the same concept but expressed in units of time (for example, hours or minutes) and converts the monetary elements (parking charges, fuel costs, etc) to time units using vehicle operating costs. Generalised time is sometimes also referred to as ‘generalised cost’.

Travel/transport capacity

The maximum number of travellers or vehicles, typically by travel mode, that can pass through a system or a specific point in a set period of time. For example, the maximum number of vehicles that can pass through a traffic lane on a road each hour, or the maximum number of passengers on a bus, or the maximum number of passengers that can be carried along a rail corridor in one direction in the morning commuter period.

Travel/transport supply

The total available capacity in the transport system by travel mode and over a time period.

Supply influences people’s choices in travel patterns, such as the destination, mode or route chosen. As such, the transport system supply influences demand estimation.

Tolling

A fee charged for the use of part of a transport system, typically a road or waterway.

Road pricing

Fee charged for the use of roads. As well as tolling, the following are examples of road pricing:

- distance or time-based charges
- congestion charges
- vehicle-type charges
- fuel-type charges.

2.3 Key industry guidance and references

In New Zealand there have been two main sources of guidance related to transport demand estimation.

Historical versions of the Economic evaluation manual (EEM) and Monetised benefits and costs manual (MBCM)

Older versions of the EEM and MBCM have contained demand estimation guidance. The majority of this content has been updated or redeveloped within this chapter and Appendix 1: Demand estimation methods and guidance.

NZTA Transport model development guidelines

The key purpose of the *Transport model development guidelines* (TMDG) is to provide guidance for the comparisons carried out between observed and modelled outputs, commonly during the base model development phase of a project.

Given the focus of this chapter on estimating demand and particularly predicting future demand, there is little-to-no crossover with the TMDG. This MBCM guidance naturally follows on from guidance in the TMDG focused on developing 'base' models that typically represent current or existing transport environments and conditions.

2.4 Methods for demand estimation

There are a number of potential approaches to estimate demand, which very broadly include:

- **First principle estimates**: includes factoring, daily traffic volume estimates and broad simple estimates of predicted facility use based on comparable examples in other locations.
- **Simple mathematical models**: includes growth trend equations/calculations, trip generation rate calculations, mathematical relationship models and elasticity techniques.
- **Project transport models**: models which *do not* have the capability to provide travel demand estimates from land use. May be fed by relatively simple trip generation (and potentially distribution) calculations (or similar) to approximate future-year demand. May already exist in a study area or be specifically developed for a project. May include the application of elasticity techniques and/or other mathematical models.
- **Regional transport models:** models with the capability to provide travel-demand estimates, notably for future years, from land use inputs. May or may not have mode share estimation capabilities. As described further in section 2.10, in New Zealand access to regional models, which can provide future-year demand estimates, is relatively prevalent in urban areas. These are typically maintained as transport planning assets and not developed for specific projects. Some regional models have more comprehensive demand estimation capabilities (for example, consideration of parking cost and supply or changes in real value-of-time over time), particularly in the major urban centres. and some have more limited forecasting capabilities (for example, vehicle trips only).

Given the wide availability of transport models in New Zealand with demand estimation capability, models are likely to play some role in demand estimation in many economic assessments. This is particularly notable in assessments involving estimating future use of a transport facility, service or travel mode in an urban area. Because of this, some of the content of this chapter is focused on transport modelling. However, the core principles and approaches to demand estimation apply, irrespective of whether a more sophisticated transport model is applied or another method used (for example, trend analysis, trip rate analysis, etc).

For transport activities within urban centres, the economic assessment of many transport activities will involve transport modelling and often applying (and potentially developing) models in order to predict future demand estimates. This is particularly relevant in New Zealand's six main urban centres with populations greater than 100,000, and is likely to apply to urban areas and towns with populations down to around 30,000, depending on the activity being assessed and the local transport environment.

For these reasons, guidance in this chapter is intrinsically linked with the application of transport models and estimating future-year demand. In effect, guidance and information is targeted towards analysts utilising transport models and model outputs when carrying out economic assessments. Some guidance is also provided in other areas not involving transport modelling, for example traffic volume growth estimates. This information is briefer and more succinct because of the generally greater complexity involved with applying transport models to estimate demand.

Table 1 provides some guidance on the potential suitability and availability of key sources of demand estimation information in New Zealand, based around geographic context and transport environment.

Table 1: Guidance on potential suitability of sources of, and approaches to, demand estimation for different geographic contexts and transport environments

Geographic context/transport environment	Potential source/approach to demand estimation				
	Regional model with comprehensive forecasting capability	Regional model with more limited forecasting capability	Project models (may be fed by regional model and/or simple math models)	Simple mathematical models (eg growth trends, trip generation rate etc)	First principle estimates (eg engineering estimate of facility use)
Major urban centre	S	P	P	U	U
Moderate urban centre	S	S	P	P	U
Small urban centre	P	S	S	P	P
Township	U	U	S	S	S
Rural corridor	U	U	S	S	S

S = Generally suitable and likely to be available
P = Potentially useful and possibly available
U = Generally unsuitable and/or unlikely to be available

For some locations, it will be preferable to use combinations of models and techniques. For example, in major urban centres an analyst might apply a regional transport model that takes account of changing land use patterns, changing public transport services and the impact of new infrastructure on destination choice, in combination with a project model for more detailed and robust analysis of route choice and/or estimation in changes in travel time for a specific mode (such as vehicle trips).

It is expected that all transport models require robust information on travel demand, including induced demand, in order to input realistic information into the models.

Understanding whether induced demand is likely, helps with better demand forecasts. Induced demand is most likely to occur when new and improved road capacity reduces travel costs and travel times in congested areas.

In the absence of detailed traffic demand models there is a simplified model available for the initial assessment of any potential induced demand for new and improved road capacity. This model can also be used in the early planning stages for proposed new and improved road capacity and it will indicate whether additional modelling and assessment is warranted.

The simplified model (in the link below) is suitable for estimating travel demand at the preliminary and indicative stages of the business case process, but it is not sufficiently accurate to use for calculating the impacts and benefits of major investments at the detailed business case stage.

The simplified mathematical model for the initial appraisal of induced demand for new roads is available using the following link: https://www.nzta.govt.nz/resources/research/reports/717/, along with full documentation on how to use it. This initial appraisal output is used to indicate whether induced demand is significant (model output for induced VKT is mid-range or top of range) and whether it requires further appraisal using the methods set out in section 2.13: Fixed trip matrix and variable trip matrix assessments.

2.5 Definitions of transport model types

Table 1 above covers the broad range of methodologies that may be used to develop demand estimates for an economic assessment: first principle estimates, mathematical models, project and regional transport models. Project and regional transport models relate to more sophisticated forms of transport models that are likely to be developed and applied using purpose-built transport modelling software. The main transport models of this type can be broadly grouped and defined as:

- **Project/assignment model:** a model that assigns demand (vehicles or persons) to a network and has no direct incorporation of land use, demographics, mode choice etc. Examples include traffic assignment models, where vehicles constitute the demand, and public transport (PT) assignment models, where people using PT make up the demand. This form of model requires the demands to be specified as an input. They may be developed with a specific task or transport project in mind. These models range from single intersections to entire inter-urban areas, and are built using a wide range of types of software. Traffic assignment models will generate travel times between zones, and may produce vehicle emissions, queues, etc. PT assignment models will determine the number of people using each of the modes and services incorporated, as well as calculating travel times for people and generating fare revenues.
- **Regional transport model:** a transport model that consists of an assignment model with a demand model that responds to changes in land use and transport supply. These models are concerned with the movement of people, vehicles, or goods. Some will provide information on mode share, induced travel, heavy vehicle volumes, etc. Transport models are built on relationships between factors such as land-use activity, demographics and transport supply, and commonly cover the movement of transport demand across larger geographic areas (although not necessarily regions). The forms of these models can be 3-stage (or step), 4-stage, 5-stage, tour-based, or activity-based. May also be referred to as strategic, macro(scopic), or demand models.
- **Land-use model:** a model that estimates use of land parcels, including residential, industrial, business, etc. It is often responding to accessibility provided by the supply. When complemented with a transport model, it forms a land-use transport interaction (LUTI) model, which balances the distribution of new land use with the accessibility of the transport system.

Project/assignment models and regional transport models are relevant to demand estimation and are often directly applied to economic assessments. Currently land use models are not prevalent and less directly used in transport activity economic assessments.

2.6 Future guidance development areas

The MBCM is a living document. Currently this chapter does not cover the following areas, but there is the potential for guidance to be developed in these areas in the future:

- coastal shipping
- land use transport interaction (LUTI) modelling and how this may/can be deployed in developing demand estimates used for economic assessments
- significant technology disrupters such as autonomous vehicles (AV)
- dramatic shifts in current vehicle ownership models; for example, those brought about by car sharing, AVs or other disruptions.

- significant changes to mode share brought about by technology and/or significant policies and/or behaviour changes; for example, micro mobility technologies, electric bicycle uptake, large-scale climate change behaviour response, or significant climate change transport policy changes.

The last two points above are currently impacting travel behaviour and are therefore of interest in relation to transport demand estimation. Some aspects, for example micro mobility options (such as e-scooter share services) and electric bicycle uptake, may already be having some effect on transport. Section 7.3 Demand estimation sensitivity tests provides some further background to these issues and some suggestions around sensitivity tests that may partially reflect these changes.

Demand estimation principles and considerations

This section describes at a high level:

- the drivers of trip-making and mode share
- considerations relating to land-use projections and regional planning structures
- transport modelling in New Zealand and how this relates to demand estimation
- how demand estimates can influence economic assessments, and key factors and elements related to this (such as optimism bias in demand forecasts), and some more specific considerations relating to fixed trip or variable trip matrix assessments
- considerations relating to uncertainties in demand estimation.

2.7 Drivers of trip-making and mode share

This section describes important, high-level, background concepts that relate to transport demand and mode share estimation.

Trip-making considerations

The demand for transport is derived, it is not an end in itself. People travel in order to satisfy a need (for example, related to work, leisure or health), undertaking an activity at particular locations (Ortúzar and Willumsen 2011). Transport demand is the distribution of these activities over space and time. Transport demand and supply has a strong dynamic element, for example, in urban areas a large proportion of this activity takes place during weekday morning and evening peak periods.

Transport demand (trip-making) is influenced by various economic and socio-economic factors such as composition of household or family unit, household size, age (school or working age), employment status, disposable income, accessibility to activities and services, and social and environmental beliefs. Historically, trip-making was also considered to be influenced by vehicle availability and/or ownership, although this is likely to be evolving, particularly in larger urban areas, with access to car-sharing companies and a shift to more social and environmental responsibility.

Equilibrium of transport demand and supply

Transport demand and supply should be balanced or aligned. This has been equated with the concept that the total demand in a network across a time period should not significantly exceed the total network capacity

More generally, it is anticipated that transport demand and transport supply should be broadly correlated, particularly during typical peak periods. For example, when carrying out a study in a small town where through traffic is provided for by a two-lane road, it would be anticipated that demand passing through the town wouldn’t significantly exceed (for example, by a factor of two or greater) the capacity of a two-lane road for long periods of time (more than one to two hours) during typical peak periods.

In New Zealand's major urban centres there are clearly cases where demand exceeds supply for periods of time, and care is required in these circumstances. Some degree of 'reasonableness' in the balance between supply and demand still applies in these locations; for example, it is unlikely that people would choose to live in a location that would result in spending excessively long times (more than several hours) in stationary queues during regular day-to-day travel.

Model developers consider and account for existing and potential future congestion where feasible. For example, the current trend is to develop models (all forms) that cover increasingly larger geographic areas and longer time periods. These two factors are likely to improve the application of models to testing do-minimum and activity scenarios, and estimating economics values.

Analysts should identify in reporting scenarios where demand is exceeding supply for long periods of time, detail any adjustments or treatments that have been applied to account for or improve the robustness of the assessment due to excess demand, and note how these aspects may effect outcomes. If demand is significantly greater than supply, this will lead to undesirable situations where, for example, the model may gridlock, there may be instability in the model results, and the models may fail to reach convergence.

Mode choice considerations

Mode choice is important as it affects the general efficiency with which we can travel in urban areas, the amount of urban space devoted to transport functions, and whether a range of choices is available to travellers (Ortúzar and Willumsen 2011). The characteristics that influence mode choice include:

- the characteristics of the trip maker: vehicle availability and/or ownership, driver licence, household structure, income, cost sensitivity, residential density, and social or environmental responsibility
- the characteristics of the journey: trip purpose (for example, journey to work may be easier by public transport), time of day, whether alone or with others, weather, and the origin and destination and how well these align with access by the various available modes
- the characteristics of the transport facility:
    - quantitative aspects: travel time (in-vehicle, waiting, modal transfers, and walking), monetary costs (fares, tolls, fuel, etc), availability and cost of parking, reliability of journey travel time, and regularity of service
    - qualitative aspects: comfort, convenience, safety, perception of safety, opportunity to complete other tasks while travelling
    - relativity of these aspects with other available modes and facilities.

Where there are several methods and/or routes available, an individual's choice of mode can be broadly reflected in the modelling system as minimising their generalised cost while considering qualitative aspects that cannot be valued. In a transport model, the public transport generalised cost is likely to be made up of some, or many, of the above quantitative aspects of the transport system (as is the choice to travel by public transport). Some characteristics influencing mode choice cannot be explicitly represented in a transport model and simplifications and/or factors are incorporated. For example, it is difficult to explicitly model qualitative aspects of transport facilities, and the social and environmental beliefs of individuals.

> Estimating demands and mode share for the purpose of an economic assessment, particularly in future years, effectively includes considering, and often accounting for, quantitative aspects (for example, travel time) and qualitative aspects (for example comfort and perceived safety).

2.8 Land use projections and regional planning structures

As described in section 2.1: Key concepts, land use data is an input to regional transport models. Future-year travel demand estimates are developed from the projected future land use, an agreed description of the future transport supply (infrastructure, services, etc), and, for some models, assumptions on policies and/or charges.

Population is a component of land use data. Importantly, Statistics NZ produces population estimates and projections. In this context, estimates describe the size and characteristics of the population at a past date. Projections describe trends to show what the population may be like in the future. These population projections are a key driver of future travel demand and are likely to be an important input to travel demand estimation.

Land use data is often provided by local authority planning departments. It is often their role to develop and check this data, and transport planners may inherit this information for developing travel demand estimates.

In addition to population, other land use data that may be input to regional transport models includes the number of households, household composition, work or labour force, vehicles, employment by type, and school roll.

In some regions, the road controlling authorities have systems and structures in place that may develop a 'given' set of future land use projections, which are sometimes linked to the Statistics NZ population projections. In addition, a 'given' set of transport system supply and service assumptions may exist. These in turn will feed an associated set of future-year travel demand estimates. In other regions these structures may be less formalised.

This data and these regional systems and structures are important aspects to consider when receiving and/or developing future demand estimates. Where regional assumptions around land use projections are less structured, more effort may be required by the analyst to check the underlying assumptions feeding demand estimates and to be particularly mindful of the potential for optimism bias in these assumptions. Optimism bias relating to projections and demand estimates is described further in the section 2.11.

An Excel workbook is available on the MBCM web page to record checks on model specification, as well as coarse and detailed checks of model outputs. These are designed to help an analyst or peer reviewer to carry out and record some of the required sense checks, and provide NZTA with information for assurance purposes.

Where these regional structures do exist, a level of discussion and collaboration is anticipated between the analyst and the organisations involved in the development of land use and/or transport supply information, so that the underlying assumptions in the demand estimates used in an economic assessment are well established and understood. For example, existing and future traffic demands for a subset area of a regional transport model may be provided for a project model. In this case, it is important to understand the assumptions in the regional transport model for the future year. What PT services are anticipated? What is the assumption of PT fares or parking costs or parking availability? All of these assumptions in the regional transport model will be inherent in the project model and the analyst should have, and communicate, a clear understanding on the basis of the demand estimate.

2.9 Mathematical methodologies and elasticities

A range of mathematical methods, approaches, and models may be used in estimating the demand for a transport activity. These range from a straightforward estimate of the number of people using a particular facility, vehicle volume trend analysis or trip generation/distribution assessments, through to more complex mathematical relationships.

Elasticity calculations and applications are one mathematical approach to estimating changes in demand. As described in section 2.1: Key concepts, elasticities are defined as the relative change of demand when compared to a causal variable. Elasticities may be used to estimate a range of demand responses, more commonly the estimated change in public transport patronage due to a change in the relevant transport service attribute (such as fares), estimated change in parking rates due to a change in service attribute (for example, parking supply or parking costs), and estimated change in freight by mode based on the relative price between road and rail transit. More information on elasticities and cross-elasticities, including public transport and freight service values, are provided in Appendix 1.

A mix of approaches and methods may be applied. For example, within a project/assignment transport model a mathematical calculation of trip generation rates and assumed trip distribution may be applied to estimate demands for a development area. Within the same model, an elasticity may be used to predict some further aspect of demand response.

2.10 Demand estimation and transport modelling in New Zealand

As described in section 2.4, transport modelling is likely to play an important role in producing demand estimates used in economic assessments in urban areas, depending on the transport activity being assessed. Broadly there are two types of models that are currently most relevant to the estimation of demands and application in economic assessments:

- regional models, which have some capability to estimate demand responses to changes in land use and transport supply
- project models, which have no direct incorporation of land use, demographics etc. where demands are specified as an input to the model.

Many of New Zealand's urban centres with populations greater than around 30,000 are represented by a regional model. All urban areas with populations above 100,000 are represented by a regional model.

The larger the population the more complex the transport environment, and generally the more components and aspects to the transport model system that are available. The transport models that cover the main urban regions (Auckland, Tauranga, Waikato, Wellington, Christchurch, Queenstown Lakes and Dunedin) have, or are likely to have in the future, some aspect of mode choice estimation capability. Some smaller urban area models have an aspect of mode choice capability, but most of these types do not.

A list of transport models is provided in the first table in Appendix A in *Urban transport modelling in New Zealand – data and practice and resourcing* (Smith 2019). This largely focuses on regional models – that is, models with capability to produce future-year demand estimates. As it is only a snapshot taken at a certain time, it cannot be considered a comprehensive list of available transport models. However, it does provide a good indication of the coverage of this form of transport model across New Zealand's urban centres.

2.11 Optimism bias

Demand estimates are often an important, if not key, driver of estimated benefits. If the use of a transport activity is projected to be low, it is more probable that the economic returns will be low and, conversely, if projected use is estimated to be high there is a higher probability that the economic returns will be greater. The following examples illustrate this point.

- If one aspect of upgrading a priority intersection to an alternative intersection form is related to reducing travel delays, the projected future-year volumes at the intersection are likely to be an important driver of the estimated value of travel time benefits in the economic outcomes.
- If assessing a significant public transport project in an urban centre, the estimated change in mode share is likely to drive a number of important economic elements, such as the benefits to PT users, potential reduction in other travel modes (for example, reducing the volume of private car trips) and the associated travel time saving benefits for these modes.

Optimism bias is an important consideration due to the likely correlation between demand estimates and economic outcomes. Optimism bias (or appraisal optimism) is the demonstrated systematic tendency for people to be overly optimistic about the outcome of planned actions. This includes overestimating the likelihood of positive events and underestimating the likelihood of negative events (Charles 2011).

In economic assessments, optimism bias has been described and recorded as resulting in costs tending to be underestimated and/or demand (and hence benefits) overestimated (Australian Transport Assessment and Planning 2018c).

Overestimation of demand and, notably, the projected use of a transport activity in economic assessments is an important concern and the analyst should be mindful of responding appropriately to this when developing and using demand estimates.

Sensitivity tests are one potential response to optimism bias in demand estimation. The following examples demonstrate this point.

- Using lower levels of land use uptake to produce alternative future-year demand estimation scenarios with fewer vehicle trips.
- Adjusting a model input, parameter or assumption that is sensitive and known to reduce PT mode share to produce an alternative future-year demand estimation with a higher volume of vehicle trips and lower number of PT trips (or vice versa). For example, reducing the frequency of planned PT services, increasing modal transfer penalties reflecting people's general dislike of transferring.

See section 7.3: Demand estimation sensitivity tests for further discussion around sensitivity tests relating to demand estimates.

Other reasonable responses to optimism bias include:

- analysts and clients being aware of the potential for it to occur and simply taking steps to avoid or reduce the influence of optimism bias (for example, by not basing economic assessments on a single demand estimation scenario with potentially high population levels and land use development)
- clearly identifying in reporting any areas of the assessment/analysis where optimism bias may be present and noting the effect it may have on outcomes.

2.12 Factors and considerations influencing demand estimation

As noted, when developing demand estimates there are a wide range of elements and factors that influence trip-making and mode choice. In some locations, environments and scenarios these factors will have little to no affect, because they are unlikely to change or influence travel responses in the future and therefore will have no real effect on the assessment of transport activities. For example, the cost of parking has no impact in a rural town where parking is predominantly free, abundant, and likely to remain so in the future. In other situations and locations, certain elements and factors will play an important role in demand estimation; for example, PT mode choice in a major urban centre with a congested road network and a significant supply of reliable PT services.

Table 2 and Table 3 provide overview guidance on when certain elements may influence demand estimation and may need to be considered when developing or using demand estimates in an economic assessment. While these should not be considered a comprehensive list of all the potential elements influencing demand estimation, they provide context of the type and form of certain aspects and where and/or when these may be important.

Table 2 is focused on project models that do not have demand estimates fed by regional models, calculations, spreadsheet methodologies, trend analyses and similar. Table 3 is focused on regional transport modelling.

Table 2: Guidance on factors affecting demand – project model and calculation focus

Factors affecting demand estimates	Project model/calculation approaches			
	Network project model (not linked to/fed by regional model)	Short corridor/ intersection model (not linked to/fed by regional model)	Spreadsheet or similar equations/ models/ calculations	Straightforward calculations
Suitability and appropriateness of elasticity methods, relationships and values	**I**	**P**	**P**	**U**
Knowledge and certainty of local land use changes	**I**	**I**	**P**	**P**
Knowledge and certainty of local transport system and supply changes	**I**	**I**	**P**	**P**
Source and suitability of trip rates	**I**	**P**	**P**	**U**
Source, method and appropriateness of distribution analysis	**I**	**P**	**P**	**U**
Suitability of factors/trends selected in factoring methods	**I**	**I**	**P**	**U**
Robustness and sample size of historical data used in trend analysis	**P**	**P**	**I**	**I**
Suitability/appropriateness of engineering estimate methods of predicted facility use	**U**	**U**	**P**	**I**

I = Generally an important element
P = Potentially or partially important
U = Generally unimportant and non-critical

Expanding on Table 2, some key high-level considerations relating to each of the elements, methods and approaches that may be used to develop demand and mode share estimates are noted below.

- **Elasticity methods, relationships and values**: elasticities are based on historical and international studies into the relationships and responses in transport demand and characteristics of the supply. An elasticity value, such as the public transport demand change response to a fare change, may be based on analysis from a particular city over a particular time period. The relevance and suitability of any elasticities used need to be carefully considered when applying them to a particular activity in a certain location. Sensitivity tests – that is, varying the elasticity value or values used – are one approach to examine the response and suitability in relation to the specific activity in the local context.
- **Local land use changes**: understanding local land use changes, and the degree of certainty related to them, are an important consideration when accounting for them in demand estimations. Examples include new residential or retail developments nearby but outside the study area, the impact of which will affect the demand estimate. Optimism bias may be an issue; for example, assuming all potential plan changes occur, and are fully developed, within a short-term horizon could overestimate future demands and the benefits associated with a particular activity.
- **Local transport system and supply changes**: as with land use, the degree of certainty around local potential transport system and supply changes and the timing of these may be an important consideration.

- **Trip rates:** the suitability of trip rates used in the development of existing and future demand estimations should be checked and understood. For example, a retirement village trip rate based on a small number of surveys in urban Sydney may not be relevant to a rural town in New Zealand.
- **Distribution analysis:** the method and data used to develop first principle trip distributions associated with a certain area and/or specific land use activity should be carefully considered. Depending on the location and scale of the activity, if a first principle distribution approach is used to estimate origin–destination demands it may be appropriate to check the estimated distribution against observed data (for example, a vehicle number plate survey determining a key distribution aspect, such as the number of trips passing directly through a town centre).
- **Factoring methods:** the relevance and suitability of any factors used to estimate demand and mode share should be considered when applying this approach to a particular activity in a certain location. For example, annual freight growth rates in rural Southland may not be appropriate in urban locations with low volumes of freight passing through the study area.
- **Trend analysis:** trend analysis, which is used in the development of existing and future demand estimations, should be carried out in a careful and considered manner. Seemingly small inaccuracies in a trend analysis may have a significant effect on future projections; for example, using a small sample of historical counts to estimate an annual growth rate and applying this growth rate to predict 20, 30 or 40 years into the future. As an example of checks and considerations, if historic traffic counts are used to estimate growth these should be based on a sufficient sample (the number of robust data points over time) and be checked for robustness (such as consistent vehicle classification data, seasonality effects, local issues/events, longer term patterns in the wider economy, etc.). Sensitivity tests may be one approach to account for broader issues such as wider economic patterns.
- **Engineering estimates of predicted facility use:** similar to elasticities and trip rates, the relevance and suitability of an engineering estimate approach should be considered when applying a method to a particular activity in a certain location. Again, using approaches that are based on examples in major urban areas and applying these to more rural locations is an example of relevancy or suitability check, and sensitivity testing may be one approach to account for this form of issue.

Table 3 provides some high-level guidance on elements that may influence demand estimation, focused on regional transport modelling.

Table 3: Guidance on factors affecting demand – transport modelling focus

Factors affecting demand estimates	Geographic context/transport environment			
	Major urban centre (population roughly greater than 500,000)	Moderate urban centre (population roughly between 100,000–500,000)	Small urban centre (population ~30,000–100,000)	Township, rural corridor/ area (population roughly less than 30,000)
Population structure/make-up (particularly age)	I	I	I	I
Household/family structure (retired, school-age children, in workforce, etc)	I	I	I	I
Vehicle availability/access to a vehicle	I	I	I	I
Access to alternatives modes and infrastructure (public transport, cycling, etc)	I	I	P	U
Public transport – service coverage, service frequency, charges	I	I	P	U
Residential density – accessibility to activities	I	I	P	U
Parking – charge and availability of supply	I	I	P	U
Road congestion/delay	I	I	I	I
Road pricing/tolling	I	P	U	U
Route choice	I	I	P	P
Policies and practices (work hours, working from home, travel plans, etc)	I	P	U	U
Technology influencing behaviour (online shopping, work/school travel plans)	I	P	U	U

I = Generally an important element
P = Potentially or partially important
U = Generally unimportant and non-critical

Expanding on Table 3, key high-level considerations relating to each of the elements, methods and approaches that may be used to develop demand and mode share estimates are noted below.

- **Population structure/make-up**: a person's age (for example, school age, working age, retirement age) and characteristics (for example, whether they are in the workforce or not) are a key driver for transport demand. This is particularly important considering localised demand around specific attractors such as schools.
- **Household/family structure:** the household or family unit strongly drives transport demand in terms of the number of trips for certain purposes.
- **Vehicle availability/access to a vehicle**: access to a vehicle influences mode choice and was historically a measure of overall trip-making, with households with more cars generally undertaking more trips.

- **Access to alternative modes and infrastructure:** examples include proximity at both ends of a trip to a bus stop/service, or whether there is a quality cycleway available. These elements will influence both transport demand (including the destination a person chooses) and mode choice.
- **Public transport coverage/frequency/charges**: access to a bus stop, a public transport service with good connectivity between a person's origin and destination, the frequency of the service, and the monetary fares will all influence demand by mode and also the destination selected (for example, for shopping, recreation, etc).
- **Residential density:** how close a person is to activities (for example, shops or school) is a key driver of demand (destination chosen and the resulting trip length) and mode choice.
- **Parking**: parking charges, availability of supply, and location of supply relative to the final destination influence mode choice and demand (destination selected, particularly for discretionary trips such as shopping or recreation).
- **Road congestion/delay:** travel times by road are a key driver of choice of mode, for example, rail verses car. Congestion and delays are a significant factor in which route a driver chooses, and a primary component of a demand estimate, for example, the demand for a proposed new bypass.
- **Road pricing/tolling:** monetary charges are a key driver of the mode a person selects, heavily influenced by the reason why that person is travelling. For example, a business traveller is more likely to pay higher out-of-pocket costs to minimise the time they are not productive. Human responses also need to be considered, as theoretically 'cheaper' choices are not necessarily preferred by all people.
- **Route choice:** the route people choose, whether by road, cycleway, or public transport service, influences the demand for each element of the transport system (for example, specific roads).
- **Policy and practices:** these include government policies and commercial and/or employment practices. Examples include whether employers offer more flexible working hours or working from home, and the influence of work or school travel plans.
- **Technology influences:** examples of technologies that influence demand and/or mode choice are online shopping, food delivery services, car sharing companies, and electric bikes and electric scooters. These technological advances influence travel behaviour in terms of how people choose to travel and where they decide to go, particularly for discretionary trips.

2.13 Fixed trip matrix and variable trip matrix assessments

As described in section 2.1: Key concepts, demand estimates assigned to the transport network are commonly represented in the form of origin–destination (OD) trip matrices. When considering the OD demand matrix in a study area for an economic assessment, there are broadly two approaches that may be carried out:

- **fixed trip matrix (FTM)**: over time, the OD demand for a particular travel mode is the same in the do-minimum and activity scenarios
- **variable trip matrix (VTM)**: over time, the OD demand for a particular travel mode is different between the do-minimum and the activity scenario due to the influence on demand response in the study area from the activity.

How significantly the demand for a particular travel mode in the study area is influenced by the activity and, associated with this, whether an FTM or VTM approach may be required, is an important consideration.

The 'rule-of-half' is a simplifying assumption that is used to the calculate the benefits to transport system users where there is a difference in the do-minimum and activity demand estimates. That is, the rule-of-half is applied in VTM analyses.

Demand responses that would typically result in a VTM assessment and have the rule-of-half applied include:

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- **pure induced demand**: entirely new trips that would not have occurred without the activity
- **re-distributed trips**: trip destination is changed due to the activity
- **mode shifted trips**: trip changes from one travel mode to an alternative due to the activity
- **macro-time shifted trips**: trip shifts from one discrete time period to another.

The following elements of potential changes relating to travel do not typically have the rule-of-half applied. Or, in other words, these responses do not result in a difference in OD demand matrices used in the do- minimum and activity scenarios;

- **micro-time shifted trips**: trip departure time is changed within a discrete period (more information is provided in Applying peak spreading in Appendix 1)
- **re-assigned trips**: a trip travelling from A to B in the same period and by the same mode but takes a different route to get there.

The above demand responses are described further in section 2: Key concepts.

A simple mathematical model for the initial appraisal of induced demand for new roads is available using the following link: https://www.nzta.govt.nz/resources/research/reports/717/, along with full documentation on how to use it. This initial appraisal is to be used to indicate whether induced demand is significant (model output for induced VKT is mid-range or top of range) and whether it requires further appraisal with the methods for available for applying fixed trip matrix (FTM) and variable trip matrix (VTM) techniques, which are described further in Appendix 1: Fixed trip matrices and Variable trip matrices.

Table 4 provides some high-level guidance on when VTM and FTM approaches may need to be considered.

Table 4: High-level guidance on potential for VTM or FTM approaches

Factors influencing variable or fixed trip matrix approaches	Geographic context/transport environment			
	Major urban centre (population roughly greater than 500,000)	Moderate urban centre (population roughly between 100,000–500,000)	Small urban centre (population ~ 30,000–100,000)	Township, rural corridor/ area (population roughly less than 30,000)
Large-scale PT/active mode activity	VTM	VTM	VTM	VTM
Moderate-scale PT/active mode activity	VTM	VTM	VTM	P
Smaller-scale PT/active mode activity	P	P	P	P
Large-scale roading-based activity	VTM	VTM	P	P
Moderate-scale roading-based activity	VTM	P	P	FTM
Smaller-scale roading-based activity	P	P	FTM	FTM

VTM = Probable that activity will influence modal demand significantly, VTM likely
P = Potential for VTM or FTM approach
FTM = Unlikely activity will influence modal demand significantly, FTM likely

Table 4 provides general guidance, rather than specifying a prescribed approach. For example, there are cases where an FTM approach could be applied to assess a large-scale roading activity in a major urban centre. This could involve assigning the do-minimum demands to the activity network scenario (or vice versa, assigning the activity demands to the do-minimum) directly in the regional model; the FTM and/or VTM approaches may be considered as a sensitivity test.

Applying regional transport models

As indicated in Table 4, a more significant activity focused on public transport and active travel modes, and which has a key or supporting objective of driving mode change and may achieve a level of demand response, is likely to involve a VTM approach for vehicle, person, and active mode demand estimations. Similarly, a large-scale roading activity in a major urban centre would also be likely to involve a VTM approach.

Where a demand response is anticipated, in New Zealand's main urban centres demand estimation and, to some degree, assessing economics outcomes of the activity is likely to involve some form of application of existing regional transport models. Review of the model is required to determine if it is suitable for the assessment. For example, the assessment of a major new cycleway in an urban area would need to consider how cyclists are represented in the modelling tools available. See section 2.10 for more information on the availability of regional models in New Zealand.

2.14 Demand estimation uncertainty

Demand estimates, and particularly estimates of future-year forecasts, all have some degree of uncertainty. This should not be considered a weakness, or necessarily a problem, but acknowledged as a reality. In many cases this can present an opportunity to test and understand the range of potential outcomes associated with an activity; for example, by considering key uncertainties in the demand estimates a range of forecasts could be developed and used as sensitivity tests on economic outcomes.

Section 7.2: Demand estimation sensitivity tests contains information and guidance relating to sensitivity tests and risk assessment with particular reference to demand forecasts.

In transport demand forecasting, there is necessarily some reliance on past and current trip-making, travel behaviour and trends. The current awareness around local and global environmental issues highlights a need to be flexible moving forward. In developing future transport estimates, analysts and the methodologies applied should consider the ability to adapt, adjust and examine elements that could have a large impact on travel demand. Important considerations into the future can and may include:

- **climate change:** particularly government policy responses and personal behavioural changes that affect transport and travel
- **social equity in transport:** analysts may need to consider the structure and specification of models and their resulting ability to assess and interrogate transport equity changes and outcomes
- **technology disruption:** particularly those leading to changes in vehicle ownership levels; for example, autonomous vehicles, micro-mobility, e-mobility, etc. Other potential future changes will bring another dimension to consider.

Forecast horizons and uncertainty

The standard analysis period is 40 years (see section 1.6). Although there are exceptions (for example, short-lived operations activities such as signal optimisation), carrying out an economic assessment will generally involve development of one or a number of future-year demand estimates. Economic inputs are then typically projected (for example, with a linear trend) between the different assessment years (for example, base year and future year(s)).

Generally, the further the forecast horizon (that is, future-year demand estimate) is from the current or base year, the greater the associated uncertainty will be. One way to think of this is that the longer the forecast horizon, the wider the range of possible futures.

The analyst will need to determine an approach to estimating the inputs to the economic assessment across the analysis period. This will include weighing up the increasing uncertainty in future-year forecasts, along with potential demand/capacity challenges in longer-term forecasts, against the ability to appropriately or adequately project economic outcomes. The discounting rate may also need to be considered; for example, there could be little value in forecasting long-term horizons where the discounted benefits in long-term future years become small.

Forecasting travel demand into the future may very broadly be thought of in terms of the following horizons:

- short-term horizon, forecasting forward 10 years or less
- medium-term horizon, forecasting forward 10–20 years.
- long-term horizon, forecasting forward more than 20 years.

In congested urban centres, regional models can and do produce longer-term demand forecasts. However, there is a noted challenge and often concern with use of longer-term forecasts in project models being applied for economic assessment, particularly the types of project models where vehicles are physically represented on the network, for example, microsimulation traffic models. Techniques for scenarios where demand exceeds network capacity are described further in Appendix 1 (Fixed trip matrices and Variable trip matrices).

The issue of congested urban networks and project model application complicates considerations around forecasting horizons for economic assessments.

Some broad considerations around forecast horizons are noted below:

- **Rural area, smaller town and similar** (largely uncongested): for smaller-scale activities, although short- to medium-term forecasts may be sufficient for an uncomplicated projection and economic assessment, in contrast it may be straightforward to produce a small number of long-term forecasts without the sensible analysis of scenarios suffering from issues associated with higher levels of congestion.

  For larger-scale activities, it is likely to be relevant to develop a small number of longer-term forecasts. That is, develop several sensitivity test scenarios for demand estimates 20 years or more into the future.

- **Small- to moderate-sized town, inter-urban area, urban periphery and similar** (low to medium levels of congestion): for smaller-scale activities, a small number of short- and medium-term forecasts are likely to be sufficient for economic assessments.

  For larger-scale activities, several medium- to longer-term forecasts may be appropriate, and there is the potential that applying longer-term forecasts in project models may generate the need to apply techniques to manage scenarios (for example, the do-minimum) where the demand exceeds network capacity or breaches analytical limits.

- **Moderate to major urban centre** (medium to high levels of congestion): for smaller-scale activities, several short- to medium-scale forecasts and demand sensitivities may be appropriate.

  Large-scale activities in congested networks are the most complex scenario and require more careful consideration around the development and treatment of forecasts. As noted above, regional models can and do produce longer-term forecasts; however, there are issues with these. such as the level of uncertainty in the estimates and the levels of congestion that these forecasts may produce in project models.

  A consideration in carrying out economic assessments in larger urban areas, where higher levels of congestion are experienced, is to test economic outcomes in two models: a regional model, utilising longer-term forecasts where demand may not be constrained to supply when passing through the network; and a project model, utilising short- to medium- term forecasts where the demand and capacity representation is more overt. The project model application is likely to include techniques to manage demand exceeding capacity. Sensitivity tests of demand forecasts would be likely in both models.

2.15 Checks, reporting and reviewing

There are several pieces of information that are expected to be derived and reported, regardless of the methodology or methodologies that are used to develop demand forecasts and/or predict the use of a transport facility, service or travel mode. Some are expected in order to complete certain analysis procedures described in this manual, and/or as generally anticipated information to be provided in assessment documentation and through review processes.

This section describes reporting that is expected in relation to MBCM analysis procedures, the sections that follow describe more general demand estimation and forecast checks and potential reporting elements.

Reporting demand estimates

Methodologies and assumptions

It is anticipated that the methodology or methodologies that are used to develop demand estimates in the do-minimum and/or activity scenarios are described in reporting. This includes any assumptions made, particularly regarding future transport numbers and growth rates.

Some further information and guidance on reporting information around demand estimates and forecasts is provided in Sense checking forecasts.

Demand estimates and forecasted facility use

The following information is generally anticipated to be reported:

- For an existing specific facility, the current or 'base' number of users and the change anticipated by the activity. For example, improvements to an existing facility, such as widening, safety improvement to an existing active mode facility, or increasing the PT service rate. This also includes any anticipated change in the future trend in user numbers; for example, an anticipated higher rate of growth from year X to year Y compared to the do-minimum.
- For a new specific facility, the estimated numbers predicted to use the facility and the source of these new users. For example, a new roading connection, active mode connection, or new public transport service. This includes any anticipated trends in user numbers; for example, rate of growth from year X to year Y. Identifying new users may include mode transfer, newly generated trips, or change from a parallel existing facility to the new facility.
- Total existing and future-year study area demands, by time period and by mode, and associated growth (absolute difference, percentage difference, and it is often useful to express it as the percentage growth per annum).
- In situations where a variable trip matrix approach is being applied or is being considered, the differences between the do-minimum and the activity demands, by time period, and by mode.
- Where there may be a potential change in mode share, the range of information provided is likely to increase. For example, modelled parameters and assumptions may require more detailed documentation and explanation.
- The time period demand estimates and any interpolation applied to estimate outcomes. For example, information may be only be available for, or focused on, weekday morning, interpeak, and evening periods, and estimates may be made of overnight, daily, and/or weekend/holiday periods. Reporting should describe any time period factors, interpolation, and/or methodologies.
- For activities that feature user charges (for example, public transport facilities and services), the assumptions around the user charges applied in the assessment will need to be documented. Including any base existing average user charge, proposed user charges and potentially the maximum charge users may be willing to pay. In this manual the maximum user charge is defined to be the price above which no one would use the service under consideration.

Sense checking forecasts

This section describes some more general sense checking and reporting that may be carried out in association with demand estimates, with a particular focus on transport modelling.

Regional model transport demand forecast checks and reporting

While not an exhaustive list, the following are key elements that are likely to be checked and reported when producing a set of forecasts from a regional transport model. This may apply to general regional transport modelling tasks; for example, updating the transport demand forecasts for a region, and may be relevant to directly applying a regional transport model to estimate demand forecasts for a transport activity.

- Growth in model inputs compared with estimated transport demand growth. For example, input land use growth (population, households, and vehicle availability being the most critical) compared with total trips growth.
- Total trips by travel mode year to year, and the mode split year to year.
- Estimated base and future trip rates (for example, trips per person or trips per household).
- Sector-to-sector travel growth trends. Sense checking the geographic travel pattern growth trends between key areas of the network (for example, central business district to/from north, south, east, west) against the areas of anticipated future land use development.
- Sense checking the trip length distribution. For example, if an urban area is ‘spreading’, it may be anticipated that future years have longer trips.
- Plots/figures of changes are likely to be useful. For example, network flow difference plots (base to future) and/or figures showing transport trip growth by geographic location.

The above information may be reported for any sensitivity tests and/or scenarios that have been developed. Reporting would include noting what parameters have been adjusted as a sensitivity and the logic behind this.

Project/assignment transport demand forecast checks and reporting

For a project/assignment model that is not fed by a regional transport model (for example a project model which uses first principles trip generation/distribution demand inputs), the above sense checks and reporting are likely to apply.

For a project model that is fed by a regional transport model, the following key elements are likely to be checked and reported, with sense checks focused to some degree on comparison between the regional model input and the project model incorporation of these inputs.

- Total OD matrix growth by time period, and where appropriate, vehicle classification and travel mode (absolute difference, percentage difference, and it is often useful to express it as a percentage growth per annum).
- Sector growth by time period and, where appropriate, vehicle classification and travel mode. Particularly relevant may be the percentage sector growth in the regional model inputs (for example, cordon matrix), compared with the percentage sector growth in the estimated project model demands. Similar geographic patterns would be anticipated; for example, growth to/from areas where higher rates of future land use development are anticipated.
- Trip length distribution by time period and, where appropriate, vehicle classification and travel mode, comparing the regional model input (for example, cordon matrix) with the calculated project model growth.
- Flow difference plots and geographic location growth figures are also likely to be useful.

Reporting would be expected to describe the method and calculations used to develop forecasts from a regional model into a project/assignment model, any factors applied (for example, factors where the project model represents different time periods than the regional model), and any adjustments made to the ‘raw’ growth estimated from the regional model (for example, any growth constraint techniques applied, such as those described in Appendix 1 (Fixed trip matrices procedures).

Any sensitivity tests developed are likely to be reported and include sense checks, such as those described above. Reporting would include describing the logic behind any sensitivity test scenarios used.

Mathematical methodologies and elasticities

Any growth rates (for example, trend rates, trip generation rates and similar) and any elasticity values used in demand estimation should be directly reported. Key reported information relating to forecasted or estimated demand is likely to include:

- per annum demand growth rate by time period and, where appropriate, vehicle classification and travel mode
- total study area demand growth/change by time period and, where appropriate, vehicle classification and travel mode
- change in travel mode by time period (total trip change and percentage mode split change)
- change in study area demand with and without an activity.

Any sensitivity tests developed are likely to be reported and include the key information above.

3. Benefits

NZTA has developed a common Land Transport Benefits Framework for use across the entire benefit management process. These benefits are mode neutral and are aligned to the Ministry of Transport's enduring Transport Outcome Framework (MoT TOF). High level benefit clusters have been developed to demonstrate meaningful alignment between the new mode neutral benefits and the MoT TOF.

In addition, the assessment process has evolved towards a more comprehensive approach through the introduction of appraisal summary tables (AST). AST systemise the inclusion of non-monetised impacts in the appraisal process alongside monetised benefits and costs. Thus, the new benefits framework includes both monetised and non-monetised benefits.

In summary, the new benefits framework:

- is aligned with the enduring MoT TOF
- is used in all stages of benefit management, from business cases to economic analyses, and through to post-implementation benefits realisation
- includes three groups of benefits: monetised, quantitatively described and qualitatively described
- captures the actual benefits to people, society and the environment, rather than functioning as benefit indicators
- is mode neutral
- is direction neutral, by using the term 'impacts' to cover benefits, disbenefits and costs.

> This manual only provides guidance on the monetisation of the benefits with provided standard monetary value. Qualitative and quantitative measures, associated to all of the benefits included in the benefits framework except wider economic benefits, are provided in the *Land Transport Benefits Framework measures manual*.

If the benefits provided in this manual are not sufficient or relevant for the improvements under consideration, then the benefit and cost parameters can be adjusted, subject to agreement from NZTA in writing. Table 5 shows the whole framework in relation to the benefits specified in the now-superseded EEM. The benefits included in this manual are highlighted in turquoise.

> The monetary values presented in this manual have been measured and monetised at different points in time and therefore have varying base dates. To update these values to the current year NZTA provides update factors annually. The update factors also account for any escalation in construction costs. The update factors for benefits and constructions costs are available on the NZTA website.

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Table 5: Relationship between benefits included in the NZTA Land Transport Benefits Framework and the EEM

MoT TOF	Benefit cluster	Benefit Monetised	In EEM indicated by Monetised
Healthy and safe people	1. Changes in user safety	Impact on social cost of deaths and serious injuries	Crash cost savings (social cost of crash)
		Impact on a safe system	n/a
	2. Changes in perceptions of safety	Impact on perceptions of safety and security	-
	3. Changes in human health	Impact of mode on physical and mental health	Walking and cycling health benefits
		Impact of air emissions on health	Vehicle emission reduction benefits (air pollutants)
		Impact of noise and vibration on health	Other external benefits (noise)
			Other external benefits (vibration)
Resilience and security	4. Changes in impact of unplanned disruptive events on access to social and economic opportunities	Impact of system vulnerabilities and redundancies	Risk reduction benefits (natural/environmental risks, eg water flows)
			Risk reduction benefits (human-made risks)
Economic prosperity	5. Changes in transport costs	Impact on system reliability	Journey time reliability benefits
		Impact on network productivity and utilisation	Travel time saving
			Vehicle operating cost savings
			Parking user cost savings
			PT users cost savings due to change in the user charge
			Walking and cycling cost savings
	6. Wider economic impact	Wider economic benefit (productivity)	(WEB) Productivity
		Wider economic benefit (employment impact)	(WEB) Labour supply
		Wider economic benefit (imperfect competition)	(WEB) Imperfect competition

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MoT TOF	Benefit cluster	Benefit	In EEM indicated by
		Monetised	**Monetised**
Environmental sustainability	7. Changes in natural environment	Impact on water	External benefits (water quality and flows)
		Impact on land and biodiversity	Other external benefits (ecological impact)
	8. Changes in climate	Impact on greenhouse gas emissions	Vehicle emission reduction benefits (greenhouse gas emissions)
	9. Changes in resource consumption	Impact on resource consumption	-
Inclusive access	10. Changes in access to social and economic opportunities	Impact on user experience of the transport system	Driver frustration reduction benefits
			Seal extension benefits
			User benefits from new or improved facilities: public transport and cycling
		Impact on mode choice	-
		Impact on access to opportunities	-
		Impact on community cohesion	Other external benefits (community severance) Other external benefits (isolation)
	11. Changes in liveability of places	Impact on heritage and cultural values	Other external benefits (special area)
		Impact on landscape	Other external benefits (visual impacts)
		Impact on townscape	Other external benefits (overshadowing)
	12. Changes to te ao Māori	Impact on te ao Māori*	Other external benefits (eg iwi, Māori values)

* It is not part of either the MoT TOF nor the Government Policy Statement on Land Transport priorities, but a requirement of the NZTA Māori strategy, *Te ara kotahi*

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3.1 Impact on social cost of deaths and serious injuries

This section (and its related Appendix 2: Crash analysis) provides guidance on calculating crash costs for the do-minimum and option scenarios for a route or site.

For the purposes of this manual, a crash is an event involving one or more transport system users that results in personal physical injury, including to pedestrians and cyclists, and any damage to property.

Crash rates, crash prediction models and crash reduction factors can be found in the *Crash estimation compendium*.

Changes in crash costs 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.

Deciding whether to conduct a crash analysis

Not all project analyses require a crash analysis. Several factors affect the decision as to whether or not to undertake a crash analysis; these include:

- the nature of the site (eg average annual daily traffic (AADT) and length)
- the availability of reliable crash history and crash rates or crash prediction models
- whether crash savings are claimed as part of a project analysis
- the size and type of a project.

Crash cost analysis can generally be separated into four groups.

Safety improvement projects
These are projects in which most of the benefits are the result of a reduction in crashes. Safety improvement projects are undertaken where a route or site (eg curve, railway crossing, bridge etc) has a high occurrence of crashes, or when the risk of crashes is considered high. For guidance on identifying high-risk sites and routes refer to the *High-risk intersections guide* and *High-risk rural roads guide*. Given that the majority of benefits for such schemes arise from a reduction in crashes, it is important that a robust assessment is undertaken. Analysts should avoid basing their assessment on a small number of historical crashes or using unsuitable crash rates, crash prediction models or crash reduction factors. It is also important to undertake sensitivity testing to understand how sensitive the benefit–cost ratio is to the crash history, crash prediction and crash reduction factors.

Other roading improvement projects
These are projects where reducing crashes is not the primary outcome sought, but there are safety impacts that need to be included in the economics (eg installation of a bus transit lane, extension of turn lanes, traffic capacity focused schemes). For these projects, benefits arise primarily from travel time and vehicle operating costs savings. Crash benefits can still be a key contributor to the benefit–cost ratio, but they are unlikely to be the key determinate in whether a project is funded.

While the majority of roading improvement projects will reduce crashes, some may increase them, especially if safety is not given adequate consideration in their design. Examples of projects that may result in an increase in crashes include four- and six-lane roads with bus or high-occupancy vehicle lanes, and seal extensions in curvy and tortuous terrain. The safety disbenefit in these cases can be minimised or eliminated through high-quality design. For example, on seal extensions through curvy realignment, providing improved delineation and safety barriers may mitigate the safety disbenefits that would otherwise arise.

Large projects
Large projects, for example a new motorway link, will have a network-wide impact on crashes. However, in most cases the crash benefits of such a project are only a small proportion of the overall benefits. When this is the case, it may be appropriate to use a more basic level of analysis than that specified in Appendix 2: Crash analysis, although some of the crash rates and costs provided can still be used. When considering projects of an area-wide nature, such as the analysis of an urban traffic network (eg for transport planning or a traffic management study), it is insufficient to calculate crash costs from changes in global totals of vehicles per kilometre 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, using crash rates appropriate to its intended design, speed limit and intersections along it can be applied. In some situations, the use of the site (or route) specific crash rates may be more appropriate than using the crash rates provided in the *Crash estimation compendium*.

> The full analysis process for calculating crash costs for area-wide changes in traffic networks is not outlined in this manual, and practitioners should refer to an expert in the field of crash analysis during this process.

Walking and cycling projects

Some new or improved walking and cycling facilities effectively eliminate hazards along an established route used by pedestrians or cyclists, such as through the 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 procedure in Appendix 2: Crash analysis.

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 analysis should quantify, preferably through surveys or research, the extent to which the existing hazards are an impediment to new users, or additional use, and provide supporting information on pedestrian or cycle numbers.

There is also 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.

Crash analysis steps

The general process for a crash analysis is as follows:

1. Select the appropriate analysis procedure(s) using Appendix 2: Crash analysis and, depending on the method(s) selected:
    i. determine the historic crash performance via analysis of crash records, typically over the last five years
    ii. select crash rates or crash prediction models for the do-minimum and option cases from the *Crash estimation compendium*.
2. Apply crash reduction factors or crash modifying factors (CMFs) as required.
3. Calculate the annual crash performance and corresponding crash costs for the do-minimum and the option scenarios. Adjust for general trends in crash occurrence.
4. 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.

Crash analysis methods

There are three types of crash analysis methods available:

- method A: crash-by-crash analysis
- method B: crash rate analysis
- method C: weighted crash procedure.

Follow the flowchart steps in Figure 1 to determine the need for a crash analysis and the selection of crash analysis method(s). Details on each step in the process are discussed Appendix 2: Crash analysis.

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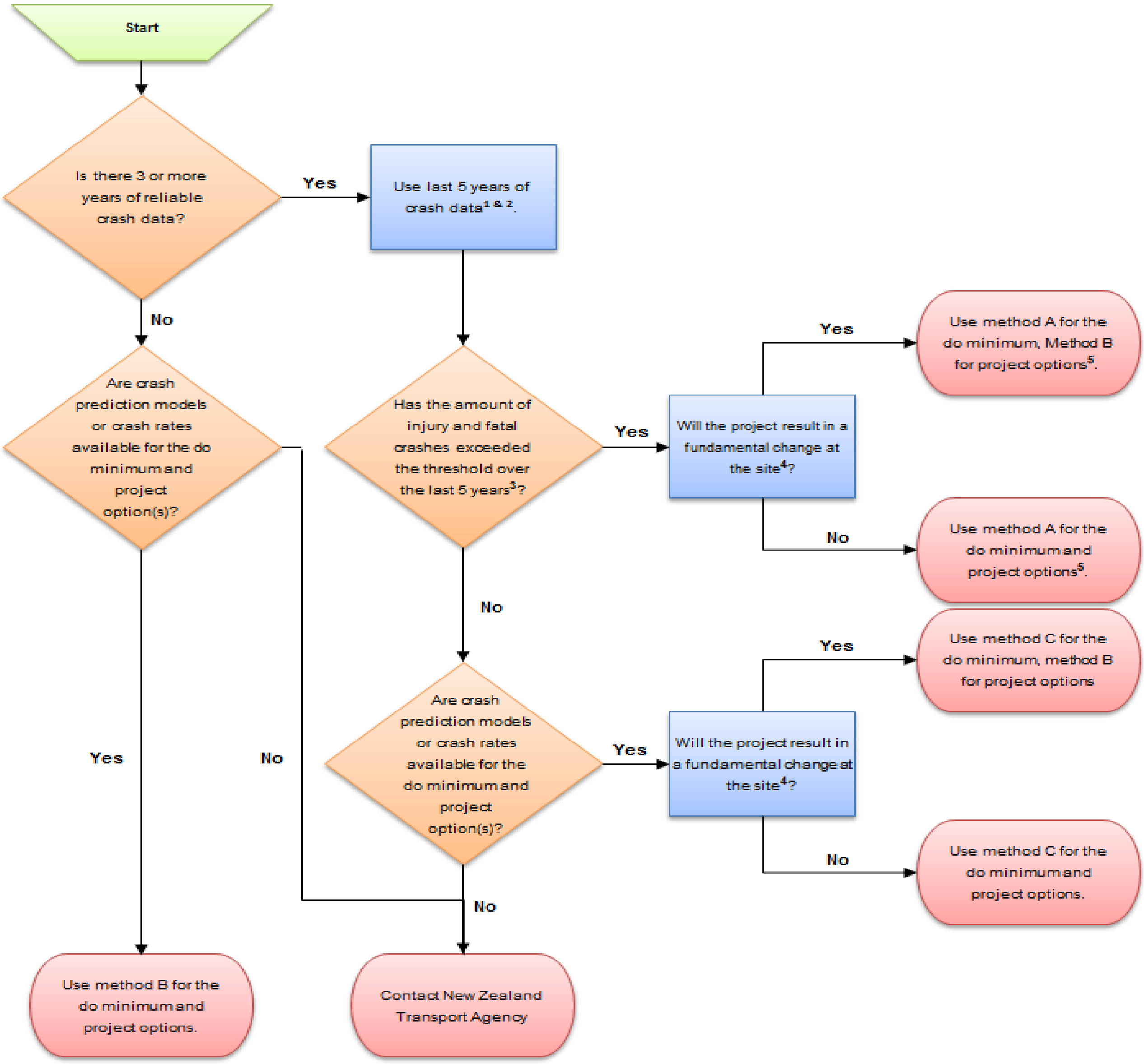
Figure 1: Decision process for selecting crash analysis methods



NOTES

1. If 3-5 years of crash data is available then use data that is available.

2. Up to 10 years of data can be used at low volume sites (<1500 AADT) or when looking at vulnerable road users (e.g. pedestrian and/or cyclist). Need to check that there has not been fundamental change or high traffic growth.

3. Threshold for intersections/road sections <1km: 5 or more injury crashes or 2 or more serious and fatal crashes at the site in the last 5 years?
Threshold for road sections >1km: 3 or more injury crashes per kilometre or 1 or more serious and fatal crashes per kilometre at the site in the last 5 years?

4. Fundamental change is defined in Appendix A6.9

5. Option of using method A or method B when analysing a high risk intersection/link (as defined in the NZ Transport Authority's High-risk Intersection Guide and High-risk Rural Roads Guide).

Crash migration

When undertaking a crash analysis, it is important that the potential crash migration is considered. It is possible that when a site (or route) is upgraded, crashes will be reduced at the site but may migrate to a different site downstream. In this case the benefits that have occurred at the site will be offset by the disbenefits that occur downstream. Ideally the potential for crash migration should be identified and addressed.

Crash migration downstream of the treated site is normally not an issue in the urban road environment (under 70km/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 a narrow bridge) is more likely than migration to a similar element 20km downstream.

To assess the possibility of crash migration, 1–2 kilometres either side of the study area should be considered. If road elements, such as low-design speed curves (75km/h or less), narrow bridges and railway crossings occur within this 1–2 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:

- the negative impacts (disbenefits) need to be included in the economic analysis
- improvements need to be made to downstream road elements to eliminate or reduce the crash migration, or
- a reduced estimate of crash savings should be used in the analysis.

A similar exercise should be undertaken for a longer length, up to 5 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, which significantly impact on the speed environment.

Valuation of social cost of crashes

Unit values of crash costs are provided in Appendix 2: Crash analysis for each crash type by movement category, speed limit, severity and vehicle involvement.

The values in the tables in Appendix 2 are based on Denne T (2023). The values per injury (as at July 2021) are:

- $12.5 million per fatality
- $660,100 per serious injury
- $68,000 per minor injury.

A worked example of the crash cost procedure is provided in Appendix 8: Worked examples.

3.2 Impact of mode on physical and mental health

The impact of mode on physical and mental health relates to people who change modes. This could be people who switch from private vehicle use to walking or cycling, and therefore switch from being inactive to being active.

Physical health benefits are included in benefit values for assessing pedestrian and cycling facilities. At this time there is no standard monetised value for mental health impacts.

Walking

The health benefits value for new pedestrian users is shown in Table 6.

Table 6: New pedestrian facility benefits ($/pedestrian km – 2021)

Benefit	Health benefits for new user ($/km)	Maximum annual benefit per new user
Pedestrian benefit	$9.90	$3,100

Where a new facility eliminates or improves a site (eg an underpass) that is an impediment to safe walking, a health benefit shown in Table 6 may be ascribed to new pedestrians using the facility. The benefit is irrespective of the length of the improvement. It is calculated using the average pedestrian trip length of 1 km times the value given above. The benefit is ascribed to users not users' trips.

The annual benefit calculated for each new individual pedestrian cannot exceed the maximum annual benefit shown in Table 6, which is the total estimated economic health benefit for converting an inactive person to an active person. The maximum annual benefit is irrespective of the pedestrian trip length because of diminishing returns, from a national perspective, an already active person walking additional kilometres won't deliver additional health benefit.

Cycling

Values for new cyclists using conventional and electric-assisted cycling are shown in Table 7.

Table 7: New cycle facility benefits ($/cyclist km – 2021)

Benefit	Health benefits for new user ($/km)	Maximum annual benefit per new user
Conventional cycling benefit	$4.90	$6,200
Electric-assisted cycling benefit	$2.50	$4,600

Where a new facility eliminates or improves a site that is an impediment to safe cycling, a benefit of $14.70 may be ascribed to cyclists using the facility. The benefit is irrespective of the length of the improvement. It uses the average cycle trip length of 3 km times the composite benefit given above. The benefit is ascribed to users not users' trips.

The annual benefit calculated for each new individual cyclist cannot exceed the maximum annual benefit in Table 7, which is the total estimated economic health benefit for converting an inactive person to an active person either using conventional cycling or electric-assisted cycling. The maximum annual benefit is irrespective of the cyclist trip length because of diminishing returns, from a national perspective, an already active person cycling additional kilometres won't deliver additional health benefit.

A worked example of cycling benefits is provided in Appendix 8: Worked examples.

3.3 Impact of air emissions on health

Vehicle emissions

Vehicle emissions are a complex mixture of gases and particles, with pollutants typically split into:

- **harmful air pollutants,** which cause adverse health effects and have local impacts, such as particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2) and volatile organic compounds, and
- **greenhouse gases** or climate pollutants, which cause global warming and have global impacts, for example carbon dioxide (CO_2), black carbon (BC) and methane (CH_4).

The impact and assessment of air pollution is covered within this section. The impact of transport services on greenhouse gases is described in more detail in section 3.4.

Impact of air pollution

For transport-related sources, the harmful pollutants of most concern are the following:

- Particulate matter ($PM_{2.5}$ – matter that is 2.5 microns (μm) or smaller), which predominantly impacts on respiratory and cardiovascular systems. Effects can range from reduced lung function, to increased medication use and increased hospital admissions, right through to reduced life expectancy and death.
- Nitrogen dioxide (NO_2), a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with increasingly more serious health effects, including reduced life expectancy (Kuschel et al 2022).
- Carbon monoxide (CO), a gas that is readily absorbed from the lungs into the bloodstream. It attaches more readily to haemoglobin in the blood than oxygen, causing headaches, dizziness and weakness. It can also aggravate heart conditions.
- Volatile organic compounds, hydrocarbons that include a wide range of chemicals, some of which are carcinogenic to humans. Volatile organic compounds can also react with NO_X (nitrogen oxide and NO_2) in the presence of sunlight to form ozone (O_3), which is a lung irritant.

Greenhouse gas emissions from road users contribute to global climate change. Changes in climate may also impact state highways through sea level rise, heavy rainfall and more frequent flooding.

Assessment of air pollution

NZTA has a comprehensive process for assessing the potential air quality effects of roading projects. Information on the assessment process, as well as procedures and resources for assessment, are available on the NZTA website.

Calculating traffic-related emission loads

This procedure has been developed from the Vehicle Emissions Prediction Model (VEPM). Emission rates are to be extracted from the latest version of the VEPM, which is freely available. To obtain a password to access to the spreadsheet, please email environment@nzta.govt.nz.

Emission rates are available for various speeds, gradients and traffic compositions, or other variables such as vehicle load.

Table 8: Calculating traffic-related emission loads

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td>1</td><td colspan="2">Determine the:
• traffic composition
• time period's total average travel time per vehicle (min).</td></tr>
<tr><td rowspan="4">2</td><td colspan="2">Convert the traffic composition vehicle classes into light and heavy emission classes according to % of vehicle kilometres travelled (VKT):</td></tr>
<tr><th>Emission class</th><th>Vehicle classes (Table A45)</th></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 the link road, either using a model, or according to the formula:
Speed (km/h) = 60 × length / TT
where: length = road link length (km)
TT = time period total average travel time per vehicle (min).</td></tr>
<tr><td>4</td><td colspan="2">Calculate the emission rates for light and heavy vehicle types using average speed on the link road from step 3, and emission factors from the latest VEPM version.</td></tr>
<tr><td>5</td><td colspan="2">Weight the calculated emission rates by vehicle flow composition (g/vkt):
= % light vehicles × light vehicle fleet average emission factor + % heavy vehicles × heavy fleet average emission factor</td></tr>
<tr><td>6</td><td colspan="2">Multiply the weighted emission rates by the time period's total vehicle volume and the road's length (ie VKT) to give the emission load (g).</td></tr>
</table>

While emission rates 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, such as the sustained operation of laden heavy vehicles at high speed on steep gradients. Emission rates at these extremes are not available, so the closest available rate is used.

Valuation of emissions

The external impacts of air emissions are costed using the damage cost approach. This assigns a cost to each tonne of pollutant emitted to reflect the damage done to the surrounding environment, including people and ecosystems. Emissions are calculated for each assessment scenario and then multiplied by the costs per tonne so that the likely impacts can be compared. The damage cost approach is simpler than undertaking exposure modelling, which requires detailed understanding of the sources, receptors, terrain and meteorology to arrive at predicted concentrations to which exposure response functions are then applied. However, it utilises factors which apply to the project as a whole, rather than at a local scale.

To calculate the damage cost of each option, use the total calculated emissions for each option and the damage cost per tonne from Table 9.

Damage costs in Table 9 have been calculated based on the 2021 value of life years (VoLY) derived from the 2021 value of statistical life (VoSL) of $12,500,000 (NZ$). For project analyses in future years, damage costs for all pollutants should be updated based on the update factor published for injury costs.

Table 9: Emissions damage costs ($/tonne – 2021)

Pollutant	Urban costs in NZ$/tonne	Rural costs in NZ$/tonne	National costs in NZ$/tonne
$PM_{2.5}$	$853,824.00	$49,075.00	$530,676.00
NO_X	$865,797.00	$24,040.00	$325,312.00
CO	$4.87	$0.19	$2.99
Volatile organic compounds	$1,545.00	$61.00	$949.00
SO_2	$39,334.00	$1,546.00	$24,160.00

Note: These damage costs for New Zealand have been based on Kuschel et al (2022).

The predicted value of any change in emissions should be calculated and included in the BCR. Projects which include both urban and rural areas should model and monetise urban and rural emissions separately, before summing them together. National damage costs should only be used when it is not practicable to separately model urban and rural emissions. Emissions should be quantified in tonnes and reported in the appraisal summary table.

A worked example of the Vehicle emissions procedure is provided in Appendix 8: Worked examples.

3.4 Impact on greenhouse gas emissions

The greenhouse effect is caused by greenhouse gases, particularly CO_2 and water vapour, trapping heat in the lower atmosphere. 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.

Greenhouse gas emissions from road users contribute to global climate change. Changes in climate may also impact transport system through sea level rise, heavy rainfall and more frequent flooding.

Note: Several harmful pollutants (especially black carbon) are direct climate pollutants, in that they have a direct warming effect on the atmosphere. However, many of the remaining harmful pollutants (eg SO_2 and CO) are indirect climate pollutants. This means they do not warm the atmosphere themselves, but react with other gases to increase greenhouse gas concentrations. Therefore, initiatives that address harmful air pollutants typically yield both health and climate change benefits.

Impact of CO_2

While CO_2 occurs naturally, in the last 200 years the concentration of CO_2 in the earth's atmosphere has increased by 25%. As these extra amounts of CO_2 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 alter the earth's climate.

CO_2 makes up around half of the extra greenhouse gases and a significant proportion of this extra CO_2 is emitted by motor vehicles.

Assessment of CO_2 emissions

High-level and/or indicative CO_2 emissions impacts can be estimated using the Project Emissions Estimation Tool (PEET). PEET has not been developed to provide a detailed emissions analysis of specific project elements; the tool only considers the most significant emission sources in a project life cycle. PEET is not a replacement for detailed transport modelling or a detailed emissions assessment for infrastructure design. The limitations, key assumptions and sources of uncertainty associated with any estimate made using PEET should be clearly stated in any documentation or presentation of results. Also note, PEET can be used to assess both transport (for example enabled/operational) and construction (embodied) emissions, but only the enabled emissions should be included in economic assessment.

The following procedure should be used to assess more detailed and/or monetised changes in the level of greenhouse gas (GHG) emissions as the result of transport activities.

This procedure has been developed from the Vehicle Emissions Prediction Model (VEPM) to calculate traffic-related emission loads. GHG emission rates are to be extracted from the latest version of the VEPM, which is freely available at vepm.co.nz.

Emission rates are available for various speeds, gradients and traffic compositions, or other variables such as vehicle load.

Table 10: Calculating traffic-related emission loads

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>Determine the:
traffic composition
time period’s total average travel time per vehicle (min).</td></tr>
<tr><td>2</td><td>Convert the traffic composition vehicle classes into emission classes:<table><tr><th>Emission class</th><th>Vehicle classes (Table A45)</th></tr><tr><td>Light
(vehicles less than 3.5 tonnes)</td><td>Passenger cars
Light commercial vehicles</td></tr><tr><td>Heavy
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Heavy commercial vehicle I (HCVI)
Heavy commercial vehicle II (HCVII)
Buses</td></tr></table></td></tr>
<tr><td>3</td><td>Calculate average speed on the link road, either using a model, or according to the formula:
Speed (km/h) = 60 × length / TT
where: length = road link length (km)
TT = time period total average travel time per vehicle</td></tr>
<tr><td>4</td><td>Calculate the emission rates (g/km) for light and heavy vehicle types using average speed on the link road from step 3, and emission factors from the latest VEPM version.</td></tr>
<tr><td>5</td><td>Weight the calculated emission rates by vehicle flow composition (g/vkt):
= % light vehicles × light emission rate + % heavy vehicles × heavy emission rate</td></tr>
<tr><td>6</td><td>Multiply the weighted emission rates by the time period’s total vehicle volume and the road’s length to give the emission load (g).</td></tr>
</table>

While emission rates 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, such as the sustained operation of laden heavy vehicles at high speed on steep gradients. Emission rate at these extremes are not available, so the closest available rate is used.

Valuation of CO_2 emissions

The whole-of-government agreed shadow price[1] of carbon ($ per tonne of CO_2 equivalent) emissions, in Table 11, is to be used for calculating the economic impact of carbon for transport activities.

This means applying the central price path as the default values to use in the economic analysis of transport proposals and accompanying this with sensitivity analysis based on the low and high price paths.

[1] For more information see the technical paper *Economic valuation of greenhouse gas emissions* (NZTA 2021) on the NZTA website.

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Note that these carbon values will be updated when new information on the value of $C0_2$ equivalent becomes available.

Should your analysis require shadow prices for years prior to 2024, email MBCM@nzta.govt.nz.

Table 11: Shadow price of carbon (NZ$2023 per tonne of CO_2 equivalent)

Year	Low	Central	High
2024	70	105	140
2025	77	116	154
2026	85	127	169
2027	92	138	184
2028	99	149	198
2029	107	160	213
2030	114	171	228
2031	117	176	235
2032	121	181	242
2033	124	187	249
2034	128	192	256
2035	132	198	264
2036	136	204	272
2037	140	210	280
2038	144	216	289
2039	149	223	297
2040	153	230	306
2041	158	237	315
2042	162	244	325
2043	167	251	335
2044	172	258	345
2045	177	266	355
2046	183	274	366
2047	188	282	377
2048	194	291	388
2049	200	300	400
2050	206	309	411
2051	208	318	432
2052	210	327	454
2053	212	337	476
2054	214	347	500
2055	216	358	525
2056	218	369	551

Year	Low	Central	High
2057	221	380	579
2058	223	391	608
2059	225	403	638
2060	227	415	670
2061	230	427	704
2062	232	440	739
2063	234	453	776
2064	237	467	815
2065	239	481	855
2066	241	495	898
2067	244	510	943
2068	246	525	990
2069	249	541	1040
2070	251	557	1092

A shadow price places a value on future greenhouse gas emissions emitted or reduced, usually concerning international and/or national emissions goals.

Shadow prices are different from market traded prices in the Emissions Trading Scheme (ETS), which do not currently reflect the full marginal cost of achieving New Zealand’s emission targets. An ETS is typically only one of the many policies that governments implement to meet their climate targets.

3.5 Impact of noise and vibration on health

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 absorbent and reflective surfaces, and is reduced 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.

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 spread. Also, distances between the road and dwelling locations will determine how much vibration energy actually reaches nearby properties.

Air-borne low-frequency sound below 100Hz 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.

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, subsoil geology, building characteristics and sensitivity at the receiver location.

Impact 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 3dB requires traffic volumes to double.

Design guidelines for road traffic noise

Design guidelines for the management of road traffic noise on state highways are given in the *Guide to assessing road-traffic noise, using NZS 6806 for state highway asset improvement projects*. 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 1m 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:

1. **Average noise design criteria**
   - The average noise design levels for residential buildings and educational facilities at the assessment point are set out in Table 12.
   - If it is not practicable or cost effective to meet the average design noise criterion at the assessment point given in Table 12, 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 12 minus 20dB(A), or 40dB(A) $L_{eq(24\ hour)}$, and for educational facilities the internal noise level criterion is either the level given in Table 12 minus 20dB(A), or 42dB(A) $L_{eq(24\ hour)}$, in each case whichever is the higher.

Table 12: Average noise design levels ($L_{eq(24\ hour)}$)

Noise area	Ambient noise level (dB(A))	Average noise design level (dB(A))
Low	Less than 43	55
Areas with ambient noise levels of less than 50dB(A) $L_{eq(24\ hour)}$	43–50	Ambient + 12
Medium	50–59	62
Areas with ambient noise levels of 50 to 59dB(A) $L_{eq(24\ hour)}$	59–67	Ambient + 3
High	67–70	70
Areas with ambient noise levels of more than 59dB(A) $L_{eq(24\ hour)}$	more than 70	Ambient

2. **Single noise event design criterion**
    a. A single noise event is the maximum noise level emitted by a single vehicle passing the assessment point.
    b. Where the assessment point for residential buildings and educational facilities is less than 12m from the nearside edge of the traffic lane, the *Guide to assessing road-traffic noise using NZS 6806 for state highway asset improvement projects* require noise reduction measures to reduce noise by at least 3dB(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 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 1.8.

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: 2008 Acoustics – measurement of environmental sound*. Prediction of road traffic noise shall be carried out using the United Kingdom *Calculation of road traffic noise* (UK Department of Transport 1988) method, calibrated to New Zealand conditions (refer to *Traffic noise from uninterrupted traffic flow*) and converted to the appropriate L_{eq} index.

The conversion formulae to calculate L_{eq} values from the L10 values derived from the *UK Calculation of road traffic noise* (1988) method are:

$$L_{eq(24\ hour)} = L10\ (18\ hour) - 3dB(A)$$

$$Leq(1\ hour) = L10\ (1\ hour) - 3\ dB(A)$$

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 62dBA do encourage people to move out of an area more quickly (Dravitzki et al 2001).

A British survey (Tinch 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 2 to take into account the factors mentioned by Bein). Using average values for urban property of $640,000 according to residential property data (REINZ) February 2020, and occupancy of 2.8 persons according to Census 2018 data, this suggests a present value cost of $7680 per dB per property and $2740 per dB per resident affected ($495 per household or $177 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 50dB.

Costs of road noise shall be valued at:

$495(2020) per year × *dB change* × *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 12.

Guidance on predicting and managing noise impacts can be found in NZTA guidance on noise and vibration.

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 3dB(A), ie 0 to 3dB(A), >3 to 6dB(A), >6 to 9dB(A)
- the number of residents in each band
- where the predicted noise level is above the average noise design levels given in Table 12 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.

3.6 Impact on network productivity and utilisation

The impact of transport initiatives on network productivity and utilisation is measured using the following indicators:

1. changes in travel time (all modes)
2. changes to the resource costs of transport use (including public transport fares, vehicle operating costs, and cycling costs).

Changes in travel time

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. The value of travel time savings is based upon the theory that time spent travelling is an opportunity cost to both individuals and businesses, and that therefore any reduction in travel time can be represented as a cost saving. The unit value of travel time savings can be interchangeably referred to as the value of time or VoT.

This section contains values of time for vehicle occupants, public transport users, pedestrians, cyclists, and freight vehicles. The road user values are used to produce composite travel time values for the different road categories for uncongested and congested traffic conditions. Values are also provided to calculate the values for changes in road user journey time reliability. Unit values are provided for vehicle occupant, vehicle and freight-time costs, along with values for travel in congested conditions. 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 1: Demand estimation methods and guidance) 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 maximum following the rule of half.

Where a proposed walking or cycling facility improvement reduces the existing walk or cycle travel time, for example, by adding a pedestrian or cyclist priority phase at a signalised crossing, there will be travel time cost savings to existing pedestrians or cyclists other than those covered by the procedures in section 4.2. The standard values of time given in Table 14 may be used to calculate these benefits. These benefits may, however, be offset by increased delays to motor vehicles, which should also be taken into account depending on the road and community context.

Travel time estimation procedures

Travel times shall be estimated from a suitable transport model or according to the procedures in Appendix 3: Traffic data and travel time estimation. Where a specific procedure is not given, the travel time shall be determined according to a recognised procedure compatible with the procedures in the appendix.

Travel time values

This section contains travel time values for all modes. The road user values are used to produce composite travel time values for the different road categories for uncongested and congested traffic conditions. Values 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 or shorter trips

+ travel time benefits for reduced traffic congestion (if applicable)

+ travel time benefits for improved trip reliability (if applicable).

Travel time values are presented in this section under the following headings:

- Behavioural values of travel time (for demand modelling)
- Equalised values of travel time (for benefit calculations to determine the BCR)
    - Work travel time values (for vehicles and for vehicles plus occupants)
    - Composite values of travel time and congestion.

Behavioural values of travel time for demand modelling

Table 13 provides behavioural values of travel time that are to be used for **transport demand modelling purposes** (refer to Denne et al). The values are for all mode users by trip purpose in $/hour/person.

Table 13: Behavioural values of travel time for vehicle and PT occupants, pedestrians and cyclists for all road categories and all time periods ($/h/person July 2021)

Vehicle occupants, pedestrians, cyclists	Work travel purpose	Commuting to/from work	Other non-work travel purposes
Behavioural values of time for uncongested traffic ($/h/person)			
Drivers and passengers in cars, LCVs, MCVs, HCVs, motorcycles	37.92	30.90	31.21
Seated bus and train passengers	37.92	8.16	6.61
Standing bus and train passengers	37.92	11.88	10.33
Pedestrians and cyclists	37.92	11.88	10.33
Maximum increment for congestion ($/h/person)			
Drivers and passengers in cars, LCVs, MCVs, HCVs, motorcycles	26.34	26.34	24.47
Seated bus and train passengers	26.34	6.96	5.18
Standing bus and train passengers	26.34	10.13	8.10

Equalised values of travel time for benefit calculations

Table 14 to Table 16 provide travel time values to be used for the calculation of the economic benefits in the BCR calculations. These tables contain travel time values that have been equalised across modes.

Table 14 provides equalised values of travel time by trip purpose for all modes combined. These values are used for calculating travel time benefits in the economic calculations of the BCR. The values are in $/hour for all trip purposes for uncongested traffic conditions and a maximum increment for congested conditions. Note that the maximum values apply only when there is extreme congestion. Refer to the procedures for traffic congestion below

Table 14: Equalised values of travel time for all road categories, all time periods, all users* ($/hr/person July 2021)

Vehicle occupants, pedestrians, cyclists	Work travel purpose	Commuting to/from work	Other non-work travel purposes
Values of time for uncongested traffic ($/h/person)	37.92	19.53	18.91
Maximum increments for congestion ($/h/person)	26.34	16.65	14.83

***** All users means: vehicle drivers and passengers, sitting and standing PT users, pedestrians and cyclists

Work travel time values (for vehicles and for vehicles plus occupants)

Table 15 provides values of travel time for vehicles and freight where these vehicles are used for work purposes. The values are for vehicle and freight time, and vehicle and freight time plus occupants in $/hour. These tables are used for calculating travel times values for non-standard traffic compositions. For standard traffic compositions use the values in Table 16.

Table 15: Values of travel time for vehicles used for work travel purposes ($/h/vehicle July 2021)

Vehicle type	Vehicle and freight time, excluding occupants ($/h/vehicle)	Vehicle and freight time, including occupants ($/h/vehicle)	Maximum increments for congestion for work travel purposes (CRV $/h/vehicle)
Passenger car	2.16	59.04	41.67
Light commercial vehicle	4.61	61.49	44.12
Medium commercial vehicle	11.93	61.22	46.17
Heavy commercial vehicle I	30.54	79.84	64.79
Heavy commercial vehicle II	49.39	98.68	83.63
Bus	30.54	79.84	64.79

Composite values of travel time and congestion

The composite travel time values in Table 16 combine vehicle occupant time, vehicle time and freight time, based on the vehicle types for standard traffic compositions defined in Table A47. These composite values are calculated using the default traffic volumes for the four road categories defined in Table A46. Because the composite values in Table 16 include vehicle occupant time, vehicle time and freight time, the values from Table 15 (which are provided for non-standard traffic compositions) **must not** be added to the travel time values in Table 16.

Table 16 provides the **maximum** additional values for traffic congestion (CRV), to be applied as described in this manual.

Table 16: Composite values of travel time, plus maximum increments for congestion, for different road categories and different time periods ($/h/vehicle July 2021)

Road category and time period	Composite value of time ($/h/vehicle)	Maximum increments for congestion (CRV $/h/vehicle)
Urban arterial		
Morning commuter peak	35.52	24.79
Daytime inter-peak	37.78	25.12
Afternoon commuter peak	35.35	24.43
Evening/night-time	35.62	23.79
Weekday all periods	37.55	25.48
Weekend/holiday	38.32	27.00
All periods	38.24	26.17
Urban other		
Weekday	37.79	25.76
Weekend/holiday	38.63	27.33
All periods	38.36	26.38
Rural strategic		
Weekday	50.70	32.33
Weekend/holiday	50.90	34.99
All periods	49.43	32.24
Rural other		

Weekday	49.91	32.24
Weekend/holiday	50.01	34.81
All periods	48.61	32.13

Traffic congestion values (CRV)

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 Table 13, Table 14, Table 15, and Table 16. The actual additional value for congestion used in the analysis is adjusted according to the requirements for each category of delay set out in below.

Worked examples of selected traffic congestion procedures are provided in Appendix 8: Worked examples.

Treatment of passing lanes

An exception to the calculation below is made in the case of driver frustration benefits as the results of passing lane projects evaluated using the procedures in section 3.8. When a separate value for changes in driver frustration is calculated using the valuation procedure in section 3.8, 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 section, 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 2 kilometres.

Peak traffic intensity and volume to capacity (VC) ratio are first calculated in the normal manner (see Appendix 3: Traffic data and travel time estimation). 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 Figure2, Figure3 or Figure4 , or Table 17, Table 18 or Table 19. Alternatively, the formulas shown in at the bottom of Figure2, Figure3 or Figure4 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)

Percentage of time delayed has a maximum limit of 90%, and so 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%.

$$\text{Incremental value for congestion (\$/h)} = \frac{CRV \times (\text{road section traffic volume} - 70\% \text{ of road section capacity volume})}{30\% \text{ of road section capacity volume}}$$

Bottleneck delay

For all bottleneck delay, the maximum increment for congestion should be added to the base value of travel time.

Table 17: Volume to capacity (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

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PTD %	Level terrain – percentage of overtaking sight distance										
	100	90	80	70	60	50	40	30	20	10	0
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

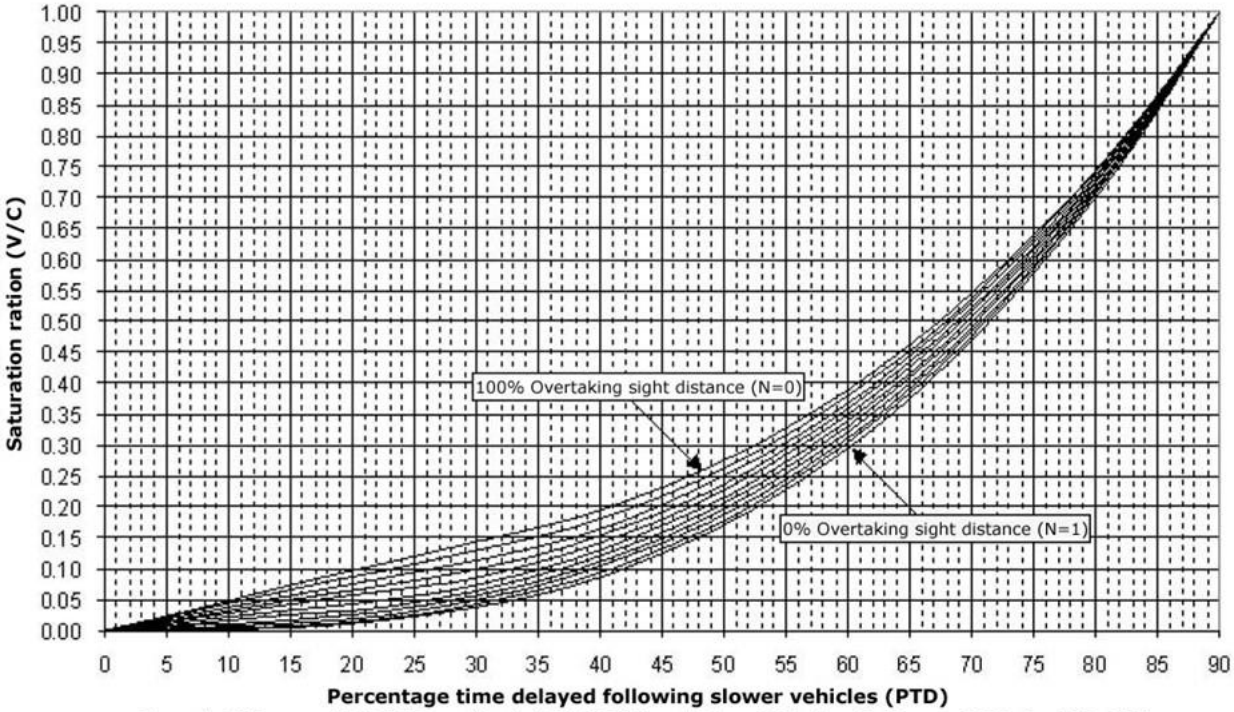
Table 18: Volume to capacity (VC) ratios for rolling terrain, overtaking sight distance and percentage of time delayed (PTD) following slow vehicles

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 19: Volume to capacity (VC) ratios for mountainous terrain, overtaking sight distances and PTD following slow vehicles

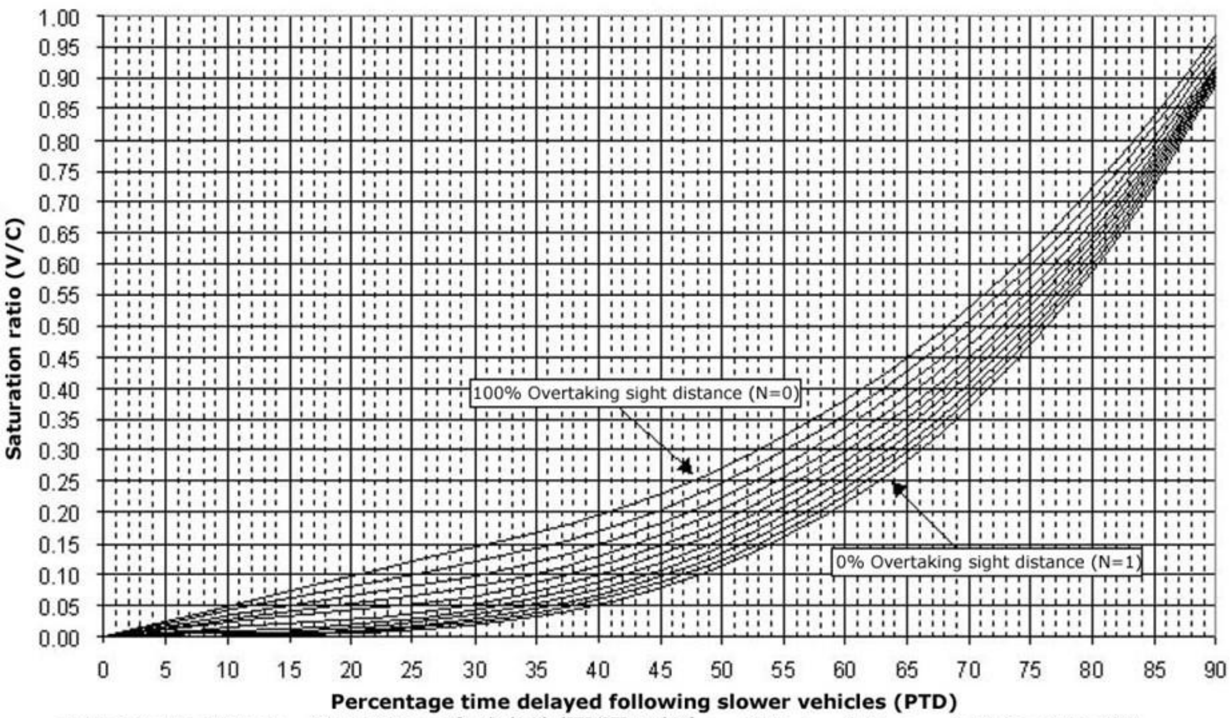
PTD %	Mountainous terrain – percentage of overtaking sight distance										
	100	90	80	70	60	50	40	30	20	10	0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.5	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
15.0	0.07	0.05	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00
22.5	0.10	0.08	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 2: Percentage of time delayed (PTD) two-lane rural roads level terrain



curve formula S/Smax = (PTD/PTDmax) [a +b. (1-N). (PTD/PTDmax)^c] a = 3.01, b = 0.47, c = -0.90, for PTD>30%

Figure 3: PTD for two lane rural roads, rolling terrain



curve formula S/Smax = (PTD/PTDmax)[a +b. (1-N). (PTD/PTDmax)^c] a = 3.51, b = 0.94, c = -0.59, for PTD>30%

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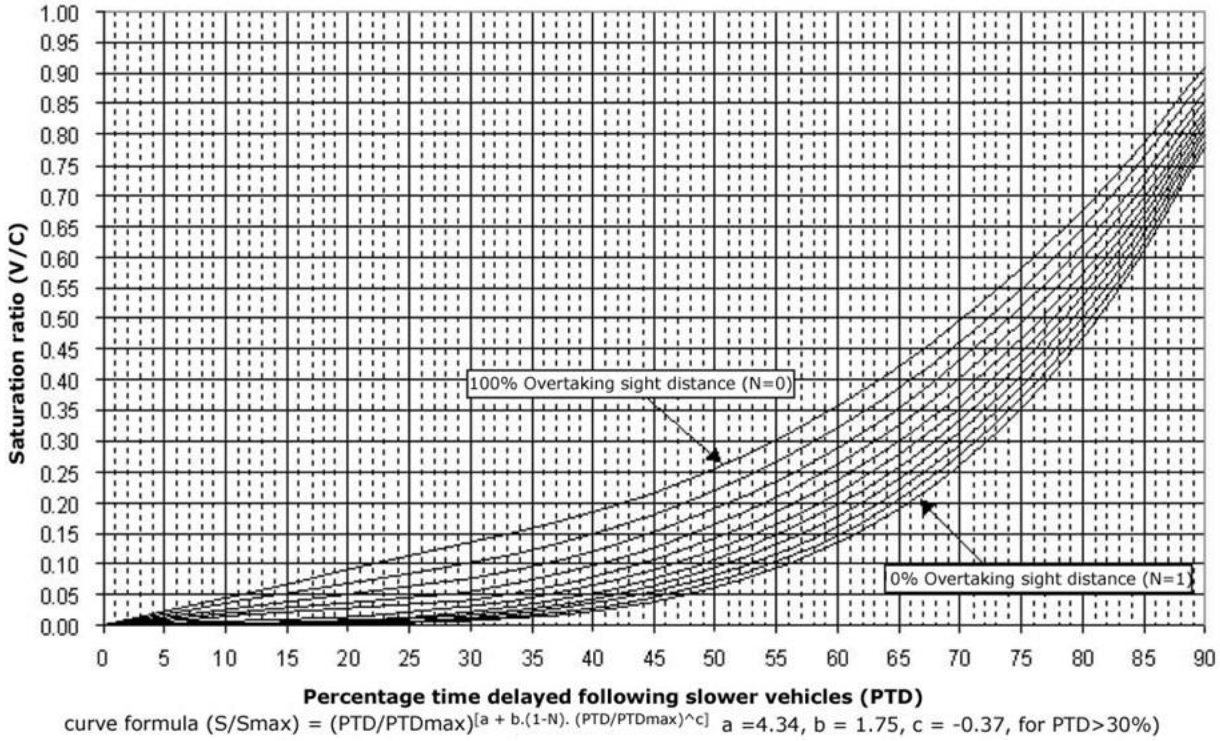
Figure 4: PTD for two lane rural roads, mountainous terrain



Changes in service frequency for public transport

Changes in service frequency may also be described as changes in waiting time, headway, or queuing time. The impact of the headway changes depends on the existing frequency of the service.

Calculate the service frequency transport service user benefits using the information in Chapter 2 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:

$Bf_{new} = FB \times (Q_2 - Q_1) \times ½$

Total service frequency benefits:

$Bf_{total} = Bf_{existing} + Bf_{new}$

where: Q_1 is the existing number of passengers (patronage)
Q_2 is the projected new total number of passengers
WTf is the wait time benefit (in minutes) from Table 20
VOT is the value of vehicle occupant time ($/minute) for by trip purpose from Table 14

For improved frequency of services waiting time is valued at two times the value of VOT.

Using the existing headway/service frequency (minutes) and the appropriate trip purpose from Table 20, identify the changes in wait time in minutes from 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 20: Increased service headway

Existing headway (minutes)	Wait time (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 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 Chapter 2 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:

$$Bi_{new} = IB \times (Q_2 - Q_1) \times ½$$

Total interchange reduction benefits:

$$Bi_{total} = Bi_{existing} + Bi_{new}$$

where: Q_1 is the existing number of passengers.
Q_2 is the projected new total number of passengers.
WTi is the existing wait and/or walking time to transfer between public transport services (minutes).
VOT is the value of vehicle occupant time ($/minute) for by trip purpose from Table 14.

For improved frequency of services waiting time is valued at 2 times the value of VOT.

Changes in resource costs of transport use

This section provides values for cost of all mode use. The costs of transport use in this section 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.

Vehicle operating costs (VOC)

This section 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.

The VOC value for each vehicle class is based on the weighted average costs of the vehicles of different types within each class. The vehicle classes are defined in Table A45 within Appendix 3: Traffic data and travel time estimation.

VOC values are provided for the standard traffic compositions using four road categories: urban arterial, urban other, rural strategic and rural other (for more information see their definitions in Table A46 within Appendix 3: Traffic data and travel time estimation). The road category costs contained in the tables in this section are for the 'all time periods' traffic mix.

The section includes:

- base VOC and VOC by speed and gradient
- VOC changes due to congestion
- VOC changes due to road surface conditions
- VOC changes due to bottleneck delay
- VOC changes due to speed change cycles.

To assist analysts, regression equations are provided which can be used to predict the VOC when using spreadsheets or other applications.

> 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.

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.

Base VOC and VOC by speed and gradient

The base VOC value is comprised of costs for 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 15) and the composite travel time values (Table 16).

The breakdown of the base VOC by component is given in Table 21.

Table 21: Breakdown of base VOC by component (%)

Vehicle class	Percentage of total base VOC by component			
	Fuel and oil	Tyres	Maintenance and repairs	Depreciation
PC	35.7	6.2	37.2	21.0
LCV	39.6	7.2	29.4	23.8
MCV	38.6	4.2	44.2	13.0
HCVI	42.0	8.3	42.1	7.6
HCVII	37.3	10.4	43.0	9.3
BUS	46.1	6.0	36.9	11.0
Road category	**Fuel and oil**	**Tyres**	**Maintenance and repairs**	**Depreciation**
Urban arterial	36.8	7.3	38.1	17.8
Urban other	36.9	6.9	37.9	18.3
Rural strategic	37.5	7.9	39.4	15.2
Rural other	37.4	7.7	39.1	15.8

Information for VOC by speed (between 10km/h and 120km/h) and gradients (between 0% and 12%) is provided in Table A79 through to Table A88 in Appendix 4: Vehicle operating cost tables. Each table is accompanied by a graph, and the tables and graphs are generated based on the regression coefficients and equation in Table 22. The tables give calculated values for each 5km/h and percentage gradient.

The values are the average of the uphill and downhill gradient costs. While VOC values 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, for example 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 is because as vehicle speeds decrease the fuel consumption is governed by the minimum fuel consumption of the vehicle. As vehicle speeds increase above 60–70km/h the graph curves start to rise due to the effects of increasing aerodynamic drag.

Table A79 through to Table A84 provides VOC values for individual vehicle classes for use when an analysis 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 VOCs for both urban and rural road categories.

Where a non-standard traffic composition is considered, the combined VOCs 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.

Table A85 through to Table A88 provides the VOC values for standard traffic compositions in the four road categories.

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.

The regression coefficients for running costs by speed and gradient are provided in Table 22.

Table 22: Running cost by speed and gradient regression coefficients (cents/km – July 2015)

Regression coefficient	Vehicle class						Road category			
	PC	LCV	MCV	HCVI	HCVII	Bus	Urban arterial	Urban other	Rural strategic	Rural other
a	22.63	18.46	28.17	0.878	-171.45	-64.59	18.22	20.08	13.80	15.73
b (× 10^{-2})	-24.11	-68.84	78.13	29.81	2,370.30	229.00	21.90	0.39	73.45	48.93
c	26.89	47.75	63.91	153.83	352.54	167.92	37.50	35.47	48.56	44.72
d (× 10^{-4})	-274.79	-112.69	2,489.40	6,744.40	9,495.20	2,018.00	62.39	59.27	523.50	396.59
e	-13.25	-21.98	-28.20	-60.64	-116.34	-62.44	-16.96	-16.38	-20.74	-19.48
f (×10^{-2})	21.93	42.74	-21.64	-51.71	-1,237.60	-29.16	-2.80	8.23	-31.06	-18.24
g (× 10^{-4})	12.11	9.64	-175.46	-389.28	-856.38	-231.53	-13.28	-10.43	-46.44	-35.85
h	1.62	2.65	3.46	6.99	12.24	7.21	2.02	1.97	2.43	2.30
i (× 10^{-3})	-34.05	-60.44	-41.35	8.86	1,605.70	-134.22	-3.59	-19.13	30.33	14.28
j (×10^{-3})	8.16	12.40	61.02	97.13	350.59	121.09	17.38	15.29	27.96	23.96

$$VOC_B = a + b \times 10^{-2} \times GR + c \times \ln(S) + d \times 10^{-4} \times GR^2 + e \times [\ln(S)]^2 + f \times 10^{-2} \times GR \times \ln(S) + g \times 10^{-4} \times GR^3 + h \times [\ln(S)]^3 + i \times 10^{-3} \times GR \times [\ln(S)]^2 + j \times 10^{-3} \times GR^2 \times \ln(S)$$

Where:
VOC_B = base vehicle operating costs in cents/km
GR = absolute value of average gradient (ie >0) over range of 0–12%
S = speed in km/h over range of 10–120km/h
ln = natural logarithm

VOC changes due to congestion

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 Table A92 through to Table A95 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 Appendix 4: Vehicle operating cost tables, Table A95, while Table 23 provides regression coefficients for predicting the congestion costs by vehicle class and Table 24 by road category.

Table 23: Additional VOC due to congestion regression coefficient by vehicle class (cents/km – July 2015)

Road type	Parameter	Regression coefficient by vehicle class					
		PC	LCV	MCV	HCVI	HCVII	Bus
Urban	a	4.41	7.12	9.03	26.03	69.54	16.75
	b	-3.81	-2.71	-1.50	-0.30	0.86	-1.03
	c	5.41	4.85	3.96	3.80	3.65	4.08
Two-lane highway	a	3.86	6.02	7.49	24.22	70.57	13.07
	b	-9.17	-12.14	-0.63	0.57	2.08	-1.25
	c	10.48	13.93	2.74	2.66	2.39	3.78

Road type	Parameter	Regression coefficient by vehicle class					
		PC	LCV	MCV	HCVI	HCVII	Bus
Motorway	a	3.30	5.00	7.20	23.10	70.02	12.07
	b	-23.38	-27.76	-4.98	-3.90	-1.75	-6.64
	c	24.51	29.32	7.13	7.13	6.21	9.14

VOC_{CONG} = min {a, exp(b + c x VC) - exp(b)}

Where: VOC_{CONG} = Additional vehicle operating costs due to congestion in cents/km.
VC = volume to capacity ratio.

Table 24: Additional VOC due to congestion regression coefficients by road category (cents/km – July 2015)

Parameter	Urban	Rural two-lane		Motorway
		Strategic	Other	
a	9.21	7.70	6.98	7.08
b	-1.90	-1.24	-1.56	-5.93
c	4.33	3.21	3.41	7.87

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). 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 8,760 h/year).

Figure 5: Procedure for estimating changes in VOC due to congestion

- Step 1 • Determine the capacity of the road (see Appendix 3: Determining the capacity of road sections)
- Step 2 • Determine the traffic flow in pcu/hr and the corresponding VC ratio, for each of the hourly flow periods, (see Appendix 3: Calculating the volume to capacity ratio).
- Step 3 • Determine the speed for each of the hourly flow periods (see Appendix 3: Travel times and speed).
- Step 4 • Determine the unadjusted VOC (including roughness, texture and deflection) for each of the hourly flow period speeds, using the VOC tables,.
- Step 5 • Determine the congestion cost corresponding to the VC ratio for each of the hourly flow periods, from Table A84 through to Table A87.
- Step 6 • Determine the total VOC for each flow period as the sum of the unadjusted VOC and the congestion costs.
- Step 7 • Determine the total annual VOC by weighting the costs for each flow period by the percentage of the year that flow is experienced.

VOC changes 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 the previous part of this section are calculated assuming zero road

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roughness (as measured on the International Roughness Index or IRI m/km scale) and shall be supplemented for the additional costs caused by road roughness when relevant to the project analysis.

Roughness costs are made up of two components: vehicle costs, and values for vehicle occupants' willingness to pay to avoid rough road conditions. The willingness-to-pay values reflect the preference of road users for driving on smooth roads and are based on New Zealand research. The willingness-to-pay values indicate that road users on rural roads have a higher willingness-to-pay value for a given roughness than urban users because of their higher average speeds. However, at very high roughness levels the willingness-to-pay values are the same for both urban and rural road users. These two components are combined in tables in Appendix 4: Vehicle operating cost tables. Table A89 and Table A90 provide the additional costs due to road roughness for individual vehicle classes for urban and rural conditions. Table A91 provides the costs for the standard traffic composition on the four road categories.

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 × IRI m/km - 1.27.

> 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.

Table 25 provides the regression coefficients for predicting the roughness costs.

Table 25: Additional VOC due to roughness – regression coefficients (cents/km – July 2015)

Road category	Vehicle class	Regression coefficients – July 2015							
		a	b	c	d	e	f	g	h
Urban	PC	-18.73	60.26	-70.37	33.96	-5.01	0.00	1.56	6.17
	LCV	-40.74	125.22	-138.55	63.63	-9.39	0.00	1.64	11.00
	MCV	-5.38	32.10	-56.08	34.69	-5.17	0.00	4.04	10.60
	HCVI	-11.80	55.79	-87.72	51.60	-7.63	0.00	5.23	17.28
	HCVII	-11.85	57.47	-93.84	56.90	-8.27	0.00	7.67	11.04
	Bus	8.22	-5.31	-20.76	21.20	-3.18	0.00	4.81	8.80
Rural	PC	-218.08	820.79	-1,196.82	841.35	-284.85	37.74	1.59	5.74
	LCV	-354.11	1,315.51	-1,894.73	1,318.30	-443.12	58.36	1.70	10.22
	MCV	-385.18	1,489.60	-2,226.16	1,597.09	-548.76	73.55	4.07	10.18
	HCVI	-615.52	2,362.79	-3,510.17	2,508.61	-860.67	115.23	5.23	17.39
	HCVII	-548.46	2,126.70	-3,187.29	2,291.28	-787.49	105.62	7.76	9.91
	Bus	-354.29	1,392.35	-2,110.17	1,530.53	-529.69	71.39	4.84	8.44
Urban	All	-20.16	65.27	-76.73	37.25	-5.49	0.00	1.77	6.96
Rural strategic	All	-267.66	1,011.64	-1,481.01	1,044.76	-354.66	47.09	2.09	7.00
Rural other	All	-261.54	987.73	-1,444.98	1,018.75	-345.70	45.89	2.00	6.87

$$VOC_{RI} = \min\left(\{a + b \times \ln(RI) + c \times [\ln(RI)]^2 + d \times [\ln(RI)]^3 + e \times [\ln(RI)]^4 + f \times [\ln(RI)]^5\}, \{g \times RI + h\} \right)$$

Where:
VOC_{RI} = additional vehicle operating costs due to roughness in cents/km
RI = max (2.5, roughness in IRI m/km)
ln = natural logarithm.

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 4: Vehicle operating cost tables are calculated on the basis of 0 texture.

The effect of surface texture on VOC is as follows:

1mm increase in surface macro texture = 0.20 cents/km/vehicle (all vehicle classes combined)

Macrotexture is expressed in millimetres 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 Table A80 through to Table A88 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 26 are added to the VOC in Table A81 through to Table A88 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 26: Increase in VOC per vehicle – kilometre per 1mm increase in Benkelman beam deflection (July 2015)

Vehicle class	Cents/veh/km
MCV	2.50
HCVI	3.90
HCVII	5.30
Bus	3.90
Road category	
Urban arterial	0.20
Urban other	0.21
Rural strategic	0.46
Rural other	0.39

VOC changes due to bottleneck delay

Table 27 and Table 28 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.

Table 27: Additional VOC due to bottleneck delay by vehicle class (cents/minute – July 2015)

PC	LCV	MCV	HCVI	HCVII	Bus
1.82	2.56	3.06	4.41	4.41	3.25

Table 28: Additional VOC due to bottleneck delay by road category (cents/minute – July 2015)

Rural other	Rural strategic	Urban arterial	Urban other
2.10	2.15	2.00	1.99

VOC changes due to speed change cycles

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.

Table A96 through to Table A115 in Appendix 4: Vehicle operating cost tables 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.

Changes in public transport fares

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. The purpose of this section is to monetise the net public transport (PT) user benefits and disbenefits of a PT proposal where there is a change in the user charge. For the purpose of this analysis, PT users are people being moved.

Table 29: Valuation of public transport (PT) user benefits/disbenefits due to a price change

Proposal	Users	Net benefits calculations description	Net benefit calculation equation and data sources
For new PT services	Those who have transferred from other modes	It is 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.	*Net user benefits* = $(P_{max} - P_{new}) \times Q_{new} \times ½$ *Where:* P_{new} *is the proposed user charge* P_{max} *is the maximum user charge* Q_{new} *is the projected number of new service users* (see Chapter 2)
	Those who are completely new users (generated trips)		
For change to existing PT services		The calculation of PT user benefits for a price change on an existing service is based on the difference between the existing average user charge and the	$Bp_{total} = Bp_{existing} + Bp_{new}$

Proposal	Users	Net benefits calculations description	Net benefit calculation equation and data sources
		proposed average user charge.	
	Existing users	Existing users receive the full benefit of the improvement.	$Bp_{existing} = (P_1 – P_{new}) \times Q_1$
	New users (including both transferred users and generated trips)	New users are considered to receive on average one half of the existing user's benefit based on the rule of half.	$Bp_{new} = (P_1 - P_{new}) \times (Q_2 - Q_1) \times ½$ (rule of half) Where: P_{new} is the proposed user charge P_1 is the existing average user charge Q_1 is the existing number of passengers (patronage) Q_2 is the projected total number of service users (see Chapter 2)

Changes in walking and cycling user costs

Cycle operating costs and walking costs are assumed to be included in the perceived costs of changing to and using these modes.

The term perceived and behavioural costs are referring to the costs that road users perceive and therefore base their mode choice decision on (Australian Transport Council 2006). 'Transport users may ignore some costs when making decisions. Car drivers may see fuel and other vehicle operating costs as a fixed cost they pay periodically, rather than a variable cost that changes with distance and speed. "Perceived cost" is derived by deducting from generalised cost the costs that users are assumed not to perceive.' (Australian Transport Assessment and Planning 2018b)

The difference between perceived and resource costs is most readily apparent for the value of travel time savings as presented in Table 13 and Table 14. For the purposes of calculating a BCR, resource costs are represented by an equity value of time, differentiated only by trip purpose, which applies to all modes (Table 14). However, the perceived value of time used for modelling differs by the type of transport user as well as trip purpose (Table 13), which allows for variation in mode choice as generalised costs change.

3.7 Impact on system reliability

Reliability relates to the uncertainty in the time taken to travel from the start to the end of a person's journey.

This section outlines how likely variations in journey time can be assessed and the benefits from improvements to trip time reliability incorporated into project analyses. 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. It contains methods for valuing the impact of public transport and road projects on journey time reliability for users.

Public transport's journey reliability

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. Therefore, an improvement in reliability generates a benefit to users in time savings and may also create demand for the service.

The number of passengers affected for the calculation of departure impacts is the number of passengers boarding, and the number of passengers affected when calculating in-vehicle travel impacts is the number of passengers already on the service. Generally, just the number of passengers boarding can be used.

Table 30 below contains the minute-late ratios for each minute the service is late.

Table 30: 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

The total reliability benefit cannot exceed any travel time saving.
Services running more than 10 minutes late should be treated as 10 minutes late.

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 = $EL \times (VTT(\$/h)/60) \times AML \times NPT$

where: EL is the equivalent time to a minute late ratio from Table 30
VTT is the vehicle travel time ($/h) from Table 15
AML is the reduction in average minutes late (minutes)
NPT is the number of passengers affected.

Road journey reliability

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 who make a particular journey at the same time every day find 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.

The following steps in the process for evaluating reliability benefits are discussed in detail in section 4.3 Evaluation of road renewal and improvement activities:

1. **Calculate the 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.

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8. **Calculate the impact of changes in trip reliability** using following formula:

   0.9 × travel time value ($/h) (Table 14, Table 15 or Table 16)

   × *(reduction in the network variability (in min)/60)*

   × *traffic volume for time period (veh/h)*

   × *correction factor* (Table 74)

   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.

3.8 Impact on user experience of the transport system

This benefit refers to the changes in user experience as the result of new or improved transport infrastructure and/or services. This benefit is additional to 'Impact on network productivity and utilisation' (ie changes to travel time and cost).

Table 31 summarises benefit indicators and their value proxies for impact of changes in user experience related to each mode.

Table 31: Summary of user experience benefits

User type	Intervention	Indicator	Value proxy
Road users	Passing lane	Driver frustration[2]	Driver frustration benefits are derived from the 'time spent following' information with a willingness-to-pay value for the provision of passing lanes of 3.5 cents per vehicle per kilometre of constructed passing lane
	Sealing an unsealed road	Comfort and productivity gain	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.
Public transport users	Infrastructure and vehicle features	In-vehicle time in relation to infrastructure and bus and train attributes	In-vehicle time value based on stated preference study
	Demand change	Probability of being left and proportion of standing passengers	Vehicle occupant time value
Pedestrians and cyclists	Cycle facilities quality improvement	Four types of cycling facility's quality improvements	Relative value for different type of cycling facilities
	Footpath and walking environment quality improvement (interim methodology)	Improvement of different aspects of the pedestrian realm	Additional time someone would be willing to spend walking to obtain the improvement (min)

[2] The procedures in Appendix 5: Passing lanes 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 5: Passing lanes, 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, then no allowance can be included for driver frustration.

Driver frustration related to passing lanes

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 (see definition in Appendix 5: Passing lanes) 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 that should be applied to the willingness-to-pay factor should be determined by multiplying the traffic volume by the road length and the change in time spent following.

The following 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

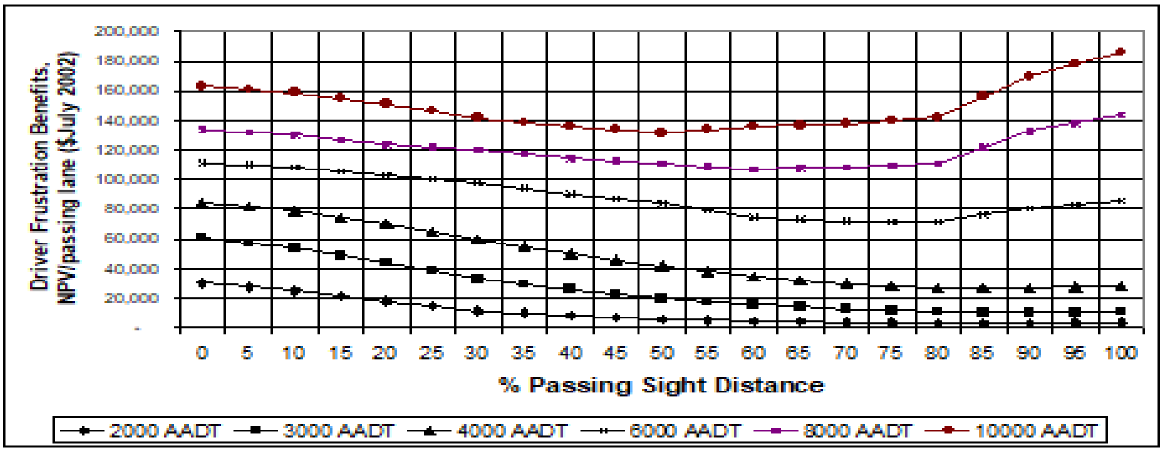
- terrain/alignment
- grades
- available passing lanes (sight distance)
- passing lane lengths and frequency

Calculate the driver frustration savings, using graphs in

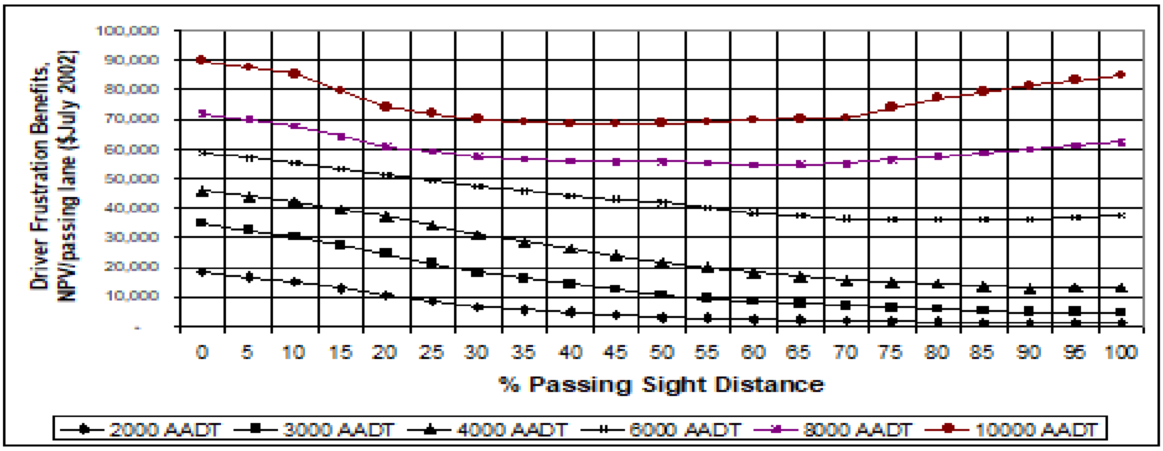
Figure 6. If necessary, multiply by the traffic growth correction factor in Table A128 and the driver frustration update factor from the most recent update factors, available on the NZTA website.

Figure 6: Graphs of driver frustration benefits for all terrain

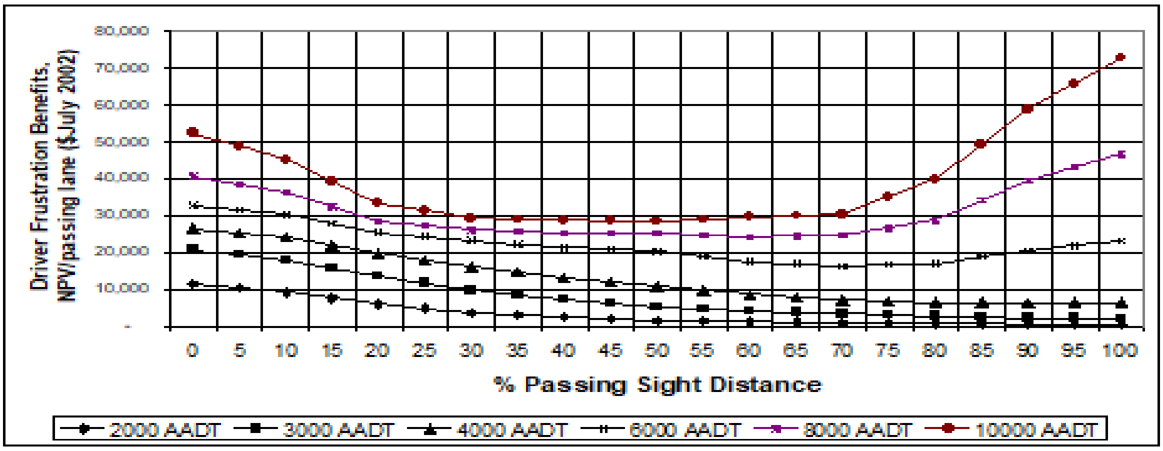
5km spacing – 2% traffic growth



10km spacing – 2% traffic growth



20km spacing – 2% traffic growth



Road users comfort due to sealing unsealed roads

Road user comfort benefits and productivity gains from sealing an unsealed road should also be taken into account. Simplified procedure *SP4 – seal extensions* 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.

Public transport user experience

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 value derived from a stated preference (SP) survey or on values derived for similar service improvements in other areas.

Public transport infrastructure and vehicle features

Public transport users value infrastructure and vehicle features. Typical user valuations expressed in terms of in-vehicle time (IVT) are provided in Table 32, Table 33 and Table 34. These may be converted to generalised costs by multiplying by the value of time given in Table 14. All values represent the difference between the do-minimum and an improvement. These values have been drawn from stated preference surveys and are the perceived benefits of an individual feature.

Table 32: Vehicle feature values for 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 33: Vehicle feature values for public transport 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 business like 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 with lots of graffiti

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Attribute	Sub-attribute	Valuation (IVT minutes)	Comment
	Exterior	0.3	Very clean everywhere compared with some very dirty areas
	Interior	0.3	Very clean everywhere compared with some very dirty areas
Facilities	Clock	0.1	Clearly visible digital clock showing correct time compared with no clock.
	CCTV	0.7	CCTV, recorded, visible to driver, and driver panic alarm compared with no CCTV
Information	External	0.2	Large route number and destination front/side/rear, plus line diagram on side relative to small route number 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

Table 34: Infrastructure features value for public transport – 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

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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 information	0.8	Up to the minute arrival times/disruptions, plus audio compared with no countdown sign
	Clock	0.1	Digital clock telling correct time compared with no clock
	Contact number	0.1	Free-phone number shown at stop compared with no number
	Location of payphones	0.1	One payphone attached to shelter compared with no payphone
	Simple timetable	0.4	Simpler more user-friendly
Stations		Up to 3.0	Includes bright lighting, CCTV, cleaned frequently, customer service staff walking around at info desk, central electronic sign giving departure times, snack bar, cash-point, newsagent, landscaping, block paving and photo-booths

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 is increased.

Service demand disbenefit = (increased waiting time × VOT) × probability of being left behind × total number of existing users.

Where: VOT is the monetary value of vehicle occupant time from Table 14.

Different types of pedestrian and cycling facilities

Where a quality improvement (amenity, comfort or security) is proposed to existing walking and cycling facilities, or where new walking and cycling facilities are 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.

The *Pedestrian planning and design guide* 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 35. The relative benefit values should be used in an incremental analysis.

Table 35: 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

NZTA (2020b) provides interim methodology and parameter values for pedestrian facilities improvements. The interim methodology may be used but is not incorporated until New Zealand specific values are estimated.

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 New Zealand Household Travel Survey. The average pedestrian trip length is estimated at 1km.

Cycling distances

Statistics on cycling provided are based on the New Zealand Household Travel Survey. The current average cycle trip length is estimated at 3km. This applies equally to new and existing users.

Wider economic benefits (WEBs)

Wider economic benefits (WEBs) are impacts that can result from transport investment. These have been used internationally to complement transport cost–benefit analysis and can be thought of as impacts that are additional to the conventional benefits to transport users. However, care is required to ensure that the estimates for any wider economic benefits are truly additional to the conventional benefits to avoid double counting, and in some cases the conventional benefits will need reducing to avoid double counting with the wider economic benefits.

Additionally, only the most significant infrastructure improvements are likely to generate WEBs. Generally, these would need to change the distribution or density of households and firms within a major metro area, or deliver significant improvements in accessibility between regions, in order for wider impacts to arise.

WEBs can be both static and dynamic.

Static WEBs are more commonly assessed. They are influenced by changes in factors such as travel times and travel costs (due to the transport investment option) based on static (unchanged) land use. The MBCM includes guidelines for assessing these effects in sections 3.10, 3.11, 3.12 and 3.13.

Dynamic WEBs estimate additional productivity benefits from a change in location or level of jobs/workers as a result of changing land use (dynamic). Given the reliance on understanding land use changes caused by a project, they are less commonly estimated. Since static WEBs leave productivity changes associated with land use change unaccounted for, capturing dynamic WEBs in addition to the traditional static WEBs can enable a more complete estimate of wider economic benefits. For transport projects with sizeable land use change assumptions or objectives, this may be material and impact upon the viability of the project.

3.9 Dynamic WEBs and land use benefits and costs

Where transport policies affect land use, this will lead to changes in people's choice of destinations, modes and routes. Allowing for dynamic land use change provides more accurate estimates of conventional transport user benefits, which comprise the bulk of benefits for most transport policies. Changes in conventional transport user outcomes are also the main channel through which wider economic benefits arise.

Part of the challenge in quantifying the benefits of land use changes is disentangling the degree to which private investment is truly additional. It may be that private investment in developing land would have occurred anyway, though the timing may be accelerated, or the location of private investment may have changed in response to the transport investment. While the magnitude of these impacts will vary, they are nonetheless likely to result in additional benefits, specifically:

- The traditional benefits of increased network capacity are larger than they otherwise would have been once the project is delivered.
- Land use and transport changes (eg higher-use redevelopment, alleviated congestion) may be realised earlier in the project lifecycle, increasing the present value of benefits.
- Agglomeration economies may form around new transport nodes, leading businesses and residents to cluster in those areas. Where people have moved from areas of lower effective density or less favourable industrial mix, the net agglomeration productivity impact arising from this dynamic 'sorting' will be positive.
- Land use outcomes may be better and more coordinated, driving higher productivity and more efficient land use.

In general, relaxing the fixed land use assumption and explicitly modelling land use change presents an opportunity to gain a more complete picture of the effects of a transport project.

Productivity gains from land use

The productivity gains from transport investments arise through several mechanisms that affect urban processes, with land use changes affecting scale, density and sector mix for business activity, as well as residential patterns. Effects include, but are not limited to, agglomeration benefits (such as industry specialisation effects). Broadly, transport investment can impact through two types of clustering:

- **Static clustering**: Transport investment alters the effective density by allowing individuals and firms to move around the location more easily, lowering transaction costs, thereby facilitating interactions. This does not change land-use patterns.
- **Dynamic clustering**: Transport investment can lead to land use change, affecting the scale, sector mix and the density of a location by inducing a change in the level and/or location of economic activity (land use change), thereby facilitating new/different interactions. Changes in the level and location of economic activity are related to labour supply and demand interactions. At the higher level, land use outcomes affect urban form and therefore affect efficiencies across urban spatial economies. This can impact effective density because interaction with other locations is improved, so that efficiency is improved and/or transaction costs lowered.

Land use change estimation

Different models and approaches have varying strengths and limitations, and there is no single best approach or model for measuring land use impacts. In practice, the adequate selection of the approach to measuring and quantifying land use impacts will depend on a number of factors, including the type of infrastructure project, the purpose behind the project, policy scenarios that need to be tested, data requirements and availability, and modelling efforts. A greater level of sophistication is to be expected in larger projects and/or those with economic appraisals that rely heavily on land use impacts. It is also dependent on where the project is in the business case lifecycle, ie high-level estimations may be appropriate for a strategic case or programme business case, while more detailed analysis would be expected in a detailed or single-stage business case. It is not expected that all projects will generate land use changes, and even projects that do may not be expected to deliver significant dynamic benefits/costs.

Therefore, all transport projects should undertake an initial qualitative analysis to estimate the scale of the land use change (and therefore the benefits associated with it) at an early stage of a project to understand whether it warrants a further investigation. If the project warrants further investigation on its potential for inducing land use change, the following quantitative analysis approaches are recommended:

- **Land capacity analysis:** This supply-side approach estimates land use changes by focusing on the ability of land in a particular location to support densification – taking into account local and district level opportunities and constraints. Geographic information system (GIS) tools are used to support this analysis.
- **Land use and transport interaction model (LUTI) or land use attractiveness model:** It is broadly accepted that these methods are able to establish the most confidence as they are typically based on historical land use relationships. The advantage of these types of statistical models is that challenges around reverse causality may be addressed.
- **Detailed corridor capacity analysis:** This approach combines supply-side and demand-side analysis and uses real-time measures to inform congestion and capacity as well as land use constraints and potential in a corridor, from a bottom-up approach. This approach provides quality results for a smaller area, ie corridor for a project, compared to the modelling approaches.

Estimating land use benefits

There are a number of qualitative and quantitative approaches that can be undertaken for estimating land use benefits and its various categories, including land value changes, public infrastructure cost changes, second round transport externalities, second round user benefits and costs, and public health cost changes. Generally, it is recommended these benefits are quantified where there is sufficient information and parameters. Tailored parameters (including elasticities) for New Zealand will be used, where available. A qualitative approach may be undertaken if the project faces time or cost constraints or the scale of the project dictates.

Types of dynamic WEBs

The primary dynamic WEBs that NZTA will consider for inclusion in an economic analysis are:

- **Dynamic agglomeration**: if the relocation of workers or firms results in an increase in net density, existing firms and workers will become more productive. These productivity gains (agglomeration benefits) are net additional to the cost–benefit appraisal. It is recommended that a full calculation of dynamic agglomeration is performed as this will capture both static and dynamic effects. Parameters for this benefit calculation already exist in the MBCM and should be utilised.
- **Move to more productive jobs (M2MPJ)**: by improving accessibility for commuters, an infrastructure project may induce workers to change their location of work. If the project induces the worker to take up a more productive job, there is an additional benefit to society. This benefit is the average tax take on the marginal increase in wages that the worker earns. It is recommended that a full calculation of M2MPJ is performed. Where parameters for this benefit already exist in New Zealand they should be utilised. Where these parameters have either yet to be established, or only exist at a different spatial level, proxy parameters may be utilised. In some cases, it may not be appropriate to assume that transport investment would cause land use change. Therefore, it is appropriate to outline the cause of dynamic land use which makes a dynamic assumption realistic when assessing project appraisal. Provided that specific guidelines are followed, there would not be a risk of any double counting of benefits or costs between static and dynamic WEBs, nor between either and conventional user benefits.

Estimating dynamic WEBS

NZTA has released a technical paper, *Transformative transport projects (dynamic WEBS and land use benefits and costs)* (NZTA 2020c), which documents emerging guidance on dynamic WEBs. This guidance will be updated as new research or methodologies become available.

3.10 Wider economic benefit (productivity)

It is widely recognised that economic density – the clustering of activity in towns and cities – has a positive impact on productivity, and that such clustering is dependent on effective transport systems. Some of the productivity effects, commonly known as agglomeration, come from interactions between different economic agents that are not fully internalised, creating market failure and wider economic benefits, as recognised in this manual.

'Agglomeration effects are characterised as the productive impact of employment in surrounding areas on a firm's production technology. Agglomeration is acknowledged to have three underlying sources, sharing, matching, and knowledge spillovers.' (Duranton and Puga 2003).

> 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.

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 sub-regional 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 that only 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 36: Data requirements

Data	Variable	Disaggregation	Source
Demand	D	Origin–destination pair, do-minimum, option, mode, purpose, year	Transport model
Generalised cost	GC	Origin–destination 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 37
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 37.

Table 37: 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	0.035
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

ANZSIC 2006	Industry	Agglomeration elasticity (ε)
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	0.087
N	Administrative and support services	0.087
O	Public administration and safety	0.087
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

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.

$$\varepsilon_i = \frac{\sum_S \left(\varepsilon_i^S \times E_i^S\right)}{\sum_S E_i^S}$$

where:
ε = agglomeration elasticity
E = employment

This operation requires data on base year workplace-based employment by study zone 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 origin–destination 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, which produces 24 origin–destination matrices. When gathering and preparing the transport data, there are a number of things to bear in mind:

- **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.
- **Separately identified user groups**: if the demand and cost data is not available separately for the required journey purposes and/or user segments, they will need to be estimated. This is feasible by adjusting the time-cost element of generalised cost for differences in values of time between user groups.
- **Complete cost matrices**: for the analysis the cost matrices need to contain cost information for all origin–destination movements where there is travel demand. This is to avoid weight being given to origin–destination 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 GIS or journey planning tools
- assumptions on average time/cost per kilometre
- 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 origin–destination pair, the relevant generalised cost for the do-minimum or options:

$$AGC_{ij}^{S} = \frac{\sum_{m,p} D_{i,j}^{*,m,p} GC_{i,j}^{S,m,p}}{\sum_{m,p} D_{i,j}^{*,m,p}}$$

where:

AGC is the average generalised cost

D is the demand

GC is the generalised cost

S is the do-minimum or option

m is the mode

p is purpose

I is origin

J is destination

Note: 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 is effective density
E is 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 is relative increase in productivity
OPT is option
DM is do-minimum
ε is agglomeration elasticity
i is 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:

dPRi is absolute increase in productivity in dollars
GDPi is 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

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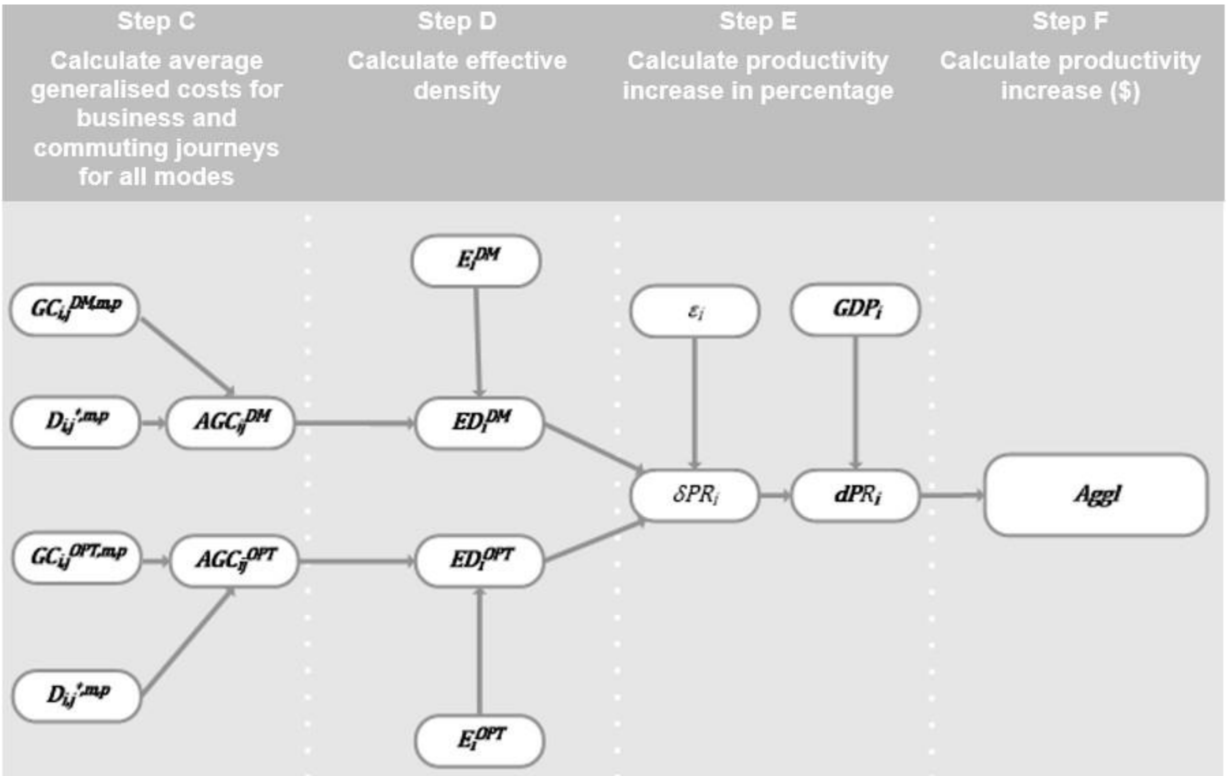
for all variables in the two equations, except for the effective densities, since these are always calculated based on total employment by sector).

Step F: Sum output increases across all zones in the study area

The final step in estimating the impact of the intervention on productivity is to sum the agglomeration gains across the study zones:

Figure 7: Step by step guidance for agglomeration benefits



$$Aggl = \sum_i dPR_i$$

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. While 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 analysis 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 economic 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.

3.11 Wider economic benefit (employment impacts)

Job creation is often held up as a major impact of transport investment, with two distinct mechanisms being suggested:

- **impact on the supply side**: better transport may make it easier for people to get to work, and may replace discouraged worker effects
- **impact on the demand side**: induced investment creating new employment opportunities when there is unemployment, ie displacement is not 100%.

The methodologies for estimating each of the employment impacts are discussed in this section.

Labour supply: participation and tax wedges

Individuals' labour force participation decisions are based on comparing the costs of working (including commuting costs), against the wages earned from a job. By reducing the cost (in time and money) of getting to work, a transport investment is likely to increase the returns to working; some people, for whom the net returns to entering the labour market were initially not worthwhile, may decide to enter. Such an increase in labour supply and employment raises gross value added (GVA) but, in the simplest circumstances, does not increase welfare. Initially, the individual was not working because the utility from leisure exceeded that from working, net of commuting costs. If a transport improvement triggers work, the benefit to the individual cannot be greater than the user-benefit received (if it were, the individual would have chosen to work in the first place). However, this conclusion changes if there is an income tax wedge (or loss of state benefits). The individual does not receive the full value of work undertaken because a fraction of it accrues to government. The full gain from entering employment is then the user-benefit plus tax revenue paid (or benefits not received).

The impact of the transport investments on labour supply should be estimated using the following steps.

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.

$$G_{ij}^{OPT,c,f} = \frac{\sum_m \left(g_{ij}^{OPT,m,c,f} + g_{ji}^{OPT,m,c,f}\right) \times T_{ij}^{DM,m,c,f}}{\sum_m T_{ij}^{DM,m,c,f}}$$

where:

$G_{ij}^{OPT,c,f}$ is the average generalised cost across mode (m), commuting purpose (c), forecast year (f), and option (OPT), between origin zone (i) and destination zone (j)

$g_{ij}^{OPT,c,f}$ is generalised cost for mode (m), purpose (p), forecast year (f), and option (OPT), between origin zone (i) and destination zone (j)

$T_{ij}^{DM,m,c,f}$ is the total number of annual home to work trips for mode (m), commuting purpose (c), forecast year (f), between home zone (i) and work zone (j) in the do minimum scenario. (Also known as the 'home to work' matrix in do-minimum (DM)

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.

$$dG_i^f = \sum_j W_{ij}^{OPT,f}\left(G_{ij}^{OPT,c,f} - G_{ij}^{DM,c,f}\right)$$

where:
dG_i^f is total annual commuting cost savings for workers living in zone (i) and forecast year (f)
$W_{ij}^{OPT,f}$ is the number of workers commuting from zone i to zone j in option (OPT) and forecast year (f)
$G_{ij}^{OPT,c,f}$ is the average generalised cost across commuting purpose (c), forecast year (f), and option (OPT), between origin zone (i) and destination zone (j)
$G_{ij}^{DM,c,f}$ is the average generalised cost across commuting purpose (c), forecast year (f), and do-minimum (DM), between home zone (i) and work zone (j)

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.

$$dE_i = \varepsilon^{ls}\frac{1}{y_i(1-\tau_l)}dG_i^f$$

where:

dE_i is total labour supply in zone (i)

ε^{ls} is the elasticity of labour supply with respect to effective (real) wages

y_i is gross mean residence based earnings in zone (i)

τ_l is factor to convert gross to net earnings

dG_i^f is total annual commuting cost savings for workers living in zone (i) and forecast year (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.

$$Labour\ supply\ impact = \sum_i dE_i \eta m_i$$

where:

dE_i is total labour supply in zone (i)

η is the productivity of marginal labour market entrants relative to the average

m_i is gross mean residence based GSP per worker in zone (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.

$$Wider\ economic\ impact\ from\ increased\ labour\ supply = Labour\ supply\ impact \times \tau^{ls}$$

where: τ^{ls} is tax take on increased labour supply

This can add up to an additional 10% of wider economic benefits over conventional benefits.

Labour demand and unemployment

In demand side, if new jobs are created in one place, then the value of output produced by each new job is the wage, and this is set against the value of what workers would have done, absent the new jobs.

For workers drawn out of involuntary unemployment the alternative is of low value, so the net benefit is large. This may be an important effect in developing economies, in regions with significant structural unemployment (or underemployment) or in special economic conditions, such as after a pandemic.

However, for long-run transport projects in reasonably well-functioning market economies it seems likely that the labour market will adjust to some 'natural rate' of unemployment which is independent of transport investment. If this is the case then an increase in labour demand is met either by increased labour force participation or by drawing workers out of other employment. If demand is met by increased labour force participation then its value is, as above, the tax wedge on income. If it is met by withdrawing labour from other activities, then the value is the alternative wage. There is no net benefit if wages are the same in both jobs. Displacement is 100%, so demand induced employment effects should, from the national perspective, be ignored.

A qualification to this argument is conceptually important, although perhaps not quantitatively large for any single transport project. To draw labour from other activities there may have been an increase in wage rates in the area affected or more broadly. Given the level of productivity, an increase in wages must be financed either by a reduction in profits (or more generally, payments to other inputs), or by an increase in prices. The increase in wages is therefore just a transfer, of no value to aggregate income, unless the people paying for it (consumers and recipients of profits) are, for some reason, people that we do not value. A standard approach would be to suggest that benefit arises to the extent that the increase in price is paid by foreigners, ie represents a terms of trade improvement, so the country is able to sell its exports at higher price. This is an additional source of benefit, although one that is unlikely to be quantitatively significant for any single transport project (Venables 2016).

Labour demand is more likely to impact through the national labour market and, as suggested above, is likely to displace workers from other jobs.

3.12 Wider economic benefit (output change in imperfectly competitive markets)

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, markets that operate in imperfect competition have price-cost margins, which 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. This means, when there is a decrease in the transport costs faced by a business in imperfect competition, that business will increase their output, which will increase the market quantity, reduce the market price, and, effectively, reduce the degree of market distortion owing to the lack of perfect competition.

Parameters to use for the analysis of imperfect competition

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, this gives an estimated wider economic benefit from output change under imperfect competition of 10.7% of business user benefits (refer NZTA research report 448, the link is: https://www.nzta.govt.nz/resources/research/reports/448/).

Table 38: Imperfect competition parameters

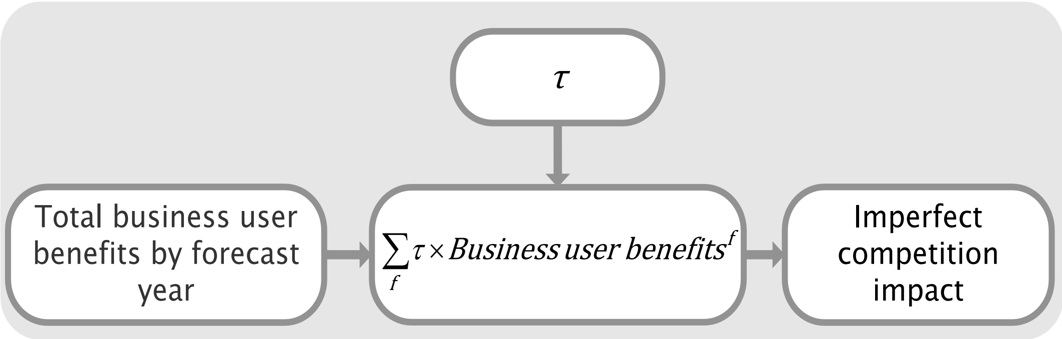
Parameter	Description	Value
τ	Output change under imperfect competition resulting in uplift to business user benefits	0.107

$$Imperfect\ competition\ impact = \sum_{f} \tau \times Business\ user\ benefits^{f}$$

where: *Business user benefits* is total conventional business user benefits from travel time and vehicle operating cost savings

f is forecast year
τ is imperfect competition uplift factor.

Figure 8: Estimating output changes under imperfect competition



This can typically add up to an additional 5% of wider economic benefits over conventional benefits.

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3.13 Composite value for abatement of marginal congestion costs

In the presence of traffic congestion, ie where the road corridor has at least one point that operates at greater than 80% capacity during the peak period, 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 impact. 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.

A composite benefit is defined for valuation of benefits related to changes to road traffic that usually include impact on network productivity and utilisation (travel time cost and vehicle operating cost), and impact on social cost of deaths and serious injuries.

Impact on greenhouse gas emissions, which was included as part of the composite values in the previous version of the MBCM, is no longer included in the values as it needs to be calculated using the new procedure (see section 3.4) and reported separately in the AST.

Road traffic reduction benefits critical to the outcome of the analysis 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 analysis 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.

Extra caution for double counting is required when the composite value for abatement of marginal congestion costs is used to calculate activities benefits.

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.

For a new walking or cycling facility, in addition to the walking and cycling benefits a composite benefit for the abatement of marginal congestion costs of $0.22 ($2021) per km of trip length may be applied for each new pedestrian or cyclist using the new facility.

The composite values in Table 39 are used in the simplified procedures, SP8 Freight services, and SP9 New public transport services.

Table 39: Diversion rates and composite benefit values ($2021) for abatement of marginal congestion costs for major urban corridors (refer also to simplified procedure SP9 worksheet SP9.5)

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 – $2021)
Auckland	0.725 (72.5%)	$2.99
Wellington	0.777 (77.7%)	$1.83
Christchurch/other	0.675 (67.5%)	$0.40

The composite values in Table 40 are used in simplified procedure SP10 Existing 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.

Table 40: Composite benefit values ($2021) for abatement of marginal congestion costs for major urban corridors by PT modes ($/additional passenger boarding) (refer also to simplified procedure SP10 worksheet SP10.4)

Urban area	Mode	Average trip length (km)	Road traffic reduction benefits ($/additional passenger boarding – $2021)	
			Peak	Off peak
Auckland	All	7.70	19.77	1.88
	Rail	16.50	27.50	3.42
	Bus	6.60	18.27	1.69
Wellington	All	12.14	20.40	2.57
	Rail	22.76	27.23	3.65
	Bus	6.97	18.73	2.05
Christchurch	All	8.05	4.24	3.20
Other	All	7.86	2.63	2.32

Where the trip length for a public transport activity is significantly different to the average trip length indicated in Table 40, calculate the traffic reduction benefits using the diversion rates and road traffic reduction benefits ($/vehicle/km per year) from Table 39.

3.14 Transport resilience impacts

Transport resilience impacts broadly fall into three categories:

- changing the vulnerability of the transport system (that is, increasing the ability of the transport system to physically withstand disruptive events would confer resilience benefits)
- changing the duration of any such disruption (that is, reducing the time and/or cost to repair/reinstate the transport system would confer resilience benefits), and/or
- changing the level of redundancy in the transport system (that is, decreasing the quantity and/or quality of alternative transport routes/modes would confer resilience disbenefits).

Transport resilience refers to the transport system's ability to accommodate extreme disruptive events. Disruptive events cause significant and/or sustained impediment to the normal use of the transport system, and include, but are not limited to, the examples in Table 41.

Table 41: Examples of potential disruptive events

Natural disruptive events	Human-made disruptive events
Earthquakes	Infrastructure maintenance/improvements
Volcanic eruptions	Vehicular accidents
Landslides	Industrial accidents
Flooding	Malicious activity[3]
Wildfires	
Rising sea levels	

Risk of a disruptive event

The risk of a disruptive event is determined by the likelihood of the event occurring and the expected consequences of that event. The likelihood factor needs to consider both the chance/frequency of an event and the expected duration of outage, while the consequence factor should consider both the criticality of the route and the availability of detours. For more information on the likelihood and consequence parameters see the risk analysis procedures in section 7.5 and the risk assessment methodology report prepared as part of NZTA's National Resilience Programme Business Case.

For economic appraisal, the key variables related to the risk of a disruptive event are:

a) *the Annual Recurrence Interval (ARI)*

ARI, or "return period", is the average or expected period between events that exceed a given magnitude (that is, that would cause disruption). ARI is often expressed in years, for example an ARI of 50 means a disruptive event is expected once every 50 years.

b) *the Annual Exceedance Probability (AEP)*

AEP is the probability that a disruptive event occurs in a given year, and is approximately equal to the inverse of the ARI, for example an ARI of 50 would mean an AEP of 2% (1÷50).

c) *the Average Annual Time of Closure (AATOC)*

AATOC is the amount of time a transport route/mode is expected to be closed (that is, disrupted) on average in a given year, for example if the AEP is 5% and the expected duration of closure is 7 days, then the AATOC will equal 0.35 days or 8.4 hours (7 days x 5%).

[3] For example, protests, terrorism, property damage, cyberattacks, anti-social behaviour, etc.

Multiple disruptive events

Depending on the specific location and nature of the transport infrastructure being assessed, a separate AATOC should be calculated for each applicable disruptive event. For mutually exclusive/independent events which cannot happen at the same time, the AATOC of each event can be simply summed together to generate the total AATOC. However, for disruptive events which can occur at the same time, the probability of two or more events occurring simultaneously must be accounted for.

For example, suppose a given segment of the transport network is only susceptible to two types of disruptive events, event A with an AATOC of 5 days and event B with an AATOC of 7 days. If events A and B are independent, the total AATOC will equal 12 days (5 days + 7 days). However, if the events can occur simultaneously, the total AATOC will instead equal 11.9 days (5 days + 7 days – 0.1 days,[4] the latter being the probability of both events occurring simultaneously).

Data for disruptive event probability

For human-made disruptive events, historic frequency of occurrence provides a reasonable starting point for analysis, assuming that any trends and/or population/traffic growth is also accounted for. However, due to climate change and the increasing frequency and severity of some types of natural disasters, ARI based on historic events may underestimate the future ARI for some natural disruptive events. Historic natural disaster ARIs should, therefore, only be used to inform the ‘best-case’ or lower-bounds of future disruptive event probability.

Potentially useful sources of data to assist in the estimation of disruptive event probability can be obtained from several sources, including but not limited to NZTA’s National Resilience Programme Business Case (2020), press reports from NZTA’s Traffic Road Event Information System (TREIS), the National Institute of Water and Atmospheric Research (NIWA), and Geological and Nuclear Sciences Limited (GNS). Depending on the region being assessed, there may also be useful regional and local sources of relevant data. Whatever data are used should be robust and referenced clearly.

Transport resilience benefits and disbenefits

There are two primary benefits or disbenefits resulting from altered transport resilience, namely:

- decreased (benefit) or increased (disbenefit) reinstatement/repair costs, and
- decreased (benefit) or increased (disbenefit) user disruption costs.

Reinstatement/repair costs

Activities that reduce the vulnerability of transport infrastructure may reduce the respective reinstatement/repair costs that would otherwise be necessary in the occurrence of a severe disruptive event. The average annual reinstatement/repair cost (ARP) is equal to the AEP multiplied by the expected cost to reinstate/repair the infrastructure. Therefore, the change in reinstatement/repair costs can be calculated by subtracting the ARP of the intervention (ARP_i) from the ARP of the counterfactual (ARP_c) as per the following formula:

$$\text{Change in reinstatement/repair costs} = \sum_{y=1}^{n} \text{ARP}_{\text{c,y}} - \text{ARP}_{\text{i,y}}$$

Where *n* is the number of years in the period of analysis.

The change in repair costs will not necessarily always be a positive impact (that is, a reduction in repair costs). While activities which reduce transport infrastructure vulnerability will reduce the AEP,[5] the improved/new infrastructure may also carry with it an increased expected cost of reinstatement/repair per event compared to the counterfactual. It is therefore necessary to calculate the change in repair costs before one can conclude whether it will have a positive or negative impact.

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[4] 365 x (5/365 x 7/365). Note, this simplified estimation of the probability of events occurring at the same time does not account for the possibility of only partial simultaneity. However, full conditional probability estimation is unnecessary as the level of mathematical precision it would provide is immaterial relative to the inherent uncertainty of any AEP.

[5] By increasing the event magnitude necessary to trigger disruption.

For further information and guidance on estimating reduced reinstatement/repair costs, see the risk analysis procedures in section 7.5.

User disruption costs

When encountering an extreme disruptive event, transport users may:

- postpone their trip(s) while they wait for the disruption to be resolved
- divert their trip(s) via an alternative route or mode, and/or
- cancel their trip(s) outright.

Therefore, the main user benefits of enhanced transport resilience are the avoided costs of disruption, specifically:

a) waiting cost savings – user costs of the delay or postponement of a trip
b) diversion cost savings – user costs of diverting via alternative routes or modes, and
c) cancellation cost savings – user costs of not being able to perform a trip.

Estimating behavioural response to disruption

Estimating the proportion of transport users that wait, divert, or cancel their trip(s) in response to a disruptive event is a crucial step in estimating the benefits of enhanced resilience. Behaviour will be influenced by many factors, including but not limited to the:

- trip origin/destination
- purpose of each trip
- quality and quantity of alternative routes and/or transport modes
- time of day/week
- degree of forewarning
- certainty of expected disruption duration.

Depending on the scope and nature of the proposal being analysed, it may be impractical to model all these behavioural factors, and analysts may instead focus on the relative user costs to help estimate the proportion of transport users who will wait, divert or cancel their trip(s).

User costs of waiting

Transport users can be expected to wait for disruption to be resolved, rather than divert or cancel their trip(s), when their expected cost of waiting is less than either their cost of diverting or their cost of cancelling. The expected cost of waiting for a given transport user is equal to their behavioural value of travel time (see Table 13) multiplied by the duration of their disruption.

User costs of diverting

Transport users can be expected to divert their trip(s) via an alternative route or transport mode, rather than wait for the disruption to be resolved or cancel their trip(s), when their cost of diverting is less than either their expected cost of waiting or their cost of cancelling. The cost of diverting for a given transport user is equal to the increase in their generalised cost (for example travel time for a cyclist, travel time and vehicle operating costs for a private vehicle user, and travel time and fare cost for a public transport user, etc) of travel for the best alternative route/mode. The *best* alternative route/mode will depend heavily on the location of the trip origin/destination.

User costs of cancelling

Transport users can be expected to cancel their trip(s), rather than wait for the disruption to be resolved or divert their trip(s), when their cost of cancelling is less than either their cost of diverting or waiting. The cost of cancelling a trip is difficult to estimate as in reality it would depend on the utility a transport user receives from said trip, which itself would depend on the nature and purpose of the trip (for example commuting, tourism, etc). At a minimum, the cost of cancelling a trip for a given transport user must be at least equal to the generalised cost of their normal (pre-disruption) trip; this simply recognises the fact that trips would not take place were the utility they provide not greater than the cost of making them.

However, some trips will not be cancelled even if doing so would be the lowest-cost option. This would be especially true for initial trips in the immediate aftermath of a disruptive event, where many transport

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users may find themselves located away from their home. In contrast, some trips which are valuable enough to warrant waiting or diverting may nevertheless be cancelled if they are very time-sensitive, and thus incapable of being delayed.

Historical evidence of waiting, diverting, and cancelling trips

Given the aforementioned challenges of estimating the proportion of transport users who wait, divert or cancel their trips, historical evidence based on previous closures, where available, may provide assistance. Any use of historical examples should be based on the most similar transport systems and the most similar disruptive events possible. For reference, behavioural evidence from two historic disruptive events is provided in Table 42 and Table 43. Both tables were developed based on surveys conducted after their respective disruptive events.

Table 42: Changes in travel behaviour following a severe storm in Wellington (2013) [6]

Date	Earlier departure time	No change in departure time	Late departure time	Trip cancelled
Friday 21 June	28%	17%	10%	45%
Monday 24 June	54%	28%	7%	11%
Wednesday 26 June	47%	29%	7%	17%

Table 43: Changes in travel behaviour following weather disruption in the UK (2013)[7]

Activity	Delayed start	Delayed finish	Postponed	Cancelled	New destination	Conducted at home	Other
Commute	49%	32%	8%	41%	2%	12%	5%
Business travel	21%	17%	41%	41%	2%	5%	4%
Return home	26%	46%	16%	16%	4%	0%	5%
Health	7%	7%	48%	37%	0%	0%	7%
School or childcare	14%	5%	10%	80%	0%	3%	2%
Other care	22%	23%	34%	25%	1%	8%	9%
Shopping	16%	8%	46%	34%	5%	5%	2%
Sport	3%	1%	24%	75%	1%	0%	0%
Leisure	5%	3%	28%	59%	2%	1%	7%
Family or Friends	9%	4%	46%	45%	2%	2%	1%
Other	12%	8%	15%	24%	1%	1%	11%

Estimating avoided user disruption costs

Three parameters are needed in order to estimate avoided user disruption costs, these are:

- the average annual time of closure (AATOC) in days
- the average annual daily traffic (AADT), and

[6] Ministry of Transport. (2013). The transport impacts of the 20 June 2013 storm: The effects of closing the Hutt Valley rail line between Petone and Wellington for multiple days.
[7] Laird, J., Marsden, G., & Shires, J. (2014). Evaluating transport and land use policies under disruption. Universities' Transport Study Group (UTSG) 46th Annual Conference, 6–8 January 2014.

- the proportion of transport users who wait (PW), divert (PD), and cancel (PC) their trips.

Avoided user disruption costs can be estimated by subtracting the sum of annual waiting costs (AWC), annual diversion costs (ADC), and annual cancellation costs (ACC) for the intervention (i) from the sum of AWC, ADC, and ACC of the counterfactual (c), as per the following formulae:

$$\text{Avoided user disruption costs} = \sum_{y=1}^{n} (\text{AWC} + \text{ADC} + \text{ACC})_{c,y} - (\text{AWC} + \text{ADC} + \text{ACC})_{i,y}$$

$$\text{AWC} = \text{AATOC x AADT x PW x VoT}_{o}$$

$$\text{ADC} = \text{AATOC x AADT x PD x } (\text{AGC}_{d} - \text{AGC}_{p})$$

$$\text{ACC} = \text{AATOC x AADT x PC x AGC}_{p}$$

Where *n* is the number of years in the period of analysis

VoT_o is the other non-work value of travel time from Table 14

AGC_d is the average generalised cost of a diverted trip

AGC_p is the average generalised cost of a pre-disruption trip

As the preceding formulae show, user disruption costs can potentially be reduced by any proposal that reduces AATOC, alters the PW/PD/PC composition, or reduces the average generalised cost of a diverted trip (for example, by reducing the travel time of a diverted trip).

A note on transport resilience uncertainty

There is significant uncertainty in the analysis of transport resilience in terms of the likelihood and severity of disruptive events, the behavioural response to disruptive events, and the degree of vulnerability and/or redundancy that can be enhanced by proposed activities. While the guidance in this section seeks to assist and standardise the consideration of transport resilience within business cases, analysts may still need to rely on a number of subjective and/or arbitrary assumptions to complete their analysis. As such, it is highly recommended that expert judgement is sought early and often (from geotechnical engineers, for example).

Examples

Transport resilience activities can vary widely, depending on the objective(s) of the proposal and type(s) of disruptive events that are being accommodated. The preceding methodology can be applied to any proposal considering the PARA (Protect, Accommodate, Retreat or Avoid) framework, but it is unlikely that any single example could cover all possible uses of the preceding methodology. Three examples are provided in Appendix 8: Worked examples which each demonstrate specific aspects of this methodology.

3.15 Other monetised impacts

The benefits framework provides a comprehensive list of transport benefits, however, not all of these are assigned a standardised value in this manual. These benefits may be monetised subject to data availability and agreement with NZTA in writing. Some common valuation methodologies and data sources are described below.

Valuation methods

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

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.

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 ask 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 include 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 would 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.

Analysts may wish to consult other sources for guidance as to the design and implementation of SP surveys to derive willingness-to-pay values. NZTA may be able to provide some assistance in this regard.

Benefit transfer is also one of the common methods used for economic analysis and specifically for environmental benefits:

Benefit transfer, also known as value transfer, is simply using results of previous studies of analogous situations (source values) to provide information about values of the case under consideration (study values). Benefit transfer can be inexpensive and rapid if suitable source studies are available. Source values can be transferred to the study project as point estimates, value functions, or as meta-analyses.

Meta-analyses, which draw information from a large number of previous studies, provide useful information on source study valuation contexts, and identify adjustments required to transfer source estimates to the study case. Meta-analysis also provides an indication of the variability of value estimates and so is recommended rather than point and value function transfers from individual sources or a small number of studies.

Great care is required to match source and study scenarios. Non-market values are highly sensitive to context and can vary because of differences in the nature of the resource, the availability and prices of substitutes and complements, underlying preferences, cultural context, environmental value orientations, socio-economic characteristics, demographics, population density, transport availability, and other matters.

Even the most careful and comprehensive benefit transfer studies can be extremely inaccurate. Hence, benefit transfer is recommended primarily as a useful aid in determining whether non-market values are likely to be significant for the project under consideration, and whether a primary valuation study is warranted.

Data and information sources

As Treasury (2015a) says: ‘The international Environmental Valuation Reference Inventory (EVRI http://www.evri.ca/) provides source study information for benefit transfer from many thousands of non-market studies undertaken worldwide, including studies from New Zealand. However, international benefit transfer adds additional complications because of currency and cultural differences.

NZTA has commissioned research to develop a database of values and valuation methods for monetisation of other potentially monetisable benefits. It will also provide guidance on how to use the database. A link to the research results and database will be provided when it is ready for publication later in late 2021.

3.16 Impacts during implementation/construction

Disbenefits considered in the economic analysis during implementation should in most cases be restricted to travel-time delays only, but this applies to all modes. It does 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 analysis. Where the impact of disruption is material, then the disbenefits of the activity/option shall be included in the analysis.

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 analysis 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 analysis of the disbenefits must be undertaken. If the adjusted BCR falls more than 10% then a detailed analysis should be undertaken.

Where disbenefits are included, they should cover the disbenefits to existing users and existing transport services (public transport operators) as well as the costs of dislocation and disruption to all modes.

Generally, these costs/disbenefits could include:

- increased travel time
- increased travel discomfort
- loss of service
- change in demand for public transport
- loss of revenue
- any significant costs to the wider community during construction.

3.17 Behavioural change composite benefits

This section provides guidance on the monetisation of changes in workplace, school and household/community-based travel plans. Analysis is based on the reduction in private car travel resulting from travel plans being initiated.

Composite benefit values have been derived for a range of travel behaviour change (TBhC) activity types and situations. The composite benefit values include benefits to the people 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 NZTA) to forecast a diversion rate and calculate a composite benefit value for any TBhC proposal.

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Table 44: 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.

Table 45: 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

Table 46: Household 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

4. Analysis procedures

4.1 Introduction to procedures

In this manual, analysis procedures have been grouped according to the type of activity to be assessed and are designed to be read as a whole.

Before undertaking an analysis, in-depth consideration must be given to the problem that is to be solved or mitigated. This initial work to define the problem and consider potential solutions is part of the Business Case Approach undertaken by an approved organisation and is included in their regional land transport plans (RLTPs). These procedures do not include this initial problem definitional work but rather start following the problem definition. As a result of the analysis the potential solutions and improvement options may be adjusted or changed during the process due to the availability of additional or new information as the process develops.

This section includes the analysis procedures for the following major types of activities:

- walking and cycling
- roading activities
- public transport services
- travel demand management
- education, promotion and marketing
- freight activities
- private sector financing and road tolling.

Each analysis procedure offers two methods for assessing activities, and the choice of an appropriate assessment methodology will depend on an activity's size, risk and complexity.

Table 47 illustrates the relationship between the individual simplified procedures and the types of improvement activities that are covered by full procedures. While some simplified procedures are directly relevant to a single type of activity, there are other simplified procedures that may be used to assess multiple transport and non-transport improvement activities.

The simplified procedures are designed to simultaneously establish the project impacts and the monetised benefits and costs of undertaking activities that are low-cost and have low levels of risk and complexity. The full procedures are designed to first establish the impacts of proposed options and then assign these impacts monetary values, in order to establish the monetary benefits, before calculating the BCR and other economic indicators.

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Table 47: Simplified procedures in relation to full procedures

Types of activities / Simplified procedure	Roading activities	Travel demand management	Public transport services	Walking and cycling	Education, promotion and marketing	Freight activities	Private sector financing and road tolling
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 simplified and full assessment methodologies are described below in more detail.

Simplified procedures

The simplified procedures are designed for the appraisal of activities that are low-cost and have low levels of risk and complexity. Thresholds for activity value also apply (see Table 48).

This manual contains simplified procedures for the following types of sub-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[8]
- 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 applicable for deciding whether a proposal is of low-cost, risk or complexity are described at the beginning of each evaluation procedure.

Each simplified procedure is a stand-alone procedure. They are designed to be applied directly to each option being considered. Table 48 provides a summary of all 12 simplified procedures covered in this manual.

[8] There is no SP7. A gap has been left to accommodate future simplified procedures for roading or public transport activities. Since two earlier manuals were combined into the EEM there has only been one new SP developed: SP6, which was brought into play when the Vehicle Dimensions and Mass (VDAM) Rule 2016 was established and allowed the use of high productivity motor vehicles (HPMV).

Input values for the simplified procedures may be obtained from:

- the default figures provided, or
- activity specific data collected, or
- the information in the analysis procedures.

Analysis which alters components of the simplified procedure should not be used as this will compromise the assumptions on which the procedure is based. In these instances, the full procedures should be used instead.

Table 48: Simplified procedure summaries

Use	If the activity is …
SP1	A road renewal, namely: • sealed road pavement rehabilitation • drainage renewals • preventive maintenance. Geometric improvements are excluded. Where the undiscounted whole-of-life cost ≤$15,000,000.
SP2	A structural bridge replacement or renewal, where one of the following: • undiscounted whole-of-life cost is ≤$15,000,000 and the AADT ≥50 vpd • undiscounted whole-of-life cost is ≤$1,000,000, the AADT ≤50 vpd and a low-cost option is not suitable • undiscounted whole-of-life 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.
SP3	A general road improvement (including seal widening), where the undiscounted whole-of-life cost ≤$15,000,000. Traffic management facilities, new roads, road improvements and property purchases may be assessed using this SP.
SP4	A seal extension, where the undiscounted whole-of-life cost ≤$15,000,000.
SP5	An isolated intersection improvement where the undiscounted whole-of-life cost ≤$15,000,000. Traffic management facilities, new roads and road improvements may be assessed using this SP.
SP6	A roading infrastructure improvement(s) specifically required to establish high productivity motor vehicle routes and where the undiscounted whole-of-life cost ≤$15,000,000. Structure component replacements, replacements of bridges and structures, and road improvements may be assessed using this SP.
SP8	A freight transport service, where the undiscounted funding gap ≤$15,000,000 over the first three years of operation.
SP9	A new public transport service, where the undiscounted funding gap ≤$15,000,000 over the first three years of operation. Bus services, passenger ferry services and passenger rail services may be assessed using this SP.
SP10	An improvement to an existing public transport service, where the undiscounted funding gap ≤$15,000,000 over the first three years of operation. Bus services, passenger ferry services and passenger rail services may be assessed using this SP.
SP11	A walking or cycling facility, where the undiscounted whole-of-life cost ≤$15,000,000.
SP12	A travel behaviour change activity, where the undiscounted whole-of-life cost ≤$15,000,000.
SP13	A road safety promotion activity, where the undiscounted whole-of-life cost ≤$15,000,000.

Full procedures

The full procedures are to be used to appraise economic efficiency when the assumptions contained in the simplified procedures, including any cost limits, 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 analysis should be adjusted or added to as appropriate for the activity type.

As much as possible, the full procedures are standardised to follow the same period of analysis and utilise the NZTA worksheets, available on the MBCM page on the NZTA website.

Analysis period

The standard analysis period for improvement activities is 40 years from the year in which significant benefits or costs commence, unless otherwise agreed with NZTA in writing. For activities with short-lived assets, or activities where benefits dissipate quickly, it may only be necessary to assess the activity over a 5- to 10-year period.

There are three critical times to be set up for the analysis process:

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

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.

Worksheets

The full procedures contain two worksheets to guide the calculations and encourage consistency of analysis. The two worksheets are Crash cost savings and Transport modelling checks. These worksheets are to be used as far as is practical when preparing analyses. Non-standard worksheets may be submitted with analysis reports provided the necessary information can be readily obtained from such worksheets and the information 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 analyses are exactly the same.

Summary of the analysis results will be reflected in the appraisal summary table (AST) and much of the information required in AST and worksheets contributes to the NZTA funding allocation process. The expectation is that the data entered in AST and worksheets can be transferred to Transport Investment Online (TIO) and vice versa as appropriate.

Blank worksheets can be downloaded in MS Excel format from the MBCM page on the NZTA website.

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

4.2 Analysis of walking and cycling activities

This section describes the specific procedures to be used to evaluate the economic efficiency of walking and cycling facilities. Activities may be stand-alone interventions, or a component of a wider transport solution.

Improvements may be of two types:

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

Cycling and walking promotion is addressed as part of the analysis procedures for education, promotion and marketing in section 4.6.

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 New Zealand Travel Survey. The average pedestrian trip length is estimated at 1km.

Statistics on cycling provided are based on the New Zealand Household Travel Survey. The current average cycle trip length is estimated at 3km. This applies equally to new and existing users.

Integration with other travel demand management initiatives

For walking and cycling activities to be effective, continuous lanes or paths should be provided. Provision should also be made for 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. Useful sources include:

- Barnes et al (2005), which sets out a framework and priorities for development of walking and cycling activities
- NZTA *Cycling network guidance*, which provides guidance for cycle network and route planning
- NZTA *Pedestrian planning and design guide*, which is New Zealand's comprehensive official guide to planning and design for walking. It sets out ways to improve New Zealand's walking environment.

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

Simplified procedure for walking and cycling activities

The simplified procedure is designed to consider one option at a time. All suitable options for the proposed activity 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.

SP11 for walking and cycling activities

Simplified procedure SP11 provides the appraisal methods for walking and cycling initiatives with an undiscounted whole-of-life cost of less than $15 million. SP11 assumes that the activity does not include signalised crossings over roads.

A description of all options considered should be included in SP11 worksheet 1 (SP11-1) and the options should be tested in the incremental analysis worksheet SP11-8. 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 the current number of pedestrians and cyclists and estimate their future growth rate. These must be based on local counts and realistic projections. For cyclists these can be obtained using SP11-7.

The simplified procedure may be used as part of a multi-modal analysis. Any such analysis could cover travel behaviour change (TBhC) activities, and infrastructure and public transport service improvements. The procedure uses a 4% discount rate and a 40-year analysis 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.

Guidance for completing the SP11 Walking and cycling facilities (template worksheets) is provided below in Table 49 and Table 50.

Table 49: SP11 Walking and cycling facilities procedure template

Worksheet	Worksheet purpose	Description
SP11-1	Evaluation summary	Provides a summary of the general data used for the evaluation as well as the results of the analysis.
SP11-2	Cost of the do-minimum	Used to calculate the PV cost of the do-minimum. The do-minimum is the minimum level of expenditure necessary to maintain a minimum acceptable level of service and generally consists of maintenance work.
SP11-3	Costs of the option	Used to calculate the PV costs of the option 1. A separate worksheet is required for each option evaluated. Up to 3 options in addition to do-minimum can be evaluated.
SP11-4	Travel time cost savings	Used for calculating travel time cost savings.
SP11-5	Benefits for walking and cycling facilities	Used for calculating the health and environmental benefits of walking and cycling facilities.
SP11-6	Crash cost savings	Used for calculating crash cost savings using crash-by-crash analysis method (method A in Appendix 2: Crash analysis).
SP11-7	Cycle demand	Used for calculating cycle travel demand using the ‘buffers’ methodology
SP11-8	BCR and incremental analysis	Used for relative comparison of the options.

Table 50: Steps in the SP11 analysis of walking and cycling activities

Step	Description
1	Complete items 1 to 3 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Cost of do-minimum
3	Complete Worksheet 3 – Cost of option(s)
4	Complete Worksheets 4 to 7 for the option(s) being evaluated
5	Complete Worksheet 8 – Incremental analysis (if more than one option is considered)
6	Select the preferred option and finalise Worksheet 1 for the preferred option

Table 51 provides the required benefits factor for different types of cycle facilities.

Table 51: 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

Full procedure for walking and cycling activities

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

The following table outlines the stages of analysis in the economic efficiency evaluation. The do-minimum and any other options must be assessed at every stage.

Table 52: Full procedure for walking and cycling activities

Stage	Description	Refer
1	Complete the activity description including a description of the do-minimum, alternatives and options.	Current section and Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Forecast the demand. Note: The demand estimate is used for calculating user benefits for new and existing pedestrians and cyclists, and road traffic reduction benefits. Care should be taken to ensure assumptions are compatible with economic analysis requirements.	Current section
3	Calculate the benefits.	Current section and Chapter 3: Benefits
4	Calculate the costs of the proposal.	Section 1.8: Costs
5	Discount the monetised benefits and costs over the analysis period to obtain present values.	Chapter 5: Discounting
6	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
7	Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options.	Chapter 6: Benefit–cost ratios
8	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the evaluation outcome(s).	Chapter 7: Sensitivity and risk analysis
9	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1: Describe the do-minimum, options and alternatives

The do-minimum for analysis 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 and renewal schedules and any planned service changes must also be included. Improvements are committed if they have been assessed in accordance with the NZTA assessment procedures and have been approved for funding.

Any investment plans that are not committed must be included in the analysis 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.

It is extremely important to:

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

Stage 2: Demand estimates

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.

Factors influencing the demand for walking and cycling include:

- the availability of facilities
- the type and quality of facility, including cycle parking, signage and safety of use
- the location of the facility, the route length, and connectivity of walking and cycling paths or lanes

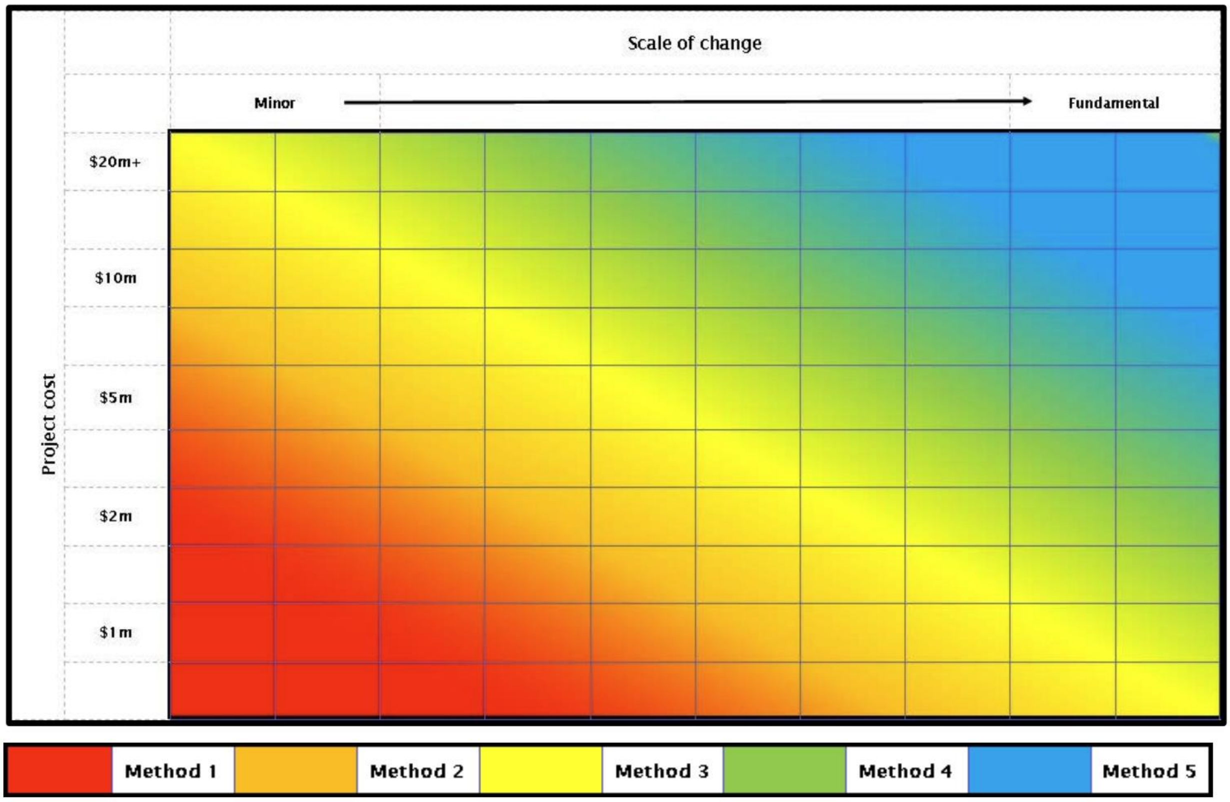
- the population served by the facilities, and
- any education, promotion and marketing.

Studies have shown a positive correlation between the number and quality of facilities provided and the percentage of people who use cycle for transportation 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.

Education, promotion and marketing are significant drivers for generating demand for walking and cycling, and any associated mode shift from private vehicles. The methodology for estimating travel impacts in section 2.2 of this manual should be referenced to estimate the number of private vehicle trips diverted to new or improved walking and cycling facilities, when this is part of a package that includes travel behaviour change (TBhC) activities.

Beetham J et al has summarised the methods for walking and cycling demand estimates in five groups, including a decision tree for determining the right method for demand forecasting based on the size of the transport proposal and the scale of the change (see Figure 9 below).

Figure 9: Walking and cycling demand methods and selection matrix



Method 1	**Method 2**	**Method 3**	**Method 4**	**Method 5**
Cycling: Sketch plan equation Walking: Informed expert estimation.	Cycling: Sketch plan equation with informed expert calibration. Walking: Informed expert estimation.	Comparison approach combined with an analysis of level of service and potential use. Employ modifying factors based on local context.	Geospatial assessment combined with an analysis of level of service and potential use. Employ modifying factors based on local context.	Transport model with locally specific data and factors.

Where a new or improved walking or cycling facility provides an improved quality of service, then trips in addition to those diverted from private vehicles may be generated depending on the extent of the quality change of the improvement.

Table 53 (which is part of simplified procedure SP11) provides a cycle demand model for estimating cycle trips generated by a new or improved cycling facility.[9] This method is based on the number of jobs in each buffer zone. It includes variables for the quality of service (QoS) of a facility and (optionally) the directness of a proposed project compared to the most direct route possible. This model falls in the category of geospatial analysis methods (3 and 4) in Figure 9. Table 53 can be used to estimate the demand for a new cycle facility if cycle counts are not available or the counts are considered unreliable.

The total demand for a cycle facility may be estimated by referencing the procedures in sections 2.2, 2.3 and 2.4 of this manual.

Table 53: Cycle demand

New and existing cyclists				
	Buffers (km)	<0.4	0.4 to <0.8	0.8 to ≤1.6
1	Jobs in each buffer (solid shape)			
2	Jobs in each buffer (annular shape)			
3	Likelihood of new cyclist multiplier	1.04	0.54	0.21
4	Weighted jobs [sum of (2) x (3)]			
5	Average quality of service (QoS) score from Auckland Transport QoS method			
6	Transformed QoS average score (6) = (4) – (5)			
7	Directness			
8	Actual cyclists before intervention – predicted cyclists before intervention. If (7) is omitted, leave this blank.			
9	Total new and existing cyclists			
10	Experienced evaluator judgement of additional cyclists not modelled			
11	Predicted total cyclists after intervention (9) + (10)			

Table 53 calculates number of jobs within catchments surrounding the facility. It then applies a probability factor to estimate the number of new cyclists who will use the facility by considering their distance from the facility and the current mode share of cyclists.

The **buffer distances** are defined as <0.4km, 0.4km to <0.8km, and 0.8km to ≤1.6km. 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. Therefore, the table **only requires row 1 or 2** to be filled out.

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 **quality of service** (QoS) score is computed using the Auckland Transport QoS method, which is available on their website.

[9] The full model and its underlying assumptions are available from the NZTA Planning and Investment Knowledge Base (PIKB).

Calculate segment, intersection, and overall average[10] QoS for the proposed project. If the facility is 3.0m wide, then you can select from two width bands in the QoS tool. Choose the higher (better) score if the facility is consistently >= 3.0m and/or high-quality, and the lower score if there are pinch points.

Directness is an optional input. Divide the length of the shortest route by the subject route. If there is no alternative shorter route or the data is not available, then this may be left blank. Table 53 applies the correct model formula.

If the average daily cyclists before intervention is known, run the model using the existing conditions and then subtract the known existing average daily riders from the total predicted daily riders to get the number of new daily riders. If you don't have an existing count or you don't calculate directness, then leave this value set to zero.

Table 53 enables the analyst to incorporate any additional daily cyclists expected due to other route-specific conditions not accounted for in the model, for example a large school with high cycling mode share. The analyst can use bike shed counts (doubled, to account for round-trip travel). Any value entered must be justified with supporting documentation.

Table 54: Cycling commute share – has been deleted

Back to 2.2 Forecasting demand: procedures for travel behaviour change activities >>

Stage 3: Calculate walking and cycling improvements benefits

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

This manual includes procedures to monetise some of the benefits of walking and cycling projects.

The benefits of walking and cycling monetised in this manual include:

- impact on social cost and incidents of crashes
- impact on physical and mental[11] health
- impact on productivity and network utilisation
- wider economic impact (productivity)
- wider economic impact (land use change).

These benefits arise primarily as a result of changes in road traffic volumes, changes to mode share, and changes to user benefits from decreased travel time and increased safety.

Cycle operating costs and walking costs are assumed to be included in the perceived costs of changing to and using these modes.

Activities that combine walking and cycling may claim benefits for both modes, but safety issues arising from pedestrian or cycle conflicts must be addressed. If there are likely to be additional crashes these must be accounted for in the analysis.

Disruption costs to existing users of walking and cycling facilities during the implementation of new or improved facilities must be included in the analysis as a disbenefit (negative benefit).

Possible disbenefits include:

- increased travel time, and
- travel discomfort.

Calculate net user benefits for users of a new walking and cycling facility using following procedure to determine the projected number of new service users. The calculation of net benefits for users of a new

[10] Auckland Transport recommends that an average is not used because a single poor-quality segment can render the rest of the corridor quality a moot point for a prospective rider. However, as long as the analyst clearly acknowledges such potential failure points, the averaging method has shown to be statistically sound for the modelling purpose.

[11] Impact on mental health is not covered in the manual.

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.

Net user benefits = $P_{max} \times Q_{new} \times ½$

where: P_{max} is the willingness to pay value for the new facility
Q_{new} is the projected number of new users

The value of walking or cycling facility user benefits, other than time saving benefits, such as improved quality, comfort or security, is usually based on a willingness to pay value derived from a stated preference (SP) survey or from values derived for similar facility improvements in other areas.

Calculate the facility user benefits for users of an existing walking and cycling facility with a projected new use level, as follows:

1. Change in net total benefits for existing users

$$Bf_{existing} = P_{max} \times Q_1$$

2. Apply the rule of half for the total benefits for new users

$$Bf_{new} = P_{max} \times (Q_2 - Q_1) \times ½$$

3. Total facility benefits

$$Bf_{total} = Bf_{existing} + Bf_{new}$$

where: P_{max} is the willingness to pay value for the **improvement of the facility**
Q_1 is the existing number of users
Q_2 is the projected total number of users

Proposals to improve the quality of an existing walking and cycling facility, such as improving its amenity, comfort or security, must assess the value of different levels of quality. This assessment must also be carried out if the proposal is for a new walking and cycling facility. The valuation should be based on a SP survey or on information from similar improvements to facilities in other areas.

Pedestrian planning and design guide describes an 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, and the incremental attractiveness of that type of facility, when compared with a base case of 20 minutes of travel in traffic with road-side parking. The study is the basis of the values in Table 35.

Stage 4: Calculate costs of walking and cycling do-minimum and options

In general, the costs of walking and cycling activities are limited to:

- planning, investigation and design fees
- costs of property required for the activity
- construction costs
- maintenance and renewal costs, including repair and reinstatement
- facility operating costs.

Stage 5: Discount benefits and costs

Refer to section 1.9 and Chapter 5 of this manual for the detailed information on undertaking discounting.

Benefits and costs generally arise throughout the life of projects, and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present-worth factors have been calculated to convert future benefits and costs to their present values. (See Table 103, and Table A132, Table A133 and Table A134 from Appendix 6: Discount factors. Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.)

Stage 6: Determine the benefit–cost ratios of the options

Refer to Chapter 6 for detailed information on developing BCRs.

Stage 7: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs.

Stage 8: Perform sensitivity and risk analysis

Refer to Chapter 7 of this manual for detailed information on sensitivity and risk analysis.

Assessing the sensitivity of impact analysis and resulting benefits calculations to critical assumptions or estimates shall be undertaken using sensitivity testing, which needs to be undertaken for the critical inputs and assumptions used to choose the preferred option.

Sensitivity testing involves defining a range of potential values for an uncertain variable in the economic calculations and reviewing the variation in the results as the variable changes within the range. This will highlight the sensitivity of the estimated final outcome to changes in input variables.

Inputs to walking and cycling facility analyses that should be considered for sensitivity testing include:

- demand estimates, and
- major contributors to benefits.

Benefits critical to the outcome of the analysis may include:

- pedestrian and cyclist volumes particularly those derived from model results
- growth rates and assessments of diverted and generated traffic, and
- crash reductions.

For each significant factor the following must be listed:

- the assumptions and estimates on which the analysis 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.

The results of the sensitivity tests, along with an explanation of any assumptions or choice of test, must be reported.

Stage 9: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

4.3 Analysis of road renewal and improvement activities

The following section describes the procedures that are to be used to evaluate the economic efficiency of road improvement activities. Activities may be stand-alone improvements or a component of a package or a wider programme of transport improvements.

For the more simple and relatively standardised improvement activities with an undiscounted whole-of-life cost of $15 million or less, simplified procedures are provided for the analysis and these are explained below. For the more complicated projects, and those with an undiscounted whole-of-life cost greater than $15 million, the full procedures are provided as an alternative to the simplified procedures and are explained later in this section.

Simplified procedures for road renewal and improvement activities

The following simplified procedures (SPs) for road improvement and related activities use a 4% discount rate and a 40-year analysis period, and assume 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. The simplified procedures SP1 to SP5 are for the analysis of road activities that have an undiscounted whole-of-life cost of less than or equal to $15 million. If any of these criteria are not met then the full procedures (see below) must be used.

The simplified 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 of the preferred option need to be included.

It is necessary for all the activities covered by SP1 to SP5 to determine the expected future traffic growth rate. This can be done either by analysing the traffic count data, following the procedures in Appendix 3: Traffic data and travel time estimation, for at least the last five years and preferably for the last 10 years, or by using a default growth rate of zero percent. Simplified procedures SP1 and SP2 are for road renewals and bridge renewals respectively. These renewal activities are a type of improvement when compared to the do-nothing or do-minimum, but they are targeted at maintaining the status quo.

Procedure SP3 is for general road improvements, while SP4 is for seal extension works, and SP5 is for isolated intersection improvements. If an intersection improvement is part of an overall corridor improvement or is being undertaken with other road improvement works, then it should be considered as part of a package or programme of works.

Refer to the NZTA Planning and Investment Knowledge Base (PIKB) for guidance on issues relating to analysis of road activities, including selection of the preferred option using the Business Case Approach.

The simplified procedure templates provided must be used when undertaking simplified analyses. The completed templates are to be included in Transport Investment Online (TIO). The templates are standardised to allow automated uploading to and data extraction from TIO.

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

- the default figures provided
- activity specific data collected, or
- the information in the appendices.

Analysis that alters components of the simplified procedure should not be used as this will compromise the assumptions on which the procedures are based and full procedures should be used instead.

If the analyst has any problems with the simplified procedures templates or worksheets, please contact MBCM@nzta.govt.nz.

SP1 for road renewal activities

SP1 provides a simplified method of appraising the economic efficiency of work to be funded under work categories within the maintenance activity classes, for example pavement rehabilitation.

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. SP 1 therefore stands apart from all other simplified procedures by solely comparing the whole-of-life costs of each option and excluding any calculation of benefits.

Under these procedures the present-value 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.

Guidance for completing the SP1 Road renewals (template worksheets) is provided below in Table 55 and Table 56.

Table 55: SP1 Road renewals procedure template

Worksheet number	Worksheet purpose	Description
SP1-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP1-2	Cost of existing maintenance strategy	Used to calculate the PV cost of the existing maintenance strategy.
SP1-3	Cost of the option(s)	Used to calculate the PV cost of the option.

Table 56: Steps in the SP1 analysis of road renewal activities

Step	Description
1	Complete items 1 to 3 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Existing maintenance strategy
3	Complete Worksheet 3 – Cost of option(s)
4	Select preferred option – refer to work category 214: Sealed road pavement rehabilitation on PIKB
5	Complete items 4 to 7 of Worksheet 1 – Evaluation summary

SP2 for bridge renewal activities

SP2 provides 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 in Figure 10.

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 from 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.

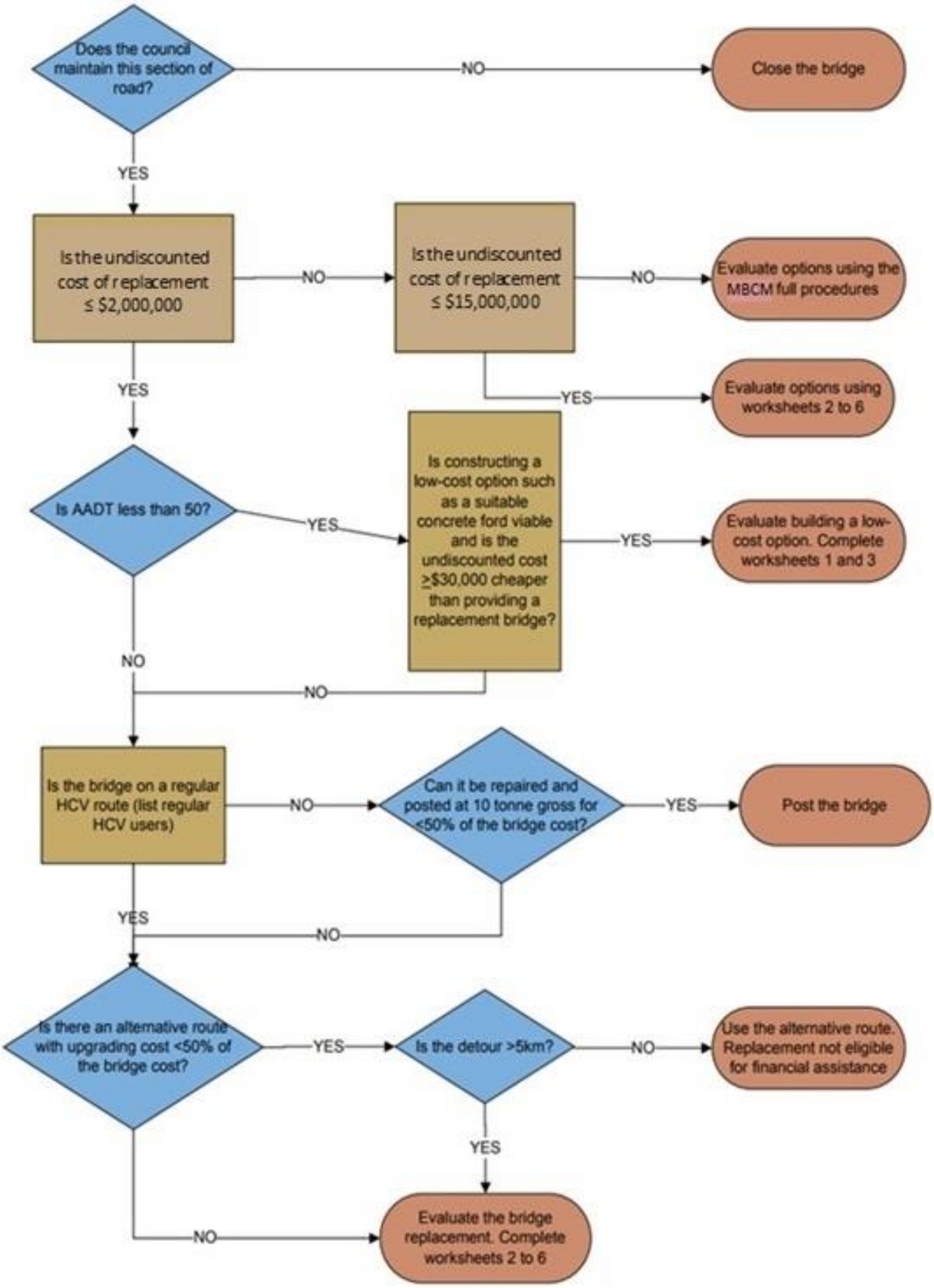
Once this has been done, the decision chart (Figure 10) can be used to determine the appropriate course of action and analysis procedure.

Exception to the standard do-minimum

The do-minimum for most road activities shall only include work that is absolutely essential to preserve a minimum level of service. However, 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. The do-minimum must be clearly determined for each bridge renewal under consideration.

Note: 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.

Figure 10: Decision chart for bridge replacement



Guidance for completing the SP2 Structural bridge renewals (template worksheets) is provided below in Table 57 and Table 58.

Table 57: SP2 Structural bridge renewals procedure template

Worksheet number	Worksheet purpose	Description
SP2-1	Building a ford on a low-volume road	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP2-2	Evaluation summary for bridge renewal	Used to calculate the PV cost of the do-minimum. The do-minimum is the minimum level of expenditure necessary to keep a road open.
SP2-3	Costs of the option(s)	Used to calculate the PV costs of the option. A separate worksheet is required for each option evaluated. Up to three options in addition to do-minimum can be evaluated.
SP2-4	HCV user costs when there is an alternative route	Used for calculating travel time cost savings.
SP2-5	HCV user costs when there is no alternative route	Used for calculating vehicle operating cost (VOC) savings.
SP2-6	BCR and incremental analysis	Used for comparison of the options considered.

Table 58: Steps in the SP2 analysis of structural bridge renewal activities

Step	Description
1	Complete Worksheet 1 if building a ford is an option – if it is not an option leave blank
2	Complete items 1 to 3 of Worksheet 2 – Evaluation summary
3	Complete Worksheet 3 – Cost of option(s) and determine which option is do-minimum
4	Complete Worksheet 4 – HCV user costs – when there is an alternative route
5	Complete Worksheet 5 – HCV user costs – when there is no alternative route
6	Complete Worksheet 6 – Incremental analysis (if more than one option is possible)
7	Select the preferred option and finalise Worksheet 2 for the preferred option*

Table 59 provides freight cost factors for use within this simplified procedure.

Table 59: Cost factors for different type of heavy trucks

% 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 for road improvement activities

SP3 provides a simplified method of appraising the economic efficiency of road improvements, including road reconstruction, seal widening, new roads and new structures. SP3 specifically excludes road renewals (SP1), bridge renewals (SP2), seal extension work (SP4), and isolated intersection improvements (SP5).

Guidance for completing the SP3 Road improvement activities (template worksheets) is provided below in Table 60 and Table 61.

Table 60: SP3 Road improvement activities procedure template

Worksheet number	Worksheet purpose	Description
SP3-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP3-2	Cost of do-minimum	Used to calculate the PV cost of the do-minimum. The do-minimum is the minimum level of expenditure necessary to keep a road open.
SP3-3	Cost of the option(s)	Used to calculate the PV costs of the option. A separate worksheet is required for each option evaluated. Up to three options in addition to do-minimum can be evaluated.
SP3-4	Travel time cost savings	Used for calculating travel time cost savings.
SP3-5	Vehicle operating cost savings	Used for calculating vehicle operating cost (VOC) savings.
SP3-6	Crash cost savings	Used for calculating crash cost savings using crash-by-crash analysis method (refer Appendix 2: Crash analysis).
SP3-7	BCR and incremental analysis	Used for comparison of the options considered.

Table 61: Steps in the SP3 analysis of road improvement activities

Step	Description
1	Complete items 1 to 3 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Cost of do-minimum
3	Complete Worksheet 3 – Cost of option(s)
4	Complete Worksheets 4 to 6 for the option(s) being evaluated
5	Complete Worksheet 7 – Incremental analysis (if more than one option is considered)
6	Select the preferred option and finalise Worksheet 1 for the preferred option

SP4 for seal extension activities

SP4 provides a simplified method of appraising the economic efficiency of proposed seal extension works. The method is for the analysis of activities that have an undiscounted whole-of-life cost less than or equal to $15 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 SP4-1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option need to be included.

Guidance for completing the SP4 Seal extensions (template worksheets) is provided below in Table 62 and Table 63.

Table 62: SP4 Seal extensions procedure template

Worksheet number	Worksheet purpose	Description
SP4-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP4-2	Cost of do-minimum	Used to calculate the PV cost of the do-minimum. The do-minimum is the minimum level of expenditure necessary to keep a road open.
SP4-3	Cost of the option(s)	Used to calculate the PV costs of the option. A separate worksheet is required for each option evaluated. Up to two options in addition to do-minimum can be evaluated.
SP4-4	Travel time cost savings	Used for calculating travel time cost savings.
SP4-5	Vehicle operating cost savings	Used for calculating vehicle operating cost (VOC) savings.
SP4-6	Crash cost savings	Used for calculating crash cost savings using crash-by-crash analysis method (refer Appendix 2: Crash analysis).
SP4-7	BCR and incremental analysis	Used for comparison of the options considered.

Table 63: Steps in the SP4 analysis of seal extension activities

Step	Description
1	Complete items 1 to 6 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Cost of do-minimum
3	Complete Worksheet 3 – Cost of option(s)
4	Complete Worksheets 4 to 6 for the option(s) being evaluated
5	Complete Worksheet 7 – Incremental analysis (if more than one option is considered)
6	Select the preferred option and finalise Worksheet 1 for the preferred option

SP5 for isolated intersection activities

SP5 provides a simplified method of appraising the economic efficiency of isolated intersection improvements. 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.

Guidance for completing the SP5 Isolated intersection improvements (template worksheets) is provided below in Table 64 and Table 65.

Table 64: SP5 Isolated intersection improvements procedure template

Worksheet number	Worksheet purpose	Description
SP5-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP5-2	Cost of do-minimum	Used to calculate the PV cost of the do-minimum. The do-minimum is the minimum level of expenditure necessary to keep a road open.
SP5-3	Cost of the option(s)	Used to calculate the PV costs of the option. A separate worksheet is required for each option evaluated. Up to 4 options in addition to do-minimum can be evaluated.
SP5-4	Travel time cost savings	Used for calculating travel time cost savings.
SP5-5	Vehicle operating cost savings	Used for calculating vehicle operating cost (VOC) savings.
SP5-6	Crash cost savings	Used for calculating crash cost savings using crash-by-crash analysis method (refer Appendix 2: Crash analysis).
SP5-7	BCR and incremental analysis	Used for comparison of the options considered.

Table 65: Steps in the SP5 analysis of isolated intersection activities

Step	Description
1	Complete items 1 to 3 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Cost of do-minimum
3	Complete Worksheet 3 – Cost of option(s)
4	Complete Worksheets 4 to 6 for the option(s) being evaluated
5	Complete Worksheet 7 – Incremental analysis (if more than one option is considered)
6	Select the preferred option and finalise Worksheet 1 for the preferred option

Table 66 provides default values for use within this simplified procedure.

Table 66: 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

Full procedures for road improvement activities

The full analysis procedures for road improvement activities are to be used to appraise the economic efficiency of activities when the simplified procedures are not appropriate or sufficient.

There are many types of improvements that can be considered when using these procedures, including specialised improvements such as passing lanes, bridge improvements, etc.

The primary purpose of this section of the manual is to establish the impacts of making road improvements (ie the changes that occur between the do-minimum and the options) when using the full procedures. Following on from calculating the impacts, the analyst will need to assign monetary values to the impacts and then calculate the benefits and the benefit–cost ratios (BCRs).

These procedures cover the range of stages listed above, however, many of the actions for these stages are covered in greater detail in other sections or appendices of this manual and in external documents for which links have been provided. A significant focus of the road improvement procedures is on the calculation of activity impacts, in particular stages 4 to 6 in Table 67.

These procedures are designed to calculate the impacts one at a time and then, after assigning monetary values to the impacts, they can be added together, including any disbenefits, to establish the total benefit of the options under consideration. To assist in this process a set of standardised worksheets have been developed to help guide the analyst, and to aid in the process of checking for completeness and accuracy.

The following table outlines the stages of analysis for road improvement activities. The chapters and sections of this manual that apply to each stage of the analysis are referenced in the table below.

Table 67: Full procedures for analysis of road improvement activities

Stage	Description	Refer
1	Consider and describe: a. the do-minimum b. improvement alternatives and options c. whether the improvement(s) should be part of a package and/or programme of activities.	Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Assemble information on the transport route (lengths, road classifications, etc) together with current and forecast vehicle, cycle and pedestrian traffic demand (including suppressed demand and induced traffic).	Chapter 2: Demand estimation and mode share
3	Consider the use of transport models and calibration. If a transport model is being used, then undertake calibration checks for the improvement options as required.	Transport model development guidelines
4	Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options, including: • impact on social cost and incidence of crashes • impact of mode on physical and mental health • impact of air emissions on health • impact on greenhouse gas emissions • impact of noise and vibration on health • impact on network productivity and utilisation • impact on system reliability • impact on user experience of the transport system • wider economic benefits • other benefits that can be monetised – these are not included in this manual but can be included if there is sufficient supporting evidence and the approach is accepted by NZTA.	Current section and Chapter 3: Benefits
5	Describe and evaluate any mitigation measures necessary for the options under consideration.	Section 1.8: Costs
6	Undertake risk analysis when there are significant unpredictable events that may affect or be affected by the improvement activity.	Chapter 7: Sensitivity and risk analysis
7	Calculate the costs for the do-minimum and improvement options, including (but not exclusively): • investigation and design • property • construction, including preconstruction and supervision • maintenance, renewal and operation • risk management • mitigation of external impacts • residual values.	Section 1.8: Costs
8	Discount the monetised benefits and costs over the analysis period to obtain present values.	Chapter 5: Discounting

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Stage	Description	Refer
9	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
10	Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options.	Chapter 6: Benefit–cost ratios
11	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the evaluation outcome(s).	Chapter 7: Sensitivity and risk analysis
12	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1a: Describe the do-minimum

Generally, the do-minimum for road activities shall only include committed and funded transport activities and 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.

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.

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.

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 that 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).

Most forms of activity analysis 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 or activity may be required to maintain a minimum level of service. This minimum level of expenditure or activity and the resultant performance is known as the do-minimum and should be used as the basis for analysis, rather than the do-nothing. It is important not to overstate the scope of the do-minimum.

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.

In some situations, the do-minimum can be the most effective solution to a problem and therefore it can be the 'preferred option'.

For some situations the best outcomes may be delivered through the do-minimum option, eg lowering the operating speed to a safe and appropriate level through the use of speed-limit signs and/or minor infrastructure improvements that go with the new speed limits. In this case, the do-minimum will be the preferred option.

For safety activities where reducing the speed limit is a potential option, the do-nothing scenario is the existing baseline conditions of the network, based on the existing speed limit, operating speed, infrastructure and services.

Where a road-controlling authority decides to introduce one or more interventions to address unacceptable levels of collective and/or personal risk, to re-set the speed limit, and/or to manage speeds on a particular piece of road, the do-minimum can include benefits and costs of implementing a new safe and appropriate operating speed.

In such situations the do-minimum should be compared to both the do-nothing and the other activity options in order to determine whether the do-minimum is the preferred option (ie the optimal solution), or whether additional improvements are justified over and above the do-minimum, and if these additional improvements are therefore the preferred option.

When undertaking safety interventions addressing speed the following information should be referenced:

- Land Transport Rule: Setting of Speed Limits
- the NZTA *Speed management guide*, and
- the NZTA MegaMaps tool, which is used in conjunction with the *Speed management guide*.

The crash costs associated with speed management interventions should be calculated using the predictive crash cost models in Appendix 2: Crash analysis of this manual.

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.

The activity costs required for determining benefit–cost ratios (BCRs), including incremental benefit–cost assessment (Chapter 6), and also first-year rate of return (section 1.10) 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.

Stage 1b: Describe the alternatives and options

Rigorous consideration of alternatives and options is a requirement of the Land Transport Management Act 2003 (LTMA). To ensure these obligations are met, evaluators should carefully articulate the problem or issue that they are seeking to resolve and avoid approaching the analysis with a preconceived solution in mind.

Alternatives are different means of achieving the same objective as a proposed activity, while options are variants of a proposed activity. These alternatives and options should not be constrained to a specific mode, or even to transport solutions, as changes to existing policy may be suitable responses to the identified problem. As a result, it may be necessary to apply other procedures contained within this manual as part of the analysis.

Stage 1c: Consider if an activity is stand-alone, part of a package or part of a programme

NZTA seeks to encourage, where appropriate, approved organisations to develop packages or programmes of interrelated and complementary activities, either individually or in association with other approved organisations.

This is particularly important to ensure that a wide range of options and alternatives are considered and evaluated in full. Doing so may help avoid issues that arise from narrowing the scope too early 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.

Stage 2: Route and network information

Road improvement activities need to be divided into sections with similar geometric and traffic flow characteristics, and with similar costs of construction and

. In some cases it may be necessary to separately consider individual traffic movements at intersections. In other cases, benefits and disbenefits 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 route should be divided into sections over which the terrain, road width, road roughness, speed limit and traffic volumes (for all modes) 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.

Activity location and layout

Information on location and layout to be provided shall 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
- intersection approaches and traffic movements
- identifying numbers for each road section, intersection approach and traffic movements
- 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.

Data

For each route and defined section of the route and/or network the relevant data to be collected should include, but is not limited to:

- route lengths, average gradients
- route surface condition – ie roughness levels (averages and length specific if available)
- traffic data for all modes for each time period for each route (including volume, composition, vehicle occupancy and trip purpose, for all modes)
- travel times and speeds
- travel time reliability data
- crash data for each route and for network if required
- resilience, vulnerability, and redundancy data.

For guidance on preparing route and traffic data see Appendix 3: Traffic data and travel time estimation.

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.

For activities with congested conditions it may be necessary to consider growth suppression or variable matrix techniques (see Appendix 1: Demand estimation methods and guidance).

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.

Stage 3: Vehicle, cycle and pedestrian demand estimate

There are two approaches that can be used for calculating transport demand for the different modes and mode shift(s). The first approach is to use a transport model and the second approach is based on willingness to pay surveys combined with data on current users together with information on existing or proposed user charges. This second approach is set out in Chapter 2 of this manual.

Where there are congested networks and the potential for induced/generated traffic, refer to Appendix 1: Demand estimation methods and guidance.

Use of transport models and calibration

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 transport modelling documentation is available on the NZTA website. These checklists should be completed for each analysis time period.

Note: if the analyst is not using a transport model to calculate travel times then they must refer to Appendix 3: Traffic data and travel time estimation for the procedures on how to calculate travel times.

Model validation

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.

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.

The objective of the course checks is to determine whether the travel time benefits calculated are of the right order of magnitude. More information on the required coarse model checks is contained in the *Transport model development guidelines*.

The objective of the detailed checks 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.

Modelling congested networks and induced traffic

Guidelines are provided in Appendix 1: Demand estimation methods and guidance 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 the option, and is then used in the standard fixed trip matrix (FTM) analysis procedure. Refer to Appendix 1: Demand estimation methods and guidance for detailed 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 economic calculations should incorporate an analysis of induced traffic effects and Appendix 1: Demand estimation methods and guidance contains procedures for evaluating these effects.

Stage 4: Calculate road improvement benefits

Calculate the benefits (for each mode) on the route, network, and/or transport system by quantifying, for the do-minimum and options, the changes that occur for the factors listed in the stages below when an improvement option is considered. The results of the route and network information collected in stage 2, and any modelling should be used to estimate the changes needed for benefits valuation:

Note that the benefit calculations should include any negative impacts (disbenefits) during implementation/construction.

The benefits that have currently (as at 2020) been ascribed standardised monetary values are listed below. The benefits (ie the differences in the parameter outcomes between the do-minimum and the options) are ascribed monetary values in Chapter 3 of this manual.

Parameters other than those listed below can be monetised, but the process and values ascribed to these parameters must be agreed with NZTA in writing before they are included in the analysis, and supporting information to validate the inclusion of these parameters must be provided.

Stage 4a: Impact on social cost and incidence of crashes

For the purposes of this manual, a crash is a transport-related event involving one or more road vehicles that occurs on the transport network and that results in personal physical injury and/or damage to property.

Crash analysis for analyses related to road improvement activities can be separated into three groups:

- a safety improvement activity (eg guardrail installation, black-spot upgrade) where most of the benefits are the result of a reduction in crashes
- other road improvement activities where the key outcome is not to primarily reduce crashes but where there are safety benefits or disbenefits that need to be included in the economics (eg installation of a bus transit lane, extension of turn lanes, traffic capacity focused schemes)
- large projects (eg a new motorway link), which will have a network wide impact on crashes.

To undertake a crash analysis the appropriate crash rates, crash prediction models and crash reduction factors can be found in the NZTA *Crash estimation compendium* (2024).

Refer to section 3.1 and Appendix 2: Crash analysis of this manual for detailed information on the calculation and monetisation of crash numbers, and their severities, for the do-minimum, alternatives and options. These calculations allow assessment of the crash incidence reductions that can be expected from the alternatives and options under consideration. Evaluators can also refer to the NZTA Standard safety intervention (SSI) toolkit.

Stage 4b: Impact of mode on physical and mental health

Refer to section 3.2 of this manual for detailed information on the calculation and monetisation of impact of mode on physical and mental health.

Stage 4c: Impact of air emissions on health

Vehicle emissions are a complex mixture of gases and particulates, and in terms of human health the primary harmful air pollutants that cause adverse health effects and have local impacts are particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and hydrocarbons (HCs).

Nitrogen dioxide (NO_2) is a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with increasingly more serious health effects, including reduced life expectancy (Kuschel et al 2022). Particulate matter (PM_{10}, which is smaller than 10µm) impacts predominantly on respiratory and cardiovascular systems. Effects can range from reduced lung function, increased medication use, and more hospital admissions, through to reduced life expectancy and death.

Refer to section 3.3 of this manual for information on the calculation and monetisation of the impacts of vehicle emissions on human health.

Stage 4d: Impact on greenhouse gas (GHG) emissions

Greenhouse gases are pollutants that cause global warming and impact globally, eg carbon dioxide (CO_2), black carbon (BC) and methane (CH_4)

Note: Several harmful pollutants (especially BC) are direct climate pollutants, in that they have a direct warming effect on the atmosphere. However, many of the remaining harmful pollutants, eg sulphur dioxide (SO_2) and carbon monoxide (CO), are indirect climate pollutants. This means they do not warm the atmosphere themselves but react with other gases to increase greenhouse gas concentrations. Therefore, initiatives which address harmful air pollutants typically yield both health and climate change benefits.

Refer to section 3.4 of this manual for information on the calculation and monetisation of greenhouse gas emissions.

Stage 4e: Impact of noise and vibration on health

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 reduced 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.

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.

Refer to section 3.5 of this manual for information on the calculation and monetisation of the impacts of noise and vibration on human health.

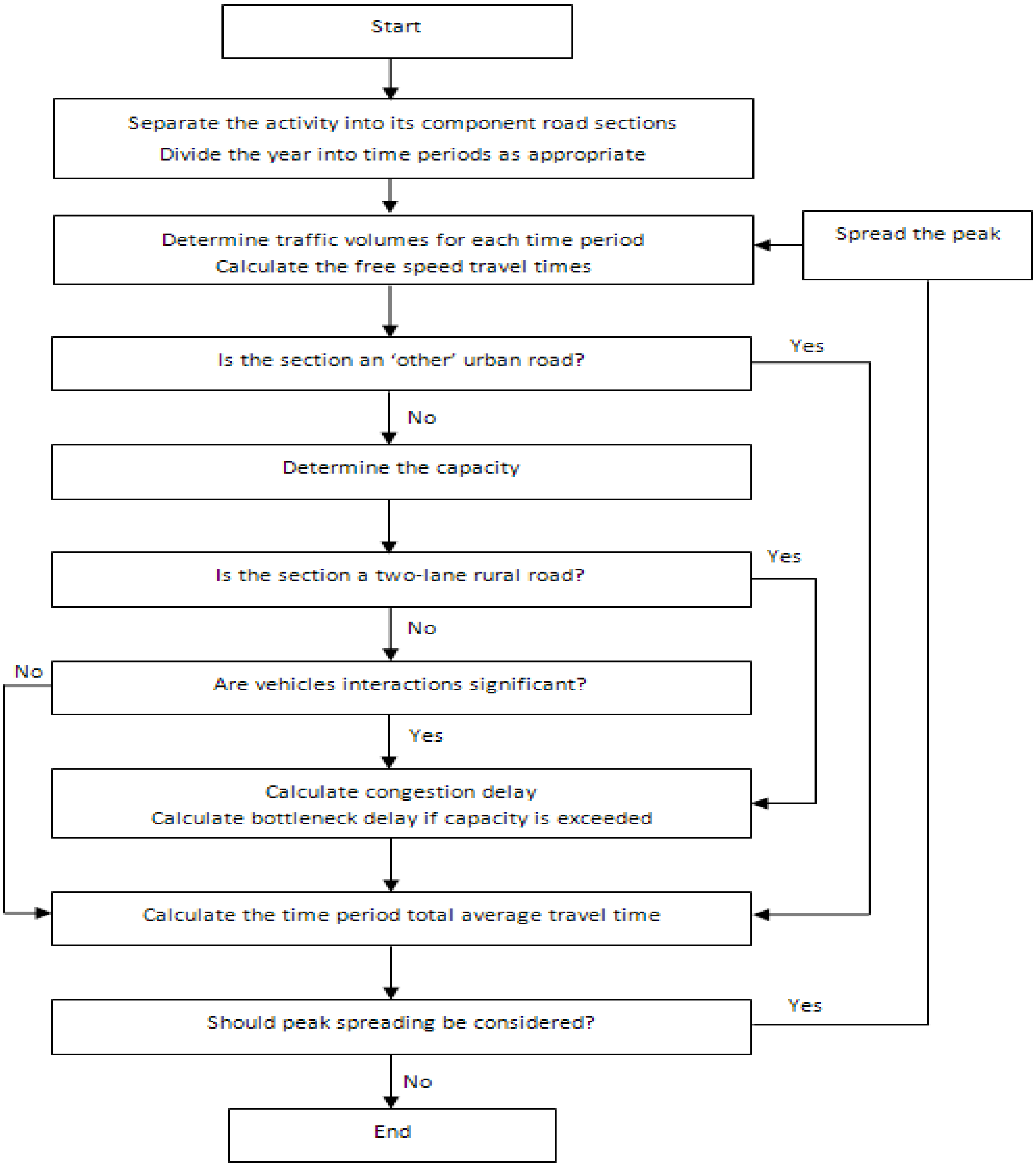
Stage 4f: Impact on network productivity and utilisation

Changes in travel time (for all modes)

Travel times shall be estimated according to the procedures in Appendix 3: Traffic data and travel time estimation of this manual. Definitions for classifying traffic data and default traffic data values are also provided in Table A45, Table A46 and Table A47. 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 Appendix 1: Demand estimation methods and guidance and Appendix 3: Traffic data and travel time estimation.

The flow chart in Figure 11 shows the basic stages for estimating road section travel time (the stages are slightly different for intersections).

Figure 11: Stages for estimating travel time



Use of 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 the modelling checks worksheet.

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 the procedures in Appendix 3: Traffic data and travel time estimation during analysis. To adhere to this, it is suggested that the functions implied by the procedures be used as a starting point and modified as necessary to get a satisfactory validation.

Note that, wherever practical, measured travel time information shall be obtained in preference to the default values given in the tables in this manual.

Refer to Appendix 3: Traffic data and travel time estimation of this manual, which sets out the procedures for estimating travel times for the do-minimum and the options for various road and intersection types. Additionally, refer to section 3.6 of this manual for information on the monetisation of travel time impacts.

Vehicle operating costs

Vehicle operating costs (VOC) are 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. VOC 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.

Refer to section 3.6 of this manual for information on the calculation and monetisation of vehicle operating costs.

Traffic composition

Appendix 4: Vehicle operating cost tables also provides VOC for the standard traffic compositions using the four road categories defined in Table A46, 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.

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.

Regression equations

To assist analysts, regression equations are provided (refer to Table 22, Table 23, Table 24 and Table 25) which can be used to predict the VOC when using spreadsheets or transport models. Note that 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.

Base vehicle operating costs

The base VOCs 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 in Table 15 and the composite travel time values in Table 16.

The breakdown of the base VOC by component is given in Table 68 below.

Table 68: Breakdown of vehicle operating costs (VOC) by component

Vehicle class	Percentage of total base VOC by component			
	Fuel and oil	Tyres	Maintenance and repairs	Depreciation
PC	35.7	6.2	37.2	21.0
LCV	39.6	7.2	29.4	23.8
MCV	38.6	4.2	44.2	13.0
HCVI	42.0	8.3	42.1	7.6
HCVII	37.3	10.4	43.0	9.3
BUS	46.1	6.0	36.9	11.0
Road category	**Fuel and oil**	**Tyres**	**Maintenance and repairs**	**Depreciation**
Urban arterial	36.8	7.3	38.1	17.8
Urban other	36.9	6.9	37.9	18.3
Rural strategic	37.5	7.9	39.4	15.2
Rural other	37.4	7.7	39.1	15.8

Table 69: Recommendations on diversion rates to/from public transport from changes in car travel costs

Car travel cost variable	Typical diversion rates (% of deterred car users switching to public transport)	Comments on estimates by market segment
Parking Charges	Dependent on market segment	• Regional CBD, work trips: 75% • Regional CBD, non-work trips and suburban CBD work trips: 50% • Other areas: not defined, likely to be much lower

Table based on Wallis (2004)

Stage 4g: Impact on system reliability

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 when calculating the travel time values (including congestion values).

Trip journey time reliability is a different type of variability, which is much less predictable to the driver. (For example, car drivers who make a particular journey at the same time every day find some days it takes as little as 20 minutes, and on other days as much as 40 minutes.) Hence, when the car 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 this section.

Journey 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.

Journey 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.

Process for evaluating reliability benefits

1. Calculate the standard deviation of travel time on each link between intersections and for each intersection movement or approach.

   Travel journey 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:

   $$\text{Standard deviation of journey travel time} = s_0 + \frac{\left(s - s_0\right)}{1 + e^{b\left(\frac{v}{c} - a\right)}} \text{ (min)}$$

   where: the VC ratio is represented by s, s_0, b and a are taken from Table 70 below.

Table 70: Coefficients to calculate standard deviation of travel time

Context	S	b	a	S_0
Motorway/multi-lane highway (70–100km/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 (50km/h)	1.17	-19	1	0.050

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Context	S	b	a	S_0
Rural highway (70–100km/h) (two 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: Economic evaluations of small retail areas on 50km/h sections of a rural highway should use the urban other (50km/h) context.

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.

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

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.

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.

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*: $(F_x)(SD_x)$

and, for trips travelling through both source *x* and *y*: $(F_{x.y})\sqrt{(SD_x)^2 + (SD_y)^2}$

where:
F_x is trips that travel through only source *x*
$F_{x.y}$ is trips that travel through both *x* and *y*
SD_x is standard deviation of travel time for trip at source *x*
SD_y is standard deviation of travel time for trip at source *y*

For each of the three sources of variability, the reliability estimate is the sum of the individual components below:

Through source x only: $(F_x)(SD_x)$

Through sources x and y only: $(F_{x,y})\sqrt{(SD_x)^2 + (SD_y)^2}$

Through sources x and z only: $(F_{x,z})\sqrt{(SD_x)^2 + (SD_z)^2}$

Through sources x, y and z only: $(F_{x,y,z})\sqrt{(SD_x)^2 + (SD_y)^2 + (SD_z)^2}$

where: Fx,y,z = trips that travel through all three sources x, y and z.

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.

Rural two-lane roads

Table 71, Table 72 and Table73 contain travel time variability values for rural two-lane roads of varying terrain and the volume to capacity (VC) ratio (see Appendix 3: Calculating the volume to capacity ratio). The time period used to calculate the VC ratio must contain a relatively constant level of traffic volume.

Table 71: 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 72: Travel time reliability – 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 73: 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

7. Assess the percentage of variance occurring outside of the selected study area and select the adjustment factor.

   In many cases, an economic analysis will consider a defined area that 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 74 below gives some illustrative contexts where different factors might apply. An estimation of the variance of journey times that occurs outside of the analysis area must be made and the appropriate correction factor from Table 74 applied.

   The trip time reliability benefit is adjusted by multiplying the calculated variability benefit by the factor.

Table 74: Adjustment factors to apply to variability calculations table

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

8. Calculate the impact of changes in trip reliability using following formula:

   0.9 × travel time value ($/h) (Table 14 or Table 16)
   × (reduction in the network variability (in min)/60)
   × traffic volume for time period (veh/h)
   × correction factor (Table 74)

   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.

   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). 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. Assessing this type of variability is best handled separately from normal day-to-day variability and could also be part of the calculations of system vulnerability, which is outside the scope of the procedure just outlined.

A worked example of the trip reliability procedure is provided in Appendix 8: Worked examples.

Stage 4h: Impact on user experience of the transport system

There are two standard values related to this benefit in this manual as follows:

1. Impact on driver frustration derived from 'time spend passing'. This is an indicator of changes that passing lane generate in road users experience.
2. Impact on road users' comfort and productivity due to sealing unsealed roads.

Refer to section 3.8 of this manual for information on the calculation and monetisation of the impact on user experience of the transport system.

Driver frustration

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 analysis 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.

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.

An alternative method based on multiple simulations and the unified passing model is described in Appendix 5: Passing lanes, and is available in the *Provisional passing & overtaking guidelines* on the NZTA website. 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.

Road user comfort from seal extension

Road user comfort benefits and productivity gains from sealing an unsealed road should also be taken into account.

Stage 4i: Wider economic benefits

Refer to sections 3.9 to 3.13 of this manual for information on the calculation of wider economic benefits.

Wider economic benefits (WEBs) are impacts that can result from transport investment. They can be thought of as impacts that are additional to the conventional benefits to transport users (illustrated in the following diagram) and they can be both positive and negative. WEBs include changes to productivity including agglomeration impacts, employment impacts, and output changes under imperfect competition.

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.

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.

New Zealand application of WEBs

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.

Stage 4j: Other significant impacts that can be monetised

Refer to section 3.15 on transport resilience.

Stage 5: Describe and evaluate any mitigation measures

Where mitigation measures are required to conform to the Resource Management Act 1991, these measures must be described and the mitigation costs included in the economic analysis.

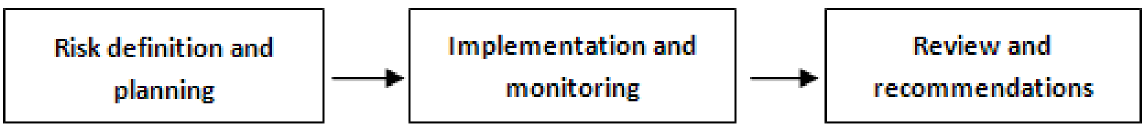
Stage 6: Undertake risk analysis for significant unpredictable events

Refer to Chapter 7 of this manual for detailed procedures on risk analysis.

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.

Figure 12: Risk analysis process



Start of project stage:

- Identify risks.
- Assess risk management strategies (reduction, mitigation, avoidance, quantification through date collection etc).
- Choose preferred strategy.

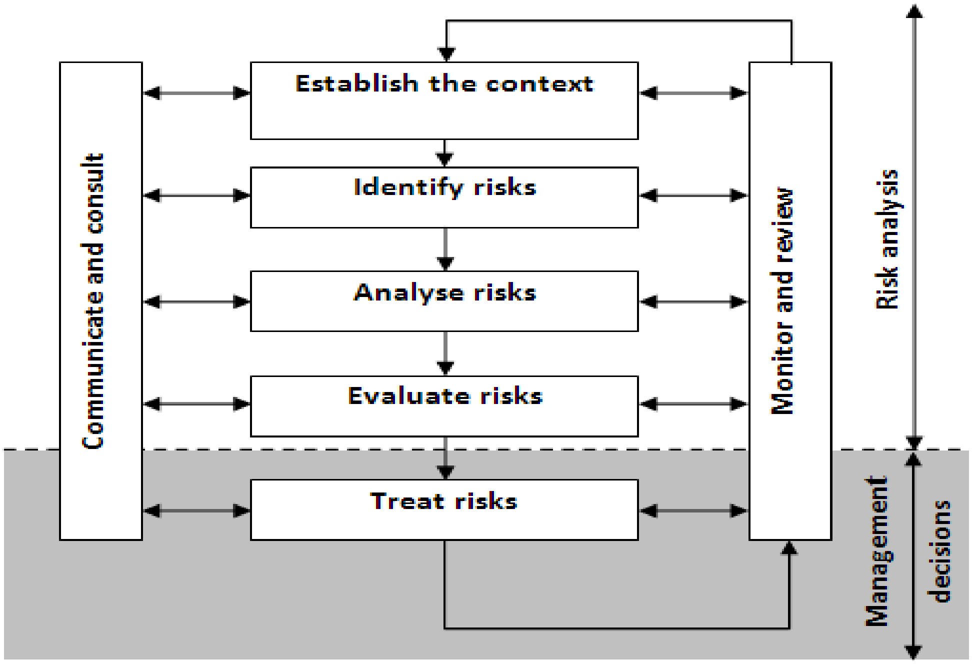
During the project stage:

- Implement preferred strategy.

At end of project stage:

- Report on outcomes of strategy.
- Assess implications for next stage of project.

Figure 13: Risk analysis steps



Stage 7: Calculate costs for do-minimum and improvement options

For road improvement activities, costs 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
- residual value.

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 analysis).

Land costs

Where land has to be acquired for road development, its resource cost shall be assumed to equate to its market value for analysis 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 analysis.

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.

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 1991 or other legislation, then the cost of the feature shall be treated as an integral part of the activity cost.
- If the feature **is 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 presented in an incremental BCR calculation.

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

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:

Table 75: Contingency allowances

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

Some long-life assets can yield benefits beyond the normal analysis period of 40 or 60 years. Normally, if the expected useful life of an asset is greater than 40 years, then the analyst can decide to use a 60-year analysis period rather than consider residual values.

The advantages of an extended analysis period diminish in significance when evaluated at a discount rate greater than 1% or 2%, such as the 4% discount rate set out as the default in this manual, where the future benefits rapidly decrease as a result of the discounting. Consequently, the future benefits beyond the analysis period are generally disregarded.

If in some exceptional circumstances there is a need to consider residual values in the BCR calculations (and advice on this approach should be sought from NZTA prior to inclusion of these values in the BCR), there are two main ways to calculate it:

- straight-line depreciation of capital costs (the most common approach)
- benefit-based methods, which estimates net benefits for the remaining life of the asset outside of the analysis period.

In the BCR calculations, the discounted residual value should be subtracted from the denominator (that is, the present value of the net project cost). If other methods regarding residual value are considered, please contact NZTA in the first instance (MBCM@nzta.govt.nz).

Stage 8: Discount benefits and costs

Refer to section 1.9 and Chapter 5 of this manual for the detailed information on undertaking discounting.

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present worth factors have been calculated to convert future benefits and costs to their present values (see Table 103, and Table A132, Table A133 and Table A134 from Appendix 6: Discount factors). Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.

Stage 9: Determine the benefit–cost ratios of the options

Refer to Chapter 6 for detailed information on developing BCRs.

Stage 10: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs

Stage 11: Sensitivity testing on the preferred option

Refer to Chapter 7 of this manual for the details on sensitivity testing.

Assessing the sensitivity of an economic analysis to critical assumptions or estimates shall be undertaken using sensitivity testing, which needs to be undertaken for the critical inputs and assumptions used to choose the preferred option.

Sensitivity testing involves defining a range of potential values for an uncertain variable in the analysis and reviewing the variation in the analysis as the variable changes within the range. This will highlight the sensitivity of the estimated final outcome to changes in input variables.

Stage 12: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

Specific types of road improvement activity

There are several types of road improvements that require specialised consideration and there are other improvements for which the analyses have been standardised, such as the standard safety intervention (SSI) toolkit of improvement activities. These later activities, including wide medians, centre and roadside barriers, etc, can be evaluated using the procedures in the Standard safety intervention toolkit available on the NZTA website.

Passing lane procedures

One of the specialised procedures that can be used is for passing lanes and details are provided in Appendix 5: Passing lanes of this manual on the analysis of the impacts of passing lanes.

4.4 Analysis of public transport service activities

The following section describes the procedures that are to be used to evaluate the economic efficiency of public transport (PT) activities. Activities may be stand-alone improvements or a component of a package or a wider programme of transport improvements.

For simpler and relatively standardised improvement activities with an undiscounted funding gap less than $15 million, simplified procedures are provided for the analysis, and these are explained below. For more complicated projects and those with an undiscounted funding gap greater than $15 million, the full procedures are provided as an alternative to the simplified procedures and are explained later in this section.

Simplified procedures for public transport services

The following simplified procedures (SPs), for a new PT service (SP9) or for improvements to an existing PT service (SP10), use a 4% discount rate and a 40-year analysis period. The capital costs of new, and improved, PT activities may extend into year two if the expected construction duration is longer than 12 months. 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.

Simplified procedures SP9 and SP10 adopt the following approaches:

- Benefits accrue to public transport users and road users.
- Public transport user benefits can include time savings, better reliability and better vehicle and PT infrastructure quality.
- Road user benefits result from reduction in road traffic, 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 greater than 80% capacity during the peak period.

The simplified procedures for PT are for the analysis of activities that have an undiscounted funding gap of less than or equal to $15 million over the first three-year period of operation. If this criteria is not met then the full procedures must be used.

The simplified 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 of the preferred option need to be included.

Refer to the Planning and Investment Knowledge Base (PIKB) for guidance on issues relating to analysis of PT activities, including selection of the preferred option using the Business Case Approach.

The simplified procedure templates provided must be used when undertaking simplified analysis. The completed templates are to be included in Transport Investment Online (TIO). The templates are standardised to allow automated uploading to and data extraction from TIO.

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

- the default figures provided
- activity specific data collected, or
- 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 procedures are based, and full procedures should be used instead.

If the analyst has any problems with the simplified procedures templates or worksheets, please contact MBCM@nzta.govt.nz.

SP9 for new public transport services

Procedure SP9 provides a simplified method of appraising the economic efficiency of new public transport services and associated capital infrastructure. The procedure assumes that benefits accrue to new public transport users and to road users.

A description of all options considered should be described in worksheet SP9-1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option need to be included.

Guidance for completing the SP9 New public transport services (template worksheets) is provided below in Table 76 and Table 77.

Table 76: SP9 New public transport services procedure template

Worksheet number	Worksheet purpose	Description
SP9-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP9-2	Service provider costs	Used to calculate the PV cost to the service provider of a new service. The cost includes capital, operation and maintenance costs.
SP9-3	Funding gap analysis	Used to determine whether the new service is commercially viable.
SP9-4	Public transport user benefits	Used to calculate the PV of public transport user benefits based on users' willingness to pay for the new service.
SP9-5	Road traffic reduction benefits	Used to calculate the PV of benefits for other transport system users
SP9-6	BCR and incremental analysis	Used for comparison of the options considered.

Table 77: Steps in the SP9 analysis of new public transport service activities

Step	Description
1	Complete items 1 to 6 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Service provider costs
3	Complete Worksheet 3 – Funding gap analysis
4	Complete Worksheet 4 – Public transport user benefits
5	Complete Worksheet 5 – Road traffic reduction benefits
6	Complete Worksheet 6 – Incremental analysis (if more than one option is considered)
7	Select the preferred option and finalise Worksheet 1 for the preferred option

SP10 for existing public transport services

Procedure SP10 provides a simplified method of appraising the economic efficiency of improvements to existing public transport services through service and/or capital infrastructure enhancements.

The procedure includes the following assumptions:

- Benefits accrue to new and existing public transport users and to road users.
- 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.

A description of all options considered should be described in worksheet SP10-1 and included in the incremental analysis; for all other worksheets, only the details for the preferred option need to be included.

Guidance for completing the SP10 Existing public transport services (template worksheets) is provided below in Table 78 and Table 79.

Table 78: SP10 procedure template

Worksheet number	Worksheet purpose	Description
SP10-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP10-2	Service provider costs	Used to calculate the PV cost to the service provider of a new service. The cost includes capital, operation and maintenance costs.
SP10-3	Funding gap analysis	Used to determine whether the new service is commercially viable.
SP10-4	Net benefits	Used to calculate the PV of benefits for new and existing PT users, as well as benefits for other transport system users.
SP10-5	BCR and incremental analysis	Used for comparison of the options considered.

Table 79: Steps in the SP10 analysis of new public transport service activities

Step	Description
1	Complete items 1 to 7 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Service provider costs
3	Complete Worksheet 3 – Funding gap analysis
4	Complete Worksheet 4 – Net benefits
5	Complete Worksheet 5 – Incremental analysis (if more than one option is considered)
6	Select the preferred option and finalise Worksheet 1 for the preferred option

Full procedures for public transport services

The full analysis procedures for PT activities are to be used to appraise the economic efficiency of activities when the simplified procedures are not appropriate or sufficient.

The primary purpose of this section of the manual is to establish the impacts of introducing new PT services or improving existing services (ie the changes that occur between do-minimum and the options) when using the full procedures. Following on from calculating the impacts, the analyst will need to assign monetary values to the impacts and then calculate the benefits and the benefit–cost ratios (BCRs).

These procedures cover the range of stages listed above, however, many of the actions for these stages are covered in greater detail in other sections or appendices of this manual and in external documents for which links have been provided. A significant focus of the PT service procedures is on the calculation of activity impacts and the service provider's funding gap, in particular stages 3 to 6 in Table 80.

These procedures are designed to calculate the impacts one at a time and then, after assigning monetary values to the impacts, they can be added together, including any disbenefits, to establish the total benefit of the options under consideration. To assist in this process a set of standardised worksheets have been developed to help guide the analyst through the economic calculations and to aid in the process of checking for completeness and accuracy.

The following table outlines the stages of analysis when evaluating the impacts of introducing a new PT service or improving an existing one. The chapters and sections of this manual that apply to each stage of the analysis are referenced in the table below.

Table 80: Stages of analysis for public transport services

Stage	Description	Refer
1	Consider and describe: a. the do-minimum b. improvement alternatives and options c. whether the improvement(s) should be part of a package and/or programme of activities.	Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Forecast the PT demand either from a transport model or by using PT demand elasticities including: • public transport direct elasticities – short run • public transport direct elasticities – by market segment • public transport direct elasticities – longer run ('ramp-up') effects • impacts of public transport initiatives on demand for alternative modes (diversion rate) • non-public transport cross-modal (diversion rate) effects on public transport travel.	Current section and Chapter 2: Demand estimation and mode share
3	Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options, including: • impact on social cost and incidence of crashes • impact of mode on physical and mental health • impact of air emissions on health • impact of noise and vibration on health • impact on system reliability • impact on network productivity and utilisation • impact on greenhouse gas emissions • impact on user experience of the transport system • wider economic benefit (productivity) • wider economic benefit (labour supply) • wider economic benefit (imperfect competition) • wider economic benefit (land use change) • other impacts that can be monetised – these are not included in this manual but can be included if there is sufficient supporting evidence and the approach is accepted by NZTA.	Chapter 3: Benefits
4	Undertake risk analysis when there are significant unpredictable events that may affect or be affected by the improvement activity.	Chapter 7: Sensitivity and risk analysis

Stage	Description	Refer
5	Calculate the costs to the government of services for the do-minimum and improvement options, including (but not exclusively): • land costs • funding assistance from government • maintenance, renewal and construction cost savings • construction costs, including property, for any additional infrastructure required • maintenance costs not already included in service contracts. Bus operating costs must also be calculated either from detailed operating cost information or the standardised values in this section.	Current section and section 1.8: Costs
6	Discount the monetised benefits and costs over the analysis period to obtain present values.	Chapter 5: Discounting
7	Calculate the funding gap and any net cost to government by: • calculating service provider costs • calculating service provider revenue • performing cash-flow analysis • calculating the service provider's funding gap • performing sensitivity tests on the funding gap analysis.	Current section
8	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
9	Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options.	Chapter 6: Benefit–cost ratios
10	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the analysis outcome(s).	Chapter 7: Sensitivity and risk analysis
11	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1a: Describe the do-minimum

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

The do-minimum must include any costs and resulting demand implications of committed transport infrastructure and PT service improvements during the analysis period. Activities are committed if they have been evaluated in accordance with the NZTA economic analysis procedures and have been approved for funding. Any investment plans that are not committed must be included in the analysis as options. Maintenance, renewal/replacement schedules and any planned public transport service changes must also be included.

Most forms of activity analysis 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 or activity may be required to maintain a minimum level of service. This minimum level of expenditure or activity and the resultant performance is known as the do-minimum and should be used as the basis for analysis, rather than the do-nothing. It is important not to overstate the scope of the do-minimum.

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.

In some situations, the do-minimum can be the most effective solution to a problem and therefore it can be the 'preferred option'.

Stage 1b: Describe the alternatives and options

Rigorous consideration of alternatives and options is a requirement of the Land Transport Management Act 2003 (LTMA). To ensure these obligations are met, evaluators should carefully articulate the problem or issue that they are seeking to resolve and avoid approaching the analysis with a preconceived solution in mind.

Alternatives are different means of achieving the same objective as a proposed activity, while options are variants of a proposed activity. These alternatives and options should not be constrained to a specific mode, or even to transport solutions, as changes to existing policy may be suitable responses to the identified problem. As a result, it may be necessary to apply other procedures contained within this manual as part of the analysis.

Stage 1c: Packages and/or programme of activities

NZTA seeks to encourage, where appropriate, approved organisations to develop packages or programmes of interrelated and complementary activities, either individually or in association with other approved organisations.

This is particularly important to ensure that a wide range of options and alternatives are considered and evaluated in full. Doing so may help avoid issues that arise from narrowing the scope too early such as:

- neglecting options that differ in type or scale, eg an extension to an existing bus route may eliminate the need to introduce a new service
- neglecting significant externalities, eg the impacts of a growth area on future demand for PT services
- inconsistencies with wider strategic policies and plans, eg generous parking policies in a CBD that undermine PT use.

If public transport options are part of a wider package, then a multi-modal analysis may be necessary. This may involve analysing public transport components and road infrastructure components separately, using the relevant procedures in this section and section 4.3, and aggregating the results.

Stage 2: Demand estimates

General guidance on travel demand forecasting and mode change estimation is provided in Chapter 2 of this manual.

For significant PT investments, realistic demand estimation is a critical first step in the analysis process. Mode change analysis using elasticities of demand may not be sufficient, and therefore it may be more appropriate to use multi-modal and multi-stage models to approximate future demand. Peer review of demand estimates will be required in these scenarios. For PT investments that are limited in scope or scale it may be appropriate to use standardised elasticities of demand. These elasticities may also be used to calibrate microscale models such as those for corridor improvements. The elasticity of demand is a measure commonly used to summarise the responsiveness of demand to changes in the factors determining the level of demand, such as the level of fares or frequency of service provided.

This section describes recommended demand elasticities for public transport travel, drawing on New Zealand, Australian and international evidence and various literature reviews. In cases of uncertainty regarding the appropriateness of analytical methods, analysts are asked to seek advice from NZTA via MBCM@nzta.govt.nz

This section of the manual includes recommended values for:

- public transport direct (own mode) elasticities, ie the effects on public transport system demand of changes in public transport attributes
- cross-modal demand effects ('diversion rates') resulting from changes in system attributes for non-PT modes, eg the effects on public transport demand resulting from changes in fuel prices or parking charges

- cross-modal demand effects ('diversion rates') resulting from changes in public transport system attributes, eg the effects on car travel demand resulting from changes in public transport service frequency.

Public transport direct elasticities and diversion rates (or cross-elasticities) to/from other modes cover changes in the following public transport attributes:

- fares
- service changes (including service frequencies, route and network redesign, etc)
- travel time (expected) changes
- travel time reliability changes, and
- overall ('generalised cost') changes.

Diversion rates (or cross-elasticities) for public transport demand with respect to changes in the attributes of other (non-PT) modes include changes in fuel prices and parking charges.

The primary focus of the recommended elasticity and diversion rate values is on 'short' run demand impacts, ie taken as patronage changes within roughly 12 months of any change in service attributes. Estimates are also provided for 'long run' elasticity values, based on expected responses after 5–10 years (or more) following any attribute change.

All evidence indicates that the market responses (represented by elasticities) can differ substantially by the time period analysed such as the time of day or day of the week. In particular, there are substantial differences between peak period and off-peak period travel, with off-peak responses themselves then differing between weekday interpeak, weekday evening and weekend periods. Recommended values for different time periods are therefore provided where available.

The research evidence indicates that underlying demand elasticities for a given attribute, market segment and time period etc show a strong similarity across urban areas in most developed countries. Given this, the elasticity values recommended in this section draw firstly on New Zealand evidence and secondly on Australian evidence, supplemented by evidence from other developed countries where appropriate (principally where the New Zealand/Australian evidence is very limited).

The basic expression of elasticity is:

E = Proportional change in demand/proportional change in explanatory variable

$= (\Delta y/y)/(\Delta x/x)$

where: Δ y is the change in the demand y, Δ x is the change in the explanatory variable x.

Point elasticity: the above definition refers to a change Δx which is vanishingly small, so may be expressed mathematically as:

$$Ep = (\partial y/y)/(\partial x/x) = (\partial y/\partial x).x/y$$

This elasticity represents the slope of the demand curve ($\partial y/\partial x$) at a particular point multiplied by the ratio of the explanatory variable (x) to the level of demand (y) at this point.

This is referred to as a point elasticity measure, representing the elasticity only at a particular point on the demand curve. In practice, point elasticities cannot be computed from empirical data unless the shape of the demand curve is known (or postulated) and its parameters may then be estimated from the observed data. Therefore, other elasticity formulations, which do not require the slope of the demand curve are often applied.

Arc elasticity: The arc elasticity concept is frequently employed in practical analysis, to estimate the elasticity from observations for two points on the demand curve: for small changes it approximates the point elasticity. If we assume a constant elasticity demand function over the range of change, the arc elasticity can then be calculated as:

$$E_A = \frac{\Delta \ln y}{\Delta \ln x} = \frac{\ln y_2 - \ln y_1}{\ln x_2 - \ln x_1} = \frac{\ln(y_2/y_1)}{\ln(x_2/y_2)}$$

This is equivalent to $(y_2/y_1) = (x2/x_1)^E$, consistent with the constant elasticity demand function:

$$Y = k.(x)^E$$

When applying the elasticity approach to public transport systems, the dependent variable is the demand or patronage (P), while the independent variable is the attribute of the system that is being varied, eg service level or fares (S). Hence the formula for the elasticity of patronage with respect to service frequency is expressed as:

$$E = ln\ (P_2/P_1)/ln\ (S_2/S_1)$$

This (natural) logarithmic (ln) function has a number of advantages over alternative elasticity functions for analysis and application purposes.[12] It also assumes that the demand elasticity is constant over the range of changes under consideration. While this assumption is open to significant debate, it provides a reasonable approximation except possibly in situations of very large changes in the independent variable (eg fares or service levels).[13]

There are common issues that can arise during the estimation and application of elasticities. Table 81 provides some advice to assist analysts in estimating the patronage impacts, and hence demand elasticities, from PT initiatives that have been or are being implemented. This advice is also relevant to forecasting the likely impacts of initiatives being considered for implementation.

Table 81: Issues in elasticity estimation and application

Issue	Comments
1. Demand effects by route versus corridor	Improvements in services (eg increased service frequencies) on a single route will generally result in some existing PT passengers switching from broadly parallel routes, such that the net system patronage increase may be substantially lower than the increase measured on the route in question. Any patronage and elasticity analyses need to cover a sufficiently broad corridor to cover all routes likely to be affected.
2. Demand effects by PT mode	This is a particular case of the issue above. For example, in a case where train fares are increased relative to bus fares in a given corridor, if only the change in train passengers is measured, an apparently very high fares elasticity may well result. But the overall PT fares elasticity may be much smaller, as a large proportion of the loss in train patronage may switch to the parallel bus routes.
3. Demand effects by time period	If services are improved at a particular time period, measurement of the patronage changes only at that time period may under-state or over-state the overall effects on patronage: some of the additional passengers resulting from the service improvements may switch from travelling at other time periods; but some may also make additional trips (eg return trips) at other time periods. Generally, the latter effect is likely to be dominant, but any before versus after surveys need to be of sufficient scope to assess the overall impacts.
4. Timescale of demand impacts	This is discussed in detail in stage 2b and demonstrated in Figure 14. In general, an ‘after’ survey 6–12 months following introduction of most types of initiative (if preceded by an appropriate ‘before’ survey, and allowing for any seasonal effects), should provide a good guide to the shorter-term and potentially the medium- and longer-term effects of an initiative.
5. Use of control groups	In general, any analyses to estimate the patronage impacts of PT initiatives should make use of control groups, so as to enable adjustment of results for any patronage changes through the analysis period which may have been independent of the initiative being analysed. In cases of doubt, the analyst should seek advice on the selection and analysis of suitable controls.

[12] A significant advantage is that, if S varies from S1 to S2 and then S3, the patronage estimates will be consistent whether the change from S1 to S3 is calculated directly or via S2; and similarly, if S varies from S1 to S2 and then back to S1, the formulation will show zero net patronage change.
[13] The evidence indicates that fare and service elasticities tend to increase with higher fares and with higher service headways (lower frequencies).

Stage 2a: Public transport direct elasticities – short run

In the majority of situations, analysts will be interested in applying elasticities to estimate the effects on public transport demand of changes in a single attribute (eg fares, service frequency, travel time). A set of overall (short-run) elasticities for this purpose is provided in Table 82.

The 'generalised costs' (GC) of a journey represent the weighted sum of all the separate journey attributes, usually on a door-to-door basis (eg walk to bus stop, wait for bus, time on bus, time walking to destination, fares paid). For estimating demand impacts, the GC approach is often preferable to the individual elasticity approach as it gives more consistent results over a range of situations. The empirical evidence is that GC elasticities appear to be sensibly constant (for a given market) over a wide range of journeys with different component costs and elasticities; on the other hand, individual component elasticities tend to vary according to the proportionate contribution of the component to the total generalised cost (eg in situations where fares are relatively high, the corresponding fares elasticity is likely to be high).

The following points should be noted:

- Elasticities are generally sensitive to the market segment under consideration, particularly in terms of the time period (peak, off-peak, etc) to which any attribute changes apply. Disaggregation of elasticity values by time period and other market segments is provided in Stage 2b below. The Table 82 values should generally only be used for assessing attribute changes applying 'across the board', or where specific time period changes are not defined.
- The same elasticity estimates (eg as in Table 82) may be applied for all urban public transport modes: the evidence indicates that there are minimal intrinsic differences between elasticities for different PT modes, other than those relating to trip lengths, service frequencies etc.
- Fare elasticities should always be applied in real terms, ie after adjusting nominal fares before and after a fare's change for any effects of inflation.

One convenient property of generalised costs is that the generalised cost elasticity for a journey is the absolute sum of all the elasticity estimates for the individual journey components. Table 82 includes a best estimate GC elasticity of -1.30: it is seen that this is approximately equal to the sum of the absolute values of the component elasticities.

Table 82: Overall (short run) direct elasticity estimates (at 12 months after service etc change)

Attribute	Overall best estimate[a]	Typical range[b]
Fare levels[c,d]	-0.35	-0.2 to -0.6
Service levels[e]	+0.45	+0.2 to +0.7
In-vehicle time[f]	-0.40	-0.1 to -0.7
Total generalised cost[g]	-1.30	-0.8 to -2.0

Notes:

a. These are best estimate short-run elasticities for each attribute for typical urban public transport journeys, averaged over all market segments and time periods. More disaggregated estimates, as given in Table 83 should be used where information is available. Positive values indicate that demand increases when the attribute increases; negative values indicate the opposite (eg fare increases result in reduced demand). The 'short-run' here refers to the impacts roughly 12 months after the change in the service attribute.
b. Represents the typical range of elasticity values found across different locations and market segments/time periods (refer Table 83 for further details).
c. All fare elasticity estimates relate to fare changes in **real terms** (ie after netting off any effects of inflation on fare levels).
d. In situations with competing PT modes or services, the estimates given here assume that the fares on all such modes/services are adjusted in the same proportions (ie these are 'conditional' elasticities).

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e. The service level attribute is often calculated as the number of in-service bus kilometres in the area of interest. For situations where the route structure is unchanged but the levels of service on the existing routes are adjusted, the service frequency (number of bus trips per hour) may be taken as the measure of service level.
f. In-vehicle time may be taken as being the time that the 'typical' passenger spends on the service, between initial vehicle boarding and final vehicle alighting.

In practice, the total generalised cost may not always include all journey attributes, depending on the attributes of interest (ie the elasticity may be subject to change).

Stage 2b: Public transport direct elasticities – by market segment

This section provides disaggregated information on the variation of typical (short-run) elasticities for fares, service levels and in-vehicle time (as given in Table 82) by trip characteristics, service characteristics and type of service change (refer Table 83 below).

Note: Table 84 provides additional information disaggregating fares and service level elasticities between peak period and off-peak periods, relative to the all periods average elasticities as in Table 82. Weekday off-peak elasticities are around twice peak period elasticities and weekend elasticities are generally higher than weekday off-peak values. It is recommended that the Table 82 relativities be used in the absence of any segment-specific information.

Table 83: Summary of evidence on component elasticities for key variables

Aspect	Elasticity variable		
	Elasticity variable	Aspect	Elasticity variable
Trip purpose/ time period	Off-peak/non-work typically about twice peak/work; weekend most elastic	Off-peak/non-work typically about twice peak/work; weekend most elastic (may be partly due to frequency differences)	Inconclusive re relative elasticities, although most evidence is that off-peak is more elastic than peak
Mode	Bus elasticities typically somewhat greater than rail (but largely reflects shorter bus trip lengths)	No evidence of significant differences (apart from variations with headway)	Bus elasticities typically lower than rail (reflecting longer trips by rail with in-vehicle time a greater proportion of generalised costs)
Base level of variable	Elasticities increase with base fare level, but less than proportionately	Elasticities increase with headways, but less than proportionately. Typical values are around 0.2 for frequent services (10 mins or better), increasing to around 0.5–0.6 for infrequent services (hourly or less)	No firm evidence, although expect elasticities to increase with proportion of total trip (generalised costs) spent in-vehicle
Trip distance	Highest at very short distances (walk), lowest at short/medium distances, some increase and then decrease for longest distances (beyond urban area)	Highest at short distances (walk alternative)	Limited evidence – longest trips more elastic than short/medium distance trips
City size	Lower in larger cities (over 1 million population) – US evidence	Higher in larger cities – EU evidence	No evidence
Magnitude of change	No significant differences in elasticities with	No significant differences in elasticities with magnitude of change (most studies)	No evidence

Aspect	Elasticity variable		
	Elasticity variable	Aspect	Elasticity variable
	magnitude of change (most studies)		
Direction of change	No significant differences for fare increases and decreases (most studies)	Evidence indicates no significant differences between service level increases and decreases	No evidence

Notes:

- **Trip purpose/time period.** Strong systematic variations in elasticities exist between trip purposes and time periods (these two aspects being strongly correlated for all three variables).
- **Mode**. The literature indicates some differences between modes, for all three variables. However, these differences appear largely to reflect differences in other attributes (eg trip length, service frequency) rather than being intrinsic to the different modes.
- **Base level of variable**. Both fare elasticity and service elasticity vary strongly, although rather less than proportionately, with the magnitude of the base fare or service frequency. This is particularly significant in regard to service frequencies: a typical service elasticity would be around 0.2 at high frequencies (every 10 minutes or better) increasing to around 0.5 or 0.6 or more at lower frequencies (hourly or longer). These variations are broadly consistent with a constant generalised cost elasticity formulation.
- **Trip distance**. Elasticities vary in a complex way with trip distance: this can be explained, in part, by the availability of substitutes, with high elasticities for short trips having the alternative of walking and, in part, by the importance of the component measure in the total trip generalised cost.
- **City size**. Elasticities vary with city size, although the fare effect and the service level effect appear to be opposite. However, data relating to this issue is rather limited.
- **Magnitude and direction of changes**. Most studies show no significant differences in fare elasticities between fare increases and decreases, or between large and small fare changes. Similarly, the limited evidence on service elasticities suggests no significant differences in elasticities between service increases and decreases, or between large and small service changes.

Table 84: Typical fare and service level (short-run) relative elasticities by time period

Time period	Elasticities relative to overall average	
	Service levels	Fares
All	100	100
Weekday peak	65	75
Weekday interpeak	100	110
Weekday evening	130	
Weekend interpeak	150	150
Weekend evening	210	n/a

Sources: Wallis (2004), Wallis (2013)

Notes:

- Figures relative to the all-periods averages given in Table 82.
- The literature indicates some differences between modes, for all three variables. However, these differences appear largely to reflect differences in other attributes (eg trip length, service frequency.

Stage 2c: Public transport direct elasticities – shorter and longer run effects

Strategic transport demand models generally assume that travel demand changes to a new equilibrium level instantaneously in response to changes in the road network, public transport fares, etc. However, this assumption is far from valid in practice. Typically, in the case of public transport services, infrastructure, and fare changes, there is a rapid initial patronage response to the change, which then continues to grow over time but at a gradually decreasing rate. The elasticity values in the prior sections apply to the situation 12 months after the introduction of the change. This section outlines the extent of demand responses (relative to the 12-month values) expected within both the initial 0–12 month period and the ongoing subsequent responses, up to five years or longer.

The term ’ramp-up‘ is often applied, for public transport (and other modes) initiatives, to the pattern of demand growth over time from the introduction of an initiative until the demand reaches its ‘equilibrium’ state (typically after five years or more). This ’ramp-up‘ effect refers only to the underlying growth in demand towards equilibrium; any other changes that may occur over the ramp-up period (eg as a result of changes in demographic or economic factors, or in the transport system) need to be addressed separately and, as appropriate, added to the ramp-up effect.

NZTA and Australian research (MRCagney and Ian Wallis Associates 2012; and Wallis 2013) found that patronage ‘ramp-up’ profiles follow a saturation curve pattern, with the ‘sharpness’ of the curve being dependent on the type of initiative. The saturation curve that best fits the data in most cases is of the following form:

$$Q_t = Q_S * t/(B + t)$$

Where: t = time since introduction of the initiative

Q_S = estimated patronage impact (growth) at equilibrium situation (‘saturation’)

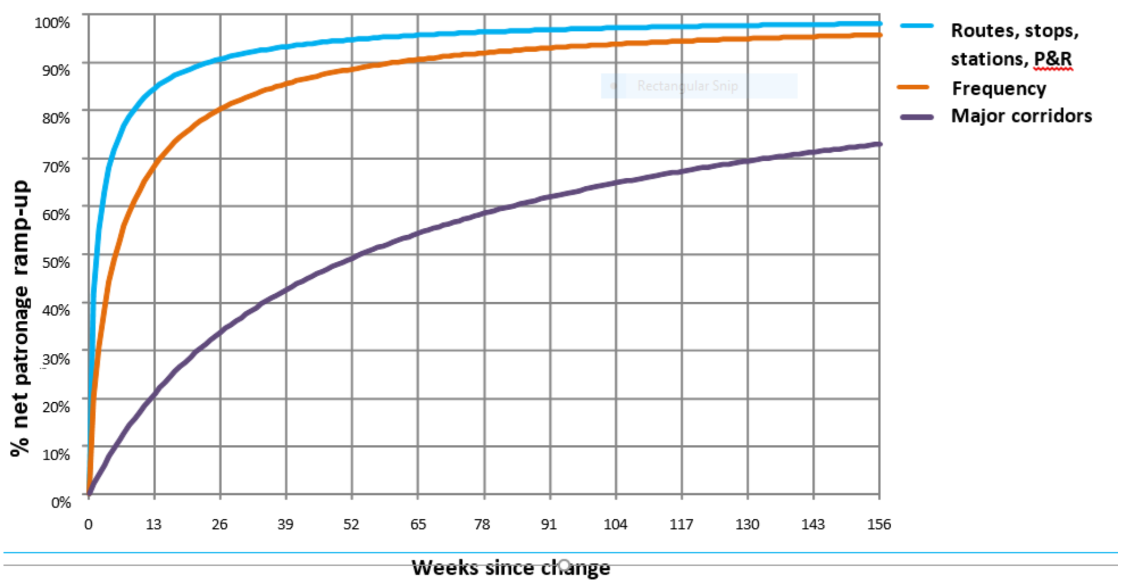
Q_t = patronage impact at time t

B = constant (reflecting the ‘sharpness’ of the saturation curve, dependent on the type of initiative). B represents the time at which patronage growth in response to an initiative reaches 50% of its saturation level (when $P_t/P_S = 0.5$, t = B).

Figure 14 shows typical ramp-up profiles for each of the following categories of public transport initiatives analysed for up to three years (156 weeks) following their introduction:

- route and connectivity changes (all PT modes, including multi-modal) – including new routes, route variations, new/upgraded stops and stations, park and ride facilities (upper curve in Figure 14: B = 2.2 weeks)
- service frequency changes on existing routes (principally bus mode) – both increases and reductions (middle curve in Figure 14: B = 6.1 weeks)
- major corridor initiatives (all modes) – including large-scale bus and/or rail corridor improvements, typically with substantial infrastructure components (lower curve in Figure 14: B = 54.9 weeks).

Figure 14: Typical public transport patronage ramp-up profiles from service changes



Source: MR Cagney and Ian Wallis Associates (2012)

For each of the typical profiles Table 85 sets out the numerical data represented in Figure 14:

- The 'B' value (ie the number of weeks at which the patronage growth reaches 50% of its estimated saturation level). This varies from some two weeks for category A schemes up to 55 weeks for category C schemes.
- The proportion of the equilibrium (*saturation) patronage growth* that occurs by the *end* of each quarter or year, for up to 3 years from scheme introduction (data given in the first column under each initiative category).
- The proportion of the ***12 months/52 weeks patronage growth*** that occurs by the ***end*** of each quarter or year (data given in the second column for each category). These percentages should be applied to the short run (12 months) elasticity estimates given in Table 83 and Table 84 to derive estimates required for any specific time horizon following scheme implementation.
- The saturation (long run) patronage changes forecast relative to the 12-month changes (data given in bottom row of table). It is seen that these are 104% (ie 4% more than the 12-month figure), 112% and 206% for the three categories.

Table 85: Patronage ramp-up profile data by category of initiative

	Initiative category					
		1. Route and connectivity changes[a]		2. Service frequency changes[b]		3. Major corridor initiatives[c]
'B' value (weeks)		2.2		6.1		54.9
	% of saturation	% of end year 1	% of saturation	% of end year 1	% of saturation	% of end year 1
End Q1 (13 weeks)	85	89	69	77	21	43
End Q2 (26 weeks)	91	96	80	90	34	69
End Q3 (39 weeks)	93	98	86	97	43	88
End year 1 (52 weeks)	95	100	89	100	49	100
End year 2 (104 weeks)	97	102	94	106	65	133
End year 3 (156 weeks)	99	104	96	108	73	149
Saturation	100	104	100	112	100	206

Source**:** MRCagney and Ian Wallis Associates, 2012

Notes:

- Includes new, extended and realigned routes, new/upgraded bus/train/ferry stops, stations and park and ride.
- Includes service frequency changes (increases and reductions).
- Includes large-scale bus and rail improvements in metropolitan/urban areas.

It is notable that the weight of international evidence in the economic literature is that long-run (ie saturation) elasticities are typically around twice (in the range 1.5 times to 3.0 times) the short-run (typically 12 months) values (Balcombe et al 2004; Wallis IP 2004). It is evident from the last point above that this ratio appears to be valid for the major corridor initiatives (category C – factor 2.06), but that the long-run: short-run ratios are very much less than this for the other two categories (category A 1.04, category B 1.12).

The ramp-up profiles recommended in this section are based primarily on experience with bus service and bus/rail infrastructure changes – very limited evidence is available for other types of PT enhancements. In the absence of better information, we recommend that for:

- **fare changes** – adopt the category B ramp-up profile
- **major service changes** – adopt category C ramp-up profile.

Stage 2d: Impacts of public transport initiatives on demand for alternative modes (diversion rate)

Where public transport services are improved, the additional patronage attracted to the public transport system may be estimated by various methods, including the use of direct demand elasticities (as outlined in stages 2a and 2b). This section addresses the sources of this increased patronage (demand), in terms of the previous mode of travel of the 'mode switchers'.

Additional patronage may originate from a variety of prior modes and other sources, principally:

- previous car use (as driver or passenger) for the trip in question
- previous active mode use (as pedestrian or cyclist)
- 'pure' generated trips also known as 'induced demand' (ie the same or a similar trip would not have been made at all without the public transport improvements).

Two alternative approaches (simple 'models') are often used to estimate cross-modal demand effects of public transport initiatives. These involve the application of:

- diversion rates, or
- cross-elasticity relationships.

The 'diversion rate' approach, as described below, is considered more appropriate for application here.[14]

The 'diversion rate' to/from an alternative mode resulting from public transport initiatives is defined as the proportion of the 'new' public transport passengers who previously made the trip in question by the specified mode (eg as car drivers). In this context, the 'new' public transport passengers are those who did not previously use public transport for their trip.

Research following the implementation of major urban public transport initiatives internationally (including several projects in New Zealand and Australia) reached the following findings on the previous modes of travel for users of these new initiatives:

- some 60%–70% of the new initiative users would have previously made the same or similar trip by public transport
- for the remainder of the new initiative users their previous modes of travel are as summarised in Table 86.[15]

These findings relate to typical results for major public transport initiatives. In addition, it should be noted that:

- For public transport initiatives particularly oriented to attracting motorists, higher car driver diversion rates are appropriate. These include initiatives such as park and ride facilities and express bus services, each with diversion rates from car drivers of over 50% and in some cases as high as 70–80%.[16]
- For those public transport initiatives with a more 'social' focus, lower car driver diversion rates are appropriate. These include off-peak fare schemes and suburban bus route enhancements. For such schemes, the diversion rates from car driver may be as low as 20–30%.

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[14] More information on the two approaches, their inter-relationships and their relative merits are given in Wallis (2004).

[15] More details of international research findings on this topic are given in Australian Transport Assessment and Planning (2018a).

[16] Initial research following the opening of the Auckland Northern Busway found that 56% of the busway users had previously used other public transport services in the corridor, 44% were new public transport users for the trip in question. Of this latter group, around 90% were previous car users (of which three-quarters were car drivers, one-quarter car passengers).

Table 86: Prior modes of new public transport passengers resulting from urban public transport initiatives

Prior mode	% of new PT trips	Notes
Car (driver/passenger)	c.50%	Approximately 75% of these previously car drivers, 25% previously car passengers.
Active modes (walk, cycle, etc)	c.10%–15%	Depends very much on characteristics of the PT initiative.
Other modes	c.10%–15%	
Did not make equivalent trip	c.20%–25%	
Total new PT trips	100%	

Note: The above should be taken as a guide only. Given the considerable range of results round in the literature, it is recommended that the evaluator should consult with NZTA staff where good estimates of the previous modes of new users of a public transport scheme are significant to the overall analysis.

Stage 2e: Impacts of car travel cost changes on public transport demand (diversion rate)

This section provides advice and recommendations on the proportion of previous car users changing their travel mode in response to changes in car travel costs who switch to/from public transport. Car travel costs in this context include fuel prices, other car operating costs, parking charges, toll charges and car travel (in-vehicle) time.

As in the previous section, the focus is on diversion rates between car and alternative modes rather than cross-elasticity values, but estimates are provided for the public transport mode only (ie the proportion of deterred car users who switch to public transport). These estimates can provide the basis for sensitivity tests on how forecasts of public transport patronage would be affected by plausible changes in car travel costs. Table 87 provides recommended values for the diversion rates to/from public transport in response to changes in the various car travel cost components. The following comments may assist in interpretation of these recommendations:

- Diversion rates are sensitive to two main factors:
  1. The 'competitiveness' of the public transport service offered relative to car travel. For example, much higher diversion rates apply to CBD-oriented trips than to typical inter-suburban trips.
  2. The ’trip purpose‘, where work trips typically have diversion rates around twice those for non-work trips. In practice, the trip purpose/time period effect and the public transport service effect are difficult to separate.
- Diversion rates are lower than average for shorter trips (where walking and cycling are competitive modes), and higher for longer trips (where any car cost changes, eg resulting from increases in fuel prices, comprise a relatively high proportion of the total trip generalised costs).
- Diversion rates for time components are believed to be lower than for cost components (although evidence is limited on this point).
- Long-run and short-run diversion rates are assumed to be similar, although the evidence on this is inconclusive: it seems likely that, in the longer run, the public transport diversion rates tend to reduce, as people may well be able to take advantage of a wider range of behavioural changes (eg change in home or employment location).

It is assumed that these diversion rates are equally applicable to increases and decreases (in real terms) in car travel time and costs, although there is little evidence on this point.

Table 87: Recommendations on diversion rates to/from public transport from changes in car travel costs

Car travel cost variable	Typical diversion rates (% of deterred car users switching to PT)	Comments on estimates by market segment
Fuel price/ vehicle operating costs	30%	• Long versus short run: inconclusive, assume equal • Time period/purpose: peak/work proportion approx. twice off-peak/ non-work proportion • PT service quality: higher proportions where high level/ quality of PT service • Trip length: higher for longer trips, lower for shorter trips
Toll charges	c.40%	• Proportions depend on nature of scheme (all day versus peak only, etc) and location (primarily CBD trips, all trips, etc.) • For area-wide/all-day scheme, would expect similar diversion rates as for fuel prices/VOC
Parking charges	Dependent on market segment	• Regional CBD, work trips: 75% • Regional CBD, non-work trips and suburban CBD work trips: 50% • Other areas: not defined, likely to be much lower.
In-vehicle time	20%	• As for fuel prices/VOC (above).

Source: Wallis (2004)

Back to 2.2 Forecasting demand: procedures for travel behaviour change activities >>

Stage 3: Calculate public transport improvements impacts

This section provides guidance on the calculation of impacts on public transport users, arising from activities that change the attributes of public transport services or infrastructure, and the impact of diverted road traffic on the wider network. Impacts for all other modes should still be calculated on the route, network and/or transport system, by quantifying, for the do-minimum and options, the changes that occur for the factors listed in the stages below when an improvement option is considered.

Note that the impact calculations should include any negative impacts (disbenefits) during implementation/construction.

Public transport user impacts can be calculated by estimating the ‘consumer surplus’. This quantifies the economic benefits or disbenefits experienced by PT users after fare revenues have been accounted for. Consumer surplus therefore measures the total economic value of the service to passengers.

Consumer surplus benefits can be supplemented or supplanted, where this is justified, to take into account the calculation of PT user benefits arising from reduced journey time, improved service frequency, interchange time reductions, and reliability improvements. Public transport service user time savings are based on the mode-neutral values of value of time (VoT) by trip purpose in Table 14 of this manual. Depending on circumstances, it is possible for VoT increments for congestion and standing to both apply to public transport services.

Specific care needs to be taken when calculating reductions in waiting time from increased service frequencies or changes to transfer times between services, as the VoT is modified according to specific weights for the perceived effect of these reductions.

For other types of non-price public transport aspects, such as improvements to trip quality, greater comfort and better facilities, user benefits are based on attribute values which represent the amount of in-vehicle time (IVT) each attribute represents.

The benefits that have currently (2020) been ascribed standardised monetary values are listed below. The impacts (ie the differences in the parameter outcomes between the do-minimum and the options) are ascribed monetary values in Chapter 3 of this manual in the list of stages required to complete an economic analysis and calculate a BCR.

Parameters other than those listed below can be monetised, but the process and values ascribed to these parameters must be agreed with NZTA in writing before they are included in the analysis and supporting information to validate the inclusion of these parameters must be provided.

Stage 3a: Impact on social cost and incidence of crashes

For the purposes of this manual, a crash is a transport related event involving one or more road vehicles that occurs on the transport network that results in personal physical injury and/or damage to property. Where road traffic is diverted onto new or improved PT services there is likely to be a reduction in the quantum of crashes.

To undertake a crash analysis, the appropriate crash rates, crash prediction models and crash reduction factors can be found in the NZTA *Crash estimation compendium* (2024).

Refer to section 3.1 and Appendix 2: Crash analysis of this manual for detailed information on the calculation and monetisation of crash numbers and severities for the do-minimum, alternatives and options, and the crash reductions that can be expected from the alternatives and options under consideration.

> For incremental service improvements, or where a new service is limited in scope, it may be appropriate to use the compound road traffic reduction benefit value from Table 39 or Table 40, which includes an allowance for a reduction in crashes per kilometre of vehicle traffic removed from the network.

Stage 3b: Impact of air emissions on health

Vehicle emissions are a complex mixture of gases and particulates, and in terms of human health the primary harmful air pollutants that cause adverse health effects and have local impacts are particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and hydrocarbons (HCs).

Nitrogen dioxide (NO_2) is a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with increasingly more serious health effects, including reduced life expectancy (Kuschel et al 2022). Particulate matter (PM_{10}, which is smaller than 10µm), impacts predominantly on respiratory and cardiovascular systems. Effects can range from reduced lung function, increased medication use and more hospital admissions, through to reduced life expectancy and death.

Refer to section 3.3 of this manual for information on the calculation and monetisation of the impacts of vehicle emissions, including those generated by PT vehicles with internal combustion engines, on human health.

Stage 3c: Impact on greenhouse gases (GHG)

Greenhouse gases are pollutants which cause global warming and impact globally eg carbon dioxide (CO_2), black carbon (BC) and methane (CH_4)

Note: Several harmful pollutants (especially BC) are direct climate pollutants, in that they have a direct warming effect on the atmosphere. However, many of the remaining harmful pollutants, eg sulphur dioxide (SO_2) and carbon monoxide (CO) are indirect climate pollutants. This means they do not warm the atmosphere themselves but react with other gases to increase greenhouse gas concentrations. Therefore, initiatives which address harmful air pollutants typically yield both health and climate change benefits.

Refer to section 3.4 of this manual for information on the calculation and monetisation of greenhouse gas emissions.

Stage 3d: Impact of noise and vibration on health

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 reduced 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.

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.

Refer to section 3.5 of this manual for information on the calculation and monetisation of the impacts of noise and vibration on human health.

Stage 3e: Impact on network productivity and utilisation

Changes in travel time estimation

Travel times for PT services may be estimated according to the procedures in Appendix 3: Traffic data and travel time estimation of this manual. These procedures will be most suitable when the PT services are expected to share lane capacity with other road users and a model is not available.

Definitions for classifying traffic data and default traffic data values are also provided in Table A45, Table A46 and Table A47. 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 Appendix 1: Demand estimation methods and guidance and Appendix 3: Traffic data and travel time estimation.

The stages for estimating travel time

The flow chart in Figure 15 shows the basic stages for estimating road section travel time when PT services are expected to share lane capacity with other road users. Note that the stages are slightly different for intersections.

Use of transportation models

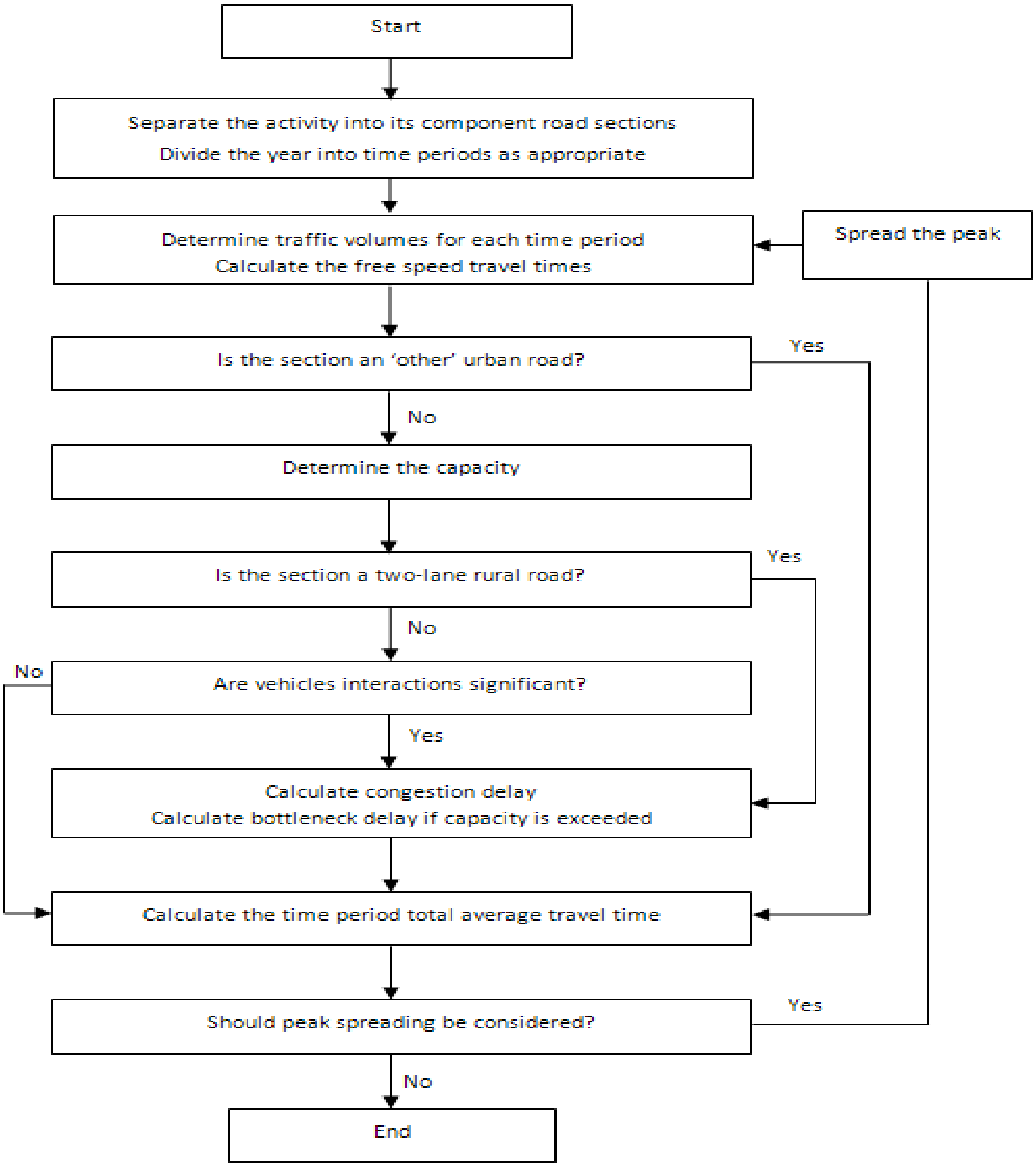
When a transportation model is used for activity analysis, the model shall have been satisfactorily validated on both traffic volumes and travel times. Checklists for validating transportation models are provided in the Transport modelling checks worksheet.

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 the procedures in Appendix 3: Traffic data and travel time estimation during analysis. To adhere to this, it is suggested that the functions implied by the procedures be used as a starting point, and modified as necessary to get a satisfactory validation.

Note that, wherever practical, measured travel time information shall be obtained in preference to the default values given in the tables in this manual.

Refer to Appendix 1: Demand estimation methods and guidance and Appendix 3: Traffic data and travel time estimation of this manual, which sets out the procedures for estimating travel times for the do-minimum and the options for various road and intersection types.

Figure 15: Flow chart for estimating road section travel time



Changes in time spent waiting for services

In addition to standard travel time savings, PT service users may also experience changes in the time spent waiting for a service to arrive when service frequencies are improved, or changes in the amount of time that it takes to transfer between services when facilities are improved. These are known as 'increased service frequency' and 'interchange reduction' benefits respectively.

Both increased service frequency and interchange reduction benefits may be added to the journey time benefits. Specific procedures for calculating the additional benefits are outlined within section 3.6. These procedures must be applied to calculate increased service frequency and interchange reduction benefits as the value of time is weighted to account for users' perceptions of the time spent waiting.

Vehicle operating costs

Vehicle operating costs (VOC) are 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. VOC 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.

Refer to section 3.6 of this for information on the calculation and monetisation of vehicle operating costs.

For incremental service improvements, or where a new service is limited in scope, it may be appropriate to use the compound road traffic reduction benefit value from Table 39 or Table 40 which includes an allowance for a reduction in vehicle operating costs per kilometre of vehicle traffic removed from the network.

Stage 3f: Impact on system reliability

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 when calculating the travel time values (including congestion values).

Trip journey time reliability is a different type of variability, which is much less predictable to a transport system user. For example, car drivers who make a particular journey at the same time every day find some days it takes as little as 20 minutes, and on other days as much as 40 minutes. Hence, when the car drivers plan their trips, they have to consider not just the expected travel time but also its variability.

PT service users may experience trip journey time reliability impacts while waiting for a service to arrive, while they are on board a service, or a combination of both. For this reason, specific procedures exist to calculate PT journey reliability benefits, taking into account the differences in the perception of service delays when waiting for the service and while on board the service.

Refer to section 3.7 of this manual for information on the calculation and monetisation of reliability impacts.

Stage 3g: Impact of user experience of the transport system

Public transport users value infrastructure and vehicle features. In addition, a new level of demand as the result of PT improvement might not be ideal for existing users and should be measured as a disbenefit.

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.

Section 3.8 provides a methodology for calculating impacts on PT user experience when vehicles or facilities are improved. The impact of these improvements is expressed as ‘in-vehicle time’, which is equivalent to the number of minutes of travel time that would need to be saved to equal the value of the improvement. This allows monetisation to occur using the value of time.

Refer to section 3.8 of this manual for the monetisation of PT user experience impacts.

Stage 3h: Wider economic benefits

Only the most significant PT infrastructure improvements are likely to generate wider economic benefits (WEBs). Generally, these would need to change the distribution or density of households and firms within a major metropolitan area and deliver significant improvements in PT accessibility in order for wider effects to arise.

Refer to sections 3.9 to 3.13 of this manual for information on the calculation of wider economic benefits.

WEBs are impacts that can result from transport investment. They can be thought of as impacts that are additional to the conventional benefits to transport users, and they can be both positive and negative. WEBs include changes to productivity including agglomeration impacts, employment impacts, and output changes under imperfect competition, and land use changes.

Great care is required to ensure that the estimates for WEBs 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 WEBs for increased productivity have to be additional to these direct user benefits.

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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 WEBs 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.

New Zealand application of WEBs

The following wider economic benefits are applicable to PT activities 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.

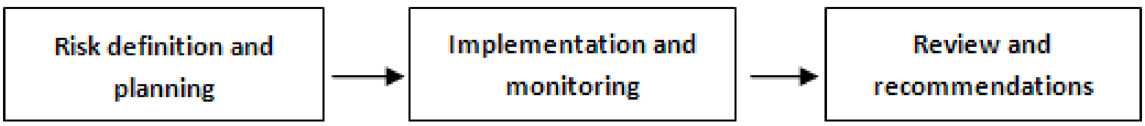
Stage 4 – Undertake risk analysis for significant unpredictable events

Refer to Chapter 7 of this manual for detailed procedures on risk analysis.

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.

Figure 16: Risk analysis process



Start of project stage:

- Identify risks.
- Assess risk management strategies (reduction, mitigation, avoidance, quantification through date collection etc).
- Choose preferred strategy.

During the project stage:

- Implement preferred strategy.

At end of project stage:

- Report on outcomes of strategy.
- Assess implications for next stage of project.

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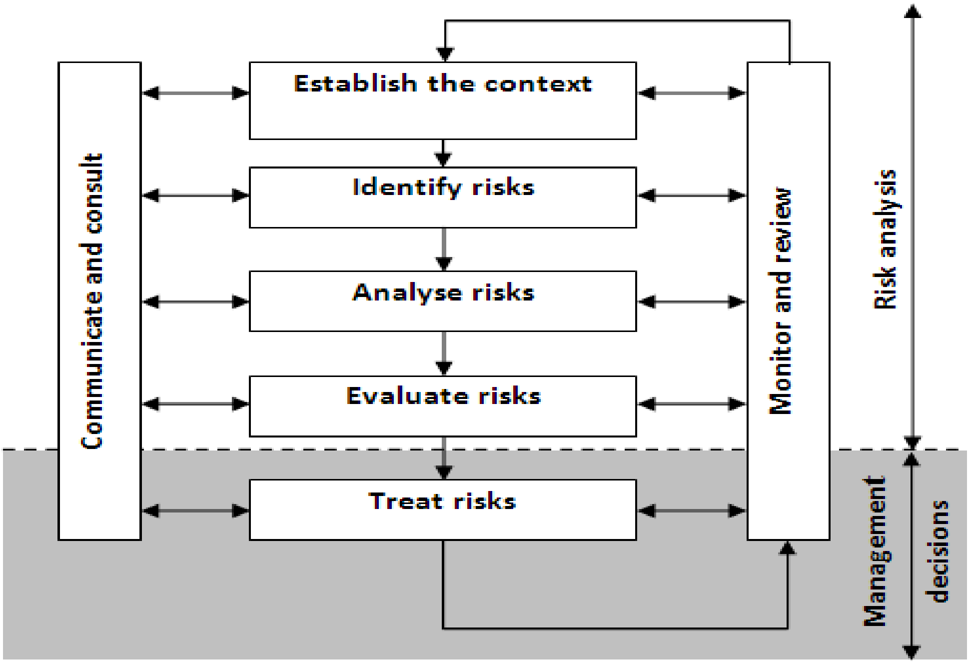
Figure 17: Risk analysis steps



Stage 5a: Calculate general costs of public transport do-minimum and options

The costs to government of services include:

- funding assistance from government
- maintenance, renewal and construction cost savings
- construction costs, including property, for any additional infrastructure required
- maintenance costs not already included in service contracts.

Land costs

Where land has to be acquired for PT infrastructure, its resource cost shall be assumed to equate to its market value for analysis purposes.

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.

Road maintenance, renewal and construction cost savings

Some service proposals will provide a cost saving to government if future planned road construction costs are avoided. Cost savings may also occur if there is a reduction in road maintenance and renewal expenditure from traffic being removed from the network by the implementation of new PT services.

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 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 are significant road traffic reduction benefits associated with the transport service proposal.

Stage 5b: Calculate bus operating costs:

Where detailed operating cost information is not available, the following standardised bus unit operating cost rates and guidance may be used to calculate operating costs. The operating costs specifically exclude any infrastructure costs.

Costing variables and categories

Bus operating costs can be calculated based upon the following three variables, which are summarised in Table 88:

- 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 88: Bus 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).
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 administration costs or system facility costs, such as passenger information and enquiry services, that fall upon any local or regional authority.

A description of the main bus unit cost categories and their associated variables are set out in Table 89.

Table 89: 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 and 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

Unit cost values

Table 90 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 90 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:

- between diesel buses and trolley or electric buses, and
- for diesel buses of 'non-standard' sizes.

Table 90: 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 GVM); 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).

Stage 6 – Discount benefits and costs and calculate BCRs

Refer to section 1.9 and Chapter 5 of this manual for the detailed information on undertaking discounting.

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present worth factors have been calculated to convert future benefits and costs to their present values (see Table 103, and Table A132, Table A133 and Table A134 from

Appendix 6: Discount factors). Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.

For the analysis of new or improved PT services, a shorter analysis period may be appropriate.

Stage 7: Funding gap analysis

This section provides guidance on the application of funding gap analysis to be used in the appraisal of public transport options. The funding gap is the level of investment required to ensure that a public transport service operator obtains a reasonable level of return.

Cash-flow and funding gap analysis is not necessary for determining the BCR of a PT activity, but is a key component of the decision-making process.

Stage 7a: Calculate service provider costs

Service provider costs are calculated either from industry standard unit costs, or from cost estimates provided by 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 the 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 analysis.

Guidance on the estimation of bus operating costs, excluding infrastructure, is available in stage 5b. Indicative New Zealand bus industry standard unit operating cost rates are also provided.

Indicative quotes may be used when costs cannot be obtained or calculated, but are most likely to be used when there is a sole service provider. Estimates of service provider costs are not a commitment to funding and therefore indicative quotes are acceptable during planning stages.

Service provider costs must be calculated for the do-minimum and for all options considered. These costs must be exclusive of GST.

Activity costs

Cost details should include any of the following:

- investigation, design and supervision costs
- physical infrastructure construction and land acquisition costs
- vehicle, vessel or rolling stock acquisition costs.
- disruption costs during construction/implementation, if substantial.
- operating and maintenance costs
- costs of decommissioning and salvage values
- environmental mitigation costs
- contingency allowance.

In the case of the do-minimum, costs may include essential rehabilitation.

Where expenditure on an activity has already been incurred, it must still be included in the appraisal if the item has a market value which can be realised, for example land.

Costs which have been irrevocably committed and have no salvage or realisable value, are termed ‘sunk costs’ (these may include investigation, design or other costs already incurred), and must not be accounted for in economic appraisal.

Disruption costs to the service provider during implementation may be included when these are expected to be substantial.

Operating and maintenance costs

Estimate operating and maintenance costs for the service over the analysis period.

Maintenance costs should include routine and periodic maintenance costs, as well as any refurbishment and replacement costs that occur in the appraisal period.

Treatment of depreciation

Depreciation is a non-cash item and must not be included as a separate item in the cash flows used to estimate the net present value of a proposal in the financial analysis. Only actual cash flows associated with maintenance and asset replacement, which already fully account for the depreciation of capital assets, are to be included in the analysis.

Treatment of interest

Interest expenses associated with financing an activity 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 to be included in discounted cash flows, the interest charges would be double counted; therefore, the proposal's funding gap would be overstated and the BCR understated.

Salvage value

In some instances, assets will have a longer lifespan than the appraisal period. The salvage value of capital assets should be included where:

- items have a market value, and
- there is an alternative use (for example, a bus can provide urban passenger services or could be used for school services or tours), or
- there is a scrap demand for items.

Stage 7b: Calculate service provider revenue

This section describes the information that should be included in the financial analysis of activity options that generate revenue. The process for forecasting the revenue of an improved service is different from that for a new service, and the methods for each type of service are described below.

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. Any future funding assistance required will be to facilitate improvements to the service rather than to fund the existing service.

Using the demand estimate information generated in stage 2, calculate the change in service provider revenue:

$$\text{Change in service provider revenue} = (Q_2 \times P_{new}) - (Q_1 \times P_1)$$

where:
P_1 is the base average fare
P_{new} is the proposed average fare
Q_1 is the current annual patronage
Q_2 is the 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 fare to give the expected annual service provider revenue from a new service.

Using the demand estimate information generated in stage 2, calculate the annual service provider revenue.

$$\text{Annual service provider revenue} = (Q_{new} \times P_{new})$$

where:
P_{new} is the proposed average fare
Q_{new} is the projected annual patronage.

Stage 7c: Perform cash-flow analysis

A new or improved transport service will usually involve some initial capital expenditure followed by ongoing annual operating and maintenance costs. These costs are offset to an extent by the 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:

$$\text{Annual net cash flow} = (\text{revenue} + \text{funding gap}) - (\text{capital costs} + \text{operating and maintenance costs})$$

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

Analysts should use a post-tax rate of return. Care must be taken to ensure that service provider costs and revenues are calculated accordingly.

Period of financial analysis

The period of the financial analysis should, if possible, be sufficient to allow projected revenue to offset the initial capital cost. Care must however be taken to ensure that the analysis period is not unrealistically long. Uncertainties in demand for the proposed service should also be taken into account when setting the length of the analysis period.

Stage 7d: Calculate service provider's funding gap

The funding gap is the deficit in cash flow that needs to be reimbursed by local and central government if the option is to be financially viable from the service provider's point of view. This is based on the best estimate of the service provider's expected revenue and their 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 (either spread over the construction period or paid at the end of construction), or
- spread over the first few operating years of the proposal, or
- 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 is required to operate a subsidised service but does not necessarily mean that funding assistance is justified from a government (public policy) point of view.

Worksheet 3 of SP 9 New public transport services, contains a table with an inbuilt 'goal seek' function that may be used for determining the funding gap.

A worked example of funding gap analysis is provided in Appendix 8: worked examples.

Funding gap sensitivity tests

The financial analysis required to calculate the funding gap involves making assumptions and estimates of an uncertain future. Some assumptions may be subjective in nature. As a result, assessments of the sensitivity of the funding gap to variations in critical assumptions must be undertaken on the preferred option.

There are three sensitivity tests that should be performed on the funding gap analysis to estimate upper and lower bounds. This helps to establish the potential effect of these variations on the present value of the funding gap of the proposal. The sensitivity tests are set out in Table 91.

Table 91: Sensitivity tests

Sensitivity test variables	Description
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 present value of the funding gap.
Timing of capital expenditure	Where significant capital expenditure is a feature of the proposal, sensitivity testing shall include the effect on the present value 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 present value of the funding gap shall be presented.

Stage 8 – Determine the benefit–cost ratios of the options

Refer to Chapter 6 for detailed information on developing BCRs.

Stage 9: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs.

Stage 10: Sensitivity testing on the preferred option

Refer to Chapter 7 of this manual for the details on sensitivity testing.

Assessing the sensitivity of the analysis to critical assumptions or estimates shall be undertaken using sensitivity testing, which needs to be undertaken for the critical inputs and assumptions used to choose the preferred option.

Sensitivity testing involves defining a range of potential values for an uncertain variable in the analysis and reviewing the variation in the analysis results as the variable changes within the range. This will highlight the sensitivity of the estimated final outcome to changes in input variables.

Stage 11: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

4.5 Analysis of travel demand management activities

This section describes the procedures to be used to evaluate the economic efficiency of travel demand management (TDM) activities.

Where the road network is working inefficiently, for example where there is congestion, traditionally the solution has been to provide more road capacity. TDM is about stepping back from this capacity approach and seeking to achieve the objective of improved mobility by improving the efficiency of the network and influencing travel behaviour, particularly where, when, how and even if travel is needed at all. It aims to give people more choice by improving and informing them of their travel options while at the same time influencing and guiding travel decisions to achieve better outcomes. In effect, it seeks to achieve more sustainable travel behaviour.

TDM attempts to change travel behaviour and transport demand through provision of options, pricing, financial incentives, travel information, and enforcement.

There are a range of TDM activities available for use in New Zealand including (but not exclusively):

- transport infrastructure, including for public transport
- intelligent transport systems (ITS)
- traffic management
- priority lanes
- tolling and road pricing
- new or improved public transport services
- freight movement management
- walking and cycling alternatives to car and public transport options
- policing
- traveller information services
- work and study travel policies
- urban parking management
- land use design/management
- improved communications
- education, promotion and marketing.

Most TDM activities will be undertaken as part of a package and/or programme of activities. Many activities will operate to support and enhance other transport management measures. For instance, if parking management is introduced at the same time as bus priority measures, it is likely there will be more use of the enhanced bus services than if bus priority was introduced in isolation. Similarly, enhanced pedestrian facilities in addition to a bus priority scheme could act as more of an incentive for public transport use by providing more attractive and direct pedestrian connections to those bus services.

Intelligent transport systems (ITS) activities can include (amongst other options):

- variable message signs, which deliver safety and travel condition messages to vehicle drivers
- real time public transport passenger information systems, which result in travel behaviour changes, and which in turn potentially result in travel time impacts, decongestion impacts and other user impacts.

If a TDM package contains substantial infrastructure or public transport components, then a composite analysis is necessary. Road infrastructure components of a package should be evaluated using the procedures in section 4.3 and the public transport and other service based TDM components evaluated using the procedures in section 4.4. The results are then aggregated, taking care to avoid double counting of benefits.

For the analysis of TDM activities involving education, promotion and marketing refer to section 4.6 of this manual.

Simplified procedures for TDM

A range of simplified procedures available in this manual may be used to evaluate TDM activities with an undiscounted whole-of-life cost of less than or equal to $15 million. SP11 Walking and cycling, SP12 Travel behaviour, and SP13 Safety promotion are the simplified procedures most relevant to TDM activities. These procedures have been discussed in detail elsewhere within Chapter 4.

Table 47 (simplified procedure in relation to type of activities) may be referred to select the appropriate procedure.

Full procedures for TDM

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

The following table outlines the stages of analysis for TDM activities. The chapters and sections of this manual that apply to each stage of the analysis are referenced in the table below.

Table 92: Stages of analysis for TDM

Stage	Description	Refer
1	Consider and describe: a. the do-minimum b. improvement alternatives and options c. whether the improvement(s) should be part of a package and/or programme of activities.	Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Collect data to assess travel impacts: • target population • demand estimates and modal share • uptake • level of diversion. Where possible use transport models to assess the impacts and undertake calibration of the transport models for the activities under consideration.	Current section and Chapter 2: Demand estimation and mode share

3	Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options, including: • impact on social cost and incidence of crashes • impact of mode on physical and mental health • impact of air emissions on health • impact of noise and vibration on health • impact on system reliability • impact on network productivity and utilisation • impact on greenhouse gas emissions • impact on user experience of the transport system • wider economic benefit (productivity) • wider economic benefit (employment impact) • wider economic benefit (imperfect competition) • wider economic benefit (land use change) • other impacts that can be monetised – these are not included in this manual but can be included if there is sufficient supporting evidence and the approach is accepted by NZTA.	Chapter 3: Benefits
4	Undertake risk analysis when there are significant unpredictable events that may affect or be affected by the improvement activity.	Chapter 7: Sensitivity and risk analysis
5	Quantify the costs of the improvement activities including: • investigation and design • property • construction • maintenance, renewal and operation • risk management; mitigation of external impacts • residual values. If there is a service provider, determine service provider costs, service provider revenue and the funding gap (see section 4.4). Quantify the net costs to government of the funding gap.	Section 1.8: Costs
6	Discount the monetised benefits and costs over the analysis period to obtain present values. Then use to calculate the benefit–cost ratio(s).	Chapter 5: Discounting
7	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
8	Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options,	Chapter 6: Benefit–cost ratios
9	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the evaluation outcome(s).	Chapter 7: Sensitivity and risk analysis
10	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1a: Describe the do-minimum

Generally, the do-minimum for TDM activities shall only include committed and funded transport activities and work that is absolutely essential to preserve a minimum level of service. However, when TDM activities are implemented as part of a wider package that includes roading or PT activities, the do-minimum may need to be specified differently. For more guidance refer to the do-minimum descriptions within the roading (section 4.3) and public transport (section 4.4) procedures.

Stage 1b: Scale and scope of TDM options

TDM activities, like most economic programmes, will eventually have diminishing marginal benefits. 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 before the costs exceed the benefits.

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 attempting to expand the rideshare programme with soft measures, 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 it is necessary to carefully evaluate investments in cycle paths to ensure that they are cost effective. There may be better ways to support cycling, such as education and encouragement programmes.

Stage 1c: Packages and/programme activities

Most TDM programmes include a combination of positive and negative incentives. However, there are cumulative and synergetic impacts, therefore it is important to evaluate TDM activities as a package, rather than as stand-alone activities or an individual strategy.

The procedure for evaluating road improvement packages involving analysis of the timing of individual components is not appropriate for TDM packages unless the package contains substantial infrastructure or public transport components.

There are two types of TDM packages: TDM packages involving substantial infrastructure, and TDM packages involving travel behaviour change infrastructure.

Stage 2: Demand estimates and modal share

General guidance on travel demand forecasting and mode change estimation is provided in Chapter 2 of this manual.

TDM activities 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 impacts associated with a TDM activity, it is necessary to estimate the impact that the activity is likely to have on travel behaviour, including changes in mode share (refer to section 2.1). A commuter trip reduction activity can reduce vehicle trips to a particular worksite place, 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. Forecasting these changes in demand is a crucial step in the analysis of TDM activities.

A well-managed TDM activity can also affect a significant portion of total travel. Comprehensive TDM activities can achieve cost-effective reductions in private vehicle travel compared with no TDM efforts, although most activities 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. 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.

Stage 3: Calculate TDM impacts

All TDM programmes have the objective of changing travel or travel behaviour. Many TDM analyses involve users’ perceptions of costs, rather than resource costs as discussed in section 1.7 of this manual. This requires a consumer surplus approach to measure the value that consumers place on a change in the price or quality of the goods they consume (travel is considered a ‘consumer good’).

Analyses of TDM activities must consider not only direct impacts but also the benefits and costs to individuals 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 activity 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.

Impacts to be considered in the economic efficiency analysis of TDM activities are (refer to Chapter 3 of this manual):

- impact on social cost of deaths and serious injuries
- impact of mode on physical and mental health
- impact of air emissions on health
- impact on greenhouse gases
- impact of noise and vibration on health
- impact on network productivity and utilisation
- impact on system reliability
- impact on user experience of the transport system
- wider economic benefit (productivity)
- wider economic benefit (employment impact)
- wider economic benefit (imperfect competition)
- other monetised impacts (refer to section 1.7 and Chapter 3 of this manual)
- impacts during implementation/construction (primarily travel time delays).

If a TDM package contains substantial infrastructure or PT components, then a composite analysis is necessary. Road infrastructure components of a package should be evaluated using the procedures in section 4.3 of this manual, while PT components should be evaluated using the procedures in section 4.4. The results of the component analyses are to be aggregated taking care to avoid double counting of benefits.

For any travel behaviour change (TBhC) components in a package, the appropriate composite benefit value is used to calculate the 'new user' benefits for the TBhC target population/area. Section 3.17 of this manual provides guidance as to the appropriate analysis 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 BCR for a composite TBhC package is the sum of the TBhC benefits and the non-TBhC benefits.

> Impacts 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.
>
> Impacts to businesses that are not direct travel time or vehicle operating cost impacts, are considered transfers rather than national economic benefits. However, they can be an important factor in assembling a strategic case for a TDM activity and obtaining funding for workplace-based activity and they should, therefore, be quantified and reported as part of the non-monetised analysis (separately from the economic efficiency calculation).

Stage 4: Undertake risk analysis for significant unpredictable events

Refer to Chapter 7 of this manual for detailed procedures on risk analysis.

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.

Stage 5: Calculate costs for do-minimum and improvement options

Costs of TDM activities are the costs to government (NZTA and local government) and the service provider costs and revenue (where a service provider is involved). Activity costs include the costs of:

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

The estimated costs for investigation and design should be identified separately from those for implementation. The initial indicative cost estimates for TDM activities can be obtained from past experience or judgement. The cost estimate will then need to be refined and the analysis 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 analysis period following completion of the activity should be estimated based on local experience and knowledge.

An activity's 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 analysis 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 does however increase if a rideshare vehicle must drive out of its way to pick up passengers, 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.

Notes:

- The impact on mode choice of any increase in fare resulting from the purchase of extra vehicles must also be evaluated.
- If increased patronage results in uncomfortably crowded vehicles, then this disbenefit should be included in the analysis.
- Irrespective of the TBhC package composition, the total costs for all components of the package are included in the denominator of the BCR. Where a new or improved public transport service is involved, the costs include the 'funding assistance' costs (ie the cost that needs to be funded by local and central government if the activity is to proceed).
- A funding gap analysis is only necessary when a service provider is contracted to deliver a new or improved service (refer to section 4.4 for the funding gap analysis procedure).

Stage 6: Discount benefits and costs

Refer section 1.9 and Chapter 5 of this manual for the details on undertaking discounting.

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present worth factors have been calculated to convert future benefits and costs to their present values (see Table 103, and Table A132, Table A133 and Table A134 from Appendix 6: Discount factors). Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.

For the analysis of TDM activities, a shorter analysis period is likely to be appropriate.

Stage 7: Determine the benefit–cost ratios of the options

Refer to Chapter 6 for detailed information on developing BCRs.

Note: The numerator of the BCR for a composite TBhC package is the sum of the TBhC benefits and the non-TBhC benefits.

Stage 8: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs.

Stage 9: Sensitivity testing on the preferred option

Inputs to TDM analysis that should be considered for sensitivity testing 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 needs to be listed:

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

Refer to Chapter 7 of this manual for detailed information on sensitivity and risk analysis.

Stage 10: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

4.6 Analysis of education, promotion and marketing activities

This section describes the procedures to be used to evaluate the economic efficiency of education, promotion and marketing activities. These activities target travel behaviour change (TBhC) and include travel planning, education, promotion (including road safety promotion) and marketing related travel demand management.

TBhC activities tend to result in small impacts to a large number of people. These activities are more difficult to evaluate than other activities because the impacts tend to be different for each participant, whereas for road improvement activities most users tend to gain the same benefit. This means there is a compromise between procedures that accurately reflect all of the different individual responses to TBhC activities and procedures that are cost effective to use but involve significant approximations and averaging of the effects on different participants. NZTA has developed TBhC procedures that strike a balance between accuracy and cost of application, and these a described in more detail within this section of the manual.

Simplified procedures for education, promotion and marketing activities

A range of simplified procedures available in this manual may be used to evaluate education, promotion and marketing activities with an undiscounted whole-of-life cost of less than or equal to $15 million. SP11 Walking and cycling, SP12 Travel behaviour, and SP13 Safety promotion are the simplified procedures most relevant to TDM activities in general. These procedures have been discussed in detail elsewhere within Chapter 4.

Table 47 (simplified procedure in relation to type of activities) may be referred to select the appropriate procedure.

Full procedures for education, promotion and marketing activities

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

The following table outlines the stages of analysis for education, promotion and marketing activities. The chapters and sections of this manual that apply to each stage of the analysis are referenced in the table below.

Table 93: Stages of analysis for education, promotion and marketing activities

Stage	Description	Refer
1	Consider and describe: a. the do-minimum b. improvement alternatives and options c. whether the improvement(s) should be part of a package and/or programme of activities.	Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Collect data to assess travel impacts: • target population • demand estimates and modal share • uptake • level of diversion. Where possible use transport models to assess the impacts and undertake calibration of the transport models for the activities under consideration.	Current section and Chapter 2: Demand estimation and mode share
3	Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options, including: • impact on social cost and incidence of crashes • impact of mode on physical and mental health • impact of air emissions on health • impact of noise and vibration on health • impact on system reliability • impact on network productivity and utilisation • impact on greenhouse gas emissions • impact on user experience of the transport system • wider economic benefit (productivity) • wider economic benefit (employment impact) • wider economic benefit (imperfect competition) • wider economic benefit (land use change) • other impacts that can be monetised – these are not included in this manual but can be included if there is sufficient supporting evidence and the approach is accepted by NZTA.	Chapter 3: Benefits
4	Quantify the costs of the improvement activities including: • investigation and design • property • construction • maintenance, renewal and operation • risk management; mitigation of external impacts • residual values. If there is a service provider, determine service provider costs, service provider revenue and the funding gap. Quantify the net costs to government of the funding gap.	Section 1.8: Costs
5	If the present value of the total government costs is greater than $1 million dollars, undertake a detailed risk analysis.	Chapter 7: Sensitivity and risk analysis
6	Discount the monetised benefits and costs over the analysis period to obtain present values. Then use to calculate the benefit–cost ratio(s).	Chapter 5: Discounting

Stage	Description	Refer
7	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
8	Where the options being evaluated are mutually exclusive, use incremental analysis to select the preferred option.	Chapter 6: Benefit–cost ratios
9	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the economic evaluation outcome(s).	Chapter 7: Sensitivity and risk analysis
10	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1a: Describe the do-minimum

Generally, the do-minimum for education, promotion and marketing activities shall only include committed and funded transport activities and work that is absolutely essential to preserve a minimum level of service. However, when education, promotion and marketing activities are implemented as part of a wider package that includes roading or PT activities, the do-minimum may need to be specified differently. For more guidance refer to the do-minimum descriptions within the roading (section 4.3) and public transport (section 4.4) procedures.

Stage 1b: Scale and scope of education, promotion and marketing activities options

Overseas experience indicates that the most effective, and lowest cost, method for encouraging people to change their travel behaviour is to provide them with customised information about what is available locally. The scale of education, promotion and marketing activities is therefore usually limited, but the scope of their impacts may be significant. Travel plans targeting workplaces, schools, or households and communities are one such type of activity where, geographically, the scope is highly targeted but the resulting travel behaviour changes affect the wider network.

The actual impact on travel is highly 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.

Stage 1c: Packages and/programme activities

Education, promotion and marketing activities are most effective at changing travel behaviour when implemented alongside new or improved PT services or walking and cycling facilities, or in conjunction with other TDM measures.

Consideration should be given to whether a proposed education, promotion and marketing activity is best delivered as a part of a package or programme.

Stage 2: Demand estimates and modal share

General guidance on travel demand forecasting and mode change estimation is provided in Chapter 2 of this manual.

> TBhC activities tend to result in small impacts to a large number of people. These activities are more difficult to evaluate than other activities because the impacts tend to be different for each participant, whereas for road improvement activities most users tend to gain the same benefit.

Stage 3: Calculate TBhC impacts

For the TBhC components of a package, the appropriate composite benefit value is used to calculate the 'new user' benefits for the TBhC target population/area. Section 3.17 provides guidance as to the appropriate analysis 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.

Impacts to be considered in the economic analysis of education, promotion and marketing activities are (refer to Chapter 3 of this manual):

- impact on social cost of deaths and serious injuries
- impact of mode on physical and mental health
- impact of air emissions on health
- impact on greenhouse gases
- impact of noise and vibration on health
- impact on network productivity and utilisation
- impact on system reliability
- impact on user experience of the transport system
- wider economic benefit (productivity)
- wider economic benefit (labour supply)
- wider economic benefit (imperfect competition)
- wider economic benefit (land use change)
- other monetised impacts (refer section 1.7 and Chapter 3 of this manual).

An issue for analyses of travel plans is whether the impacts of TBhC programmes persist or decay after the completion of the programme.

The following four possibilities exist:

1. impacts decay over time
2. impacts can be maintained by ongoing 'maintenance' expenditure
3. impacts are durable without maintenance
4. impacts increase over time.

Impact decay due to reversion to old travel modes is more likely in cases where people are persuaded to change to a less convenient travel option because it is more environmentally sustainable.

Analyses of household and community TBhC projects can generally assume that improvements will be retained in future years with little or no maintenance expenditure. However, workplace travel plans and school travel plans are more likely to require ongoing maintenance expenditure. The school travel plans have to estimate staff and student turnover. In the case of workplace travel plans some of this maintenance expenditure will become part of the companies' cost of business, but in the case of school travel plans any ongoing expenditure needs to be estimated and included in the analysis.

Stage 4: Calculate costs of TBhC activity

If a TBhC activity is implemented as part of a package alongside new or improved PT services (section 4.4) or walking and cycling facilities (section 4.2), or in conjunction with other TDM measures (section 4.5), then the costs of the components must be calculated according to the relevant procedure.

The availability of suitably trained and experienced people to establish and manage travel plans is an important aspect of TBhC activities and this can be a significant cost which must be included.

The cost of annual expenditure required to maintain the benefits of travel plans over the analysis period following completion of the activity should be estimated based on local experience and knowledge. For household-based or 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 the benefits.

Irrespective of the TBhC package composition, the total costs for all components of the package are included in the denominator of the BCR. Where a new or improved public transport service is involved, the costs include the funding assistance costs (ie. the costs that need to be funded by local and central government if the activity is to proceed).

Road construction, maintenance and operating cost savings are assumed to be negligible for the number of private vehicle trips and/or vehicle kilometres that are likely to be removed by the implementation of education, promotion and marketing activities.

Stage 5: Risk analysis

Detailed risk analysis and risk management are undertaken for education, promotion and marketing activities that have a net cost to government of $1 million or more. These risk processes start at the project inception stage and proceed through to project completion and should involve all relevant parties. Refer to Chapter 7 for detailed information on risk analysis.

Stage 6: Discount benefits and costs

Refer to section 1.9 and Chapter 5 of this manual for the detailed information on undertaking discounting.

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present worth factors have been calculated to convert future benefits and costs to their present values (see Table 103, and Table A132, Table A133 and Table A134 from Appendix 6: Discount factors). Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.

For the analysis of TBhC activities, a shorter analysis period is likely to be appropriate.

Stage 7: Determine the benefit–cost ratios of the options

Refer to Chapter 6 for detailed information on developing BCRs.

Stage 8: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs.

Stage 9: Sensitivity testing on the preferred option

Refer to Chapter 7 of this manual for detailed information on sensitivity on sensitivity testing. Possible significant factors that should be considered for sensitivity testing include:

- demand estimates (refer to Chapter 2 of this manual for more details on sensitivity testing of demand estimates)
- impact changes
- major contributors to impacts
- commencement of the proposal.

Stage 10: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

4.7 Analysis of freight activities

The following section describes the procedures that are to be used to evaluate the economic efficiency of freight service activities and high productivity motor vehicle (HPMV) routes. Activities may be stand-alone improvements or a component of a package or a wider programme of transport improvements.

Simple and relatively standardised HPMV route improvements, with an undiscounted whole-of-life cost of less than or equal to $15 million, may be evaluated using a simplified procedure. Similarly, a separate simplified procedure may be used to evaluate new rail or sea freight services with an undiscounted funding gap of less than or equal to $15 million over a three-year period. Both of these simplified procedures are explained in more detail below. For more complicated activities, and activities that breach the cost limits of the simplified procedures, the full procedures are provided as an alternative and are explained later in this section.

Simplified procedures for freight

The following simplified procedures (SPs), for HPMV route improvements (SP6) and new rail or sea freight services (SP8), use a 4% discount rate and a 40-year analysis 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 do-minimum and the options they are not included in the analysis. All costs are to be exclusive of GST.

The simplified 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 of the preferred option need to be included.

Refer to the Planning and Investment Knowledge Base (PIKB) for guidance on issues relating to analysis of PT activities, including selection of the preferred option using the Business Case Approach.

The simplified procedure templates provided must be used when undertaking simplified analyses. The completed templates are to be included in Transport Investment Online (TIO). The templates are standardised to allow automated uploading to and data extraction from TIO.

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

- the default figures provided
- activity specific data collected, or
- the information in the appendices.

Analysis that alters components of the simplified procedure should not be used as this will compromise the assumptions on which the procedures are based and full procedures should be used instead.

If the analyst has any problems with the simplified procedures templates or worksheets, please contact MBCM@nzta.govt.nz.

SP6 for high productivity motor vehicle (HPMV) route improvements

Procedure SP6 provides a simplified method of evaluating the economic efficiency of HPMV routes and associated capital, maintenance and renewal costs. The procedure’s benefits are primarily derived from a reduction in heavy vehicle trips, with associated reductions in vehicle operating costs, greenhouse gas emissions, crash costs, and travel time costs.

It is assumed that 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 crash cost savings procedures described in Appendix 2: Crash analysis should be applied instead.

Only the 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. In some cases (eg where pavements are weak), it may be necessary to compare the costs of the freight transport option with a road reconstruction option for the affected road network.

Guidance for completing the SP6 High productivity motor vehicles (template worksheets) is provided below in Table 94 and Table 95.

Table 94: SP6 HPMV route improvements procedure template

Worksheet number	Worksheet purpose	Description
SP6-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP6-2	Cost of the option(s)	Used to calculate the PV costs of the option. A separate worksheet is required for each option evaluated. Up to two options can be evaluated.
SP6-3	Vehicle operating cost savings, CO_2 reductions and travel time cost savings	Used for calculating vehicle operating cost savings, CO_2 reduction and travel time cost savings.
SP6-4	Crash cost savings	Used for calculating crash cost savings using crash rate analysis method (refer Appendix 2: Crash analysis).
SP6-5	BCR and incremental analysis	Used for comparison of the options considered.

Table 95: Steps in the SP6 analysis of HPMV route improvement activities

Step	Description
1	Complete items 1 to 7 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Cost of option(s)
3	Complete Worksheets 3 to 4 for the option(s) being evaluated
4	Complete Worksheet 5 – Incremental analysis (if more than one option is considered)
5	Select the preferred option and finalise Worksheet 1 for the preferred option

SP8 for freight services

Procedure SP8 provides a simplified method of evaluating the economic efficiency of rail and sea freight transport services, with or without capital expenditure.

The procedure assumes:

- There are costs to users that 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.
- Other benefits (positive or negative) are not significant. Allowance can be made for additional benefits if they are found to be significant.
- 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 crash cost savings procedures described in Appendix 2: Crash analysis should be applied instead.

It is necessary to complete a funding gap analysis for the proposed service in worksheet SP8-2. A 12% service provider rate of return is assumed, and the funding gap may be calculated using the embedded goal seek function.

Worksheet SP8-8 provides a feasibility analysis 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.

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Guidance for completing the SP8 Freight services (template worksheets) is provided below in Table 96 and Table 97.

Table 96: SP8 Freight services procedure template

Worksheet number	Worksheet purpose	Description
SP8-1	Evaluation summary	Used to summarise the general data considered for the evaluation plus the results of the economic analysis.
SP8-2	Service provider costs	Used to calculate the PV cost to the service provider of a new service. The cost includes capital, operation and maintenance costs.
SP8-3	Funding gap analysis	Used to determine whether the new service is commercially viable.
SP8-4	Freight service user benefits	Used to calculate the PV of benefits for freight service users.
SP8-5	Net cost savings to government	Used to calculate the PV of net government cost savings, including road user charges forgone.
SP8-6	Road traffic reduction benefits	Used to calculate the PV of benefits for other transport system users.
SP8-7	BCR and incremental analysis	Used for comparison of the options considered.
SP8-8	Feasibility evaluation	Used as an alternative appraisal methodology in the absence of congestion or crash cost savings.

Table 97: Steps in the SP8 analysis of freight service activities

Step	Description
1	Complete items 1 to 6 of Worksheet 1 – Evaluation summary
2	Complete Worksheet 2 – Service provider costs
3	Complete Worksheet 3 – Funding gap analysis
4	Complete Worksheet 4 – Freight service user benefits
5	Complete Worksheet 5 – Net cost savings to government
6	Complete Worksheet 6 – Road traffic reduction benefits
7	Complete Worksheet 7 – Incremental analysis (if more than one option is considered)
6	Complete Worksheet 8 – Feasibility evaluation (optional)
7	Select the preferred option and finalise Worksheet 1 for the preferred option

Full procedures for freight services

The full analysis procedures for freight activities are to be used to appraise the economic efficiency of activities when the simplified procedures are not appropriate or sufficient.

The primary purpose of this section of the manual is to establish the impacts of introducing new freight services or improving existing services (ie the changes that occur between do-minimum and the options) when using the full procedures. Following on from calculating the impacts, the analyst will need to assign monetary values to the impacts and then calculate the benefits and the benefit–cost ratios (BCRs).

These procedures cover the range of stages listed above, however, many of the actions for these stages are covered in greater detail in other sections or appendices of this manual and in external documents for which links have been provided. A significant focus of the freight service procedures is on the calculation of the net cost savings to the government and the service provider's funding gap, in particular stages 3 to 6 in Table 98.

These procedures are designed to calculate the impacts one at a time and then, after assigning monetary values to the impacts, they can be added together, including any disbenefits, to establish the total benefit of the options under consideration. To assist in this process a set of standardised worksheets have been developed to help guide the analyst through an analysis and to aid in the process of checking for completeness and accuracy.

The following table outlines the stages of analysis for introducing a new freight service or improving an existing one. The chapters and sections of this manual that apply to each stage of the analysis are referenced in the table below.

Table 98: Stages of analysis for freight activities

Stage	Description	See
1	Consider and describe: a. the do-minimum b. improvement alternatives and options c. whether the improvement(s) should be part of a package and/or programme of activities.	Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Forecast the freight demand either from a transport model or by using demand elasticities.	Current section and Chapter 2: Demand estimation and mode share
3	Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options, including: • impact on social cost and incidence of crashes • impact of air emissions on health • impact of noise and vibration on health • impact on system reliability • impact on network productivity and utilisation • impact on greenhouse gas emissions • impact on user experience of the transport system • wider economic benefit (productivity) • wider economic benefit (labour supply) • wider economic benefit (imperfect competition) • wider economic benefit (land use change) • other impacts that can be monetised – these are not included in this manual but can be included if there is sufficient supporting evidence and the approach is accepted by NZTA.	Chapter 3: Benefits
4	Undertake risk analysis when there are significant unpredictable events that may affect or be affected by the improvement activity.	Chapter 7: Sensitivity and risk analysis
5	Calculate the costs to the government of services for the do-minimum and improvement options, including (but not exclusively): • funding assistance from government • forgone road use charges (RUC) • maintenance, renewal and construction cost savings • construction costs, including property, for any additional infrastructure required	Current section and Section 1.8: Costs

Stage	Description	See
	• maintenance costs not already included in service contracts.	
6	Discount the monetised benefits and costs over the analysis period to obtain present values.	Chapter 5: Discounting
7	Calculate the funding gap and any net cost to government by: • calculating service provider costs • calculating service provider revenue • performing cash-flow analysis • calculating the service provider's funding gap • performing sensitivity tests on the funding gap analysis.	Current section
8	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
9	Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options.	Chapter 6: Benefit–cost ratios
10	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the evaluation outcome(s).	Chapter 7: Sensitivity and risk analysis
11	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1a: Describe the do-minimum

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

The do-minimum must include any costs and resulting demand implications of committed transport infrastructure and freight service improvements during the analysis period. Activities are committed if they have been evaluated in accordance with the NZTA analysis procedures and have been approved for funding. Any investment plans that are not committed must be included in the analysis as options. Maintenance, renewal/replacement schedules and any planned freight service changes must also be included.

Most forms of analysis 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 or activity may be required to maintain a minimum level of service. This minimum level of expenditure or activity and the resultant performance is known as the do-minimum and should be used as the basis for analysis, rather than the do-nothing. It is important not to overstate the scope of the do-minimum.

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.

In some situations, the do-minimum can be the most effective solution to a problem and therefore it can be the 'preferred option'.

Stage 1b: Describe the alternatives and options

Rigorous consideration of alternatives and options is a requirement of the Land Transport Management Act 2003 (LTMA). To ensure these obligations are met, evaluators should carefully articulate the problem or issue that they are seeking to resolve and avoid approaching the analysis with a preconceived solution in mind.

Alternatives are different means of achieving the same objective as a proposed activity, while options are variants of a proposed activity. These alternatives and options should not be constrained to a specific mode, or even to transport solutions, as changes to existing policy may be suitable responses to the identified problem. As a result, it may be necessary to apply other procedures contained within this manual as part of the analysis.

Stage 1c: Packages and/or programme of activities

NZTA seeks to encourage, where appropriate, approved organisations to develop packages or programmes of interrelated and complementary activities, either individually or in association with other approved organisations.

This is particularly important to ensure that a wide range of options and alternatives are considered and evaluated in full. Doing so may help avoid issues that arise from narrowing the scope too early such as:

- neglecting options that differ in type or scale, eg an extension of an existing HPMV route may eliminate the need improve alternative routes
- neglecting significant externalities, eg the impacts of a new business park on future demand for freight services
- inconsistencies with wider strategic policies and plans, eg investing in road improvements or renewals when significant rail network renewals are planned.

If all transport system users are affected by improvements, then a multi-modal analysis may be necessary. This may involve analysing freight components and other transport system users separately, using the relevant procedures in this section and the rest of Chapter 4, and aggregating the results.

Stage 2: Demand estimates

General guidance on travel demand forecasting and mode change estimation is provided in Chapter 2 of this manual.

For freight service investments that are limited in scope or scale it may be appropriate to use the standardised cross-price elasticities of demand between road and rail. The values in Table 99 are indicative only and represent the percentage change in rail volume with respect to the percentage change in rail to road price.

Table 99: 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

The elasticities depend primarily on the level of inter-modal competition. 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. Transit time (generally used as a proxy for distance) appears to be a significant determinant of mode choice, therefore, the greater the distance, the less likely truck transport will be chosen.

For significant freight service investments, or where there is significant interaction between freight and other transport system users, the use of models is encouraged.

Stage 3: Calculate freight service improvement impacts

This section provides guidance on the calculation of impacts on freight service users and the impact of diverted road traffic on the wider network. Impacts for all other modes should still be calculated on the route, network and/or transport system, by quantifying, for the do-minimum and options, the changes that occur for the factors listed in the stages below when an improvement option is considered.

Note that the impact calculations should include any negative impacts (disbenefits) during implementation/construction.

Freight service user impacts can be calculated by estimating the ‘consumer surplus’. This quantifies the economic benefits or disbenefits experienced by freight service users after freight haulage rates have been accounted for. Consumer surplus therefore measures the total economic value of the service to the service users. Freight haulage rates are usually expressed in $/tonne.

Consumer surplus benefits can be supplemented or supplanted, where this is justified, to take into account the calculation of freight service user benefits arising from reduced journey time, improved reliability, and changes to the service quality.

For the calculation of travel time saving benefits, Table 15 contains values of time (VoT), expressed in $/hour/vehicle, that should be used when vehicles and are used for work purposes to transport freight. Section 3.6 contains more information on the VoT and adjustment factors that may be applied in highly congested conditions.

Care needs to be taken to include any additional user costs, such as re-handling or inventory adjustment costs, as a disbenefit in the analysis. Additionally, 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 also be included as a disbenefit in the analysis.

The benefits that have currently (2020) been ascribed standardised monetary values are listed below. The impacts (ie the differences in the parameter outcomes between the do-minimum and the options) are ascribed monetary values in Chapter 3 of this manual in the list of stages required to complete an economic analysis and calculate a BCR.

Parameters other than those listed below can be monetised but the process and values ascribed to these parameters must be agreed with NZTA in writing before they are included in the analysis, and supporting information to validate the inclusion of these parameters must be provided.

Stage 3a: Impact on social cost and incidence of crashes

For the purposes of this manual, a crash is a transport related event involving one or more road vehicles that occurs on the transport network that results in personal physical injury and/or damage to property. Where freight is diverted from road-based services to rail or shipping, there is likely to be a reduction in the quantum of crashes. Likewise, a new or improved HPMV route may reduce the quantum of crashes if the number of heavy vehicle trips is reduced.

To undertake a crash analysis, the appropriate crash rates, crash prediction models and crash reduction factors can be found in the NZTA *Crash estimation compendium* (2024).

Refer to section 3.1 and Appendix 2: Crash analysis of this manual for detailed information on the calculation and monetisation of crash numbers and severities for the do-minimum, alternatives and options, and the crash reductions that can be expected from the alternatives and options under consideration.

> For minor route improvements, or where a new service is limited in scope, it may be appropriate to use the compound road traffic reduction benefit value from Table 39 or Table 40 which includes an allowance for a reduction in crashes per kilometre of vehicle traffic removed from the network.

Crash rates for rural freight services

For a freight transport service activity, 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.

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.

Stage 3b: Impact of air emissions on health

Vehicle emissions are a complex mixture of gases and particulates, and in terms of human health the primary harmful air pollutants that cause adverse health effects and have local impacts are particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and hydrocarbons (HCs).

Nitrogen dioxide (NO_2) is a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with increasingly more serious health effects, including reduced life expectancy (Kuschel et al 2022). Particulate matter (PM_{10}, which is smaller than 10µm) impacts predominantly on respiratory and cardiovascular systems. Effects can range from reduced lung function to increased medication use and more hospital admissions through to reduced life expectancy and death.

Refer to section 3.3 of this manual for information on the calculation and monetisation of the impacts of vehicle emissions, including those generated by PT vehicles with internal combustion engines, on human health.

Stage 3c: Impact on greenhouse gases (GHG)

Greenhouse gases are pollutants which cause global warming and impact globally, eg carbon dioxide (CO_2), black carbon (BC) and methane (CH_4).

Note: Several harmful pollutants (especially BC) are direct climate pollutants, in that they have a direct warming effect on the atmosphere. However, many of the remaining harmful pollutants, eg sulphur dioxide (SO_2) and carbon monoxide (CO), are indirect climate pollutants. This means they do not warm the atmosphere themselves but react with other gases to increase greenhouse gas concentrations. Therefore, initiatives which address harmful air pollutants typically yield both health and climate change benefits.

Refer to section 3.4 of this manual for information on the calculation and monetisation of greenhouse gas emissions.

For minor route improvements, or where a new service is limited in scope, it may be appropriate to use the compound road traffic reduction benefit value from Table 39 or Table 40 which includes an allowance for a reduction in GHG emissions per kilometre of vehicle traffic removed from the network.

Stage 3d: Impact of noise and vibration on health

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 reduced 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.

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.

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Refer to section 3.5 of this manual for information on the calculation and monetisation of the impacts of noise and vibration on human health.

Stage 3e: Impact on network productivity and utilisation

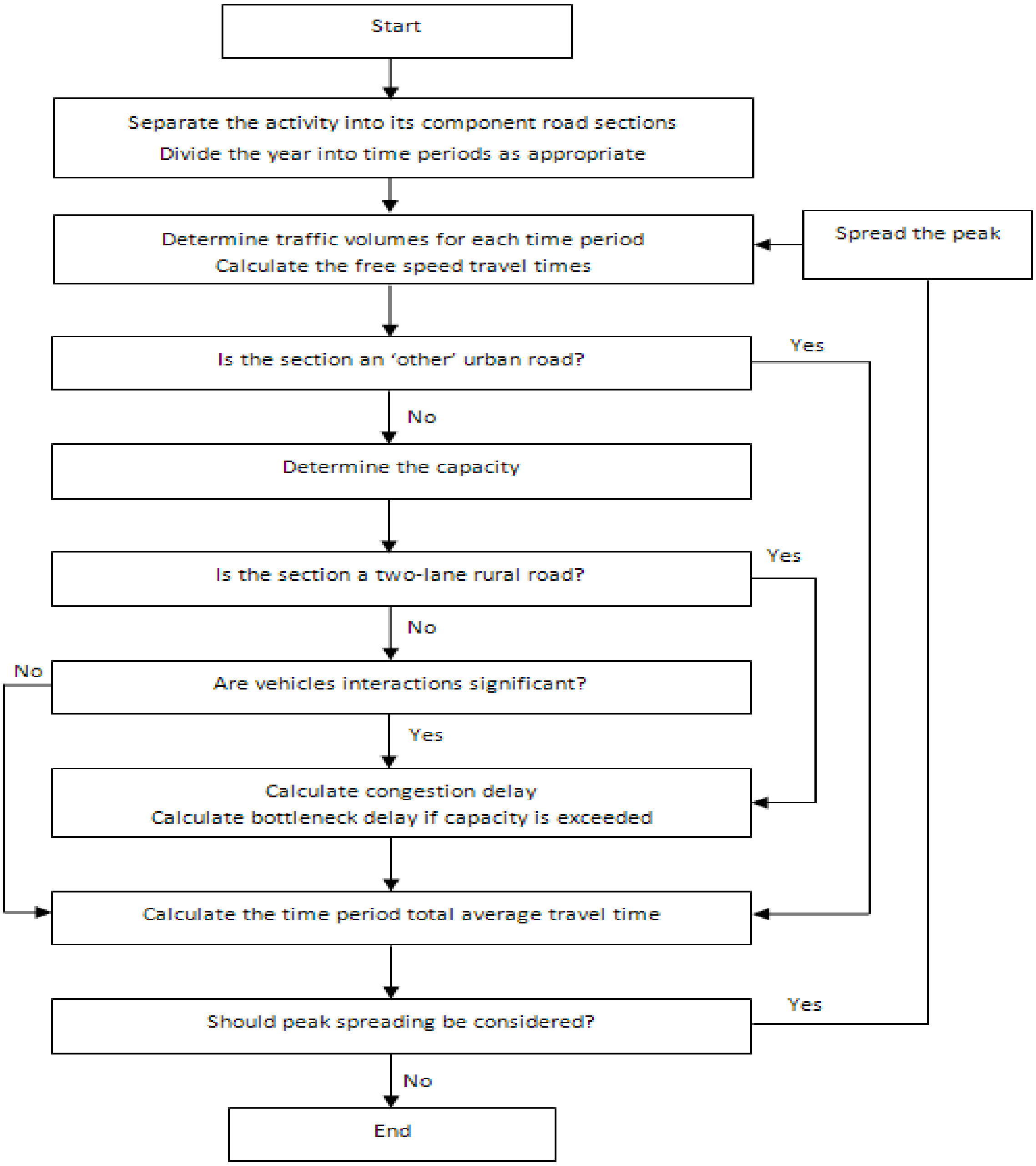
Changes in travel time estimation

Travel times for freight services may be estimated according to the procedures in Appendix 3: Traffic data and travel time estimation of this manual. Definitions for classifying traffic data and default traffic data values are also provided in Appendix 3: Traffic data and travel time estimation. 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 Appendix 1: Demand estimation methods and guidance and Appendix 3: Traffic data and travel time estimation.

The stages for estimating travel time

Figure 18 shows the basic stages for estimating road section travel time. Note that the stages are slightly different for intersections.

Figure 18: Flow chart for estimating road section travel time



Use of 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 the Transport modelling checks worksheet.

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 the procedures in Appendix 3: Traffic data and travel time estimation during the analysis. To adhere to this it is suggested that the functions implied by the procedures be used as a starting point, and modified as necessary to get a satisfactory validation.

Note that, wherever practical, measured travel time information shall be obtained in preference to the default values given in the tables in this manual.

Refer to Appendix 1: Demand estimation methods and guidance and Appendix 3: Traffic data and travel time estimation of this manual, which sets out the procedures for estimating travel times for the do-minimum and the options for various road and intersection types.

Vehicle operating costs

Vehicle operating costs (VOC) are 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. VOC 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.

Refer to section 3.6 of this manual for information on the calculation of vehicle operating costs.

User costs

Where freight service users incur additional handling, inventory or other related costs, or face decreased flexibility in freight schedules, these must be accounted for in the analysis as disbenefits. This manual does not include standardised values for the disbenefits.

> For minor route improvements, or where a new service is limited in scope, it may be appropriate to use the compound road traffic reduction benefit value from Table 39 or Table 40, which includes an allowance for a reduction in vehicle operating costs per kilometre of vehicle traffic removed from the network.

Stage 3f: Impact on system reliability

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 when calculating the travel time values (including congestion values).

Trip journey time reliability is a different type of variability, which is much less predictable to a transport system user. For example, car drivers who make a particular journey at the same time every day find some days it takes as little as 20 minutes, and on other days as much as 40 minutes. Hence, when the car drivers plan their trips, they have to consider not just the expected travel time but also its variability.

Journey 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.

Journey 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 reliability procedure for road based activities in section 4.3.

Stage 3g: Impact of user experience of the transport system

There are two standard values related to this benefit in this manual as follows:

1. Impact on driver frustration derived from 'time spend passing'. This is an indicator of changes that passing lane generate in road users experience.
2. Impact on road users' comfort and productivity due to sealing unsealed roads.

Driver frustration

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 analysis 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.

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.

An alternative method is based on multiple simulations and the unified passing model described in Appendix 5: Passing lanes is available in the *Provisional passing & overtaking guidelines* on the NZTA website. 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.

Road user comfort from seal extension

Road user comfort benefits and productivity gains from sealing an unsealed road should also be taken into account. Simplified procedure SP4 Seal extensions 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.

Stage 3h: Wider economic benefits

Only the most significant infrastructure improvements are likely to generate wider economic benefits (WEBs). Generally, these would need to change the distribution or density of households and firms within a major metro area or deliver significant improvements in accessibility between regions in order for wider effects to arise.

Refer to sections 3.9 to 3.13 of this manual for information on the calculation of wider economic impacts.

WEBs are impacts that can result from transport investment. They can be thought of as impacts that are additional to the conventional benefits to transport users. WEBs include productivity including agglomeration impacts, employment impacts, output changes under imperfect competition, and land use changes.

Great care is required to ensure that the estimates for WEBs 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 WEBs for increased productivity have to be additional to these direct user benefits.

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 WEBs 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.

New Zealand application of WEBs

The following wider economic benefits are applicable to freight activities 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.

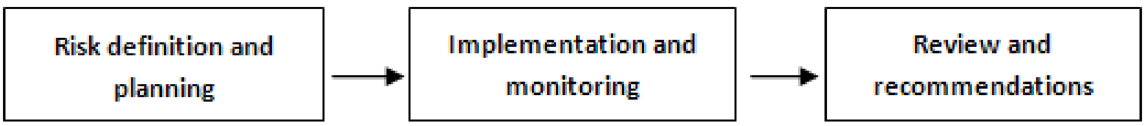
Stage 4 – Undertake risk analysis for significant unpredictable events

Refer to Chapter 7 of this manual for detailed procedures on risk analysis.

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.

Figure 19: Risk analysis process



Start of project stage:

- Identify risks.
- Assess risk management strategies (reduction, mitigation, avoidance, quantification through date collection etc).
- Choose preferred strategy.

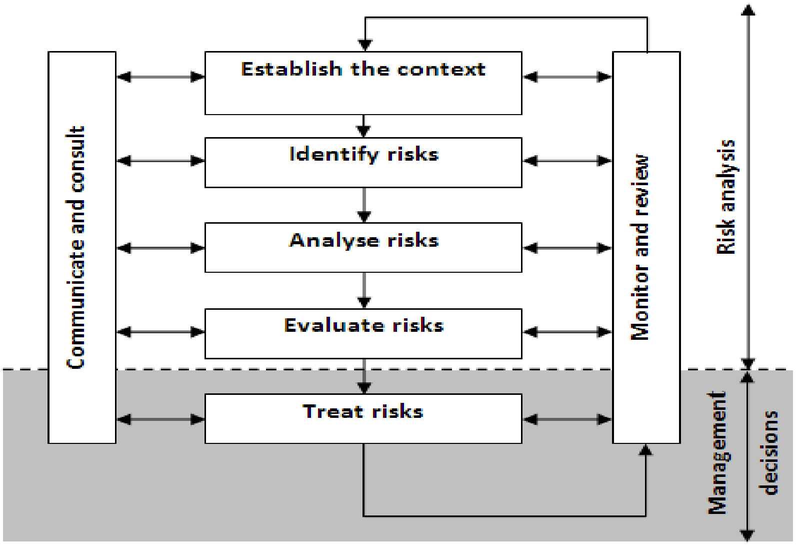
During the project stage:

- Implement preferred strategy.

At end of project stage:

- Report on outcomes of strategy.
- Assess implications for next stage of project.

Figure 20: Risk analysis steps



Stage 5a: Calculate general costs of freight service do-minimum and options

The costs to government of services include:

- funding assistance from government
- maintenance, renewal and construction cost savings
- construction costs, including property, for any additional infrastructure required
- maintenance costs not already included in service contracts.

Land costs

Where land has to be acquired for infrastructure, its resource cost shall be assumed to equate to its market value for activity analysis purposes.

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.

Road maintenance, renewal and construction cost savings

Some service proposals will provide a cost saving to government if future planned road construction costs are avoided. Cost savings may also occur if there is a reduction in road maintenance and renewal expenditure from traffic being removed from the network by the implementation of new freight services or HPMV routes.

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

The proposed freight service and any other options are assessed to determine any planned road construction savings and 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 are significant road traffic reduction benefits from freight diverting to rail and sea services.

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 SP8 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. If the amount of the freight traffic removed from the road network varies from year to year, separate calculations are required for each year.

Stage 5b: Calculate road user charges forgone

In New Zealand, road user charges (RUC) are levied against all diesel-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 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. It is assumed that heavy commercial vehicles will be removed from the road as a result of new or improved HPMV routes, or a new freight service. 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.

Determine the reduction in RUC revenue as a result of the introduction of a freight service using the following procedure in Table 100.

Table 100: Calculate reduction of road user charges (RUC) revenue

Step	Action
1	From the demand estimate information generated in stage 2, list the following for each travel time period: • the existing number of road trips by the vehicle type affected by the transport service proposal, and • 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 one 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 NZTA, 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.

Stage 6 – Discount benefits and costs and calculate BCRs

Refer to section 1.9 and Chapter 5 of this manual for the detailed information on undertaking discounting.

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present worth factors have been calculated to convert future benefits and costs to their present values (see Table 103, and Table A132, Table A133 and Table A134 from Appendix 6: Discount factors). Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.

For the analysis of new or improved freight service, a shorter analysis period may be appropriate if the freight carried is a non-renewable resource with a finite life.

Stage 7: Funding gap analysis

This section provides guidance on the application of funding gap analysis to be used in the appraisal of freight service options. The funding gap is the level of investment required to ensure that a freight service operator obtains a reasonable level of return.

Cash-flow and funding gap analysis is not necessary for determining the BCR of a freight service activity, but is a key component of the decision-making process.

Stage 7a: Calculate service provider costs

Service provider costs are calculated either from industry standard unit costs, or from cost estimates provided by 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 the 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 analysis.

Indicative quotes may be used when costs cannot be obtained or calculated, but are most likely to be used when there is a sole service provider. Estimates of service provider costs are not a commitment to funding and therefore indicative quotes are acceptable during planning stages.

Service provider costs must be calculated for the do-minimum and for all options considered. These costs must be exclusive of GST.

Activity costs

Cost details should include any of the following:

- investigation, design and supervision costs
- physical infrastructure construction and land acquisition costs
- vehicle, vessel or rolling stock acquisition costs
- disruption costs during construction/implementation, if substantial
- operating and maintenance costs
- costs of decommissioning and salvage values
- environmental mitigation costs
- contingency allowance.

In the case of the do-minimum, costs may include essential rehabilitation.

Where expenditure on an activity has already been incurred, it must still be included in the appraisal if the item has a market value which can be realised, for example land.

Costs which have been irrevocably committed and have no salvage or realisable value, are termed ‘sunk costs’ (these may include investigation, design or other costs already incurred), and must not be accounted for in economic appraisal.

Disruption costs to the service provider during implementation may be included when these are expected to be substantial.

Operating and maintenance costs

Estimate operating and maintenance costs for the service over the analysis period.

Maintenance costs should include routine and periodic maintenance costs, as well as any refurbishment and replacement costs that occur in the appraisal period.

Treatment of depreciation

Depreciation is a non-cash item and must not be included as a separate item in the cash flows used to estimate the net present value of a proposal in the financial analysis. Only actual cash flows associated with maintenance and asset replacement, which already fully account for the depreciation of capital assets, are to be included in the analysis.

Treatment of interest

Interest expenses associated with financing an activity 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 to be included in discounted cash flows, the interest charges would be double counted; therefore, the proposal's funding gap would be overstated and the BCR understated.

Salvage value

In some instances, assets will have a longer lifespan than the appraisal period. The salvage value of capital assets should be included where:

- items have a market value, and
- there is an alternative use, or
- there is a scrap demand for items.

Stage 7b: Calculate service provider revenue

This section describes the information that should be included in the financial analysis of activity options that generate revenue. The process for forecasting the revenue of an improved service is different from that for a new service, and the methods for each type of service are described below.

Existing freight services

Where there is an existing freight service, it is the increase in service provider revenue that is used in calculating the funding gap. Any future funding assistance required will be to facilitate improvements to the service rather than to fund the existing service.

Using the demand estimate information generated in stage 2, calculate the change in service provider revenue:

$$\text{Change in service provider revenue} = (Q_2 \times P_{new}) - (Q_1 \times P_1)$$

where: P_1 is the base average user charge
P_{new} is the proposed average user charge
Q_1 is the current annual freight volume
Q_2 is the projected annual freight volume.

New freight transport services

For a new freight service, the projected annual freight volume 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 stage 2, calculate the annual service provider revenue.

$$\text{Annual service provider revenue} = (Q_{new} \times P_{new})$$

where: P_{new} is the proposed average user charge
Q_{new} is the projected annual freight volume.

Stage 7c: Perform cash-flow analysis

A new or improved freight service will usually involve some initial capital expenditure followed by ongoing annual operating and maintenance costs. These costs are offset to an extent by the 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

Analysts should use a post-tax rate of return. Care must be taken to ensure that service provider costs and revenues are calculated accordingly.

Period of financial analysis

The period of the financial analysis should, if possible, be sufficient to allow projected revenue to offset the initial capital cost. Care must however be taken to ensure that the analysis period is not unrealistically long. Uncertainties in demand for the proposed service should also be taken into account when setting the length of the analysis period.

Stage 7d: Calculate service provider's funding gap

The funding gap is the deficit in cash flow that needs to be reimbursed by local and central government if the option is to be financially viable from the service provider's point of view. This is based on the best estimate of the service provider's expected revenue and their 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 (either spread over the construction period or paid at the end of construction), or
- spread over the first few operating years of the proposal, or
- 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 is required to operate a subsidised service but does not necessarily mean that funding assistance is justified from a government (public policy) point of view.

Worksheet 3 of SP8 Freight services, contains a table with an inbuilt 'goal seek' function that may be used for determining the funding gap.

A worked example of funding gap analysis is provided in Appendix 8: worked examples.

Funding gap sensitivity tests

The financial analysis required to calculate the funding gap involves making assumptions and estimates of an uncertain future. Some assumptions may also be subjective in nature. As a result, assessments of the sensitivity of the funding gap to variations in critical assumptions must be undertaken on the preferred option.

There are three sensitivity tests that should be performed on the funding gap analysis to estimate upper and lower bounds. This helps to establish the potential effect of these variations on the present value of the funding gap of the proposal. The sensitivity tests are set out in Table 101.

Table 101: Sensitivity tests

Sensitivity test variables	Description
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 present value 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 present value of the funding gap of varying the timing of such expenditure.

Sensitivity test variables	Description
Period of analysis	The effect of varying the length of the period of analysis on the present value of the funding gap shall be presented.

Stage 8: Determine the benefit–cost ratios of the options

Refer to Chapter 6 for detailed information on developing BCRs.

Stage 9: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs.

Stage 10: Sensitivity testing on the preferred option

Refer to Chapter 7 of this manual for detailed information on sensitivity testing.

Assessing the sensitivity of economic analysis calculations to critical assumptions or estimates shall be undertaken using sensitivity testing, which needs to be undertaken for the critical inputs and assumptions used to choose the preferred option.

Sensitivity testing involves defining a range of potential values for an uncertain variable in the analysis and reviewing the variation in the analysis results as the variable changes within the range. This will highlight the sensitivity of the estimated final outcome to changes in input variables.

Stage 11: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

4.8 Analysis of private sector financing and road tolling

This section 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. Wallis (2005) provides guidance on private sector participation in provision of public infrastructure.

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:

1. If the facility is government funded, the tolls are simply a transfer payment between those motorists who pay them and the government.
2. 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.
3. Alternatively, tolls can be related to negative benefits (disbenefits). The effect of the toll is to reduce overall public benefits. If a 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 of gross toll collections is the same, regardless of which way they are viewed. Provided that tolls are not double counted, the net present value of the activity (present value of benefits minus present value of costs) is also independent of the way tolls are viewed.

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.

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 through an effective consultation process.

There are several 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 considered in reaching a toll regime which that meets the overall objectives of the proposal.

Private sector financing

The purpose of private sector activities is to involve private sector funds in community facilities. Treasury guidance for Public Private Partnerships provides an overview of the New Zealand public private partnership (PPP) model and policy and is intended to set the scene for procuring entities, potential, bidders and the public.

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 (see notes on financial analysis) 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. The *Procurement manual* for activities funded through the National Land Transport Programme provides transport activity procurement guidelines for approved organisations and NZTA.

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.

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 BCRs.

Consumer surplus methodology must be used for analysis 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, VOC and toll charge).

Simplified procedures for private sector financing, and road tolling activities

A range of simplified procedures available in this manual may be used to evaluate private sector financing, and road tolling activities with an undiscounted whole-of-life cost of less than or equal to $15 million. SP6 High productivity motor vehicles, SP8 Freight transport services, SP9 New public transport services, SP10 Existing public transport services, SP12 Travel behaviour, and SP13 Safety promotion are the simplified procedures most relevant to private sector financing, and road tolling activities. These procedures have been discussed in detail elsewhere within Chapter 4. Table 47 may be referred to select the appropriate procedure.

Full procedures for private sector financing, and road tolling activities

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

The following table outlines the stages of analysis in the economic efficiency evaluation of private sector financing, and road tolling activities. The chapters and sections of this manual that apply to each stage of the analysis are referenced in Table 102.

Table 102: Stages of analysis for private sector financing, and road tolling activities

Stage	Description	Refer
1	Consider and describe: a. the do-minimum b. improvement alternatives and options.	Current section Section 1.4: Counterfactuals Section 1.5: Alternatives and options
2	Collect data to assess travel impacts: • target population • demand estimates and modal share • uptake • level of diversion. Where possible use transport models to assess the impacts and undertake calibration of the transport models for the activities under consideration.	Current section and Chapter 2: Demand estimation and mode share
3	Measure and monetise the impacts (benefits and disbenefits) for the do-minimum and options, including: • impact on social cost and incidence of crashes • impact of mode on physical and mental health • impact of air emissions on health • impact of noise and vibration on health • impact on system reliability • impact on network productivity and utilisation	Chapter 3: Benefits

Stage	Description	Refer
	• impact on greenhouse gas emissions • impact on user experience of the transport system • wider economic benefit (productivity) • wider economic benefit (employment impact) • wider economic benefit (imperfect competition) • wider economic benefit (land use change) • other impacts that can be monetised – these are not included in this manual but can be included if there is sufficient supporting evidence and the approach is accepted by NZTA.	
4	Undertake risk analysis when there are significant unpredictable events that may affect or be affected by the improvement activity.	Chapter 7: Sensitivity and risk analysis
5	Quantify the costs of the improvement activities including: • investigation and design • property • construction • maintenance, renewal and operation • risk management; mitigation of external impacts • residual values. If there is a service provider, determine service provider costs, service provider revenue and the funding gap. Quantify the net costs to government of the funding gap.	Section 1.8: Costs
6	Discount the monetised benefits and costs over the analysis period to obtain present values. Then use to calculate the benefit–cost ratio(s).	Chapter 5: Discounting
7	Financial analysis to evaluate the viability of an activity by assessing its cash flows.	Current section
8	Determine the benefit–cost ratios of the options.	Chapter 6: Benefit–cost ratios
9	Use incremental cost–benefit analysis to select the preferred option for mutually exclusive options.	Chapter 6: Benefit–cost ratios
10	Perform sensitivity tests on the preferred option to determine how robust the calculations are and whether a small change in one of the input parameters has a large change on the analysis outcome(s).	Chapter 7: Sensitivity and risk analysis
11	Verify completeness of information, accuracy of calculations and validity of assumptions.	Current section

Stage 1a: Describe the do-minimum

The do-minimum for evaluating activities with public sector financing and/or road tolling shall only include committed and funded transport activities, the existing road network with minor improvements, and potentially the provision of the new road at a much later date (if the purpose of tolling is to bring forward the provision of the new road).

Stage 1b: Scale and scope of private sector financing, and road tolling options

Economic analysis 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. Additionally, financial analysis of the toll options is required.

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.

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.

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.

Stage 2: Demand estimates and modal share

Traffic modelling for a tolled road (and the surrounding road network) is an essential input to the analysis. 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 consider 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 case 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 traffic that has the toll route as an option.

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'.

Stage 3: Calculate private sector financing and road tolling activities impacts

Once traffic impacts have been determined, the calculation of national economic benefits follows in the normal manner (see section 4.3 for the procedures required to evaluate road renewal and improvement activities, and Chapter 3 for the relevant benefits) but using the disaggregated willingness-to-pay values for travel time for benefits or disbenefits (see section 3.6).

Consumer surplus methodology must be used for analysis 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, VOC and toll charge).

For most transport activities, an average value of time is used in the economic analysis, 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 analysis 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 versus 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.

Analysis of toll roads (including tolling policies) must use a distribution of values of travel time consistent with users' willingness-to-pay 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 the economic analysis.

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.

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 who continue to use the toll road, benefits are reduced by the extent of the toll charge, which is added to their generalised cost of travel.
- The benefits to users on the toll road may be increased due to less congestion on the tolled facility
- For those who 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 who 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 with 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.

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).

In assessing the commercial feasibility of private sector funding or a debt facility the following must be considered.

Stage 4: Undertake risk analysis for significant unpredictable events

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.

Refer to Chapter 7 of this manual for detailed information on risk analysis.

Stage 5: Calculate costs for do-minimum and improvement options

Section 1.8 must be viewed from both an economic and financial point of view.

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

Even if an 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.

Stage 6: Discount benefits and costs

Refer to section 1.9 and Chapter 5 of this manual for the detailed information on undertaking discounting.

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. Based on a discount rate of 4% and an analysis period of 40 years, sets of present worth factors have been calculated to convert future benefits and costs to their present values (see Table 103, and Table A132, Table A133 and Table A134 from Appendix 6: Discount factors). Discount rates of 3% and 6% are also provided in the tables for sensitivity testing.

For the analysis of private financing and road tolling, an adjusted analysis period may be most appropriate especially where there are long-term financial obligations.

Stage 7: Financial analysis

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.

Financial analysis is a method to evaluate the viability of an activity by assessing its cash flows. This differs from economic analysis 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 costs of debt and equity are observed only in nominal terms.

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

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) – the weighted average of the required return on equity and the (interest) cost of any debt financing reflecting the appropriate risk and norms associated with the industry.

Accounting, depreciation, economic multiplier effect and sunk costs should be excluded in the financial analysis. The effect of dividend imputation needs to be considered 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 (WACC) is used in financial analysis. 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 of cash flows
- net present value per $ of capital invested
- internal rate of return (IRR) of cash flows
- payback period
- profitability indices.

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

Stage 8: Determine the benefit–cost ratios of the options

The principles of economic appraisal apply to the analysis of toll road activities and activities involving private sector financing, however, the BCRs are calculated slightly differently. Refer to Chapter 6 for detailed information on developing BCRs, including toll road facilities.

In the present value calculations, all costs and benefits are expressed in current dollars and no allowance is made for price inflation or cost escalation. The discount rate is applied to the costs and benefits in each year to determine the present value of the costs and benefits which are then summed to get the total costs and benefits over the analysis period.

Stage 9: Incremental cost–benefit analysis

Where alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options is 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.

Refer to section 6.3 for detailed information on developing incremental BCRs.

Stage 10: Sensitivity testing on the preferred option

Sensitivity testing applies to both financial analysis and economic efficiency analysis. Refer to Chapter 7 of this manual for detailed information on sensitivity testing.

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.

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.

Stage 11: Verification of results

Verify completeness of information, accuracy of calculations and validity of assumptions.

5. Discounting

Benefits and costs generally arise throughout the life of projects and to calculate their present worth or present value they need to be discounted back to time zero. 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 2020, shall be 4% per annum. This is the rate calculated by NZTA as being appropriate for transport investment and is subject to ongoing review.

Based on a discount rate of 4%, sets of present worth factors have been calculated to convert future benefits and costs to their present values. Tables for discount rates of 3% and 6% are also provided for use in 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 present value. The annual SSPWF table for discount rates of 3%, 4% and 6% is provided in Table 103. A quarterly SSPWF table for the same discount rates is provided in Table A132 of Appendix 6: Discount factors.

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) should be used to discount the amounts to a present value, depending on whether the amounts are uniform or increase arithmetically over time (eg traffic and patronage growth). USPWF and AGPWF tables for discount rates of 3%, 4% and 6% are provided in Table A133 and Table A134 respectively of Appendix 6: Discount factors.

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

When discounting crash benefits the traffic growth rate will need to be adjusted in accordance with the procedures in Appendix 2: Crash analysis 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 present value of monetised impacts.

Worked examples of discounting using the SSPWF, USPWF and AGPWF are provided in Appendix 8: Worked examples.

5.1 Single payment present worth factor

Where a single benefit or cost arises at some future time, a SPPWF shall be applied to calculate its present value.

The formula for determining SPPWF factors is:

$$SPPWF^{i}_{n} = \frac{1}{(1+i)^{n}} = \frac{1}{1.04^{n}}$$

for a 4% discount rate, where: n is time in years after time zero, and
i is the discount rate expressed as a decimal, ie for 4% i = 0.04.

Table 103: Annual single payment present worth factors

Time (years from time zero)	4% Discount rate SPPWF	3% Discount rate SPPWF (sensitivity test)	6% Discount rate SPPWF (sensitivity test)
0	1.0000	1.0000	1.0000
1	0.9615	0.9709	0.9434
2	0.9246	0.9426	0.8900
3	0.8890	0.9151	0.8396
4	0.8548	0.8885	0.7921
5	0.8219	0.8626	0.7473

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Time (years from time zero)	4% Discount rate SPPWF	3% Discount rate SPPWF (sensitivity test)	6% Discount rate SPPWF (sensitivity test)
6	0.7903	0.8375	0.7050
7	0.7599	0.8131	0.6651
8	0.7307	0.7894	0.6274
9	0.7026	0.7664	0.5919
10	0.6756	0.7441	0.5584
11	0.6496	0.7224	0.5268
12	0.6246	0.7014	0.4970
13	0.6006	0.6810	0.4688
14	0.5775	0.6611	0.4423
15	0.5553	0.6419	0.4173
16	0.5339	0.6232	0.3936
17	0.5134	0.6050	0.3714
18	0.4936	0.5874	0.3503
19	0.4746	0.5703	0.3305
20	0.4564	0.5537	0.3118
21	0.4388	0.5375	0.2942
22	0.4220	0.5219	0.2775
23	0.4057	0.5067	0.2618
24	0.3901	0.4919	0.2470
25	0.3751	0.4776	0.2330
26	0.3607	0.4637	0.2198
27	0.3468	0.4502	0.2074
28	0.3335	0.4371	0.1956
29	0.3207	0.4243	0.1846
30	0.3083	0.4120	0.1741
31	0.2965	0.4000	0.1643
32	0.2851	0.3883	0.1550
33	0.2741	0.3770	0.1462
34	0.2636	0.3660	0.1379
35	0.2534	0.3554	0.1301
36	0.2437	0.3450	0.1227
37	0.2343	0.3350	0.1158
38	0.2253	0.3252	0.1092
39	0.2166	0.3158	0.1031
40	0.2083	0.3066	0.0972
41	0.2003	0.2976	0.0917
42	0.1926	0.2890	0.0865
43	0.1852	0.2805	0.0816
44	0.1780	0.2724	0.0770
45	0.1712	0.2644	0.0727
46	0.1646	0.2567	0.0685
47	0.1583	0.2493	0.0647
48	0.1522	0.2420	0.0610
49	0.1463	0.2350	0.0575
50	0.1407	0.2281	0.0543
51	0.1353	0.2215	0.0512
52	0.1301	0.2150	0.0483
53	0.1251	0.2088	0.0456
54	0.1203	0.2027	0.0430
55	0.1157	0.1968	0.0406
56	0.1112	0.1910	0.0383
57	0.1069	0.1855	0.0361
58	0.1028	0.1801	0.0341
59	0.0989	0.1748	0.0321
60	0.0951	0.1697	0.0303

5.2 Uniform series present worth factor

Where a series of equal benefits or costs arise each year or continuously over a period, USPWF should be applied to calculate the present value of these costs and benefits.

The formula for determining USPWF factors is:

$$USPWF^{i}_{n} = \frac{(1- (1 + i)^{-n})}{\log_e(1 + i)}$$

where: n is the time in years after time zero
i is the discount rate expressed as a decimal i.e. for 4% $i = 0.04$.

The present value of a time stream of equal annual benefits or costs shall be calculated as follows:

$$Present\ value = annual\ benefit\ (or\ cost) \times (USPWF_e - USPWF_s)$$

where: s is the start year
e is the end year of the cost or benefit stream.

The USPWF factors in Table A133 assume that the annual benefits or costs are evenly spread over each year and are continuously compounded.

5.3 Arithmetic growth present worth factors

Where costs or benefits increase (or decrease) each year arithmetically, arithmetic growth present worth factors (AGPWF), together with the corresponding USPWF factors, should be applied to calculate the present values of these costs and benefits.

It is assumed in this manual that traffic growth is arithmetic.

The formula for determining 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 is time in years after time zero
i is the discount rate in percent

The present value of a time stream of benefits or costs which increase or decrease arithmetically shall be calculated as follows:

$$Present\ value = annual\ benefits \times \{(USPWF_e - USPWF_s) + (R\ x\ (AGPWF_e - AGPWF_s))\}$$

where: R is the arithmetic growth rate at time zero
s is the start year
e is the end year of the cost or benefit stream.

The AGPWF factors in Table A134 assume that the annual benefits or costs occur continuously throughout the year and are continuously compounded.

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6. Benefit–cost ratios

The activity costs required for determining benefit–cost ratios (BCRs), incremental benefit–cost ratios, and the first-year rate of return, are 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. In this sense, all of the BCRs calculated for transport activities are incremental BCRs

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.

6.1 National benefit–cost ratio

NZTA uses the national benefit cost ratio as a measure of economic efficiency from a national perspective. A national benefit cost ratio must be calculated for all the short-listed options.

The formula for determining the national benefit cost ratio is:

National benefit cost ratio is the present values of national economic benefits divided by present value of national economic costs:

$$BCR_N = \frac{B}{C}$$

National economic benefits are defined as the net direct benefits and disbenefits experienced by transport users, the net indirect benefits and disbenefits experienced as externalities by the population outside the transport system, and all other monetised impacts.

Where the national economic benefits include wider economic benefits (WEBs) it is a requirement that the national benefit cost ratio is calculated with and without the WEBs included. This is described in more detail below.

National economic costs are defined in one of two ways. Where there is no service provider, national economic costs are the net cost to NZTA and approved organisations. Otherwise, national economic costs are the net cost to NZTA and approved organisations, plus net service provider costs.

National benefit–cost ratio with WEBs

If a transport activity generates productivity impacts including agglomeration impacts, employment impacts, , or output changes under imperfect competition, these impacts may be monetised and included in the calculation of national economic benefits. However, when these WEBs are present, it is a requirement that two national benefit–cost ratios are calculated and reported.

Firstly, a national benefit–cost ratio excluding WEBs must be calculated. For the BCR excluding WEBs, the present value of national economic benefits less the present value of WEBs is divided by the full national economic costs of the activity. The core sensitivity tests are undertaken using this BCR.

Secondly a national benefit–cost ratio including WEBs must be calculated. For the BCR including WEBs the full present value of national economic benefits is divided by the full national economic costs of the activity. The BCR including WEBs is treated as a sensitivity test.

Presenting the national benefit–cost ratio

When presenting the national benefit–cost ratio, the BCR should be rounded to one decimal place if the BCR is less than 10.0, including where the BCR is less than 1.0. If the BCR is 10 or greater the BCR should be rounded to the nearest whole number.

6.2 Government benefit–cost ratio

The government benefit–cost ratio (BCR_G) is used to indicate the level of benefits obtained from investment of local and central government funds in situations where government funding is supplemented by the availability of third-party funding or tolling revenue, or where it is necessary to cover service provider costs in the event of a funding gap for the operation of PT services.

The BCR_G is not an alternative to the BCR_N and it will not replace the BCR_N in the NZTA Investment Prioritisation Method (IPM). Rather the BCR_G is additional information that is helpful when considering both the business case and the financing of an activity.

Note:

- All costs are exclusive of GST, including tolls, farebox revenue, private sector contributions.
- Net cost to government should include cost incurred to enable private sector contributions (for example. tolling infrastructure and transaction costs).

The BCR_G formula is:

$$BCR_G = \frac{B - C_p}{C - C_p} = \frac{B - C_p}{C_g}$$

Where:

B is the PV of national economic benefits (including disbenefits). In the estimate of the total benefit the suppression impact (for example) of tolling on demand should be taken into account.

C is the PV of national economic costs. It includes costs incurred to enable private sector contributions (for example tolling infrastructure and transaction costs) and the maintenance costs associated with maintaining a facility (for example toll road facilities).

C_p are the costs borne by parties outside the NLTF system (for example the PV of gross toll revenue in the case of toll roads, farebox revenue in the case of PT services, or private sector contributions to enable an activity to proceed that otherwise would not proceed).

C_g is the PV of net costs to government = $C - C_p$ (that is, PV central and local government costs less PV private sector contributions).

Examples of BCRG

BCR_G for a toll road is:

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

Where:

National economic benefits	= net direct and indirect benefits and disbenefits to all affected transport users plus all other monetised impacts
Tolls	= total toll collections (excl. GST)
Net government costs	= PV costs to NZTA and approved organisations.

BCR_G for public transport services with fare revenue included is:

$$BCR_G = \frac{present\ values\ of\ national\ economic\ benefits - present\ value\ of\ farebox\ revenues}{present\ value\ of\ net\ government\ costs}$$

Where:

National economic benefits	= net direct and indirect benefits and disbenefits to all affected transport users plus all other monetised impacts
Farebox revenue	= total revenue from tickets (excl. GST)

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Net government costs = PV costs to NZTA and approved organisations.

BCR_G for a private sector contribution is:

$$BCR_G = \frac{present\ values\ of\ national\ economic\ benefits - present\ value\ of\ private\ setor\ contributions}{present\ value\ of\ net\ government\ costs}$$

Where:

National economic benefits	= net direct and indirect benefits and disbenefits to all affected transport users plus all other monetised impacts
Private sector contributions	= total private sector contributions (excl. GST) over and above the normal central and local government contributions (for example contributions made in line with the IFF Act 2020[17])
Net government costs	= PV costs to NZTA and approved organisations.

Note: for the purposes of calculating the BCR_G the normal NZTA discount rate of 4% is used together with sensitivity testing using a discount rate of 6%. For known high-risk projects sensitivity testing using an 8% discount rate is recommended as well as using the 4% and 6% rates.

Three worked examples of the BCR_G procedure are provided in Appendix 8: Worked examples.

6.3 Incremental cost–benefit analysis

Where activity alternatives and options are mutually exclusive, incremental cost–benefit analysis of the alternatives and options must be used to identify the optimal activity from an economic efficiency standpoint.

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 more economically efficient.

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

The formula for determining the incremental BCR is:

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

Procedure for calculating the incremental BCR

The following procedure should be used to calculate the incremental BCR of mutually exclusive options:

1. Rank the options in order of increasing cost.
2. Starting at the lowest-cost option, consider the second to lowest-cost option and calculate the difference between the present value of the benefits of the lowest cost-option and the second to lowest-cost option. These are the incremental benefits.
3. Next, calculate the difference between the present value of the costs of the lowest cost-option and the second to lowest-cost option. These are the incremental costs.
4. Calculate the incremental BCR by dividing the incremental benefits by the incremental costs.

[17] Infrastructure Funding and Financing Act 2020. This act provides for a new way to fund and finance infrastructure projects that support housing and urban development. The act enables a long-term property tax to be pledged to special project debts (called ‘revenue bonds’) to provide alternatives to governments’ general obligations (that is, tax-backed) debts.

5. If the incremental BCR is equal to or greater than the target incremental BCR, discard the lower-cost option and use the second to lowest-cost option as the comparison basis with the next higher-cost option.
6. 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.
7. Repeat the procedure from steps 2 to 6 until all options have been analysed.
8. Finally, select the option with the highest cost which has an incremental BCR equal to or greater than the target incremental BCR.

A worked example of the incremental BCR procedure is provided in Appendix 8: Worked examples.

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 from the guidance below, the analyst must provide a detailed explanation supporting the chosen value. The following guidance is provided:

- 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.
- Where the BCR of the preferred option is greater than 3.0 but less than 5.0, the target incremental BCR shall be 3.0.
- Where the BCR of the preferred option is greater than or equal to 5.0, the target incremental BCR shall be 5.0.

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 alternative or option, the results of this sensitivity test must be described and included in the activity's economic case. For example, if the target incremental ratio is 2.0, the choice of alternative or option should also be tested by using a target incremental ratio of 3.0, and how this affects the choice of option should be reported.

6.4 First year rate of return

First year rate of return (FYRR) is used to indicate the optimal start date of an activity.

FYRR, expressed as a percentage, is calculated by dividing the present value of benefits in the first full year following completion of construction by the activity's full present value of net costs. The formula for determining the FYRR is:

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

The FYRR is useful for sequencing activities when funding is constrained, but it should not be used to evaluate whether an activity is economically efficient. The FYRR indicates the extent to which the benefits of an activity arise immediately, or are dependent on future growth, but the overall economic efficiency cannot be evaluated on the basis of the activity's benefits in the first year of operation.

It is a requirement that the FYRR is calculated for the preferred option.

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7. Sensitivity and risk analysis

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
- uncertainty about the 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 economic analyses to critical assumptions or estimates must be undertaken using either a sensitivity analysis or risk analysis, or both, as appropriate.

Sensitivity analysis involves defining a range of potential values for an uncertain variable in the analysis and reviewing the variation in the economic analysis outcomes 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 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. For a risk analysis to be possible, both the impact arising from each of the possible outcomes and their probability of occurrence have to be estimated.

A recent development in the consideration of risk and uncertainty is the adaptive decision-making approach, a procedure that provides the analyst with additional flexibility during the assessment process where there is deep uncertainty, by considering all possible outcomes when selecting options for further investigation. This approach is referred to in section 7.6.

The use of sensitivity and risk analysis can support development of ways of minimising, mitigating and managing uncertainties.

7.1 Sensitivity analysis overview

The application of the benefit quantification procedures in this manual will generally result in point estimates. This implies a level of precision and accuracy that is not realisable in real world settings due to the inherent uncertainty in forecasting future conditions.

While the real BCR of an activity is uncertain and unknowable *ex-ante*, this does not invalidate the use of BCRs to forecast efficiency. The BCR is a decision support tool, and sensitivity analysis, when properly applied, can improve the quality of decision-making by highlighting the critical assumptions and conditions required for an activity to be efficient *ex-post*.

Sensitivity analysis is useful for quickly testing the veracity of the analysis and demonstrating to decision-makers the robustness of the BCR to often extreme changes in key assumptions. For transport analysts, it can also indicate where more effort is required to quantify the uncertainty affecting the estimation of benefits and as a precursor to full risk analysis.

At a minimum, sensitivity analysis can be conducted simply and quickly by varying a single assumption variable while holding all others constant. It is however recommended that multiple assumptions, representing a range of future scenarios, are varied at the same time to identify the extreme bounds of the BCR.

7.2 Sensitivity tests

This section lists a selection of sensitivity tests that should be considered during appraisal. These lists are not exhaustive and professional judgement should be applied to select the most appropriate sensitivity tests based upon the type of activity under consideration and any uncertainties identified during activity development.

The results of the sensitivity tests, along with explanation of any assumptions or choice of test, should be reported as upper and lower bounds on the BCR as a component of an activity's economic case.

Discount rate

While the base analysis uses the standard 4% discount rate, sensitivity testing should be carried out at discount rates of 3% and 6%. In particular, sensitivity testing at the lower rate of 3% can be used for activities with 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 Table 103 (SPPWF) from Chapter 5 as well as Table A133 (USPWF) and Table A134 (AGPWF) from Appendix 6: Discount factors.

Demand estimation

As all forecast benefits and disbenefits are derived from future demand estimates, particular emphasis should be placed on testing the drivers or demand. This is described in detail in section 7.3.

Benefit and cost estimation

Inputs to the quantification of benefits, disbenefits and costs that should be tested include:

- maintenance costs, particularly where there are significant savings
- cost overruns
- traffic volumes
- service or infrastructure quality
- travel speeds
- road roughness
- crash reductions.

For sensitivity tests of benefits, disbenefits and costs it is not acceptable to limit analysis to variations of variables by ±20%. Appropriate bounds should be selected based upon professional judgement and activity specific conditions. These bounds need not be symmetrical and may have long tails in a single direction.

Safety improvements

Safety improvement activities are undertaken where a route or site (eg curve, railway crossing, bridge etc) has a high occurrence of crashes, or when the risk of crashes is considered high.

Given the majority of benefits (and hence benefit–cost ratio) for such schemes arise from a reduction in crashes, it is important that a robust assessment is undertaken. Analysts should avoid basing their assessment on a small number of historical crashes or using unsuitable crash rates, crash prediction models or crash reduction factors. It is also important to undertake sensitivity testing to understand how sensitive the benefit–cost ratio is to the crash history, crash prediction and crash reduction factors.

7.3 Demand estimation sensitivity tests

Demand estimates are important in economic assessments because the amount of predicted use of the facility, service or mode is often a key, if not critical, driver of the potential benefits. Many of the parameters used in the development of demand estimates are averages from a wide range of potential values. Sensitivity tests of demand estimates are therefore an important consideration, particularly in situations where:

- the estimated use of the activity is a critical factor; for example, projected volumes on toll roads, estimated mode share for larger PT schemes, and estimated volume of cyclists on a new significant dedicated cycleway
- the economic analysis includes longer-term (20 years into the future or longer) demand estimates, which implicitly means there is more uncertainty
- the analysis and outcomes are sensitive to the level of congestion, delays, and queueing (particularly parts of the network being highly congested for significant lengths of time) – this can relate to both the do-minimum and activity scenarios, but is often most pertinent in the do-minimum scenario where the activity may reduce congestion
- economic outcomes are particularly sensitive to smaller changes in demand estimates; for example, the level of development anticipated by certain years on a key approach to an intersection improvement assessment.

Forecast horizons and uncertainty, provides some context around different scenarios, and where and when the number and range of sensitivity tests may be important. This relates to producing short-, medium- and long-term forecasts in different locations when assessing different scales of activities.

Appendix 1: Demand estimation methods and guidance provides guidance on techniques, methods and considerations for developing demand estimates. Where these approaches and techniques can be used to develop sensitivities, this is described and noted.

Scenario testing and demand estimate sensitivities

As described in section 1.11: Scenario testing, scenarios are plausible states of the future and are a powerful approach to sensitivity analysis. Plausible future states relating to transport demand may be developed through a combination of adjustments to several sensitivity parameters; for example, to produce a ‘high private vehicle mode share’ scenario or a ‘high public transport mode share’ scenario. As described in section 1.11, this concept extends to the potential development of multiple do-minimum and activity scenarios. For example, a ‘high private vehicle mode share’ future demand scenario may have associated with it a do-minimum network that features additional vehicle optimisation improvements.

Guidance on demand estimate sensitivity tests

Table 104 and Table 105 below provide overview guidance on when certain elements may have a greater influence on demand estimation and or have higher levels of uncertainty needing further consideration. This leads to considerations of how to determine which elements may be important to alter as sensitivity tests in order to produce a range of demand estimates, particularly where the demand estimation is a key driver of the economic benefits.

This should not be considered a comprehensive list of all the potential elements influencing demand estimation, or a sensitivity test check list, rather it provides context on where and when sensitivity tests may be important in relation to demand estimation aspects.

Table 104 is focused on project models that do not have demand estimates fed by regional models, calculations, spreadsheet methodologies, trend analyses and similar. Table 105 is focused on regional transport modelling and, by association, project models that have demand estimates fed by regional models.

Table 104: Guidance on importance of sensitivity tests – project model and calculation focus

Factors affecting demand estimates	Project model/calculation approaches			
	Network project model (not linked to/fed by regional model)	Short corridor/ intersection model (not linked to/fed by regional model)	Spreadsheet or similar equations/ models/ calculations	Straightforward calculations
Elasticity methods, relationships and values	I	I	P	U
Local land use changes	P	P	P	U
Local transport system and supply changes	P	P	P	U
Application of trip rates	P	P	P	U
Application of distribution analysis	P	P	P	U
Factors/trends selected in factoring methods	P	P	I	U
Application of trend analysis	P	P	I	I
Application of engineering estimate methods of predicted facility use	U	U	P	I

I = Several sensitivity tests likely to be important
P = Small number of sensitivity tests potentially or partially important
U = Sensitivity tests unlikely to be important or critical/less applicable

Section 2.12, below Table 2 provides some expanded information on each of the elements, methods and approaches in the above table. The points below relate these considerations to potential methods and approaches for developing sensitivity tests. In some cases, several of these elements may be varied separately or together to produce a number of demand estimate sensitivities.

- **Elasticity methods, relationships and values**: sensitivity tests varying the elasticity value(s) used are likely to be a good way to examine the response and suitability in relation to the specific activity in the local context.
- **Local land use changes**: sensitivity tests could include running scenarios with and without specific land use developments that are important to the activity demand scenario, faster and slower rates of land use development uptake, etc.
- **Local transport system and supply changes**: sensitivity tests may be straightforward, for example, testing with and without a local transport system change that effects the economic assessment.
- **Trip rates:** increasing and decreasing trip rates produces straightforward demand estimate sensitivity tests, particularly where an assumed trip rate has a direct effect on the economic assessment.
- **Distribution analysis:** alterations to the distribution assumptions produce straightforward demand estimate sensitivity tests, particularly where an assumed trip distribution has a direct effect on the economic assessment.
- **Factoring methods:** varying factors is a straightforward approach to sensitivity tests and analyses.
- **Trend analysis:** where medium- and longer-term forecasts are developed from trend analysis, and the resulting demand estimates are important to the economic assessment, straightforward sensitivity tests may be developed by varying the trend factor(s), and/or adjusting the magnitude

of growth that occurs within certain timeframes (for example, large proportion of growth occurring within an early timeframe and lower growth following this, and vice-versa).

- **Engineering estimates of predicted facility use**: varying the level of predicted facility use produces sensitivity tests on the predicted outcomes.

Table 105 provides some high-level guidance on which elements may have a greater influence on and/or produce greater levels of uncertainty in demand estimates in regional transport models. These characteristics lead to guidance on altering these elements and inputs as sensitivity tests to produce a range of demand estimates.

One, two, or several of these elements may be adjusted in isolation or combination to produce demand estimate sensitivities.

Table 105: Guidance on importance of sensitivity tests – regional transport modelling focus

Factors affecting demand estimates	Geographic context/transport environment			
	Major urban centre (population roughly greater than 500,000)	Moderate urban centre (population roughly between 100,000–500,000)	Small urban centre (population ~ 30,000–100,000)	Township, rural corridor/ area (population roughly less than 30,000)
Population structure/make-up (particularly age)	I	I	I	P
Household/family structure (retired, school-age children, in workforce, etc)	I	I	I	P
Vehicle availability/access to a vehicle	I	I	P	P
Access to alternatives modes and infrastructure (public transport, cycling, etc)	I	I	P	U
Public transport – service coverage, service frequency, charges	I	I	P	U
Residential density – accessibility to activities	I	P	P	U
Parking – charge and availability of supply	I	P	P	U
Road congestion/delay	I	P	P	U
Road pricing/tolling	I	I	I	I
Route choice	P	P	U	U
Technology influencing behaviour (online shopping, work/school travel plans)	P	P	P	U

I = Important driver, several sensitivity tests liked to be important
P = Moderate impact, small number of sensitivity tests potentially required
U = Sensitivity tests unlikely to be important or critical/less applicable

Section 2.12, below Table 3, provides some expanded information on each of the elements, methods and approaches in the above table. The points below relate these considerations to potential methods and approaches for developing sensitivity tests. In some cases, several of these elements may be varied separately or together to produce a number of demand estimate sensitivities. In all cases, the likelihood of these elements changing should be assessed so that sensitivity tests are realistic.

- **Population structure/make-up**: as well as varying the overall population projection for a region (for example, through Statistics NZ's low, medium and high projections), the make-up and structure of the population could be altered to produce sensitivities.
- **Household/family structure:** the ease of varying these input assumptions as sensitivity tests will be dependent on the structure of the model. However, if significant changes in household/family structure are anticipated, then sensitivity tests should be carried out varying the number of shopping trips, work trips, etc.
- **Vehicle availability/access to a vehicle**: varying (for example, by reducing) vehicle availability/access for households is a method for providing a sensitivity test on potential changing future travel patterns (for example, less private vehicle trip-making as a result of climate change policy, behaviour changes and/or technology changes).
- **Access to alternative modes and infrastructure:** sensitivity tests may involve factoring the modal demand down; for example, reducing the car demand estimated for a road-based activity to quantify the potential reduction in economic benefits.
- **Public transport coverage/frequency/charges**: sensitivity tests here may involve adjustment to walk times (for example, due to increased micro-mobility), wait/transfer times (for example, due to technology improvements that improve the reliability and accuracy of PT arrival times), and fares (for example, due to climate change policy or behaviour changes).
- **Residential density:** sensitivity tests could involve changing where there are employment opportunities and/or schools to represent closer opportunities to shop and work, and for education. Realistic patterns should be considered.
- **Parking**: varying parking charges may produce a change in mode choice or a change in destination choice, and may be an approach to developing sensitivity tests.
- **Road pricing/tolling:** sensitivity tests could involve altering monetary charges and elements that influence the human response to cost changes. In Australia, there have been legal challenges on toll road forecasts, particularly where consortia were bidding to secure the project. Practical engineering considerations, quality reviews, and sensitivity tests are critical in these scenarios

There are several scenarios to consider in relation to developing demand sensitivity tests from regional transport models:

- **Specific activity economic assessment**: when carrying out an economic assessment of a specific type of transport activity (for example, public transport improvement or a new toll road), it is sensible and advisable to carry out targeted sensitivity tests that will directly influence the demand estimates associated with the activity (for example, parameters and assumptions effecting PT mode choice and people's responses to road pricing/tolling).
- **General demand scenario development:** a region may develop a set of demand estimates for ongoing consideration and use in assessments, or more generalised demand scenarios may need to be developed for significant projects in key locations (for example, a new bridge in a major urban centre). These are grouped below in 'themed' demand scenarios, purely as illustrative examples:
    - Historical trip-making scenario: parameters, relationships, models and equations are 'held' as per the validated base model to produce medium- and long-term demand forecasts.
    - High PT uptake: parameters and assumptions that effect the relative attractiveness (generalised cost) of PT travel versus private vehicle travel are adjusted to increase PT mode share.
    - Reduced overall trip-making: parameters and assumptions that effect the overall number of trips made by trip purpose are adjusted to reflect significantly increased working and/or shopping from home and/or higher uptake of e-mobility, etc. The result being fewer overall trips being made across the network.

The NZ Modelling User Group (NZMUGS) has been developing considerations and information relating to sensitivity tests, the content above draws from this work. Further background, references and information, there are several discussion papers on forecasting and sensitivity tests available via the NZMUGS webpage.

One recommendation from the NZMUGS work is the use of an uncertainty log, which is described further below.

Uncertainty log

Various agencies around the world have introduced the concept of an uncertainty log in relation to transport analysis. This is a record of the assumptions made in the model (and/or any calculations, mathematical models, etc) that will affect demand and supply.

In the United Kingdom (UK), an uncertainty log is included in the Department for Transport guidance. The UK guidance uses subtlety different definitions, particularly for forecasts and scenarios, than the MBCM. For more information and background, see *TAG Unit M4: Forecasting and uncertainty* (UK Department of Transport 2019).

The broad UK approach is to develop a core scenario, which is based on the most unbiased and realistic set of assumptions. This forms a central case, and alternative scenarios are developed around this. This concept could be applied to both the do-minimum and, in the case where the activity is anticipated to have a more significant effect on travel demand (for example, a large PT scheme), the activity scenario.

Alternative scenarios are then developed around the core scenario. Importantly, the alternative scenarios are developed based on key uncertainties in the core scenario.

The uncertainty log is used to summarise the significant assumptions and uncertainties in the modelling/analysis and forecasting approach. The purpose of the log is to document the central assumptions that underpin the core scenario and record the degree of uncertainty around these central assumptions. These assumptions and uncertainties can then be used as the basis for the development of alternative forecasts and/or model parameter sensitivity tests.

The uncertainty log extends to cover both elements of uncertainty in demand estimation (including base and future years) and elements of uncertainty in the specification/settings/parameters in the model (for example, vehicle route choice parameters). Another way to describe this is that broadly there are two sources of uncertainty:

1. inputs (such as size of new housing development, future population, etc)
2. error in the model parameters and specifications (how these inputs propagate through the model).

Along with the elements, considerations and methods that relate more directly to demand estimation sensitivity tests as described in the sections above, the uncertainty log and associated sensitivities could include factors such as:

- concerns or issues with the observed data that has been used to develop a model or carry out analysis
- currency of the base year models, robustness of the base year calibration/validation, and comments by the peer reviewer
- any specific identified areas of weakness in the base model; for example, a specific location in the network where the modelled versus observed comparison is poor
- currency of the inputs used to develop travel demand estimations; for example, the population projections, regional land use development plans or strategies used
- appropriateness and design of the model available for the assessment
- key parameters or settings that directly influence the model's ability to predict a key outcome; for example, balance of traffic volumes on competing routes, the operation (delays and queues) of a particular network feature (for example, a key multi-lane roundabout), queues blocking back into critical areas of the network, traffic signal coordination and associated measurement of delays between scenarios, consistency and reliability of public transport travel times.

Whether these components are used to develop sensitivity tests or not in relation to an economic assessment depends on how they are anticipated to affect the outcomes of the assessment. Greater uncertainty in relation to these elements could result in an increased number of sensitivity tests being run; for example, further future-year demand tests and/or changes to key model parameters.

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7.4 Risk analysis overview

Risk is an extensive concept that involves different aspects and levels of magnitude. The risk procedures contained within this section are not exhaustive but are designed to cover the most common types of risks that arise in transport activities.

The risk procedures are set forth with two audiences in mind:

1. Transport analysts should consider the risks that arise from the inaccurate estimation of benefits, and costs. The cost–benefit analysis and appraisal concepts in Chapter 1 of this manual should be used to guide the development of proposals and options. There are a range of uncertainties (such as the accuracy of forecasting) and limitations (such as the availability of data) that can affect the estimation of economic benefits and costs.
2. Decision makers should be aware of the risk of making sub-optimal or poor investment decisions. NZTA has legislative obligations to ensure that activities are efficient and effective (as per section 20 of the Land Transport Management Act 2003). The primary source of risk for decision making is the possibility of investing in non-efficient activities or failing to invest in efficient activities.

The risk procedures are designed to follow the principles set out in the ISO31000 standard on risk management. These principles are set out below:

- **Integrated**: Risk management is an integral part of all organisational activities.
- **Structured and comprehensive**: A structured and comprehensive approach to risk management contributes to consistent and comparable results.
- **Customised**: The risk management framework and process are customised and proportionate to the organisation’s external and internal context related to its objectives.
- **Inclusive**: Appropriate and timely involvement of stakeholders enables their knowledge, views and perceptions to be considered. This results in improved awareness and informed risk management.
- **Dynamic**: Risks can emerge, change or disappear as an organisation’s external and internal context changes. Risk management anticipates, detects, acknowledges and responds to those changes and events in an appropriate and timely manner.
- **Best available information**: The inputs to risk management are based on historical and current information, as well as on future expectations. Risk management explicitly considers any limitations and uncertainties associated with such information and expectations. Information should be timely, clear and available to relevant stakeholders.
- **Human and cultural factors**: Human behaviour and culture significantly influence all aspects of risk management at each level and stage.
- **Continual improvement**: Risk management is continually improved through learning and experience.

Risk procedure coverage

Activities

The risk procedures provide guidance on risks at an activity level rather than organisational risks. The primary purpose of this manual is to establish consistency, transparency and comparability between activities to aid the evaluation of their economic efficiency.

For organisation-wide risk management guidance and requirements please refer to Minimum standard Z/44 – Risk management practice guide.

Economic impact

The risk procedures focus on the economic impact risks of activities rather than risks associated with project delivery. Details of construction and project management risks are required as part of a business case but out of scope for this manual. The risk procedures in this manual are designed to assess the risks related to the benefits and costs of an activity.

Risk reduction benefits
Risk reduction benefits are monetisable benefits that may arise from improvements to resilience, safety or travel time reliability. A worked example of risk reduction using the Risk analysis procedure for resilience is provided in Appendix 8: Worked examples.

Risk concepts

The risk procedures are designed around a common set of concepts, which are described in more detail below.

Risk
The effect of uncertainty on objectives. An effect is a deviation from the expected. It can be positive, negative or both, and can address, create or result in opportunities and threats. Risk is usually expressed in terms of risk sources, potential events, their consequences, and their likelihood.

Risk source
An element which alone, or in combination with others, has the potential to give rise to risk.

Event
An occurrence or change of a particular set of circumstances. Events included changes that are expected to occur, but do not, or changes that are not expected to occur but do so. Additionally, an event can be a risk source.

Consequence
The outcome of an event affecting objectives. Consequences can be expressed qualitatively or quantitatively. Any consequence can escalate through cascading and cumulative effects.

Likelihood
The chance of something happening. In risk management terminology, the word 'likelihood' is used to refer to the chance of an event occurring, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).

Risk rating definitions

The risk procedures refer to a common set of definitions drawn from Z/44.

Table 106: Likelihood rating (Z/44)

	Rare	Unlikely	Possible	Likely	Almost certain
Probability (applicable to capital projects)	<= 5%	>5%–30%	>30%–55%	>55%–85%	>85%
Frequency (applicable to M&O contracts)	Less than once in 10 years	At least once in a period of 6–10 years	At least once in a period of 2–6 years	At least once in a period of 1–2 years	At least once in a period of 12 months

Consequence rating
Generally speaking, the consequence is rated according to the extent of the impact on objectives. The consequence rating includes five categories:

- insignificant
- minor
- moderate
- severe
- extreme.

Each risk is likely to have an individual definition and measurement of its consequences (both positive and negative). Consequences can be expressed qualitatively or quantitatively.

The criteria used to distinguish different consequence ratings are based upon professional experience of the key factors which affect levels of risk. Where there is any doubt as to the appropriate classification, the general quantitative rule expressed in Table 107 should be used:

Table 107: Consequence ratings

	Extreme	Severe	Moderate	Minor	Insignificant
Cost deviation	>±20%	±10%–20%	±5%–10%	±1%–5%	<±1%
Benefit deviation	>±20%	±10%–20%	±5%–10%	±1%–5%	<±1%

The consequence thresholds apply separately to each single benefit or cost risks. At a project level, the interaction of risks may result in a higher risk threshold than a simple summation of benefit and cost risks. Qualitative consequence ratings and critical thinking are recommended when determining overall project risk consequence ratings.

Table 108 provides an example of high level project risk consequence using qualitative rating criteria (Z/44).

Table 108: Risk consequence – qualitative rating criteria (Z/44)

	Deliverables and milestones (variance in working days	Scope (products, organisational)	Financial impact	Benefits	Product quality
Extreme	Slippage to project deliverable greater than 40% Slippage to milestone on critical path greater than 40%	Complete failure of project to deliver currently approved scope	Variance (+) from currently approved life of project cost of greater than 30%	Complete failure to realise agreed baseline benefits	Quality of more than one product on critical path does not meet quality criteria for product acceptance, and specified quality is not achievable
Severe	Slippage to project deliverable of between 20%–40% Slippage to milestone on critical path of between 20%–40%	Delivery of a significant portion of approved scope regarded as essential by project executive is seriously impaired	Variance (+) from currently approved life of project cost, of between 20%–30%	Significant reduction and delay in realising agreed baseline benefits	Quality of a product on critical path does not meet quality criteria for product acceptance, and specified quality is not achievable
Moderate	Slippage to project deliverable of between 10%–20% Slippage to milestone on critical path of	Delivery of a component of currently approved scope regarded as essential by project executive is impaired	Variance (+) from currently approved life of project cost, of between 10%–20%	Significant delay, but no, or minor, reduction in realising agreed baseline benefits	Quality of more than one product on critical path does not meet quality criteria for product acceptance, but

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	Deliverables and milestones (variance in working days	Scope (products, organisational)	Financial impact	Benefits	Product quality
	between 10%–20%				specified quality is achievable
Minor	Slippage to project deliverable of between 5%–10% Slippage to milestone on critical path of between 5%–10%	Delivery of a component of currently approved scope regarded as non-essential by project executive is impaired	Variance (+) from currently approved life of project cost, of between 5%–10%	Minor reduction and delay in realising agreed baseline benefits	Quality of a product on critical path does not meet quality criteria for product acceptance, but specified quality is achievable
Insignificant	Slippage to project deliverable of up to 5% Slippage to milestone on critical path of up to 5%	Delivery of a component of currently approved scope regarded as insignificant by project executive is impaired	Variance (+) from currently approved life of project cost of up to 5%	No reduction but minor delay in realising agreed baseline benefits	Quality of one or more products not on critical path does not meet quality criteria for product acceptance, but specified quality is achievable

Risk matrix (Z/44)

The classification of risks by likelihood and consequence allows a qualitative risk rating to be assigned to the benefit or cost rating according to the matrix in Table 109.

Table 109: Risk matrix

	INSIGNIFICANT	MINOR	MODERATE	SEVERE	EXTREME
ALMOST CERTAIN	Low	Medium	High	Critical	Critical
LIKELY	Low	Medium	High	Critical	Critical
POSSIBLE	Low	Medium	Medium	High	Critical
UNLIKELY	Low	Low	Medium	Medium	High
RARE	Low	Low	Low	Low	High

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7.5 Risk analysis procedures

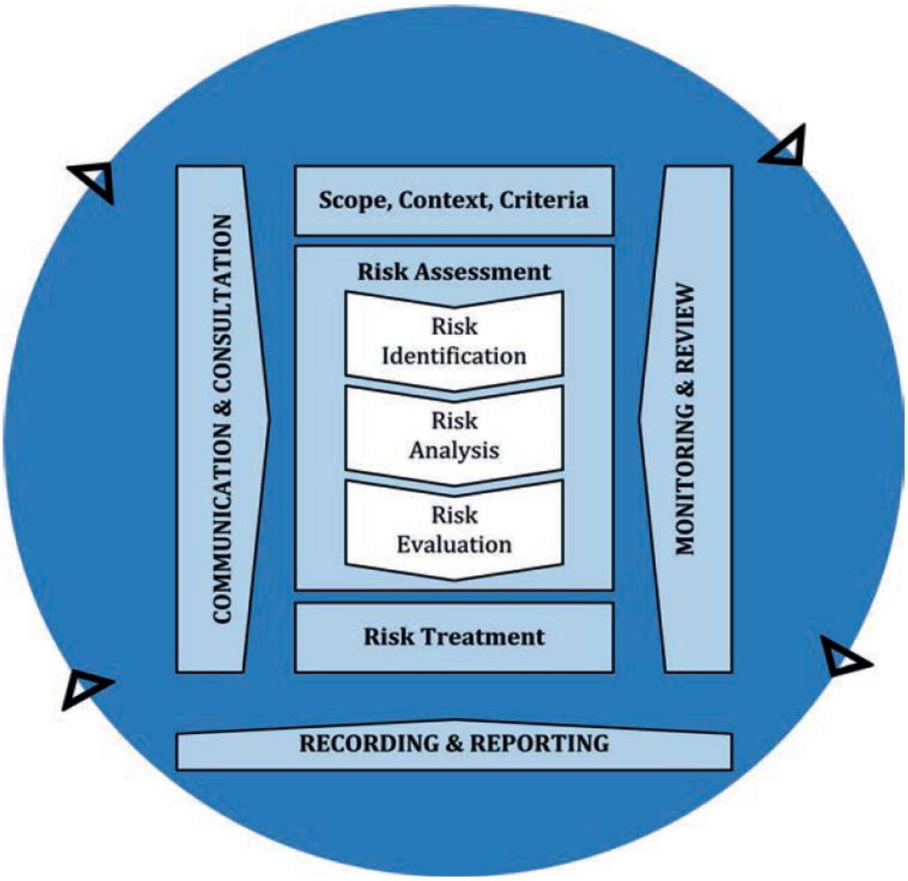
The risk analysis of an activity should be developed according to the following procedural steps.

Risk management and analysis

Process

The risk management process involves the systematic application of policies, procedures and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording and reporting risk.

Figure 21: Risk management process



Risk assessment

A risk assessment is the overall process of risk identification, risk analysis and risk evaluation. Risk assessments are to be conducted using risk analysis worksheet 1 and risk analysis worksheet 2. Risk treatments are to be captured in risk analysis worksheets 3.

Risk analysis worksheet 1 is used for both an abbreviated summary of risks for activities that are in the early stages of analysis, and for detailed reporting of risks for activities that are at the detailed (DBC) or single-stage business case (SSBC) stage.

Risk analysis worksheet 2 is to be used to provide additional detailed information on the high and critical risks identified in risk analysis worksheet 1 and an estimated quantifiable risk calculation.

Risk analysis worksheet 3 is the risk-adjusted benefits and costs and BCR risk tool.

All three risk analysis worksheets, and their associated instructions, are contained within this manual in Appendix 7: Risk analysis worksheets.

Risk identification

The purpose of risk identification is to find, recognise and describe risks that might help or prevent an activity achieving its objectives. Transport analysts may use a range of techniques to identify uncertainties that affect one or more objectives. The following factors, and the relationship between these factors, should be considered:

- tangible and intangible sources of risk
- causes and events
- threats and opportunities
- vulnerabilities and capabilities
- changes in the external and internal context
- indicators of emerging risks
- the nature and value of assets and resources
- consequences and their impact on objectives
- limitations of knowledge and reliability of information
- time-related factors
- biases, assumptions and beliefs of those involved.

Risk analysis

The purpose of risk analysis is to comprehend the nature of risk and its characteristics including, where appropriate, the level of risk. Risk analysis can be undertaken with varying degrees of detail and complexity, depending on the purpose of the analysis, the availability and reliability of information, and the resources available. Analysis techniques can be qualitative, quantitative or a combination of these, depending on the circumstances and intended use.

Risk analysis should consider factors such as:

- the likelihood of events and consequences
- the nature and magnitude of consequences
- complexity and connectivity
- time-related factors and volatility
- the effectiveness of existing controls
- sensitivity and confidence levels.

Highly uncertain events can be difficult to quantify. This can be an issue when analysing events with severe consequences. In such cases, using a combination of techniques generally provides greater insight.

Risk analysis provides an input to risk evaluation, to decisions on whether risk needs to be treated and how, and on the most appropriate risk treatment strategy and methods. The results provide insight for decisions, where choices are being made, and the options involve different types and levels of risk.

Risk evaluation

The purpose of risk evaluation is to support decisions. Risk evaluation involves comparing the results of the risk analysis with the established risk criteria to determine where additional action is required. This can lead to a decision to:

- do nothing further
- consider risk treatment options
- undertake further analysis to better understand the risk
- maintain existing controls
- reconsider objectives.

Decisions should take account of the wider context and the actual and perceived consequences to external and internal stakeholders. The outcomes of risk evaluation should be recorded, communicated and then validated at appropriate levels of decision maker.

Analysing benefit estimation risks from demand estimation

Benefit estimation may involve analysis that includes estimating the demand for the activity in current or base years, and forecasting future-year demand. Forecasting future-year demands is often linked to, or based on, base year models and historical data sources. The benefit estimation risks below are focused on the risks in any demand estimate base year data used and in the future-year demand estimation forecasts. This risk covers three main categories:

- base year/model/source data used to develop demand estimations
- growth forecasting/future-year demand estimate projections
- estimation of benefits specific to the activity.

All risks listed in Table 110, Table 111 and Table 112 are mode neutral. Risks covered in this section are not necessarily exhaustive. Transport analysts are encouraged to identify benefit risks on a case-by-case basis. Section 7.3 discusses the concept of an uncertainty log in relation to transport modelling, base year and future year demand estimation. The uncertainty log is likely to feed this risk analysis.

For each possible risk, a brief description is provided as well as possible risk sources. As a general principle, the consequence rating is extreme, severe, moderate, minor, or insignificant when the benefit estimation deviation is >±50%, ±25%–50%, ±10%–25%, ±5%–10%, or <±5%.

Table 110: Benefit risks from base year models/source data used to develop demand estimations

Source data related to base demand estimate	Description	Possible risk source
Age of data	Data source used to generate demand estimate is out of date, particularly where significant changes in the study area or travel behaviour have occurred since data source was collected.	• Older traffic counts and other data (for example travel times). • Older household travel survey data (more than 10 years old) used as basis for regional model. • Significant changes in modes available/used since the data was collected. • Other older input data (PT, signal timing, pedestrian activity etc).
Scope/coverage/ relevance of data	Data is not extensively relevant to the proposed activity's travel mode, study area, and/or critical locations within study area.	• Data is not close to and/or doesn't capture areas/locations and information which the activity is likely to have a more significant influence on. • Travel pattern data/parameters imported from other areas/countries and is not relevant.
Robustness and statistical reliability of data	Data is not representative of typical conditions in the study area and/or statistically robust.	• Traffic data from a single day sample survey, not checked against typical average values across multiple days/large sample. • Traffic data effected by incident. • Traffic data surveyed on day/period not most appropriate/relevant to activity assessment due to seasonality effects, holiday effects, day-to-day patterns, peak period coverage, etc. • The survey has a low sample or there is bias in the data collected. This includes surveys of counts, travel times,

Source data related to base demand estimate	Description	Possible risk source
		household interview/diaries, PT usages, vehicle occupancy, OD patterns, etc.
Weakness in model description, parameters and settings	Base model has overly prescribed parameters and inputs, inappropriate/unrepresentative parameters and settings, lacks key functionality for assessment.	• No independent peer review of base model, and/or review of suitability of model to specific economic assessment. • Poor documentation/reporting related to base model, leading to model weaknesses not being understood. • Lack of understanding of model quality, strengths, weaknesses and capabilities in application to economic assessment and analyses.
Model calibration/ validation	Model calibration/validation weak in the areas relating to the activity assessment (geographic and/or model predictive capability).	• Weaker overall calibration/validation. • Specific calibration/validation weakness in vicinity or key location related to the activity scenario. • Other specific calibration/validation weaknesses in relation to activity scenario assessment; for example, if key time periods, vehicle composition etc are not well represented in the base year model. • Specific calibration/validation weakness in model predictive capability important to activity assessment; for example, PT mode choice prediction, change in travel time (delay/queue/block back) prediction etc. • Available regional tools and/or models have some or several of the above weaknesses, and if the appropriateness of application is not checked or confirmed.

Note: Base demand data sources may be counts, historical surveyed data, research and guideline values, and information from transport models (particularly relates to base/base-year models).

Table 111: Benefit risks from future year forecast demand estimations

Future-year demand estimation input/source	Description	Possible risk source
Elasticities, trend analysis, mathematical models etc	The assumed elasticity value, trend calculation, factor, mathematical model etc is not realistic, not appropriate for assessment, or has fundamental weaknesses.	• Elasticity parameter may not be appropriate in local context, may have increased uncertainty/weakness/ appropriateness when applied forward in time. • Trend analysis carried out on low sample or unrepresentative sample of historical data. • Mathematical models/factors not appropriate in local context, may have increased uncertainty/weakness/ appropriateness when applied forward in time.
Trip rates, trip distribution analyses	Trip rates and/or assumed trip distributions are not realistic, not appropriate for assessment, or have significant weaknesses.	• Trip rates not appropriate to local context, may have increased uncertainty/weakness/appropriateness when applied forward in time. • Distribution analysis may have increased uncertainty/weakness/ appropriateness when applied forward in time. • Application of matrix estimation in the base year may have distorted the trip distribution. • Combined trip rate/distribution analysis to estimate future year demands is not representative and/or doesn't account for appropriate trip-making activity/ response across whole study area.
Population	The assumed population growth and/or mix is not realistic, not appropriate for assessment, or has significant weaknesses.	• Optimism bias in population projection; for example, high growth assumed in local vicinity of activity. • Outdated population projections. • Predicted do-minimum operation doesn't support assumed population growth levels. • New growth/development areas missing.
Other land use	The assumed land use development is not realistic, not appropriate for assessment, or has significant weaknesses.	• Regional land use development plans and strategies outdated, or effected by optimism bias. • Land use development not balanced across wider region. • Weaknesses in detail/content of land use data inputs. • New growth/development areas missing.

Future-year demand estimation input/source	Description	Possible risk source
Local land use/ transport supply changes	Local land use development areas and/or local transport supply has a large effect on activity scenario (including walking, cycling, PT travel related to local development(s)).	• Development-related travel (or other land use changes, such as density changes) contributes a notable proportion of, or has a significant influence on, predicted future-year travel volumes and/or direction of travel in the vicinity of the activity. Associated weaknesses/uncertainty in these assumptions. • Local transport supply changes contribute to a notable proportion of, or have a significant influence on, predicted future-year travel volumes and/or network operation in the vicinity of the activity. Associated weaknesses/ uncertainty in these assumptions.
Other key trip making assumptions/ relationships	Vehicle availability/access, household/family structure, pricing (fuel, parking, tolls etc), technology influences etc are likely to effect future travel and trip-making.	• The assumption that historical trip-making behaviours continue into future may be important to test/review/ consider in relation to the assessment. • Key assumptions (for example, parking charges, tolls, road pricing and similar) play an important role in relation to the activity scenario and/or overall travel in the region in the future.
Transport mode diversion assumption	Diversion of trips from other transport modes is a large portion of the activity demand estimation projection.	• Activity may cause diversion of trips from other transport modes (vehicle, walking, cycling, PT) and redistribution of travel demand. If such diversions are a significant part of demand estimates, the risks are likely to be higher. These risks will be further increased if there is potential variability in the extent of transport capacity to be provided as part of the activity (for example, bus frequency using a new PT corridor).

Note: Future-year demand estimation forecasts may be from calculations, trend analysis factors etc, project models taking inputs from other sources/methods, and regional transport models.

Analysing benefit realisation risks

The analysis of benefit realisation risks is focused on the uncertainty of realising the proposed activity's estimated benefits after construction is completed. Even if the estimation of benefits is accurate, most benefits are dependent on external factors in terms of their actual realisation in the future. If future conditions are unfavourable there is a benefit realisation risk.

As a general principle, the consequence rating is extreme, severe, moderate, minor, or insignificant when the benefit estimation deviation is >±20%, ±10%–20%, ±5%–10%, ± 1%–5%, or <±1%.

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Table 112: Benefit realisation risks

Benefit realisation risks	Examine all relevant dependencies for benefit realisation and assess corresponding risks. Below is only an example of possible benefit realisation risks.
Dependency on future economic conditions	If the benefit assumptions include economic growth that is higher than the historical average, then the overall risk to the benefits of lower economic growth must be assessed.
Dependency on future activities or technology	Any activities or technologies that have not been implemented at the time of assessment, and are not included in the activity's scope, but whose successful implementation is a prerequisite for benefit realisation are a risk to successful benefit realisation. If the successful implementation of other activities is assumed, these risks must be analysed.
Extreme events	Extreme events, such as earthquakes, can affect an activity's benefit realisation. If an activity is likely to be affected by a periodic or once-off extreme event, then the impact of the extreme event on the activity's benefit realisation must be considered and assessed.
Other future activities	If future activities are likely to significantly affect the activity's user volumes (greater than 10%) then the analyst must conduct sensitivity tests to determine possible future effects.
Diversion from private vehicle	Mode change benefits are likely to constitute a significant proportion of benefits for public transport service, walking and cycling, or travel behaviour change (TBhC) activities. 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 private vehicles, and the associated benefits, should be noted, unless it can be convincingly demonstrated that these risks are reduced by the particular modelling processes adopted.
Supply relationships	Supply relationships will generally include link capacities, free-flow speeds and speed-flow relationships (in the context of a traffic assignment). Parts of the network can be significantly congested. In this case transport analysts 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%.
Routing parameters	The routing parameters control the relative effects of time and distance (and any other factors) on the choice of route. If an activity is a longer distance than the existing infrastructure and of a much higher standard than existing route then the transport analyst should conduct sensitivity tests allowing the nominal parameter value to vary by ±50% or some equivalent increment.

Analysing cost risks

The cost risks set forth in Table 113 are not exhaustive but should be treated as a guide. These are expected to be managed throughout the whole project lifecycle according to the risk management methodology. At each stage the level of detail available will differ and any new or emerging risks should be managed and reported as soon as possible. Any cost risks that are specific to the activity should be managed under the same approach and methodology.

The cost risks include economic costs and financial (delivery) costs. The economic costs will generally not affect cash flow and their estimation may be less accurate than the financial cost risks. Both types of costs can affect the BCR.

As a general principle, the consequence rating is extreme, severe, moderate, minor, or insignificant when the cost deviation is >±20%, ±10%–20%, ±5%–10%, ±1%–5%, or <±1%.

Table 113: Cost risks

Environmental and planning	Concerning each of the issues, the tests of risks are the same, and concern issue identification, tractability and sensitivity and consultation.
Tangata whenua Emissions Landscape and visual Ecological effects Archaeological and historic sites Social networks and severance Economic/amenity impacts on land users Natural hazards	Identification: no environmental surveys or little consultation. Tractability: contentious issues with conflicting requirements. Sensitivity of the activity to extreme events: extreme events disrupt delivery of the activity 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.
Land and property	
Property acquisition	Property still to be acquired from several owners with opposition expected.
Property economic value	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).
Earthworks	
Knowledge of ground conditions	Required: high density of sampling; variety of techniques and data available; good exposure of conditions; data interpreted by two parties (peer review). Risk source: no or very little subsurface investigation or site exposure.
Complex/ unpredictable conditions	Swamps, marine sediments, rock masses with steeply dipping clay-filled seams, or moisture sensitive clays; high water table or pressurised aquifers.
Road design form	High cuts/fills, tunnels, bridges or viaducts.
Extent of topographical data	Hilly, mountainous terrain, heavily vegetated and little topographical data.
Source and disposal of material	High volume requirements, uncertain sourcing and resource consent ramifications.
Other engineering costs	
Engineering complexity	Complex solutions to difficult engineering issues.
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.
Services	**Underground and overhead services may include (but not be limited to) telecommunications or electricity cables, gas mains, water mains and sewers.**
Existence, location and condition	Service authorities not contacted, or services data unreliable, engineering details and condition unknown or poorly defined.
Site flexibility	Constrained (normally urban) corridor with few options to accommodate changes.
Cooperation of utilities	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.

Contingencies

Significant cost risks that cannot be realistically reduced by other means are covered by contingencies in the cost estimate. The purpose of contingency is to increase the accuracy of cost estimates according to the transport analyst's best effort.

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, then it is expected that the contingency table focuses on items 4 to 6, while for most activities, items 1 and 3 would be allowed for in uniform factors on costs; item 2 is excluded:

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.

For more information on contingency please refer to SM014 – *Cost estimation manual*.

The reasonable contingency amount should be determined and justified according to the activity's uncertainty. An assessment of the required contingency is required.

As a general principle, a contingency of between 10%–20% of the total capital cost of an activity is considered reasonable. If an activity has significant uncertainties, and a contingency above 20%, further investigation, with a focus on resolving cost estimation uncertainties, should be prioritised rather than proceeding to implementation with a higher contingency.

Risk treatments

Risk treatment involves an iterative process of:

- formulating and selecting risk treatment options
- planning and implementing risk treatment
- assessing the effectiveness of that treatment
- reporting and managing residual risks.

Risk treatments should be documented within an activity's risk register according to SM030 *Minimum standard Z/44 – Risk management practice guide*. The risk register template is available for use on all transport activities. Some content of the risk management guide has been written to specifically apply to NZTA state highway activities, but the concepts are generalisable to all transport activities.

Risk treatment options

The strategic directions available to treat risk will depend on the lifecycle of an activity. These include:

- avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk
- taking or increasing the risk in order to pursue an opportunity
- removing the risk source
- changing the likelihood
- changing the consequences;
- sharing the risk (eg through contracts, buying insurance)
- retaining the risk by informed decision.

These strategic directions may in turn lead to the following actions:

- abandon the activity
- reformulate the activity 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)

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- defer further processing of the activity until information comes available that assists in reducing the uncertainties
- defer further processing of the activity until the FYRR increases to the required cut-off level
- proceed to the next stage of processing, or to tender
- other justified actions.

Examples of risk treatment options are provided in Table 114.

When selecting risk treatment options, an organisation should consider the values, perceptions and potential involvement of stakeholders and the most appropriate ways to communicate and consult with them. Risk treatments, even if carefully designed and implemented, may not produce the expected outcomes and can result in unintended consequences. Monitoring and review need to be an integral part of the risk treatment implementation to provide assurance that the different forms of treatment become, and remain, effective.

Monitoring and review

The purpose of monitoring and review is to provide assurance and continuously improve the quality and effectiveness of process design, implementation and outcomes. Ongoing monitoring and periodic review of the risk management process, and its outcomes, should be a planned part of the risk management process with responsibilities clearly defined.

Monitoring and review should take place in all stages of the process. Monitoring and review includes planning, gathering and analysing information, recording results and providing feedback.

Table 114: Risk treatment options example

Risk	Examples of risk treatment actions	No action, accept risk	Do more work on issue in:		Purpose of risk treatment 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 activity 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	-

Risk	Examples of risk treatment actions	No action, accept risk	Do more work on issue in:		Purpose of risk treatment investment is to:		Defer
			this phase	later phase	quantify risk	reduce risk	
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	-

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7.6 Adaptive decision making

The cost–benefit analysis procedures in this manual consider risk and uncertainty as set out in the preceding sections. While risk and uncertainty are features of all activity appraisals, it is particularly important when dealing with disruption (in terms of the likelihood of outages, damage to infrastructure, and economic loss from such events), and how transport users respond to such situations. Where appropriate, these risks and uncertainties need to be considered in transport economic appraisals. Adaptive decision making may in some circumstances offer a chance to consider risk and uncertainty where there is deep uncertainty regarding future risks or occurrences.

NZTA has received a report 'Climate change adaptation and investment decision making' (Torshizian 2022), which in turn references *Decision making under deep uncertainty: from theory to practice* (Marchau 2019). The first report identifies available methods for adaptive decision making in relation to climate change and the pros and cons of the different methods. The recommendations of that report have not been adopted due to the complexity and costs in carrying out the processes, and the application of adaptive decision making may be limited to investments that involve deep uncertainty relating to risks and benefits. However, adaptive decision making may offer scope for consideration of how to deal with deep uncertainty and in such circumstances analysts are advised to seek input from NZTA investment advisors on the use of adaptive decision making.

The focus of an adaptive investment decision-making process is to allow for flexibility by considering all possible outcomes where there is deep uncertainty when selecting options for further investigation. Under scenarios of deep uncertainty, adaptive decision making relies on plans that are designed to be adaptive over time in response to how the future unfolds as deep uncertainties are resolved. A wide range of future scenarios is explored, with a plan of action to respond to the need for adaptation, so that there is greater confidence in whether an option can contribute to the outcomes and objectives that are sought.

Caveat on use of adaptive decision making

NZTA will consider the use of adaptive decision making where deep uncertainty exists. However, its use is to be preceded by discussion with, and feedback from, NZTA investment advisors.

List of commonly used acronyms

AADT	Annual average daily traffic
AGPWF	Arithmetic growth present worth factors
AST	Appraisal summary table
BCA	Business Case Approach
BCR	Benefit–cost ratio
CBA	Cost–benefit analysis
FEC	Final estimate of cost
FTM	Fixed trip matrix
FYRR	First year rate of return
GC	Generalised costs
GHG	Greenhouse gases
GIS	Geographical information system
HCV	Heavy commercial vehicle
HPMV	High productivity motor vehicles
IDMF	Investment Decision-Making Framework
IRI	International roughness index (for roads)
ITS	Intelligent transport system
MBCM	*Monetised benefits and costs manual*
MoT	Ministry of Transport
MoT TOF	Ministry of Transport's Transport Outcomes Framework
NLTF	National Land Transport Fund
NLTP	National Land Transport Programme
NPV	Net present value
PAC	Preliminary assessed cost
PIKB	Planning and Investment Knowledge Base
PPP	Public private partnership
PSD	Passing sight distance
PT	Public transport
PTD	Percentage of time delayed
PV	Present value
ROC	Rough order cost
RP	Revealed preference (surveys)
RUC	Road user charges
SIA	Social impact assessment
SP	Stated preference (surveys)

SPPWF	Single payment present worth factors
SSI	Standard safety intervention toolkit
TBhC	Travel behaviour change
TDM	Travel demand management
TIO	Transport Investment Online
USPWF	Uniform series present worth factor
VC	Volume to capacity
VEPM	Vehicle Emissions Prediction Model
VOC	Vehicle operating costs
VoSL	Value of statistical life (VoSL)
VoT	Value of time
WACC	Weighted average cost of capital
WEB	Wider economic benefit

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Appendices

Appendix 1: Demand estimation methods and guidance

Chapter 2: Demand estimation and mode share, provides background and guidance on different elements relating to travel demand estimation.

This appendix provides guidance on techniques, methods and considerations for developing demand estimates. This includes estimating and forecasting facility use by specific modes, general techniques and guidance on developing demand estimates and forecasts, guidance on traffic modelling forecasts, the specific areas of elasticity techniques and values, and evaluating congested networks (using fixed and variable matrix techniques).

This appendix also contains guidance on developing a benefit–cost ratio (BCR) after variable trip matrix methodologies have been used, and suggested checks to validate the methodology applied.

Broad approaches to demand estimation

Broadly there are four general techniques for developing demand estimates, these are described further in section 2.4 and are briefly:

- first principle estimates, such as factoring, daily traffic volume estimates, and predicted facility use estimates.
- simple mathematical models and approaches, such as growth trends, trip generation, and application of elasticities.
- development of demand estimates for project transport models, models which do not have the capability to estimate travel demands from land use
- application of regional transport models that do estimate travel demands from land use.

The sections below provide guidance, methodologies and in some cases procedures for developing demand estimates for economic assessments. For guidance on situations when it may be appropriate to use the approaches discussed below, see section 2.4 and Table 1.

Demand estimation methodologies and considerations

Estimating and forecasting facility use

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

The estimated future demand for the do-minimum and each option, including the proposal, must be calculated.

Table 53 can be used to assess demand for a cycle facility when traffic counts have not been carried out in the area.

Procedure for a new service or facility

Where a new transport service or facility is proposed, and there are no comparable services or facilities, an evaluator could undertake a consumer preference survey. A demand estimate may be drawn from the survey using a methodology appropriate to the proposed service or facility.

It is common practice to use preference values derived in other locations, including internationally, and this is a valid alternative to undertaking specific stated preference or revealed preference surveys. In this case, it is important to consider if the imported/transferred values are representative of local conditions and adjust or sensitivity test accordingly.

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

Procedure for improvements to a service or facility

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

Table A1: Forecasting demand for improvements to services or facilities

Steps	Action
1	Estimate the willingness to pay and elasticity of demand for the relevant quality improvement using one of the following two methods: • **If the activity is for a major improvement** to an existing service or facility, then a specially commissioned stated preference survey could be undertaken to estimate the willingness to pay and the elasticity of demand. Alternatively, import appropriate values from other locations (within New Zealand or internationally). • **If the activity is for a relatively small change** to an existing service or facility, then inference of the willingness to pay 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, full details of the comparison must be provided.
2	Identify the relevant elasticity and cross-elasticity values for the user charges and service quality changes. This may either be from the stated preference survey or using values from other sources. **Note**: Some values applicable to New Zealand are provided in section 4.4 and section 4.7.
3	If there is an increase in user charges, calculate the new demand for the service. The total number of new and existing users is calculated according to the following formula: $Q_{price} = [((P_1 - P_{new}) / P_1) \times UCE \times Q_1] + Q_1$ where: Q_{price} is the total demand at the new average user charge Q_1 is the existing number of users P_1 is the existing average user charge P_{new} is the new average user charge UCE is the user charge elasticity
4	Using the relevant elasticity value derived from the stated preference survey, or from an alternative source, calculate the demand for the service or facility based on the change in service quality. 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 private vehicles and other sources. Use cross-elasticity values that have been estimated for people transferring from private vehicle to alternate services where available, or use other sources such as surveys. Alternatively, section 4.4 contains appropriate indicative values. The diversion rates given in this chapter for workplace travel plans with public transport improvements may also be applicable.
6	Test the result's impact on demand by varying the user charge levels and service quality elasticity. 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 check that the estimate is credible.

Travel volume growth trend analysis

Trend analysis is the practice of collecting, collating and analysing information (typically historical travel volumes) to attempt to identify patterns to use to estimate unknown or uncertain values (typically forecasting future year travel volumes). As described in section 2.12, some care needs to be taken with trend analysis, as seemingly small inaccuracies can have a significant effect on future projections. The following are important considerations when carrying out trend analyses using historical data to predict future transport demand numbers:

- A suitably large sample of historical data points is required for robust trend analysis. Generally, the longer the forecast horizon the more historical data points that are required to be examined.
- Ideally, seasonal effects should be excluded from a trend analysis. For example, predicting year-on-year growth should be based on historical data points which are taken from periods of the year where transport volume numbers are similar to other times of the year (for example, non-holiday weekday autumn and spring periods). In some cases, where seasonality effects are more significant (for example, locations with significant tourist and holiday activities), trend analysis may need to concentrate on a specific month or time-of-year.
- Macro effects, such as national and international economic cycles, may need to be considered. For example, the global financial crisis was known to reduce traffic volume growth in many locations from 2007 to 2009. Trends calculated from datasets that include these years should be treated with care. The Covid-19 effects, starting from March 2020 onwards, are a similar if not more significant consideration, and in the Canterbury region the Christchurch earthquakes and recovery should be considered from 2011 onwards.
- Local effects may need to be checked to ensure data points are comparable year to year. For example, a larger land use development effecting nearby count sites, or a more significant change to the transport system such as a new road opening, effecting local travel patterns.
- The data used in trend analysis should not be constrained by the transport supply. For example, in the case of using road traffic counts, the data analysed should not be affected by queuing and delays. This may be accounted for by extending the time period reviewed (for example, weekday peak periods of three to five hours or considering daily traffic volumes. Re-routeing at peak times may also be a consideration – volumes across multiple links may need to be examined (commonly referred to as a screenline).
- When applied to vehicle counts, ideally light and heavy vehicle volumes should be separated and trend analysis carried out separately. Light and heavy vehicle growth rates are likely to differ in many locations.

A range of mathematical trend analysis methods are possible, such as:

- regression analysis
- annual change analysis, which is examining the growth rates between each subsequent year and performing statistical analysis on this set of results
- point-in-time to point-in-time analysis, that is examining growth over a longer period of time. There are noted risks in this approach, as it requires robust knowledge and understanding of both points analysed.

Where trend analysis is informing key inputs to an economic assessment (for example, medium- to longer-term forecast travel volumes), it may be appropriate to carry out several different trend analysis methods and compare the results. As described in section 7.3, sensitivity tests on the outcomes (for example, growth rates) from trend analyses are likely to be important and are generally straightforward to carry out.

Trip rate and distribution analysis

Trip rates and distribution analysis can be used to develop demand estimates for specific land use activities and areas as a first-principles style approach. The trip rate uses estimates of the travel volume generated by an activity (often related to peak hours or times), and the distribution analysis estimates where these trips travel to and from in the study area (usually expressed as percentages).

The traffic generation of any activity will be influenced by its location on the transport network and the practical level of access to sustainable transport modes, such as public transport, cycle or walking, as well as the time of day and day of the week. The peak period of traffic generation for the activity also needs to be taken into account, as this will not necessarily coincide with the peak period of movement on the adjacent road network. Together, these factors mean that some degree of engineering judgement is required when forecasting the likely level of traffic generation for a new activity.

There are a range of sources that can be used to inform decisions on expected traffic generation rates. These include but are not limited to:

- NZ Transport Agency research report 453: *Trips and parking related to land use*. (Douglas Consulting Services and Abley Transportation Consultants 2011)
- Institute of Traffic Engineers, *Trip generation manual*
- Transport for New South Wales, *Guide to traffic generating developments*
- TRICS (Trip Rate Information Computer System, UK based) and TDB (Trips Database Bureau, NZ Transport Group)
- New Zealand census data.

Where it is practical to do so, it is recommended that reference to recent surveys for similar activities and locations are adopted for any assessment. The TRICS/TDB source includes the most recent information for New Zealand.

Trip rate and generation considerations

Some care needs to be taken when applying trip rate and/or generation methodologies across a study area to estimate future demands for a network. Trip rates may be estimated from driveway surveys – as such across a network they may not account for trip chaining (travel involving multiple purposes and multiple destinations) and pass-by trips (such as an A to B trip becomes two trips A to C, C to B and the original A to B trip is removed). Because of these behaviours and factors, wide-spread application of trip rate and/or generation methods for multiple land-use developments in a network may overestimate traffic volumes.

In section 2.15, Sense checking forecasts includes recommendations for reporting key information. This includes the total study area demand growth and per annum demand growth rates by time period and, where appropriate, vehicle classification and travel mode. These are useful checks to confirm the appropriateness of trip rate applications, particularly when applied to multiple land use activities across a study area.

Trip distribution considerations

There are several approaches to developing trip distributions associated with trips generated by a specific land use activity; for example:

- develop from nearby location, ideally with similar land use
- first principle analysis using geo-located data; for example, census journey-to-work or journey-to-education data, electronic tracking data such as from Bluetooth sensors/mobile phones, commercial transaction data, or similar
- potentially can be developed from travel volume information (for example, a series of traffic counts), although this is noted as being unlikely to be robust as the specific activity information may not be easily isolated from movements associated with other activities in the network and/or it can be difficult to identify the actual desired origin and destinations in this form of data.

In section 2.15, Sense checking forecasts includes recommendations on checks and reporting associated with trip distributions. This includes summaries by time period and potentially vehicle classification and travel mode of sector-to-sector growth, trip length distributions, and flow difference plots and/or geographic location growth figures.

Elasticities

As described in section 2.1: Demand estimation and mode share: Key concepts, in transport demand estimation elasticities typically describe a percentage change associated with a demand response linked or related to a change in the transport system or environment.

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 increases the 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 that the future cost of private vehicle use will be low, they are more likely to choose a suburban home located where there is more dependency on using a private vehicle. Alternatively, if they anticipate significant increases in driving costs, they may place a greater premium on having alternatives to private vehicle use, 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.

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

Section 4.4: Analysis of public transport service activities and section 4.7: Analysis of freight activities contain elasticity and cross-elasticity values that may be used for public transport or freight services respectively.

Nature of demand

The demand for a new or improved service or facility depends on a number of factors such as:

- the current or base average user charge
- the nature of the change in service
- existing users' willingness to pay for the new or changed service/facility, and
- the responsiveness of demand to changes in user charges (the user charge elasticity) or another journey attribute (for example, in vehicle or walking time).

Factors affecting price elasticities

Even if stated preference surveys have been specifically conducted for an activity, caution needs to be exercised when extrapolating the elasticities. Surveys may only cover a small range of price and quality variations and therefore the calculated elasticities may not be valid for extreme changes of price or quality.

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

Type of price change

- Vehicle purchase prices and registration fees can affect the number and type of vehicles purchased.
- Fuel prices, emission fees, and government rebates for sustainable vehicles affect the type of vehicle used.
- A toll on a road may shift some trips to other routes and destinations.
- Congestion pricing may shift travel times, encourage people to change mode or destination, and reduce 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

- Commuting trips tend to be less sensitive to changes in prices 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 already discourages lower-value trips.
- Travellers with higher incomes tend to be less price sensitive than lower-income travellers.

Quality and price of alternative routes, modes and destinations

- Price sensitivity tends to increase if alternative routes, modes and destinations are of good quality and affordable.

Scale and scope of pricing

- In general, demand is more sensitive to the pricing of a narrowly defined transport attribute – for example, peak period travel on major arterials – than more broadly defined transport attributes such as total personal travel. This is because consumers have more alternatives in the narrowly defined case.

Willingness to pay surveys

The following points are noted around the potential requirements to carry out specific user willingness to pay surveys:

- Proposed activities for new transport services and or facilities or for major improvements to an existing service/facility, and any activities entailing a subsidy or price change, may require a specially commissioned study to establish users' willingness to pay and the elasticity of demand.
- For small alterations to existing services or facilities, or where the required amount of financial assistance is small, the demand estimates may be produced using willingness to pay values drawn from other comparable services.

Independently developed project models

Independently developed project/assignment transport models are not linked to or fed by a regional transport model (a model response to changes in land use and transport supply and predicts travel demand). Due to the relative prevalence of regional transport models in New Zealand (see section 2.10), independent project models are not all that common.

These models may be developed specifically for assessing a particular economic activity, or may have been developed for other transport planning or traffic engineering work in an area and may be utilised for an economic assessment

Demand estimates and forecasts in this form of model may be developed through one, or a combination, of the methodologies described above. For example, trend analysis may be used to develop growth rates on external trips passing through a network in combination with a trip rate/distribution approach to develop future demand estimates for internal trips in the study area.

Elasticities may be applied within models of this nature to estimate travel demand responses. For example, PT mode share changes resulting from significant PT service and facility improvements.

The considerations and guidance that are discussed in the sections above in relation to methodologies and approaches used to develop demand estimates apply if and where these approaches are used in independent project models.

Applying regional models

Regional transport models exist in all of the major cities and many of the larger towns around New Zealand. A list of existing transport models is provided in the first table in Appendix A in *Urban transport modelling in New Zealand – data and practice and resourcing* (Smith 2019). Generalised guidance on using regional transport models to produce demand estimates and travel forecasts is not provided as these models are complex tools and should be operated by experienced transport modellers/planners. Some commentary and considerations are noted in relation to the application of regional models to economic assessments below.

For economic assessments, regional transport models may be used in isolation, primarily in the early stages of establishing the feasibility of an activity, or applied to estimate demands that are then fed into a project model. Extended use of existing regional models through into the later stages of assessing an activity may apply to significant schemes in major urban centres effecting mode choice, such as large-scale PT activities in Auckland and Wellington. In later assessment stages, often project models that are specifically developed to assess the activity are applied. Processing the demands from a regional model for a project model is described in Project models fed by regional models.

Depending on how the regional transport model is applied, it may produce either fixed or variable trip matrices. Fixed trip matrices are where the demand for each mode, for a given time period and year, are the same for the do-minimum and activity options. Variable trip matrices are where the demand is different for the do-minimum and activity options. The default mode for almost all regional transport models in New Zealand will be to produce variable trip matrices. Changes to the demand, and whether each change will require a variable or fixed trip matrix benefit procedure, are shown in Table A2. More background on these issues is provided in section 2.13: Fixed trip matrix and variable trip matrix assessments.

Table A2: Fixed or variable trip matrices from a regional transport model

Changes	Variable trip matrix?	Fixed trip matrix?
Change in total number of trips produced (pure induced traffic)?	Yes	
Change in mode choice?	Yes	
Change in destination choice (distribution)?	Yes	
Change in macro time choice?	Yes	
Change in route choice?		No

There may be situations where a fixed trip matrix approach is adopted using a regional transport model. In this case, a demand is estimated, and the same demand is assigned to both the do-minimum and activity. It is more conservative to estimate this demand using the do-minimum, and then assign it to the activity. If the activity is used to estimate the demand, and this demand is assigned to the do-minimum, there is a higher likelihood that the do-minimum may be unrealistically congested and as a result, inappropriately high benefits are calculated.

Project models fed by regional models

As described in section 2.10 regional models are relatively prevalent in New Zealand and, as such, it is common for project models to be developed with links to a regional model. Project models with these links/systems are available in many of New Zealand's major urban areas and regional centres. The analyst should check the availability and suitability of any existing project models for a specific economic assessment.

For certain assessments (for example, single-stage and detailed business cases) it is common to develop a specific project model for the purpose of analysing the economic benefits of a certain activity. A model of this nature is also likely to be used for other components of the assessment, such as option testing, informing the design, and providing a variety of technical and detailed information to inform the assessment.

If a regional model (or regional modelling system/structure) is available, then it would be generally be expected to be used to inform demand estimates (for example, base-year travel patterns and future-year forecast growth and travel changes) in any project modelling carried out in the region and in the example of a project model developed for a specific assessment.

Rarely, if ever, will it be appropriate to use the regional future-year origin–destination (OD) demand directly within a project model. This is because in most cases the development of the project model will include refinement and adjustment to OD demand inputs inherited from a regional model, and these refinements/adjustments should be carried through in some manner to the future-year project model demands. There are a number of methods for developing growth forecasts in a project model which account for this, several are described below.

In the descriptions below, RM is regional model and PM is project model.

- **OD additive growth method**: the difference between the regional model base year (or closest forecast year to the project model base year) and regional model forecast year is added to the project model base year for each OD value. Where the base years are different, often a linear growth rate is assumed between the base and future years. For example, for a regional model base year of 2018 and a future year of 2028, 8/10ths of the growth is added to the project model 2020 base year to create the project model 2028 forecast.

The possibility of this resulting in a negative value on an OD volume needs to be considered and accounted for. One simple approach is to use the multiplicative method (described below) as a substitute in any OD cells that result in negative values from the additive calculation. That is, if the additive growth method results in negative values, multiply the project model OD base volume by the percentage reduction predicted through the regional model.

An additive method is often a straightforward and low-risk approach. It is simple to review and check, and in particular, reflects changing future travel patterns across the study area predicted by the regional model (for example, larger levels of growth in one specific geographic area due to greenfield land use development).

One weakness of the additive method is that it disconnects the growth change from an associated trip rate basis.

- **OD multiplicative growth method**: the regional model future-year OD value is divided by the regional model base-year OD value producing a factor/percentage growth which is applied to the project model base year OD value. In the same manner as the additive method, if the project model and regional model base years are different a proportion of the regional model future-year growth is applied. For OD cells where there are zero trips in the regional model base year and trips in the regional model future year, the additive approach will need to be used.

  Generally, more care is required with this approach than the additive method. In particular, large factor increases can be applied to high project model OD values resulting in inappropriately high project model future-year OD values.

- **OD combined additive and multiplicative growth method**: combining the additive and multiplicative methods is possible; for example, averaging the additive and multiplicative growth estimates or a weighted average – purely as an illustrative example: 75% additive growth and 25% multiplicative growth.

- **More complex methods, including trip-end approaches:** other growth calculations are possible, examples include:
  - Furnessing (Furness iterative balancing) the predicted regional model trip end (matrix row and column totals) growth with the row/column distribution in the base year OD matrix
  - applying the row or column growth only, and using the project model base year OD distribution to distribute the trip growth through the matrix.

These approaches may be considered when there is an understood, or established, notable strength in the distribution in the project model base year OD demand (for example, if the development of the project model and base year OD demand made more extensive use of OD surveys and/or additional OD-style observed data) and an understood or clear local weakness in the regional model distribution.

In all cases, as outlined Project/assignment transport demand forecast checks and reporting, various checks and reporting would be anticipated in the development of growth forecasts for a project model. Checking the sector-to-sector growth distribution (comparing the regional model to the project model) would be particularly important for a more complex method, such as growth Furnessing.

Walking and cycling demand estimation

Procedures for estimating bicycle demands can be found in section 4.2. Table 53 may be used for estimating the demands of a new cycle facility.

In addition, some regional transport models will estimate bicycle and walking demands and may be appropriate to estimate active mode facility use. The regional transport models forecast aggregate demand and may be too coarse for bicycle or pedestrian facility assessment. Therefore more detail is provided in relation to walking and cycling in these sections than other aspects such as public transport, where regional models may be more robust.

Several New Zealand urban centres have specific “cycle models”. If assessing a new facility, or a significant upgrade to an existing facility, the suitability, ability and appropriateness of these tools to provide cycle volume estimates for an assessment should be checked.

Methods to calculate/adjust demand in transport models

This section provides guidance on the analysis of transportation activities where networks are highly congested or where the demand in the do-minimum and the activity are different due to a change in supply introduced by the activity. The procedures describe a range of modelling techniques that can be used to estimate demand when transport models do not converge to equilibrium due to significant levels of congestion, models gridlock, or when there are significant changes to the distribution of trips or modal share.

This section also contains guidance on developing a benefit–cost ratio (BCR) after variable trip matrix methodologies have been used, and suggested checks to validate the methodology applied.

Travel behaviour change demand estimation

Procedures for travel behaviour change activities

Active mode facilities

Education, promotion and marketing can be 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 4.6 should be used to estimate the number of trips using other modes (primarily private vehicles) 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, there may be an induced demand, which is trips in addition to those diverted from other modes being generated. The total demand for the facility may be estimated using the procedures in section 4.2.

Target population

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.

Table A3: Travel behaviour change target population

Type of travel plan 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 five days per week or if there is a significant uptake of working from home.
School	The total school student 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-based or community-based programme is being implemented.

Mode shift and mode share

Gaining the full mode shift impact usually takes around three years. Maintaining this mode shift then requires constant investment of staff time and marketing resources in support of the activities.

Table A4: Composite analysis of TBhC packages

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 analysis 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.
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 analysis 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.
New or improved road infrastructure, including: • 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 road infrastructure component.	Minor road improvements including 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 'New or improved public transport service' above.

Level of diversion

The level of diversion is used for calculating user benefits for new and existing pedestrians/cyclists, assuming the main change is a reduction/transfer from private vehicle, and hence road traffic reduction benefits. Benefits arising from changing travel mode from private vehicle to PT are also considered, depending on the PT measures included in the travel plan. Care should be taken to ensure that any assumptions are compatible with the economic analysis requirements.

When conducting initial analyses for workplace and school travel plans the diversion rate should be selected based on the analyst's knowledge of the organisations involved and the area. For the final analysis for implementation, the diversion rate will be based on the actual features of the completed plan.

Workplace travel plans

There are two sets of diversion rates for workplace travel plans:

- standard – where no public transport improvements are proposed
- alternative – where there are proposed public transport improvements.

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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 TableA5.

Table A5: Scoring system for workplace travel plan diversion rates

Travel plan questions	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' schemes, etc. Use the total score from above in TableA5. First, obtain the reduction in the target population of car drivers assigned across the other modes of transport.

Table A6: 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%	16%
High	5 or 6	-12.9%	26%	57%	8%	9%

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 TableA5) 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 A7: 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, and situations where the activity will implement fewer measures than 'usual' household-based programmes. For example, where a community travel awareness campaign on its own would not achieve the standard diversion rate, public transport services and cycling and/or walking facilities in the area are poor, and no significant changes to these are envisaged as part of the travel behaviour change proposal. Assign the changes in car drivers and car passengers across public transport, cycling and walking.

Table A8: Household 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%

Fixed trip matrices
This section relates to adjusting demand in congested networks to ensure demand does not exceed supply where the same adjusted demand is then applied consistently for the do-minimum and activity/option. This is referred to as a fixed trip matrix (FTM). In almost all cases, the demand will be adjusted in the do-minimum (or the network with the least capacity) and then applied to the activity. This is to ensure the network with the least capacity is not inappropriately congested.

Growth constraint techniques are to be considered where high levels of congestion are present 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.

Procedure
Any one of the procedures listed below is 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.

Having decided that there is insufficient capacity in the do-minimum to appropriately accommodate 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 in Table A9 to apply growth constraint to the trip matrix.

Table A9: Steps to apply growth constraint to the do-minimum/activity 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 (Table A67). If so, apply peak spreading to modify the matrix and peak period.

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><th>Selected method</th><th>Go to</th></tr>
<tr><td>Matrix scaling</td><td>Applying the matrix scaling method</td></tr>
<tr><td>Incremental matrix capping</td><td>Applying the incremental matrix capping method</td></tr>
<tr><td>Shadow network</td><td>Applying the shadow network method</td></tr>
<tr><td>Elasticity methods (FTM)</td><td>Applying fixed trip matrix with elasticity methods</td></tr>
<tr><td>Demand models (FTM)</td><td>Applying fixed trip matrix with demand response models</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>

Peak spreading and matrix scaling growth constraint techniques can be applied to the do-minimum and/or the activity demand matrices to address an imbalance between supply and demand and produce specific and varied demands. Additional analysis is likely to be required if different adjustments are applied to the do-minimum and activity option, and advice on this is provided in the relevant sections.

Applying peak spreading

Peak spreading procedures may be used to spread traffic from the busiest part of the peak period to the peak shoulders. Peak spreading is also called 'micro time of day choice'. It is distinct from 'macro time of day choice' where trips shift from a peak (morning or evening) to the interpeak or off peak due to congestion.

Micro time of day choice methods may also be considered in assessing the activity, particularly in situations where the activity enables destinations to be reached distinctly more quickly. This can result in a peak contraction, and not accounting for this may misrepresent the travel time savings between the do-minimum and the activity.

The procedure below is concentrated towards using peak spreading to reduce congestion in the do-minimum.

Procedure

There are various existing procedures to calculate peak spreading. References include:

- *Design manual for roads and bridges*, Volume 12, Section 2, Part 1, Appendix F, 'The application of peak spreading' (Highways England 1996)
- a UK Government-funded project that looked at demand and assignment modelling with a focus on departure time choice resulting in a model called HADES (heterogeneous arrival and departure times based on equilibrium scheduling theory)
- 'NZMUGs micro time-of-day choice research' (New Zealand Modelling User Group 2017).

Broadly there are two styles of transport modelling that effect the application of peak-spreading:

- Models where the total OD demand is considered over a longer peak period (at least two hours, but often three to four hours) and the movement of traffic through these periods is controlled with 'profiles'. Typically a number of profiles are developed and specified, often by vehicle classification, in smaller time intervals (usually 5 to 15-minute increments). Microsimulation is one example.
- Models where the OD demand is reflected in 'peak periods', such as peak one-hour or peak two-hour OD matrices. Static assignment is one example.

For models where OD demand is profiled in shorter intervals across longer periods, the NZMUGs research is notable as it demonstrates valid application of a micro time-of-day methodology in the New Zealand context against observed data. Section 9.4 of the NZMUGs research provides a set of practical considerations for applying peak spreading methods.

As a general guide, the following points should be kept in mind if peak spreading is applied to peak period models:

- Decide whether to apply peak spreading uniformly or only to specific parts of the trip matrix. This decision will depend on the extent and location of congestion in the network, and how realistic it is for specific movements through the network to respond to congestion by adjusting their departure times.
- 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 10% of the total peak period traffic, although this will depend on the length of the time periods modelled, with shorter periods (for example, one hour) likely to have greater volumes changing their travel times due to congestion.
- 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% unless evidence or justification can be provided.
- 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.

- It is preferable to apply the same consistent peak spreading adjustment to the demands applied to both the do-minimum and activity. If different adjustments are warranted, then evidence and justification should be reported. Checks should be carried out with the do-minimum peak period adjustment, or profile, applied to both the do-minimum and the activity, and then the converse (the activity peak period profile applied to both the do-minimum and activity). The resulting benefits for each test should be compared to confirm the peak period adjustment is not inappropriately inflating project benefits.
- If the peak spreading adjustment produces a change in total demand across the entire modelled period for either the do-minimum or the activity, then variable trip matrix calculations will be required (see Variable trip matrices). This will occur if the peak shoulders are not included in the modelled period.

Applying the matrix scaling method

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.

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 is likely to reduce computed project benefits unnecessarily.

Procedure

Follow the steps below to apply matrix scaling.

Table A10: Steps 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 normally 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: calculating the volume to capacity ratio in Table A64.
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

This should be applied consistently to the do-minimum and the activity such that the demand matrix is the same in order for a fixed trip matrix technique to be appropriate. Varying the matrix scaling between the do-minimum and activity will require a variable trip matrix technique described in Variable trip matrices. If different scaling is applied to the do-minimum and activity demands, justification and evidence will be required and must be reported.

Applying the incremental matrix capping method

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 and should not be confused with incremental assignment techniques.

Procedure

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 travel 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).

Follow the steps below to apply incremental matrix capping.

Table A11: Steps to apply incremental matrix capping

Step	Action
1	Choose a series of forecast years (say, at five-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 15–25km/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.

Applying the shadow network method

The shadow network method may be used to provide location-specific capping for a trip matrix.

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.

Table A12: Steps 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 10km/h for links of average length (on very short road links, intersection 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 analysis, cordon off the matrix assigned to the real network.

Applying fixed trip matrix with elasticity methods

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 activity options.

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.

Procedure

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 regional transport 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.

Follow the steps below to apply elasticity methods.

Table A13: Steps 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.
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} is the adjusted number of trips between origin *i* and destination *j* T_{ij}^{F} is the initial estimate of the number of trips between *i* and *j* c_{ij}^{1} is the forecast journey cost (or time) between *i* and *j* c_{ij}^{P} is the pivot journey cost (or time) between *i* and *j* *E* is the 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.

As with all approaches to demand forecasting, the final matrix produced by the elasticity formulation must reasonably represent the future year 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 should reflect the sensitivity of demand to the user's perceived costs of travel, that is as used in the demand modelling process (not the resource costs, which typically will be different – refer to Table A17).

The elasticities should also be consistent with the basis on which the user costs are expressed. It is preferable that user costs and elasticities are expressed in terms of generalised costs (a combination of time costs and money costs), rather than in terms of time or money alone (but see below). The generalised cost approach allows demand to respond to both time and money changes and is found to give more consistent results over a range of situations.

The application of elasticity methods depends on the transport model being able to model travel costs realistically, and elasticities consistent with these travel costs being able to be estimated. In general, elasticities specific to a study area will not be available and values from other locations need to be used.

Table A14 provides a set of default long-run generalised cost elasticity values for use in New Zealand (principally urban) situations.

Table A14: Long-run generalised cost elasticities

Model competition	Peak period	Off-peak period
Low	-0.4	-0.7
High	-0.6	-1.0

It should be noted that:

- These elasticity values are constant, for use with a power function formula (as outlined earlier).
- These values essentially represent long-run responses, which may take some time (5+ years) to materialise (short-run values would be significantly lower than these values, but are not usually appropriate for activity analysis purposes).
- The 'low' modal competition values should generally be used. However, in corridors to/from major city central business districts where public transport has a substantial modal share, the 'high' modal competition values may be more appropriate.
- The values given do not allow for any significant time period switching effects, such as might occur with a road pricing scheme involving differential prices by time of day. For such situations, advice should be sought from NZTA and/or specific research undertaken.

If for any reason the model costs are expressed in terms of travel times only (that is, no distance component included) rather than generalised costs, then equivalent travel time elasticities may be calculated and applied. If the 'true' generalised cost function is $t + k.d$, but the model assigns on the basis of travel time t, then the equivalent elasticity is obtained by dividing the generalised cost elasticity by the factor ($1 + k.v$), where v is the average study area journey speed (in units of kilometres per minute).

Applying fixed trip matrix with demand response models

Regional transport models are commonly used to derive matrices or matrix growth factors that are sensitive to transport system travel times.

Regional transport models refer to one or more of the standard generation, distribution and (optional) mode split models generally handled by proprietary transport modelling software. In the main urban centres, regional transport models are commonly used to generate matrices. Some project models are also capable of modelling variable travel demands (for example by using trip distribution models).

Procedure

The forecast matrices derived from regional transport models are modified appropriately for the project model and used in standard FTM analysis procedures.

Project models with demand responses can be applied in a similar way to elasticity methods (see Applying fixed trip matrix with elasticity methods) using the demand response component of the model to adjust the trip matrix, rather than an elasticity formulation.

In both options, and with all approaches to demand forecasting, the resulting matrix should be a reasonable representation of demand, and the demand models should be properly validated (see the Transport modelling checks worksheet. For a fixed trip matrix technique to be appropriate, the demands must also be the same for the do-minimum and the activity.

Variable trip matrices

This section relates to cases where the demand is different in the do-minimum and activity/option for a given forecast year. Where the activity introduces more capacity for a particular mode, the demand for that mode with the activity will be higher than for the do-minimum. This is referred to as variable trip matrices (VTM), that is, the demand varies between the do-minimum and the activity.

There are specific processes to calculate economic benefits where there are variable trip matrices, which is described within this section.

Variable trip matrix methods are to be used for all complex improvements, unless:

- it can be demonstrated that:
    - the congestion level expected throughout the analysis period in the do-minimum or option will not be substantial, and
    - the peak period public transport mode share changes (in the activity compared with the do-minimum) by less than 5% based on total travel mode share -this will depend on location and current mode shares, or
- preliminary analysis shows that the fixed trip matrix benefits are unlikely to differ by more than 10% from those from a variable trip matrix approach, or
- NZTA approves the use of a fixed trip matrix approach for other reasons.

If the volume change between the do-minimum and activity increases typical peak period travel times by more than 10%, then this is an indicator that variable trip matrix techniques may be required.

Variable matrix methods provide estimates of the effects of an activity on travel patterns (that is, the difference between the do-minimum and option matrices) and on the benefits of the activity.

Procedure

Three variable matrix methods based on analytical techniques are recommended. These are:

- elasticity methods
- application of growth constraint techniques reducing the demand in the do-minimum and/or the activity to produce equilibrium of supply and demand
- demand response models.

For demand response modelling approaches, where the source of data is from a regional transport model, there may be the possibility that the regional transport model will not have sufficient sensitivity to measure the impact on the trip matrix of a single scheme (unless the single scheme is significant in nature), and the use of such models will therefore generally not generate a demand response that is considered realistic. In examples where the scheme is considered significant enough to generate a demand response, elasticity methods can be used to supplement the regional transport model.

Whatever method is applied, its results should be verified by comparison with an FTM analysis based on the do-minimum trip matrix.

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. If a variable trip matrix model (for example, a regional transport model or a project model with demand response) is available, it should be used.

Table A15: Steps to apply variable matrix methods

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td rowspan="8">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 option matrices</td><td>Applying variable trip matrix with elasticity methods</td></tr>
<tr><td>B</td><td>Use other growth constraint techniques (Table A9) for the do-minimum matrix and elasticity techniques to estimate the effects of the activity on the trip matrix</td><td>Applying variable trip matrix with elasticity methods</td></tr>
<tr><td>C</td><td>Use a demand response model (regional transport model or project model with demand response) to produce the do-minimum and activity demand matrices</td><td>Applying variable trip matrix with demand response models</td></tr>
<tr><td>D</td><td>Use a demand response model to produce the do-minimum and activity demand matrices, then apply growth constraint techniques in a project model to balance demand to supply</td><td>Applying variable trip matrix with growth constraint techniques</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. Any predetermined correction factor would require robust justification, particularly if a significant increase in benefits resulted.</td></tr>
<tr><td colspan="3">Note that project benefits will need to be calculated using a consumer surplus evaluation and reported in the appraisal summary table.</td></tr>
<tr><td>2</td><td colspan="3">Conduct a fixed matrix analysis (see Fixed trip matrices) and compare the results with those obtained from the variable matrix analysis.</td></tr>
</table>

Applying variable trip matrix with elasticity methods

Variable trip matrix (VTM) elasticity methods are referenced in Table A15 (methods A and B). The two recommended applications are:

1. where the do-minimum and activity option matrices are both estimated using elasticity methods, or
2. 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 activity option.

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.

See Applying fixed trip matrix with elasticity methods for 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.

Refer also to Applying fixed trip matrix with elasticity methods for a discussion of suggested elasticities.

Method A procedure

For method A, the processes described in Table A13 are applied separately but consistently for the do-minimum and activity option matrices. For example, if the method is pivoted on the base year matrices, then steps 1–6 in Table A13 are applied first using the do-minimum network (in step 2 for c_{ij}^1 and subsequent steps) and then repeated using the activity option network (in step 2 for c_{ij}^1 and subsequent steps).

Method B procedure

Table A16: Steps to apply variable matrix method B

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_{ij}^P.
2	Use the do-minimum matrix as the initial estimate of the forecast year matrix T_{ij}^F and assign it to the activity option network. Obtain an initial cost matrix c_{ij}^1 from the assignment results.
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 is the adjusted number of trips between origin *i* and destination *j* T_{ij}^F is the initial estimate of the number of trips between *i* and *j* c_{ij}^1 is the forecast journey cost (or time) between *i* and *j* c_{ij}^P is the pivot journey cost (or time) between *i* and *j* *E* is the 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 $\frac{1}{2}(T_{ij}^F + T_{ij}^1)$.
4	Assign the new matrix T_{ij}^1 to the activity option 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 $\frac{1}{2}(T_{ij}^1 + T_{ij}^2)$.

Automated application of elasticity methods (for example, some traffic modelling software has built-in capabilities such as ‘elastic assignment’ methods) 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 fixed trip matrix techniques in Table A9.

As for FTM elasticity methods, the final matrix produced by the elasticity formulation (in either method 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 the Transport modelling checks worksheet, Base year assignment validation).

Applying variable trip matrix with demand response models

VTM activity demand response models may be used to estimate trip matrices differentiated between the do-minimum and activity. As with other VTM approaches, these guidelines should be used only when high levels of congestion exist in both the do-minimum and activity options. Applying a regional transport model or a project model with a demand response component are options to develop VTM demand response matrices. If the regional transport model is used alone (that is, without a more detailed project model), the activity should have a significant impact, and/or the analysis should be in the earlier stages of the planning process. 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, VTM analysis procedures would be used. The stability and convergence requirements are the same as for VTM elasticity methods (see Applying variable trip matrix with elasticity methods). The validation of such models is discussed in the Transport modelling checks worksheet, Strategic demand model check.

Applying variable trip matrix with growth constraint techniques

The final situation is where a demand response model (regional transport model or project model with a demand response component) is applied to produce separate demand matrices for the do-minimum and the activity, and these demands are then fed into a project model which is applied directly the economic assessment.

While the demand response model may be in equilibrium for demand and supply, a demand/supply imbalance may occur in the project model. This typically happens when the demand forecast by the demand response model is significantly greater than the supply in the project model. In this situation, growth restraint techniques would be applied in the project model to the do-minimum and/or activity demands. Appropriate methodologies to constrain growth are listed in Table A9 and are most likely to involve the application of peak spreading and/or matrix scaling.

In all cases, these techniques will be applied to reduce demand to be more aligned with supply. These techniques should not be applied to increase demands in the do-minimum, which would result in greater levels of congestion and an inappropriate increase in benefits. Similarly, the activity demands should not be increased or decreased to artificially increase the benefits. These approaches are to reduce demand forecast by one model so that it does not significantly exceed supply when used in a second model.

Conducting cost–benefit analyses using variable trip matrix methods

Where the demand matrix for the activity is different to that of the do-minimum, VTM methods (refer Variable trip matrices) need to be applied. VTMs require more complex economic calculations than FTM methods in order to determine activity 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 the appraisal summary table.

Background

For fixed matrix analysis (where only the route of travel, at most, may change), 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. These additional journeys may be completely new trips (induced), or occur due to a change in destination (redistribution), a change in modal choice, or a change in macro time choice associated with the activity. Since the decision to make additional journeys is based on the costs perceived by users of the transport system, 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 transport system 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:

$$\text{Benefit} = \underbrace{\frac{1}{2}(T_{OPT} + T_{DM}) \times (U_{DM} - U_{OPT})}_{\text{change in road user surplus}} + \underbrace{T_{OPT}(U_{OPT} - R_{OPT}) - T_{DM}(U_{DM} - R_{DM})}_{\text{resource cost correction}}$$

Or, rearranging terms:

$$\text{Benefit} = \underbrace{(R_{DM}T_{DM} - R_{OPT}T_{OPT})}_{\text{change in resource costs}} + \underbrace{\frac{1}{2}(U_{DM} + U_{OPT}) \times (T_{OPT} - T_{DM})}_{\text{adjustment for variable trip matrix}}$$

where:

T_{DM} is the number of trips in the do minimum
T_{OPT} is the number of trips in the project option
U_{DM} is the user cost of travel in the do minimum
U_{OPT} is the user cost of travel in the project option
R_{DM} is the resource cost of travel in the do minimum
R_{OPT} is the resource cost of travel in the project option.

The implied subscripts *i* and *j* have been omitted for clarity.

For a fixed matrix analysis 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 analysis.

The values of time and vehicle operating 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 Table A17.

Table A17: Guidelines for estimating user time and vehicle operating costs

Cost component	Obtain resource costs from …	To derive the user cost …
Value of time (working)	Table 13, Table 14, Table 15 and Table 16	*User cost = resource cost*
Value of time (non-working)	Table 13, Table 14, Table 15 and Table 16	*User cost = resource cost × 1.15*
Vehicle operating cost (in urban networks):		
Tables and graphs of cost by average speed and gradient	Table A79 to Table A88	*User cost = resource cost × 1.2*
Tables and graphs of additional costs for roughness	Table 25, Table A89, Table A90 and Table A91	*User cost = resource cost × 1.125*
Tables of fuel costs due to bottleneck delay	Table A92, Table A93, Table A94 and Table A95	*User cost = resource cost × 2.0*
Graphs of additional costs for speed change cycles	Table A96 to Table A115	*User cost = resource cost × 1.9*

Matrix-based computation

For a variable matrix analysis, adopt either of the following two methods to accumulate the net benefits of project options:

1. a matrix-based analysis, where an average cost is computed for each origin–destination pair, or
2. a link-based analysis, where costs are computed separately for each link (or groups of links).

The first of these approaches enables benefits to be identified for particular travel movements, which may be useful in identifying gainers and losers. The matrix-based analysis **must** be used where the model includes time spent waiting queueing inside zones (for example, microsimulation models) and such models must be run so that all trips complete. This is so that any differences in trip volumes and trip travel times between the do-minimum and activity are not missed due to time spent waiting in the zone. This applies for both FTM and VTM.

The second approach has the advantage that it allows benefits to be estimated for a region in the network that is relatively self-contained, which can be useful for planning purposes.

Most network demand modelling software will allow benefits to be derived on a matrix (origin–destination) basis without the need for the additional model runs needed for the second approach.

Create the matrices of trips and costs required to compute the benefits as itemised in Table A18.

Using matrix manipulations, compute the benefit matrix (for a single time period).

For a road activity with no tolls or a public transport activity with no fares, the formula for estimating net benefits for any origin – destination (*ij*) pair will be:

$$B_{ij} = \left(R_{ij}^{DM}T_{ij}^{DM} - R_{ij}^{OPT}T_{ij}^{OPT}\right) + \frac{1}{2}\left(U_{ij}^{DM} + U_{ij}^{OPT}\right) \times \left(T_{ij}^{OPT} - T_{ij}^{DM}\right)$$

The total project benefit B is then given by the matrix total summed over all matrix cells.

Table A18: 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.

In the case of public transport where a fare is paid by users, the net benefit for each *ij* pair will be:

$Bij = [{}^1/_2(T_{DM} + T_{OPT})\ (U_{DM} - U_{OPT})]$ *(perceived user benefits)*

$+ [(T_{DM}\ PTR_{DM} - T_{OPT}\ PTR_{OPT})]$ *(change in public transport supply resource cost)*

$+ [(T_{OPT}\ (OU_{OPT} - OR_{OPT}) - T_{DM}\ (OU_{DM} - OR_{DM})]$ *(change in other resource costs)*

$+ [T_{OPT}\ F_{OPT} - T_{DM}\ F_{DM}]$ *(fare resource correction)*

Where, for each *ij* pair:

T is the number of trips
U is the perceived cost/trip
F is the fare/trip (as included in the perceived cost of travel)
OU is the other perceived user cost/trip (eg generalised cost of travel time)
PTR is the resource cost of providing public transport/trip
OR is the other resource travel costs (eg travel time and environment)/trip.

Subscripts:

DM = do-minimum, OPT = option, U = F + OU, and R = PTR + OR

Perceived user benefits are calculated on an origin–destination basis (ie for each *ij* pair in the transport matrix), with the total perceived user benefit being the sum of perceived benefits for all *ij* pairs. Other benefit components can be calculated on a network basis. Calculation of the change in public transport supply resource costs will generally be based on changes in the service quantity provided across a network between the do-minimum and option, rather than on a cost per passenger trip. Usually the change in public transport supply costs will be treated as a cost, in which case the item should be removed from the formula above.

The equivalent formula applies in road tolling activity, where tolls are part of the perceived cost of travel, with the value of *F* being the toll rather than the public transport fare. In addition to tolls, the value of *U* includes the perceived value of travel time and the motorists' perceived vehicle operating costs when making travel decisions. The equivalent to *PTR* will be the direct resource cost of vehicle use, and the *OR* counterpart will be the resource value of travel time, environmental and social externalities of vehicle use. Again, the total change in perceived user benefits will be the sum of the benefit for each *ij* pair. Other impacts can be estimated drawing on aggregate resources used in the network (eg total vehicle – km and person – hours of travel) and total toll revenue. Unlike changes in public transport supply resource cost, changes in the resource cost of vehicle use are treated as a benefit and so should be included as part of the benefit formula.

Link-based computation

Link-based computation of activity benefits is possible, with the change in resource costs determined by calculating resource costs multiplied by trips summed over the network ('change in resource costs'), with the component 'adjustment for variable trip matrix' calculated based on network statistics that require some extra analysis as detailed below.

First, the extra term can be expanded to four terms to read:

$$\frac{1}{2}\,(\underbrace{U_{OPT}T_{OPT}}_{I} - \underbrace{U_{DM}T_{DM}}_{II} + \underbrace{U_{DM}T_{OPT}}_{III} - \underbrace{U_{OPT}T_{DM}}_{IV})$$

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 A17.
- *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 A17.

Terms *III* and *IV* 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 activity option matrix; this is achieved by loading the activity 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 activity 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 activity 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 analysis, the assignment software must be able to handle 'crossloading'.

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 above. The result should be recorded as VOC savings. 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 recorded separately as Crash cost savings and Vehicle emission reductions.

Checking fixed or variable trip matrices

These checks are related to the procedures in Determining traffic volumes and may be used to check the appropriateness of fixed trip matrix adjustments or variable trip matrix calculations for dealing with suppressed and induced traffic, as well as changes in destination, modal, or macro time period choice. The checks supplement the general model validation guidelines given in the Transport modelling checks worksheet.

Suggested checks

Suggested checks include:

Table A19: Suggested checks for fixed and variable trip matrix calculations/adjustments

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)	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: • within the study area, in the base year and historically • between cities or across New Zealand. Based on this evidence, an indication that current traffic profiles in the study area are more peaked than in other locations or during other time periods. 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). Alternatively, for models that cover longer time periods (more than one hour) and predict behaviour for small time increments, comparison of speeds at congested times compared with uncongested where the peak spreading is to be applied.
A variable matrix technique was used (eg, elasticity method on both the do-minimum and activity option or a demand response model was applied)	Indication of adequate capacity. Differences between the do-minimum and activity 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 Transport modelling checks, Base year assignment validation). Details of the methodology applied.

Checking capacity in do-minimum and activity option

To check the do-minimum and activity 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. For models that gridlock and will not produce viable outputs, growth constraint techniques (peak spreading or matrix scaling) will need to be applied to estimate benefits.

Table A20: Suggested checks for capacity

Performance indices	Indicator of significant congestion
Level of service	Level of service F*.
Matrix feasibility	Network model is unable to achieve a stable realistic assignment. Demand response model is unable to produce stable results, based on comparing outputs (for example, person-hours travelled and person-kilometres travelled) between successive iterations of estimating demand.
Plots of link volume to capacity ratios or manual calculation of the ratio (see Calculating the volume to capacity ratio)	Ratios consistently higher than 1.0.
Link speed plots	Speeds consistently below realistic values (15–25km/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 (LOS) F is when forced or breakdown flow occurs or has reached a point that most users would consider unsatisfactory. At LOS F, the amount of traffic trying to pass a point exceeds that which can pass it. Queuing, delays and flow breakdown occur at these flow levels (Source: *Guide to traffic management part 3* (Austroads 2020)).

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Back to 4. Evaluation procedures >>

Appendix 2: Crash analysis

This appendix gives guidance on calculating crash costs for the do-minimum and option scenarios for a route or site. 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. Crash rates, crash prediction models and crash reduction factors can be found in the NZTA *Crash estimation compendium*.

Choosing the type of analysis

This section of the manual provides further guidance on the selection of different analysis methods, depending on the availability and quantum of crash data for the site. Evaluation of sites may require a combination of analysis methods to assess the do-minimum and option cases.

Selecting the crash analysis method

There are three types of crash analysis methods available:

- method A: crash-by-crash analysis
- method B: crash rate analysis
- method C: weighted crash procedure.

Follow the flowchart steps below to determine the need for a crash analysis and the selection of crash analysis method(s). Details on each step in the process are discussed in more detail following the flow chart in FigureA22.

Availability of crash history data

A reliable five-year crash history is not always available for a route or site. This can occur when there has been a major change during the last five years, for example when a new intersection has been constructed, or an intersection has been modified. If the change is likely to have altered the number and pattern of crashes then the full five year crash history is not a reliable record of the current crash risk at the site. Routes and sites that have been constructed during the last five years will also not have a full crash history.

As shown in the decision process diagram, the historical crash period can be shortened to three or four years if this is all that is available post changes. A period below three years cannot be used due to the potential for regression-to-the-mean (see Definitions). For method A the criterion in terms of number of crashes must still be met albeit with a shorter time period.

In some situations it is beneficial to use a longer crash history, as long as there has not been a major change on a route or at a site, including a period of high traffic growth. A longer crash period of up to 10 years should be considered when traffic volumes are below 1500 vehicles per day and when looking at crashes involving less common modes, such as pedestrians and cyclists.

Accuracy of crash data

The latest data available in the NZTA Crash Analysis System (CAS) should be used for crash analysis. As there is typically a lag (up to three months) between the time when a 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). It can also be useful to look at other sources of data such as public and contractor reported crashes and, where available, hospital records.

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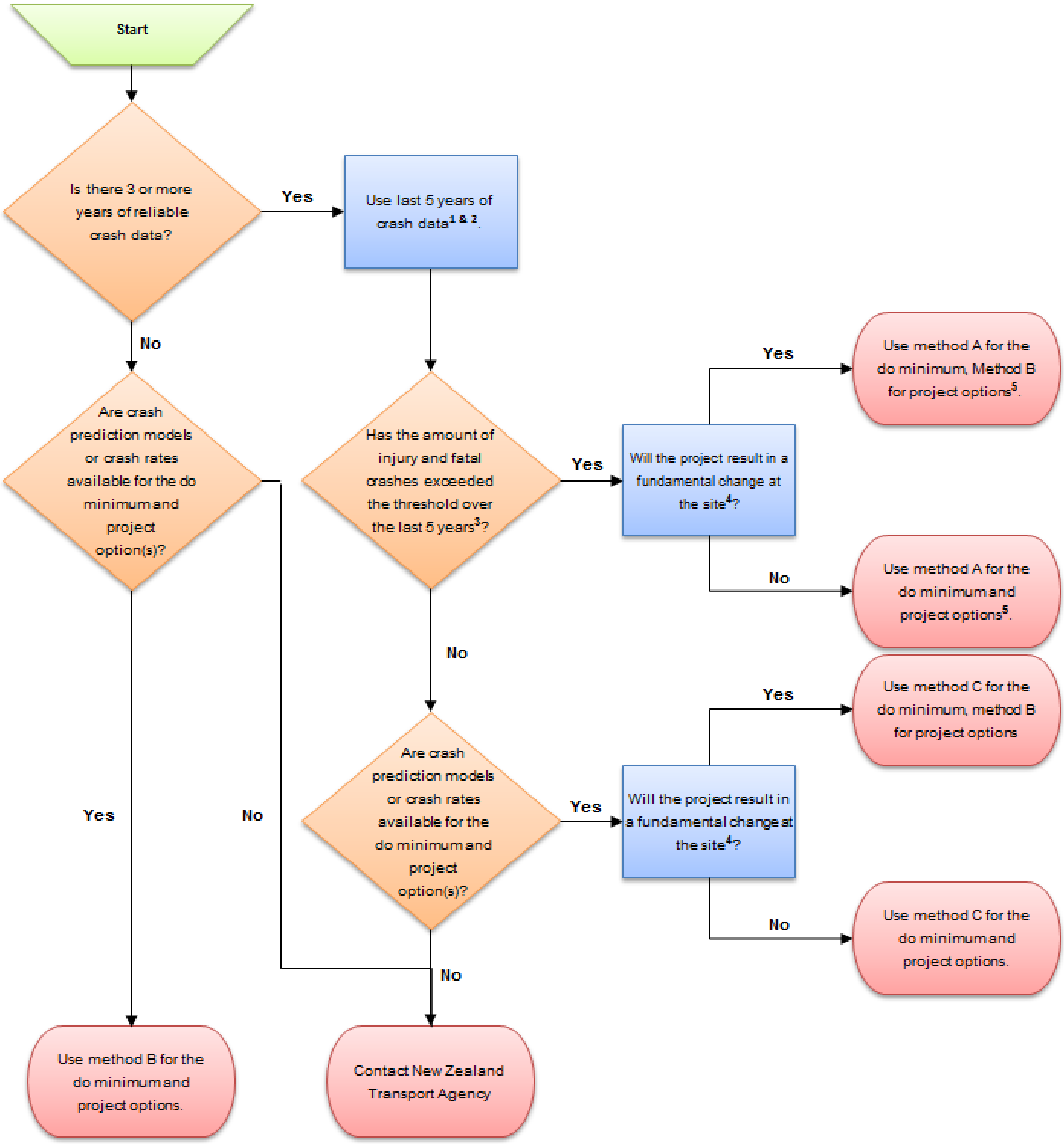
Figure A22: Decision process for selecting crash analysis methods



NOTES

1. If 3-5 years of crash data is available then use data that is available.

2. Up to 10 years of data can be used at low volume sites (<1500 AADT) or when looking at vulnerable road users (e.g. pedestrian and/or cyclist). Need to check that there has not been fundamental change or high traffic growth.

3. Threshold for intersections/road sections <1km: 5 or more injury crashes or 2 or more serious and fatal crashes at the site in the last 5 years?
Threshold for road sections >1km: 3 or more injury crashes per kilometre or 1 or more serious and fatal crashes per kilometre at the site in the last 5 years?

4. Fundamental change is defined in Appendix A6.9

5. Option of using method A or method B when analysing a high risk intersection/link (as defined in the NZ Transport Authority's High-risk Intersection Guide and High-risk Rural Roads Guide).

Minimum number of crashes required for method A

To use method A for crash analysis, there needs to be a minimum number of crashes at a site. In method A (crash by crash analysis) future benefits are estimated from a reduction in historical crashes. For each option, a reduction from 0 to 100% is applied to each historical crash.

When using method A the historical crash data from the last five years is used to predict the number of crashes that will occur at the site over the next 40 years. When the crash record has few injury crashes, or has a single serious or fatal crash, then this is often not an ideal basis on which to predict the number of crashes that might occur over such a long period. In these circumstances the benefit of a safety or roading improvement project can be overstated as the crash reduction may be applied to an over-estimated number of future do-minimum crashes or crash costs. For example, when using five years of data it can be unclear whether a single serious or fatal crash is a one in five year event or a one in 50 year event. When there are two or more serious and/or fatal crashes then it is a lot more likely that such crashes occur frequently. Hence to reduce the likelihood of crash benefits being overstated, a minimum number of crashes is specified for method A.

The criterion for method A is as follows:

At intersections or sites less than 1 kilometre in length, within the last five years there have been:

a. five or more injury crashes; and/or
b. two or more serious or fatal crashes.

At sites longer than one kilometre in length, within the last five years there have been:

c. three or more injury crashes per kilometre; and/or
d. one or more serious or fatal crash per kilometre.

Note: The number of injury, or fatal and serious crashes, is calculated by dividing the number of crashes by the length.

For sites on low volume roads, with an AADT of fewer than 1500 vehicles per day (vpd) then a longer historical crash period of ten years can be used. The 10-year history must be divided by 2 to obtain an equivalent five-year history. If the crashes in this equivalent five-year period meet the criterion above, then method A may be used.

Where a site does not meet these minimum requirements, then method C (the weighted procedure) should generally be used. Method C still gives some consideration to the historical crash record but this is combined with a prediction from rate or crash prediction model which has been developed for similar sites.

An issue arises when there are no suitable crash rates or crash prediction models available to use method C. In such circumstances there needs to be a discussion with NZTA, who may agree to method A being used even though the threshold for crash numbers have not been meet. A primary consideration in this situation is whether a recognised crash investigation specialist considers that the site has significant safety deficiency (eg high-crash-risk sites) and therefore needs to be improved.

Fundamental change

When there is a fundamental change along a route or at a site, 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 have occurred at the site.

Where there is a fundamental change at a site but no crash rates or crash prediction models are available for the do-minimum, method A may be used (subject to NZTA approval in writing) for the do-minimum. While method B is used for the option cases, providing that models are available. Refer to Definitions for more information on a fundamental change.

Availability of crash rates and models

Details on the available crash rates and crash prediction models are found in the *Crash estimation compendium*. Crash rates and crash prediction models, other than those specified in this compendium, may be used if the robustness of these rates or models can be demonstrated to NZTA or their nominated peer reviewer.

Applying the analysis methods

This section describes the general process for how to determine future annual crash numbers and costs for the do-minimum and option cases using the three analysis methods:

- method A: crash-by-crash analysis
- method B: crash rate analysis
- method C: weighted crash procedure.

Worked examples of methods B and C are provided in Appendix 8: Worked examples.

Categorisation by speed limit

Crashes are categorised according to the speed limit areas in which they occur:

- 50km/h speed limit areas (including 30 km/h, 40 km/h and 60 km/h areas)
- 70km/h speed limit areas
- 100km/h speed limit areas (including 80 km/h and 90 km/h areas).

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 A overview

Crash-by-crash analysis is based on the crash history of the site and is dependent on the number of reported crashes. The analysis uses the individual crash severity (see Definitions) 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 Crash cost savings worksheet in the full procedures, the do-minimum total estimated number of crashes per annum is calculated. Costs are assigned using the crash costs from Table A28 to Table A31 for 50km/h speed limit areas and from Table A32 to Table A35 for 100km/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 guidance provided in the *Crash estimation compendium*. The forecast percentage of crash reductions for the project option can be applied either globally or varied for each crash type and severity (eg fatal, serious, minor and non-injury).

Costs are taken from Table A29 to Table A35, as appropriate to the site. Where the mean speed of traffic for the do-minimum and/or options differs from that provided in the tables, an adjustment should be made to the costs using the formula found in Adjusting crash costs by movement and vehicle involvement.

Changes in crash severity

Options, such as crash barriers, in some cases can reduce the crash severity at a site. In this situation different crash reductions are applied to each historical crash depending on type and severity (eg fatal, serious, minor and non-injury).

Use of local crash data

NZTA 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 a crash-by-crash analysis (method A) where the data is supported by sufficient evidence to be audited and there is 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.

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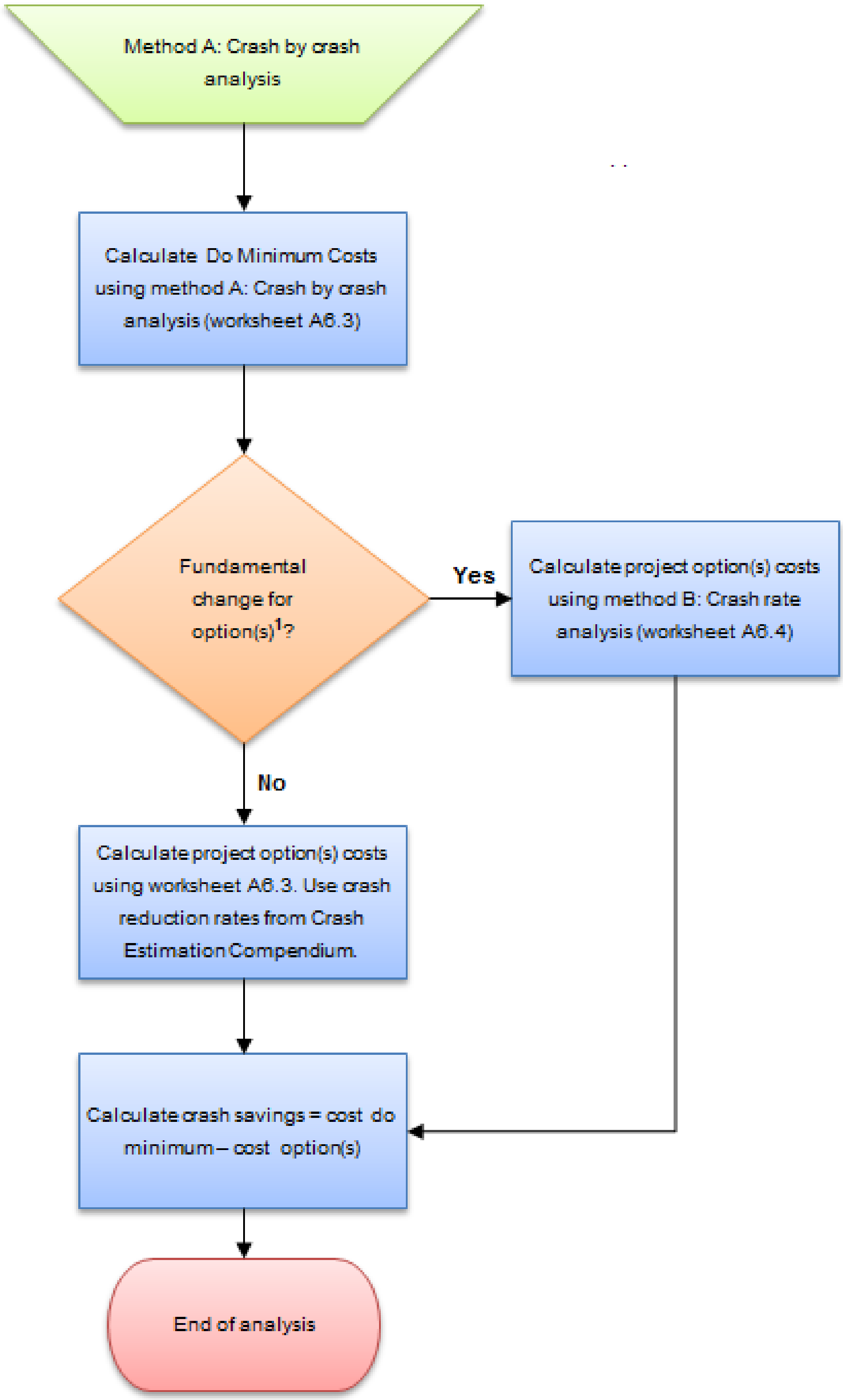
Method A: Crash by crash

Figure A23: Method A flow chart



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 Table A23, Table A24 and Table A25 for each crash type. This method applies for up to two fatal crashes and unlimited serious crashes at each site. 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 (refer to Definitions for further details).

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 under-reporting when using method A, factors are applied to reported crash numbers (TCR numbers) to estimate the total number of crashes that actually occur. Table A26 provides factors for converting from reported injury to total injury crashes, while Table A27 provides factors for converting from reported non-injury 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.

Method B overview

Method B crash rate analysis involves determining a typical crash rate (refer to Definitions) per annum as the basis for calculating the crash cost savings for a project. Typical crash rates have been calculated using either a crash rate or crash prediction model provided in the *Crash estimation compendium*, which have been derived using information from similar types of sites elsewhere.

In some cases, the rates and models used for the do-minimum and the option scenarios 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 modifying factor (CMF) from the *Crash estimation compendium* to the option crash rate or model 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 A36, Table A37 and Table A38, 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 the tables, an adjustment should be made to the costs using the formula found in Adjusting crash costs by movement and vehicle involvement.

Only reported injury crashes are considered when using crash rate analysis because of the inconsistency in non-injury reporting rates between districts. The crash costs in Table A36, Table A37 and Table A38 take into account the typical number of unreported injury crashes, the number of non-injury crashes, and the proportion of crashes of each severity (refer to Definitions) 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 the Crash cost savings worksheet.

Changes in crash severity

Changes in crash severity can be calculated using method B when methods A and C are not appropriate for the option case. Refer to the *Crash estimation compendium* for the crash modifying factors for treatments that impact on crash severity (eg safety barriers).

Calculation of future crash benefits

In most crash prediction models the relationship between traffic volume and number of crashes is non-linear. When using crash prediction models, a prediction should be produced 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. The Crash cost savings worksheet should be used.

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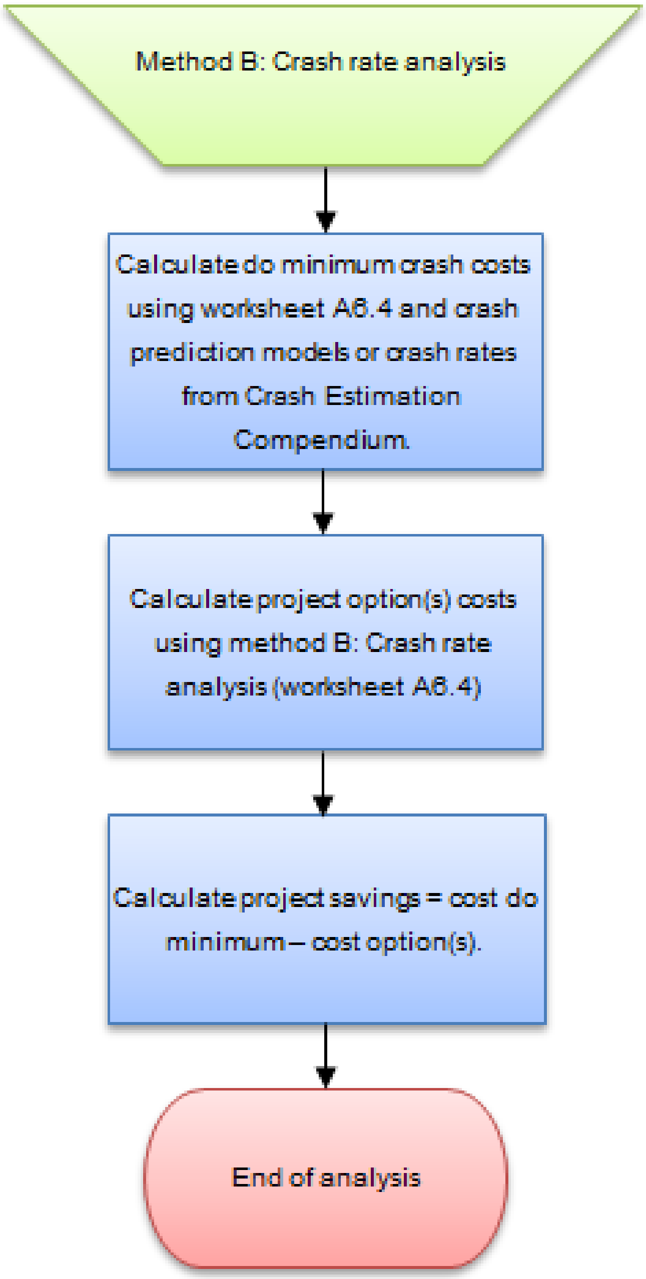
When using crash rates, future predictions are not required as the relationship between crash numbers and traffic volumes is linear. In such circumstances, only future traffic volumes need to be checked that they are within any ranges specified; otherwise, the benefits need to be capped. The Crash cost savings worksheet.

Method B: Crash rate analysis

Figure A24: Method B flow chart



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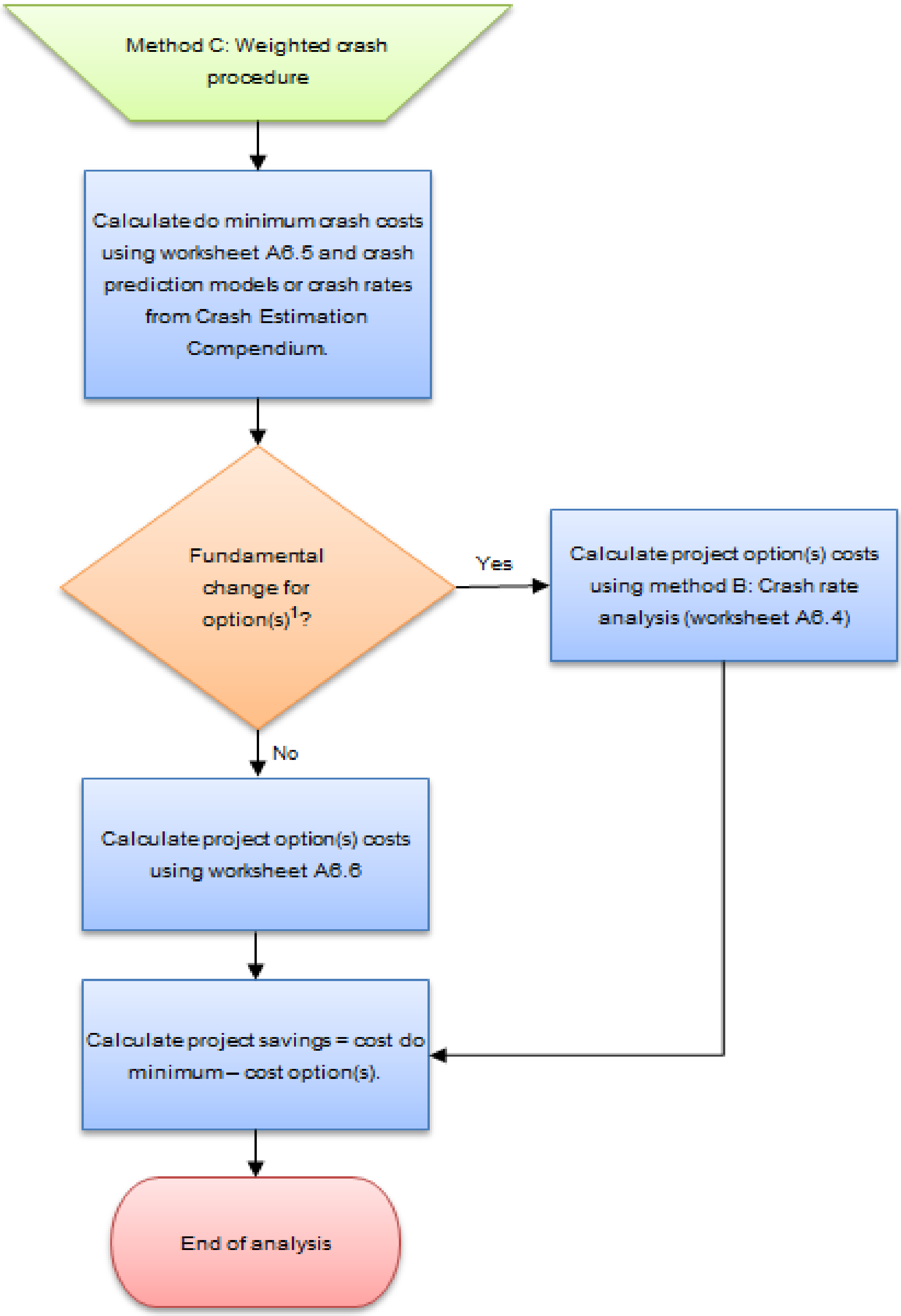
Method C overview

The weighted crash procedure uses both historical crash data relating to a particular site, and the typical crash rate (refer to Definitions) for the site. The typical crash rate is calculated using the appropriate crash rates or crash prediction models and crash modifying factors (CMFs) in the *Crash estimation compendium*.

The historical data is converted into a site-specific crash rate (refer to Definitions) 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 (refer to Definitions) for the do-minimum and the option(s).

Method C: Weighted crash procedure

Figure A25: Method C flow chart



Crash cost savings for the do-minimum and option(s) are calculated using the costs provided in Table A36, Table A37 and Table A38. Where the mean speed of traffic for the do-minimum and options differs from that provided in the tables, an adjustment should be made to the costs using the formula found in Adjusting crash costs by movement and vehicle involvement.

The weighted crash procedure also allows analysis of sites with no crash history (refer to Definitions), if 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.

Weighted crash rate for the do-minimum

The do-minimum weighted crash rate (refer to Definitions) 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 rate calculated from the appropriate crash rate or crash prediction model 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 rate or crash prediction model (method B).

When $w = 0$, the method simplifies to a crash-by-crash analysis (method A). w is calculated using the following equation; where k is specified in the *Crash estimation compendium*:

$$w = \frac{K}{k + A_T(km) \times Y}$$

where: k is a dispersion parameter (refer to Definitions)
$A_T(km)$ is typical annual crash rate per site or kilometre (for mid-blocks)
Y is the number of years of crash records

For mid-block sections, the typical crash rate (A_T) must be divided by the length of the mid-block because the mid-block k values provided in the *Crash estimation compendium* 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 or 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 the *Crash estimation compendium* is an issue when a crash rate or crash prediction model is used for:

- a different type of site, or part of a site, than that the rate or model was derived for – for example, a four-arm traffic signal model might be used for a five-arm traffic signalised intersection (the prediction would then be approximately 125% of that given by the model), and
- 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 five or six) or greater than four approach lanes or a priority seagull.

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 rate for project option

Method C can only be used for the project option when it does not bring about a fundamental change in a site (refer to Definitions). In this case, the site-specific historic crash data is still relevant for the project option analysis. 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 case
$A_{W,dm}$ is the weighted crash rate for the do-minimum
$A_{T,opt}$ is the typical crash rate calculated from the crash rate or crash prediction model for the option case. **Note:** It may be necessary to apply a crash modification factor (CMF) from the *Crash estimation compendium* if the crash rate or crash prediction model does not already take the treatment / improvement into account
$A_{T,dm}$ is the typical crash rate calculated from crash rate or crash prediction model for the do-minimum

Crash trends

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 crash numbers have decreased and traffic volumes have increased, indicating that crash rates per vehicle have decreased at a greater rate than crash numbers (Kennaird, 1995).

The combination of these two factors means that typical crash rates (refer to Definitions) 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 a project site in the future.

The adjustment to crash numbers is a two-stage procedure, with the first being to modify the crash numbers at time zero. The second 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 differences between the crash trends in 50km/h areas compared with 70km/h and above areas. Therefore, different factors are used to modify the crash numbers for the different posted speed limit areas.

TableA21 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 A22 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 analysis are to be determined for time zero. This requires adjusting the observed or predicted number of crashes assessed at the mid-point of the crash analysis period to time zero (normally five years). The procedure differs if using the crash history (method A and C) or crash rate analysis (methods B and C).

Method A adjustment

This procedure should be followed if using method A and C. From TableA21, 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 50km/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 A21: Crash trend adjustments factors

Speed limit	Traffic growth rate							
	0%	1%	2%	3%	4%	5%	6%	7%
50 and 60km/h	0.83	0.86	0.90	0.93	0.96	0.99	1.03	1.06
70km/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 method B and C. As the crash rates and crash prediction models in the *Crash estimation compendium* 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:

- -0.01 for sites with speed limits 60km/h and below
- -0.02 for sites with speed limits 70km/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 A22 provides the adjustments to use for the different speed limit areas.

Using the factors in Table A22 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 1% in 50km/h areas or 2% in 70km/h and above areas. For example, if the site is in a 50km/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 - 1 = 0.5, ie 0.5% is entered in the discounting equation.

Table A22: Growth adjustment factors

Posted speed limit	50 and 60km/h	70km/h and above
Modification to traffic growth rate	-1%	-2%

Adjusting crash costs by movement and vehicle involvement

Crash costs by movement and vehicle involvement for use in method A are provided for 30–50km/h and 80–110km/h speed limits in Table A28 to Table A35. Due to insufficient sample size, respective crash costs for 60–70km/h speeds are not provided. However, there is a strong positive correlation between speed and crash severity, therefore the cost of crashes in the 60–70km/h range fall between the higher 80–110km/h cost and the lower 30–50km/h cost. Crash costs for 60km/h or 70km/h can be calculated via interpolation using the following formula:

$$C_V = C_L + (C_H - C_L)(V - 50)/30$$

where:
C_V is the cost of crashes for the mean speed V (eg 60 or 70)
C_L is the cost of crashes in 30–50km/h speed limit areas
C_H is the cost of crashes in 80–110km/h speed limit area
V is the mean speed of traffic in km/h

Effect of speed on crash risk

Vehicle speed has a strong positive correlation with crash risk. Evidence suggests that crash risk increases exponentially as vehicle operating speed increases (Elvik et al 2019, and Elvik 2019). This means that changing speed from 80km/h to 100km/h will increase crash risk more than changing speed from 40km/h to 50m/h, despite the two sharing the same relative (percentage) change in speed.

The following formula, Elvik's Exponential Model, can be used to estimate the change in crashes as a result of changes in vehicle speed:

$$\text{Relative crashes} = e^{(\text{change in speed x coefficient})}$$

where e = Euler's number (2.71828…)
coefficient = 0.08 for fatal crashes
0.06 for serious injury crashes
0.04 for minor injury crashes
0.02 for non-injury crashes[18]

For example, to estimate the expected change in fatal crashes as a result of reducing mean operating speed from 70km/h to 60km/h: $e^{(-10 \times 0.08)}$ = 0.45, which means a 55% (1 - 0.45) reduction in the number of fatal crashes. Each crash severity must be estimated via a separate application of the formula. This estimation method should be used when vehicle operating speed is the only factor being changed. However, for more complex scenarios, readers are encouraged to consult the *Crash estimation compendium*.

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.

Tables

Introduction

Table A23 through to Table A44 are for use in the Crash cost savings worksheet provided on the NZTA website. These tables are used for calculating annual crash costs, depending on which of the crash analysis procedures are used.

Table A23 through to Table A35 and Table A39 to Table A44 are for use with method A crash-by-crash analysis, while Table A36 to Table A38 are for use with methods B and C crash rate analysis and the weighted crash procedure.

Refer to Definitions for more information.

Table A23: Ratio of fatal to serious crash severities by movement for 30–50km/h speed limit areas

Movement category	CAS movement codes	Fatal/ (fatal + serious)	Serious/ (fatal + serious)
Head on	AB, B	0.08	0.92
Hit object	E	0.04	0.96
Lost control off road	AD, CB, CC, CO, D	0.10	0.90
Lost control on road	CA	0.04	0.96
Miscellaneous	Q	0.15	0.85
Overtaking	AA, AC, AE-AO, GE	0.05	0.95
Pedestrian	N, P	0.08	0.92
Rear end, crossing	FB, FC, GD	0.04	0.96
Rear end, queuing	FD, FE, FF, FO	0.02	0.98
Rear end, slow vehicle	FA, GA-GC, GO	0.05	0.95
Crossing, direct	H	0.05	0.95
Crossing, turning	J, K, L, M	0.03	0.97
All movements		0.07	0.93

[18] Note, there is no generally agreed upon coefficient for non-injury crashes, as they are seldom included in such studies. The value of 0.02 can be used as a conservative value for non-injury crashes.

Table A24: Ratio of fatal to serious crash severities by movement for 60–70km/h speed limit areas

Movement category	CAS movement codes	Fatal/ (fatal + serious)	Serious/ (fatal + serious)
Head on	AB, B	0.25	0.75
Hit object	E	0.06	0.94
Lost control off road	AD, CB, CC, CO, D	0.16	0.84
Lost control on road	CA	0.20	0.80
Miscellaneous	Q	0.29	0.71
Overtaking	AA, AC, AE-AO, GE	0.08	0.92
Pedestrian	N, P	0.11	0.89
Rear end, crossing	FB, FC, GD	0.12	0.88
Rear end, queuing	FD, FE, FF, FO	0.04	0.96
Rear end, slow vehicle	FA, GA-GC, GO	0.12	0.88
Crossing, direct	H	0.13	0.87
Crossing, turning	J, K, L, M	0.07	0.93
All movements		0.14	0.86

Table A25: Ratio of fatal to serious crash severities by movement for 80–110km/h speed limit areas

Movement category	CAS movement codes	Fatal/ (fatal + serious)	Serious/ (fatal + serious)
Head on	AB, B	0.35	0.65
Hit object	E	0.12	0.88
Lost control off road	AD, CB, CC, CO, D	0.14	0.86
Lost control on road	CA	0.08	0.92
Miscellaneous	Q	0.22	0.78
Overtaking	AA, AC, AE-AO, GE	0.11	0.89
Pedestrian	N, P	0.37	0.63
Rear end, crossing	FB, FC, GD	0.12	0.88
Rear end, queuing	FD, FE, FF, FO	0.06	0.94
Rear end, slow vehicle	FA, GA-GC, GO	0.14	0.86
Crossing, direct	H	0.19	0.81
Crossing, turning	J,K,L,M	0.13	0.87
All movements		0.18	0.82

Table A26: Factors for converting from reported injury crashes to total injury crashes

Speed-limit area	Injured person category	Fatal	Serious	Minor
50–70km/h speed limit areas	Pedestrian	1.0	1.5	4.5
	Other			2.8
80–100km/h speed limit areas (excluding motorways)	Pedestrian	1.0	1.9	7.5
	Other			4.5
Remote rural 100km/h speed limit areas	Pedestrian	1.0	2.3	13.0
	Other			7.5
Motorways	All	1.0	1.9	1.9
All speed limit areas combined	All	1.0	1.7	3.6

Table A27: Factor for converting from reported non-injury crashes to total non-injury crashes

Speed-limit area	Urban areas	Rural areas	Motorways
All movements	7	18.5	7

Table A28: Cost per crash by movement and vehicle involvement for fatal injury crashes in 30–50km/h speed limit areas

30–50km/h speed limit area fatal injury crashes		Total cost per crash by vehicle type ($M July 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van, other	All vehicles
Head on	AB, B	12.6	12.6	15.9	15.9	14.1	14.2
Hit object	E	12.5	12.5	12.9	12.9	13.1	13.0
Lost control off road	AD, CB, CC, CO, D	12.5	13.1	13.5	13.5	13.5	13.5
Lost control on road	CA	12.5	12.5	14.7	14.7	12.5	12.7
Miscellaneous	Q	12.5	12.6	13.3	13.2	12.9	12.9
Overtaking	AA, AC, AE-AO, GE	12.5	12.5	13.3	12.5	12.8	12.8
Pedestrian	N, P	12.6	12.6	14.3	12.5	12.7	12.7
Rear end, crossing	FB, FC, GD	12.5	12.6	12.5	12.5	12.6	12.6
Rear end, queuing	FD, FE, FF, FO	12.5	12.5	12.7	12.6	12.5	12.5
Rear end, slow vehicle	FA, GA-GC, GO	12.5	12.5	12.7	12.5	12.6	12.6
Crossing, direct	H	12.5	12.8	12.9	12.9	13.1	13.1
Crossing, turning	J, K, L, M	12.5	12.5	12.5	12.5	12.5	12.5
All movements		12.5	12.6	13.3	13.2	12.9	12.9

Table A29: Cost per crash by movement and vehicle involvement for serious injury crashes in 30–50km/h speed limit areas

30–50km/h speed limit areas serious injury crashes		Total cost per crash by vehicle type ($'000 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van and other	All vehicles
Head on	AB, B	660	690	880	880	930	910
Hit object	E	660	710	900	780	710	720
Lost control off road	AD, CB, CC, CO, D	660	680	810	770	770	760
Lost control on road	CA	660	680	760	760	790	780
Miscellaneous	Q	670	690	810	760	780	770
Overtaking	AA, AC, AE-AO, GE	650	650	880	880	810	800
Pedestrian	N, P	690	780	730	730	700	710
Rear end, crossing	FB, FC, GD	660	670	690	680	830	800
Rear end, queuing	FD, FE, FF, FO	660	670	740	700	730	720
Rear end, slow vehicle	FA, GA-GC, GO	660	690	810	680	770	760
Crossing, direct	H	680	680	990	800	780	780
Crossing, turning	J, K, L, M	670	670	800	680	760	750
All movements		670	690	810	760	780	770

Table A30: Cost per crash by movement and vehicle involvement for minor injury crashes in 30–50km/h speed limit areas

30–50km/h speed limit areas minor injury crashes		Total cost per crash by vehicle type ($'000 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van and other	All vehicles
Head on	AB, B	68	72	82	82	104	100
Hit object	E	68	68	84	79	75	75
Lost control off road	AD, CB, CC, CO, D	69	69	87	75	79	78
Lost control on road	CA	68	69	78	78	71	71
Miscellaneous	Q	71	73	86	79	84	83
Overtaking	AA, AC, AE-AO, GE	71	72	81	77	83	82
Pedestrian	N, P	78	98	70	70	72	73
Rear end, crossing	FB, FC, GD	70	70	87	87	85	84
Rear end, queuing	FD, FE, FF, FO	69	69	89	81	86	84
Rear end, slow vehicle	FA, GA-GC, GO	70	71	103	80	84	83
Crossing, direct	H	70	74	102	88	91	90
Crossing, turning	J, K, L, M	70	71	87	76	88	86
All movements		71	73	86	79	84	83

Table A31: Cost per crash by movement and vehicle involvement for non-injury crashes in 30–50km/h speed limit areas

30–50km/h speed limit areas non-injury crashes		Total cost per crash by vehicle type ($'000 July 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van, other	All vehicles
Head on	AB, B	1	2	9	9	3	4
Hit object	E	1	2	9	9	3	4
Lost control off road	AD, CB, CC, CO, D	1	2	8	8	2	2
Lost control on road	CA	1	2	8	8	2	2
Miscellaneous	Q	1	2	8	8	2	4
Overtaking	AA, AC, AE-AO, GE	2	2	9	9	3	4
Pedestrian	N, P	1	2	7	7	2	2
Rear end, crossing	FB, FC, GD	2	2	9	9	3	3
Rear end, queuing	FD, FE, FF, FO	2	2	9	9	3	3
Rear end, slow vehicle	FA, GA-GC, GO	2	2	9	9	3	4
Crossing, direct	H	1	2	9	9	3	3
Crossing, turning	J, K, L, M	1	2	9	9	3	3
All movements		2	2	9	9	3	3

Table A32: Cost per crash by movement and vehicle involvement for fatal injury crashes in 80–110km/h speed limit areas

80–110km/h speed limit areas fatal injury crashes		Total cost per crash by vehicle type ($M 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van and other	All vehicles
Head on	AB, B	13.2	13.2	15.9	15.9	17.5	17.0
Hit object	E	12.5	12.5	12.8	12.8	19.0	18.0
Lost control off road	AD, CB, CC, CO, D	12.5	12.5	23.9	12.6	13.8	13.8
Lost control on road	CA	12.5	12.5	14.8	14.5	14.5	14.4
Miscellaneous	Q	12.8	13.0	15.6	15.6	14.5	14.5
Overtaking	AA, AC, AE-AO, GE	12.5	14.1	16.1	13.2	13.0	13.1
Pedestrian	N, P	12.6	14.5	12.5	12.5	12.9	12.9
Rear end, crossing	FB, FC, GD	12.5	12.5	15.0	12.9	12.8	12.8
Rear end, queuing	FD, FE, FF, FO	12.5	12.6	25.7	25.7	13.3	14.4
Rear end, slow vehicle	FA, GA-GC, GO	12.5	12.5	13.6	12.9	12.9	12.9
Crossing, direct	H	12.5	12.7	23.9	23.9	15.3	15.9
Crossing, turning	J, K, L, M	12.5	13.2	14.3	14.3	14.8	14.6
All movements		12.8	13.0	15.6	15.6	14.5	14.5

Table A33: Cost per crash by movement and vehicle involvement for serious injury crashes in 80–110km/h speed limit areas

80–110km/h speed limit areas serious injury crashes		Total cost per crash by vehicle type ($'000 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van and other	All vehicles
Head on	AB, B	720	720	1,170	810	1,120	1,070
Hit object	E	660	660	690	690	740	730
Lost control off road	AD, CB, CC, CO, D	660	680	1,370	680	780	780
Lost control on road	CA	720	720	830	830	810	800
Miscellaneous	Q	720	720	950	820	840	830
Overtaking	AA, AC, AE-AO, GE	690	690	860	860	860	840
Pedestrian	N, P	690	820	830	750	710	720
Rear end, crossing	FB, FC, GD	680	730	920	920	840	830
Rear end, queuing	FD, FE, FF, FO	680	680	880	740	840	820
Rear end, slow vehicle	FA, GA-GC, GO	670	810	1,300	690	810	800
Crossing, direct	H	670	670	1,220	1,220	880	890
Crossing, turning	J, K, L, M	700	700	930	830	910	890
All movements		720	720	950	820	840	830

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Table A34: Cost per crash by movement and vehicle involvement for minor injury crashes in 80–110km/h speed limit areas

80–110km/h speed limit areas minor injury crashes		Total cost per crash by vehicle type ($'000 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van and other	All vehicles
Head on	AB, B	72	77	118	92	112	108
Hit object	E	76	76	99	78	81	81
Lost control off road	AD, CB, CC, CO, D	72	72	130	73	80	80
Lost control on road	CA	74	74	79	78	86	84
Miscellaneous	Q	76	77	103	84	92	90
Overtaking	AA, AC, AE-AO, GE	72	72	87	80	93	90
Pedestrian	N, P	78	87	68	60	75	74
Rear end, crossing	FB, FC, GD	75	77	92	86	97	95
Rear end, queuing	FD, FE, FF, FO	80	80	112	94	91	91
Rear end, slow vehicle	FA, GA-GC, GO	73	81	124	81	94	92
Crossing, direct	H	73	76	112	112	106	104
Crossing, turning	J, K, L, M	71	71	125	88	103	100
All movements		76	77	103	84	92	90

Table A35: Cost per crash by movement and vehicle involvement for non-injury crashes in 80–110km/h speed limit areas

80–110km/h speed limit areas non-injury crashes		Total cost per crash by vehicle type ($'000 July 2021)					
Movement category	CAS movement codes	Cycle	Motorcycle	Bus	Truck	Car, van, other	All vehicles
Head on	AB, B	2	2	11	11	4	5
Hit object	E	2	2	10	10	3	4
Lost control off road	AD, CB, CC, CO, D	2	2	9	9	2	2
Lost control on road	CA	2	2	10	10	3	4
Miscellaneous	Q	2	2	10	10	2	6
Overtaking	AA, AC, AE-AO, GE	2	2	11	11	4	6
Pedestrian	N, P	2	2	10	10	2	4
Rear end, crossing	FB, FC, GD	2	2	11	11	4	4
Rear end, queuing	FD, FE, FF, FO	2	3	11	11	4	4
Rear end, slow vehicle	FA, GA-GC, GO	2	2	11	11	4	5
Crossing, direct	H	2	2	11	11	4	5
Crossing, turning	J, K, L, M	2	2	11	11	4	5
All movements		2	2	11	11	3	4

Table A36: Cost per crash

Crash site/type	Cost per crash by speed limit area ($000 July 2021)		
	30–50km/h	60–70km/h	80–110km/h
Mid-block	554	1,036	1,437
Intersection crashes:			
Uncontrolled T	520	676	1,252
Roundabout	420	445	667
Priority T & Y	514	689	1,373
Priority X	469	623	1,532
Signalised T, Y	518	759	1,659
Signalised X	451	662	977
All other sites	503	745	1,181

Table A37: Cost per crash for specific sites

Crash site/type	Cost per crash by speed limit area ($000 July 2021)		
	30–50km/h	60–70km/h	80–110km/h
Motorway crashes	N/A	N/A	495
Rural railway crossing crashes	N/A	N/A	3,375
Rural bridge crashes	N/A	N/A	1,835

Table A38: Cost per crash by mode

Crash site/type	Cost per crash by speed limit area ($000 July 2021)		
	30–50km/h	60–70km/h	80–110km/h
Heavy vehicle crashes	767	1,259	2,397
Cycle crashes	427	745	1,544
Pedestrian crashes	786	1,482	3,878

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Table A39: Ratio of fatal and serious/all injury by crash type by ONF category and by alignment for reported crashes in 80–110km/h speed limit areas

80km/h and above		Movement category												
One Network Framework	Alignment	Head on	Hit object	Lost control off road	Lost control on road	Miscellaneous	Overtaking	Pedestrian	Rear end, crossing	Rear end, queuing	Rear end, slow vehicle	Crossing, direct	Crossing, turning	All movements
Urban streets*	80km/h and above speed limits are not appropriate for these ONF categories													
Local streets														
Urban connectors														
Transit corridors	Straight and curved	0.18	0.18	0.18	0.18	0.23	0.18	0.73	0.18	0.18	0.18	0.17	0.17	0.23
	Winding and tortuous	0.18	0.18	0.18	0.18	0.23	0.18	0.73	0.18	0.18	0.18	0.17	0.17	0.23
Peri-urban roads	Straight and curved	0.53	0.38	0.18	0.18	0.27	0.38	0.56	0.14	0.14	0.14	0.18	0.18	0.27
	Winding and tortuous	0.41	0.32	0.18	0.18	0.25	0.32	0.56	0.14	0.14	0.14	0.18	0.18	0.25
Interregional connectors	Straight and curved	0.39	0.39	0.20	0.20	0.28	0.39	0.63	0.15	0.15	0.15	0.23	0.23	0.28
	Winding and tortuous	0.56	0.56	0.21	0.21	0.33	0.56	0.63	0.15	0.15	0.15	0.23	0.23	0.33
Rural connectors	Straight and curved	0.33	0.24	0.23	0.23	0.26	0.24	0.51	0.18	0.18	0.18	0.26	0.26	0.26
	Winding and tortuous	0.49	0.23	0.23	0.23	0.27	0.23	0.51	0.23	0.23	0.23	0.19	0.19	0.27
Rural roads	Straight and curved	0.34	0.43	0.26	0.26	0.32	0.43	0.55	0.23	0.23	0.23	0.29	0.29	0.32
	Winding and tortuous	0.38	0.40	0.28	0.28	0.32	0.40	0.55	0.25	0.25	0.25	0.24	0.24	0.32
Stopping places	Straight and curved	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	Winding and tortuous	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
All	Straight and curved	0.33	0.31	0.22	0.22	0.27	0.31	0.54	0.19	0.19	0.19	0.23	0.23	0.27
	Winding and tortuous	0.38	0.32	0.22	0.22	0.27	0.32	0.54	0.20	0.20	0.20	0.21	0.21	0.27

*Urban streets are civic spaces, city hubs, main streets and activity streets

Generally, 98% of urban and local streets have a speed limit of 50km/h or lower. For urban streets that do not conform, either use the corresponding speed table or revise the ONF to the most applicable classification.

Table A40: Ratio of fatal and serious/all injury by crash type by ONF category and by alignment for reported crashes in 60–70km/h speed limit areas

60–70km/h		Movement category												
One Network Framework	Alignment	Head on	Hit object	Lost control off road	Lost control on road	Miscellaneous	Overtaking	Pedestrian	Rear end, crossing	Rear end, queuing	Rear end, slow vehicle	Crossing, direct	Crossing, turning	All movements
Urban streets*	60 to 70km/h speed limits are not appropriate for these ONF categories													
Local streets														
Urban connectors	Straight and curved	0.26	0.26	0.26	0.26	0.19	0.26	0.38	0.07	0.07	0.07	0.14	0.14	0.19
	Winding and tortuous	0.26	0.26	0.26	0.26	0.19	0.26	0.38	0.07	0.07	0.07	0.14	0.14	0.19
Transit corridors	Straight and curved	0.17	0.17	0.14	0.14	0.17	0.17	0.50	0.12	0.12	0.12	0.12	0.12	0.17
	Winding and tortuous	0.17	0.17	0.14	0.14	0.17	0.17	0.50	0.12	0.12	0.12	0.12	0.12	0.17
Peri-urban roads	Straight and curved	0.24	0.24	0.20	0.20	0.20	0.24	0.42	0.10	0.10	0.10	0.16	0.16	0.20
	Winding and tortuous	0.31	0.27	0.16	0.16	0.20	0.27	0.42	0.10	0.10	0.10	0.16	0.16	0.20
Interregional connectors	Straight and curved	0.39	0.39	0.19	0.19	0.27	0.39	0.63	0.15	0.15	0.15	0.17	0.17	0.27
	Winding and tortuous	0.39	0.39	0.26	0.26	0.28	0.39	0.63	0.15	0.15	0.15	0.17	0.17	0.28
Rural connectors	Straight and curved	0.26	0.26	0.23	0.23	0.24	0.26	0.51	0.18	0.18	0.18	0.18	0.18	0.24
	Winding and tortuous	0.29	0.29	0.22	0.22	0.26	0.29	0.51	0.23	0.23	0.23	0.18	0.18	0.26
Rural roads	Straight and curved	0.23	0.23	0.24	0.24	0.27	0.23	0.55	0.23	0.23	0.23	0.29	0.29	0.27
	Winding and tortuous	0.23	0.23	0.21	0.21	0.26	0.23	0.55	0.25	0.25	0.25	0.24	0.24	0.26
Stopping places	Straight and curved	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	Winding and tortuous	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
All	Straight and curved	0.26	0.26	0.21	0.21	0.23	0.26	0.47	0.17	0.17	0.17	0.18	0.19	0.23
	Winding and tortuous	0.29	0.28	0.23	0.23	0.24	0.28	0.45	0.17	0.17	0.17	0.19	0.19	0.24

*Urban streets are civic spaces, city hubs, main streets and activity streets

Generally, 98% of urban and local streets have a speed limit of 50km/h or lower. For urban streets that do not conform, either use the corresponding speed table or revise the ONF to the most applicable classification.

Table A41: Ratio of fatal and serious/all injury by crash type by ONF category and by alignment for reported crashes in 30–50km/h speed limit areas

30–50km/h		Movement category												
One Network Framework	Alignment	Head on	Hit object	Lost control off road	Lost control on road	Miscellaneous	Overtaking	Pedestrian	Rear end, crossing	Rear end, queuing	Rear end, slow vehicle	Crossing, direct	Crossing, turning	All movements
Urban streets*	Straight and curved	0.13	0.13	0.19	0.19	0.14	0.13	0.25	0.08	0.08	0.08	0.11	0.11	0.14
	Winding and tortuous	0.13	0.13	0.19	0.19	0.14	0.13	0.25	0.08	0.08	0.08	0.11	0.11	0.14
Local streets	Straight and curved	0.12	0.12	0.19	0.19	0.13	0.12	0.25	0.08	0.08	0.08	0.11	0.11	0.13
	Winding and tortuous	0.12	0.12	0.19	0.19	0.13	0.12	0.25	0.08	0.08	0.08	0.11	0.11	0.13
Urban connectors	Straight and curved	0.16	0.16	0.17	0.17	0.14	0.16	0.27	0.07	0.07	0.07	0.12	0.12	0.14
	Winding and tortuous	0.18	0.18	0.17	0.17	0.15	0.18	0.27	0.07	0.07	0.07	0.16	0.16	0.15
Transit corridors	Straight and curved	0.17	0.17	0.10	0.10	0.12	0.17	0.27	0.05	0.05	0.05	0.08	0.08	0.12
	Winding and tortuous	0.17	0.17	0.10	0.10	0.12	0.17	0.27	0.05	0.05	0.05	0.08	0.08	0.12
Peri-urban roads	Straight and curved	0.21	0.21	0.22	0.22	0.17	0.21	0.27	0.07	0.07	0.07	0.18	0.18	0.17
	Winding and tortuous	0.21	0.21	0.13	0.13	0.16	0.21	0.27	0.07	0.07	0.07	0.18	0.18	0.16
Interregional connectors	30–50km/h speed limits are not appropriate for these ONF categories													
Rural connectors														
Rural roads														
Stopping places														
All	Straight and curved	0.16	0.16	0.17	0.17	0.14	0.16	0.26	0.07	0.07	0.07	0.12	0.12	0.14
	Winding and tortuous	0.16	0.16	0.15	0.15	0.14	0.16	0.26	0.07	0.07	0.07	0.13	0.13	0.14

*Urban streets are civic spaces, city hubs, main streets and activity streets

#Generally, transit corridors should not be coded with a speed limit of 50km/h or lower. It is recommended that the ONF classification is reconsidered prior to determining the appropriate crash ratio. Please refer to https://www.nzta.govt.nz/assets/Roads-and-Rail/onf/docs/onf-street-categories-2022.pdf for ONF definitions. Alternatively use the most appropriate speed limit table (Table 43 or Table 44). If there are any stopping places in 30–50km/h speed limit areas, use the values for stopping places from the 60–70km/h table.

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Table A42: Ratio of fatal and serious/all injury by crash type by ONF category for reported crashes in 80–110km/h speed limit areas

Movement category	Urban streets*	Local streets	Urban connectors	Transit corridors	Peri-urban roads	Interregional connectors	Rural connectors	Rural roads	Stopping places	All
Head on			0.18	0.47	0.48	0.41	0.36	0.24	0.36	0.18
Hit object			0.18	0.35	0.48	0.23	0.41	0.24	0.32	0.18
Lost control off road			0.18	0.18	0.21	0.23	0.27	0.24	0.22	0.18
Lost control on road			0.18	0.18	0.21	0.23	0.27	0.24	0.22	0.18
Miscellaneous			0.23	0.26	0.31	0.26	0.32	0.24	0.27	0.23
Overtaking			0.18	0.35	0.48	0.23	0.41	0.24	0.32	0.18
Pedestrian	60–70km/h speed limits are not appropriate for these ONF categories#		0.73	0.56	0.63	0.51	0.55	0.24	0.54	0.73
Rear end, crossing			0.18	0.14	0.15	0.20	0.24	0.24	0.19	0.18
Rear end, queuing			0.18	0.14	0.15	0.20	0.24	0.24	0.19	0.18
Rear end, slow vehicle			0.18	0.14	0.15	0.20	0.24	0.24	0.19	0.18
Crossing, direct			0.17	0.18	0.23	0.22	0.26	0.24	0.22	0.17
Crossing, turning			0.17	0.18	0.23	0.22	0.26	0.24	0.22	0.17
All movements			0.23	0.26	0.31	0.26	0.32	0.24	0.27	0.23

*Urban streets are civic spaces, city hubs, main streets and activity streets.

The majority of urban and local streets have a speed limit of 50km/h or lower. For urban streets that do not conform, either use the corresponding speed limit table or revise the ONF category to the most applicable classification.

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Table A43: Ratio of fatal and serious/all injury by crash type by ONF category for reported crashes for 60–70km/h speed limit areas

Movement category	Urban streets*	Local streets	Urban connectors	Transit corridors	Peri-urban roads	Interregional connectors	Rural connectors	Rural roads	Stopping places	All
Head on	60–70km/h speed limits are not appropriate for these ONF categories#		0.26	0.17	0.28	0.39	0.27	0.23	0.24	0.27
Hit object			0.26	0.17	0.25	0.39	0.27	0.23	0.24	0.27
Lost control off road			0.26	0.14	0.18	0.22	0.23	0.23	0.24	0.22
Lost control on road			0.26	0.14	0.18	0.22	0.23	0.23	0.24	0.22
Miscellaneous			0.19	0.17	0.20	0.28	0.25	0.27	0.24	0.24
Overtaking			0.26	0.17	0.25	0.39	0.27	0.23	0.24	0.27
Pedestrian			0.38	0.50	0.42	0.63	0.51	0.55	0.24	0.46
Rear end, crossing			0.07	0.12	0.10	0.15	0.20	0.24	0.24	0.17
Rear end, queuing			0.07	0.12	0.10	0.15	0.20	0.24	0.24	0.17
Rear end, slow vehicle			0.07	0.12	0.10	0.15	0.20	0.24	0.24	0.17
Crossing, direct			0.14	0.12	0.16	0.17	0.18	0.26	0.24	0.19
Crossing, turning			0.14	0.12	0.16	0.17	0.18	0.26	0.24	0.19
All movements			0.19	0.17	0.20	0.28	0.25	0.27	0.24	0.24

*Urban streets are civic spaces, city hubs, main streets and activity streets.

The majority of urban and local streets have a speed limit of 50km/h or lower. For urban streets that do not conform, either use the corresponding speed limit table or revise the ONF category to the most applicable classification.

Table A44: Ratio of fatal and serious/all injury by crash type by ONF category for reported crashes for 30–50km/h speed limit areas

Movement category	Urban streets*	Local streets	Urban connectors	Transit corridors#	Peri-urban roads	Interregional connectors	Rural connectors	Rural roads	Stopping places	All
Head on	0.16	0.16	0.21	0.17	0.12	30–50km/h speed limits are not appropriate for these ONF categories				0.16
Hit object	0.16	0.10	0.11	0.17	0.12					0.13
Lost control off road	0.18	0.18	0.18	0.10	0.22					0.17
Lost control on road	0.25	0.37	0.25	0.10	0.22					0.24
Miscellaneous	0.17	0.18	0.17	0.13	0.22					0.17
Overtaking	0.16	0.20	0.19	0.17	0.12					0.17
Pedestrian	0.25	0.26	0.28	0.27	0.33					0.28
Rear end, crossing	0.08	0.13	0.04	0.03	0.14					0.09
Rear end, queuing	0.04	0.13	0.05	0.03	0.14					0.08
Rear end, slow vehicle	0.17	0.13	0.13	0.03	0.14					0.12
Crossing, direct	0.10	0.09	0.11	0.08	0.23					0.12
Crossing, turning	0.12	0.13	0.13	0.08	0.23					0.14
All movements	0.15	0.17	0.15	0.09	0.21					0.16

* Urban streets are civic spaces, city hubs, main streets and activity streets.

Generally, transit corridors should not be coded with a speed limit of 50km/h or lower. It is recommended that the ONF classification is reconsidered prior to determining the appropriate crash ratio. Please refer to https://www.nzta.govt.nz/assets/Roads-and-Rail/onf/docs/onf-street-categories-2022.pdf for ONF definitions. Alternatively use the most appropriate speed limit table (Table 43 or Table 44).

If there are any stopping places in 30–50km/h speed limit areas, use the values for stopping places from the 60–70km/h table.

Definitions

Regression to the mean

For the purpose of crash analysis, generally a minimum of the past five years 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.

Defining crashes by 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'.

Dispersion parameter

'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 provided in the *Crash estimation compendium*.

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.

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 an 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
- minor improvement works.

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 an 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 an 80km/h and above area. Crashes at minor intersections are sometimes included.
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 3000 or more. Other rural sites are considered to be 'near rural'.
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.
Site	A site is the specific road infrastructure for which an analysis 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 the analysis.
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)** The crash rate for a specific site based on reported injury crashes on the record of TCRs prepared by the police and compiled by NZTA (normally five years of data). These are available from CAS. **Typical crash rate (A_T)** 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 rate or a crash prediction model from the *Crash estimation compendium*, 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.

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Appendix 3: Traffic data and travel time estimation

This appendix begins by defining standard values for traffic composition (based on the vehicle classes), vehicle occupancy and trip purpose. Guidance is also provided on measuring and estimating traffic volumes, traffic growth and speed.

The traffic data generated by these methods can be used:

- in the procedures for estimating travel time
- in the absence of measured data, or
- in the absence of data from calibrated and validated transportation models.

Following the traffic data methods, procedures for estimating travel time are detailed.

The travel time estimation procedures 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, though more precise methods are not precluded. 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.

When a transportation model is used for activity analysis, the model shall have been satisfactorily validated on both traffic volumes and travel times It is necessary that the travel times used by a model to derive the flows must be consistent with the travel times estimated by the procedures. 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.

Traffic composition

Vehicle classes

The definitions for vehicle classes are provided in Table A45.

Table A45: 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 (HCVI)	Rigid trucks with or without a trailer, or articulated vehicle with three or four axles in total
Heavy commercial vehicle II (HCVII)	Trucks and trailers and articulated vehicles with or without trailers with five or more axles in total
Buses	Buses, excluding minibuses

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Road categories

Road categories for the traffic data classifications in this appendix are provided in Table A46.

Table A46: Road categories

Road categories	Definition
Urban arterial	Arterial and collector roads within urban areas carrying traffic volumes of greater than 7000 vehicles/day
Urban other	Other urban roads, carrying fewer than 7000 vehicles/day
Rural strategic	Arterial or collector roads, connecting main centres of population and carrying over 2500 vehicles/day
Rural other	Other roads outside urban areas

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Standard traffic composition

Table A47 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.

Table A47: Traffic composition (%)

Road category and time period	Traffic composition by vehicle class (%)				
	Car	LCV	MCV	HCVI	HCVII
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

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.

Separating an activity into its component sections

Follow the steps below to separate the activity into its component sections.

Table A48: Steps to separate an activity into its component sections

Step	Action
1	Separate the activity into: • motorway sections • multi-lane roads • two-lane rural roads • other urban roads • signalised intersections • priority intersections • roundabouts.
2	Identify any bottleneck locations

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 multi-lane roads

Each motorway section or multi-lane 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.

Dividing the year into time periods

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.

The default weekday time periods are:

- morning commuter peak (0700–0900)
- daytime interpeak (0900–1600)
- evening commuter peak (1600–1800)
- evening/night-time (1800–0700).

Saturdays and Sundays do not usually need to be divided into time periods unless there are substantial demands.

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Procedure

Follow the steps below to divide the year into time periods.

Table A49: Steps to divide the year into time periods

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td>1</td><td colspan="2">Divide the year into the days specified above</td></tr>
<tr><td rowspan="4">2</td><td colspan="2">Divide each day type into time periods as follows:</td></tr>
<tr><td>If there…</td><td>Then…</td></tr>
<tr><td>are only very low levels of vehicle interaction throughout any day</td><td>no division of the day is necessary.</td></tr>
<tr><td>are significant levels of vehicle interaction</td><td>divide each day into a number of time periods to allow analysis at different flow levels, so 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.</td></tr>
</table>

Vehicle occupancy and travel purpose

Standard vehicle occupancy and travel purpose figures are provided in Table A50. 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 A50 will be required in most cases. At present there is no accepted method for 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 A50 have been derived from the New Zealand Household Travel Survey.

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Table A50: 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 interpeak	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

Traffic volumes are generally expressed in terms of annual average daily traffic (AADT), annual 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:

- *Guide to estimating AADT and traffic growth* (Transit NZ 1994)
- *Guide to estimation and monitoring of traffic counting and traffic growth* (Traffic Design Group 2001).

General information and background on demand estimation and forecasting can be found in Chapter 2: Demand estimation and mode share. Information on transport model availability in New Zealand and high level background on model capability can be found in section 2.10. Wherever properly calibrated/validated transportation models are available in a study area, they should generally be used to assess the effects of the activity on traffic volumes and predict future traffic volumes.

As well as the normal calibration/validation required to ensure that the models are operating satisfactorily, they should also be calibrated/validated in the local area containing the activity. See the *Transport model development guidelines* (NZ Transport Agency 2019), and particularly reference to model type D: Transport Agency scheme assessment/project evaluation, which outlines calibration/validation principles within the area of influence/focus for an assessment of an activity.

For background on when differences between the do-minimum and activity demands may occur, see section 2.13: Fixed trip matrix and variable trip matrix assessments and for procedures for developing demands and applying fixed trip matrix and variable trip matrix techniques see Fixed trip matrices and Variable trip matrices in Appendix 1.

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 *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 volumes

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 *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, 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.

Axel pair adjustment factors

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 vehicles, multiply by the appropriate factor.

Table A51: Axle pair adjustment factors

Road category	Axle pair adjustment factor
Urban	0.91
Rural	0.83

Traffic growth rates

Guidance for developing growth rates using trend analysis can be found in Travel volume growth trend analysis in Appendix 1. Traffic growth rates shall be arithmetic growth rates (not geometric growth rates, which compound year-on-year) and expressed as a percentage of the predicted traffic volume at the 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 future traffic volume influences described below.

Future traffic volumes

In predicting future traffic volumes, normal traffic growth, diverted traffic, generated and redistributed traffic shall be taken into account. More information on developing demand forecasts can be found in Chapter 2: Demand estimation and mode share. This includes background on the equilibrium of demand and supply, factors and considerations influencing demand estimation, and information on forecast horizons and uncertainty.

Normal traffic growth

Traffic growth, either developed from transport models or from procedures and processes described in this manual (for example, facility use, trend analysis, and trip generation methods) can be considered normal when the estimated demand does not result in excessive or an unrealistically long time spent in stationary queues (for further background, see Equilibrium of transport demand and supply). Provided estimates are robust , localised effects are accounted for (for example, localised land use development, and transport supply change), and other checks are carried out (see Sense checking forecasts), normal traffic growth is likely to be considered to provide a sound basis for predicting future traffic demands.

Re-assigned traffic

A re-assigned trip is a trip travelling from A to B in the same period and by the same mode that takes a different route to get there. Re-assigned traffic to or from the route(s) served by the activity, nearby and surrounding the activity, occurs when:

- traffic re-routes from another route because the activity (or another activity on the route) now makes this a more attractive route
- traffic re-routes to another route because an activity on that route now makes it a more attractive route
- delays/changes to the user travel cost at the activity site or elsewhere on the route cause traffic to re-route to other routes
- delays/changes to the user travel cost on other routes cause traffic to re-route to the route
- estimated changes in travel demands in the future affect one, or several, of the elements above.

These effects shall be taken into account in estimating future traffic volumes. Typically, when re-routeing traffic is, or has the potential to be, an issue, traffic models are applied. As described in section 2.13: Fixed trip matrix and variable trip matrix assessments, re-assigned trips should not result in a difference in the OD demands matrices used in the do-minimum and activity scenarios, and as such the study area for the transport model would need to cover any potential significant re-assignment changes from the effects described in the bullet points above.

Induced demand, redistributed trips, mode-shifted trips, or macro-time shifted trips

Activities that reduce the cost of travel can induce new trips, redistribute trips, result in a change of travel mode, or macro-time shift trips from one discrete time period to another. See section 2.13: Fixed trip matrix and variable trip matrix assessments. In cases where these potential effects are expected to significantly affect the analysis, then a variable matrix approach should be adopted (see Variable trip matrices in Appendix 1).

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 plate survey methods measure the average travel time over a length of road.

The floating car survey method is a 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 the 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 so 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 is spot speed measurement
N is total number of spot speed measurements

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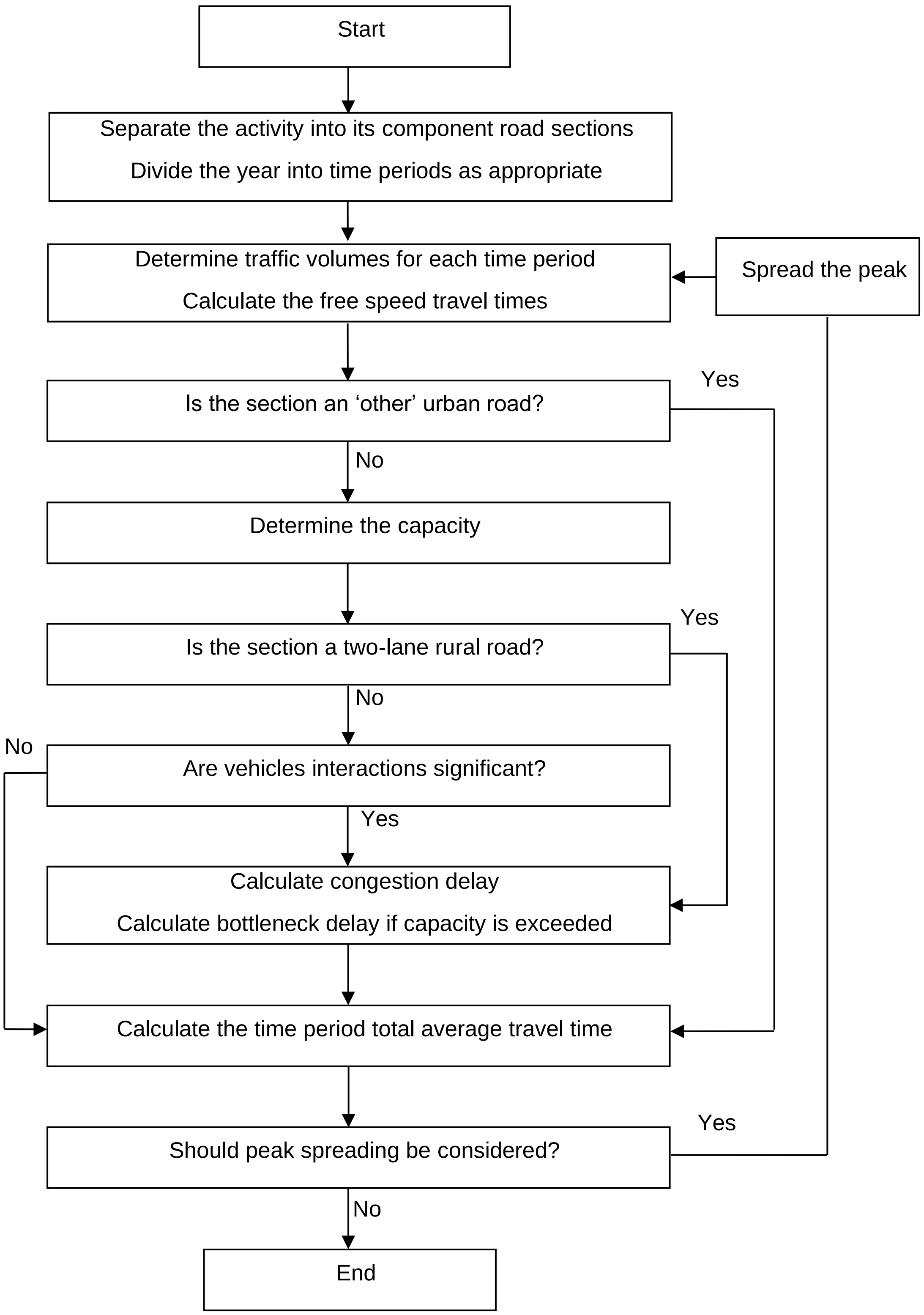
The stages for estimating travel time

The flow chart below shows the basic stages for estimating road section travel time (the stages are slightly different for intersections).

Figure A26: Stages for estimating road section travel time



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Determining traffic volumes

This procedure details the base and future year traffic volumes that need to be determined for estimating travel times.

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) has insufficient capacity to meet unrestrained travel demands and/or because of high level of forecast future demand.

In some cases, variable matrix methods may be needed to estimate the do-minimum and activity option matrices (Variable trip matrices in Appendix 1).

The base traffic volumes are the traffic volumes at the point-in-time closest to time zero. It is noted that in many cases time zero values may not be explicitly estimated and provided, for example, when the transport model used for the assessment has been calibrated/validated to a year which is several years earlier than time zero. The base traffic volumes are from:

- a recent census year, or near-future forecast year, for which travel demand estimates exist
- a year at which the transport model has been calibrated/validated to
- a year at which robust traffic count data exists.

Procedure
Follow the steps below to determine traffic volumes.

Table A52: Steps to determine traffic volumes

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>Determine the base traffic volumes for each section using the procedure outlined previously in this appendix, or by means of a transportation model.</td></tr>
<tr><td>2</td><td>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 should not result in excessive or an unrealistically long time spent in stationary queues (for further background, see Equilibrium of transport demand and supply).</td></tr>
<tr><td>3</td><td>Judge whether future year capacity problems occur.

Note: This step requires an estimate of the capacity that is not determined until Determining the capacity of road sections. A first iteration of this whole procedure may be used before judging whether this step is relevant.
<table>
<tr><th>If there …</th><th>Then …</th></tr>
<tr><td>is sufficient capacity for future year traffic volumes in the do-minimum and activity option</td><td>generally apply standard fixed trip matrices and analysis procedures.</td></tr>
<tr><td>are adequate levels of service for future year traffic volumes in the activity option, but not in the do-minimum (depends on local study area context, ranges from level of service E to F through to excessive congestion and long time periods with stationary queues)</td><td>generally improve the capacity of the do-minimum network and/or apply growth constraint techniques to the do-minimum matrix (Fixed trip matrices in Appendix 1).</td></tr>
<tr><td>is high congestion (depends on local study area context, ranges from level of service E to F through to excessive congestion and long time periods with stationary queues) in both the do-minimum and activity options</td><td>consider the use of variable matrix methods, see section 2.13: Fixed trip matrix and variable trip matrix assessments.

For verification purposes, carry out a fixed matrix analysis using growth constraint techniques (Fixed trip matrices in Appendix 1).</td></tr>
</table>
</td></tr>
</table>

Calculating free speed travel time

This procedure may be used for all road section types.

Procedure

Follow the steps below to calculate the free speed travel time.

Table A53: Steps 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 600veh/h/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 …</th></tr>
<tr><td>a motorway section</td><td>105km/h
where design speed >110km/h</td></tr>
<tr><td>a multi-lane road</td><td>Determining the free speed of multi-lane roads.</td></tr>
<tr><td>a two-lane rural road</td><td>Determining the free speed of two-lane rural roads.</td></tr>
<tr><td>other urban road</td><td>Determining the free speed of other rural roads.</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 = 100km/h
Free speed travel time = 60/100
= 0.600 min/km</td></tr>
<tr><td>4</td><td colspan="2">Determine the capacity from Determining the capacity of road sections.

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>

Determining the free speed of multi-lane roads

This procedure is required for analysis of activities to which Table A53 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, and
- density of access points.

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 multi-lane road section.

Table A54: Steps to determine the free speed of a multi-lane road

Step	Action	
1	If measured speeds are not available, then determine the **basic free speed** for the multi-lane road section as follows:	
	If the section has a posted speed limit of …	*Then use a basic free speed of…*
	100km/h	105km/h
	80km/h	90km/h
	70km/h	80km/h
	50km/h	60km/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 3km/h
3	Adjust the basic free speed to account for **lane widths** as follows:	
	If lane widths are…	*Adjustment to basic free speed*
	3.5m or greater	No reduction
	less than 3.5m	Reduce by 3km/h
4	Adjust the basic free speed to account for **lateral clearance** as follows:	
	If the section has lateral clearance of …	*Adjustment to basic free speed*
	3m or greater	No reduction
	less than 3m but at least 2m	Reduce by 2km/h
	less than 2m but at least 1m	Reduce by 4km/h
	less than 1m	Reduce by 9km/h
5	Adjust the basic free speed to account for **density of access points** along the section as follows:	
	If the section has a density of access points per km of …	*Adjustment to basic free speed*
	less than 40	0.4km/h per access point
	40 or more	16km/h

Example calculation

Below is an example calculation for the free speed of a multi-lane road section where measured speeds are not available.

Example:

Posted speed limit	=	70km/h
Median divided	=	yes
Lane width	=	3.5m
Lateral clearance	=	1.0m
Access points density	=	10 per km
Basic free speed	=	80km/h
Dividing median speed reduction	=	0km/h
Lane width speed reduction	=	0km/h
Lateral clearance speed reduction	=	4km/h
Access point speed reduction	=	*10 × 0.4 = 4km/h*
Free speed	=	*80 – 0 – 0 – 4 – 4 = 72km/h*

Determining the free speed of two-lane rural roads

This procedure is required for analysis of activities to which Table A53 applies and should be used if no measured speeds are available.

The procedure adopted in this section provides a realistic but approximate method for assessing travel times. Alternatively, the Transportation Research Board (1994) *Highway capacity manual* (HCM) provides a more detailed methodology for the analysis of local improvements, such as design speed increases, and climbing and passing lanes, and the computer programme TRARR may be used for detailed analyses.

The definition of design speed used in this section is that used by the HCM and the Austroads (1988) *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.

Table A55: Steps to determine the free speed of a two-lane rural road

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 = 0.200km Curve 1 design speed = 80km/h Curve 1 travel time = 0.2/80 × 60 = 0.150 minutes Curve 2 length = 0.150km Curve 2 design speed = 70km/h Curve 2 travel time = 0.15/70 × 60 = 0.129 minutes Curve 3 length = 0.100km Curve 3 design speed = 70km/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 100km/h in severe terrain and a maximum of 120km/h in gentler country (Austroads (1989) *Rural road design*). Example: Tangent length = 0.550km Tangent design speed = 120km/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

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Step	Action		
	Total travel time	= =	0.365 + 0.275 0.640 minutes
6	Calculate the average design speed for the road section. Example: Road section length Total travel time Average design speed	 = = = =	 1km 0.640 minutes 1.000/0.640 × 60 93.75km/h
7	Determine the free speed as follows: *If the average design speed is …* → *Then the free speed is…* above 100km/h → 105km/h below 100km/h → 105km/h minus 13km/h for every 18km/h reduction in design speed below 100km/h Example: Average design speed Free speed	 = = =	 93.75km/h 105 - ([(100 – 93.75) / 18] × 13) 100.5km/h

Determining the free speed of other rural roads

This procedure is required for analysis of activities to which Table A53 applies 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'.

Table A56: Steps 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	Multi-lane divided, undivided or two-lane with shoulders	Multi-lane 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

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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 65km/h	63km/h
	Class II	50 and 60km/h	55km/h
	Class III	45 and 55km/h	50km/h

Determining the capacity of road sections

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.

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 A57: Steps to select the appropriate procedure for determining the capacity of road sections

Step	Action	
1	Select the appropriate procedure for determining the capacity of each road section as follows:	
	If the road section is …	*Then go to …*
	a motorway section	Determining the capacity of motorways
	a multi-lane road	Determining the capacity of multi-lane roads
	a two-lane rural road	Determining the capacity of two-lane rural roads

Step	Action	
	other urban road	Calculating the time period total average travel time It is not necessary to determine capacity for travel time. However, the capacities below are required when determining the additional congestion vehicle operating cost.

Road class	Capacity
Class I	1,200 veh/lane/hour
Class II	900 veh/lane/hour
Class III	600 veh/lane/hour

Step	Action
2	Once the capacity has been determined go to Determining whether vehicle interactions are significant.

Determining the capacity of motorways

Procedure

Follow the steps below to determine the capacity of a motorway section where each direction of travel is a separate motorway section component (see Separating an activity into its component sections). Capacities are expressed as passenger car units (pcu).

Table A58: Steps to determine the capacity of a motorway section with separate motorway components in each direction of travel

Step	Action
1	Determine the basic capacity for the motorway section as follows:

If the road section has ...	*Then use a basic capacity of …*
2 through lanes	4,500 pcu/h
3 through lanes	6,900 pcu/h
4 through lanes	9,600 pcu/h

Step	Action
2	Determine the passenger car equivalent to be used for trucks for the motorway section as follows:

If the terrain type is …	*Then use a passenger car equivalent for trucks (E_t) of …*
level	1.7 pcu
rolling	4.0 pcu
mountainous	8.0 pcu

Step 3: 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

Step 4: Calculate the motorway section capacity by multiplying the basic capacity, determined in step 1, by the adjustment factor for trucks (ft) determined in step 3.

Motorway section capacity	=	basic capacity × ft
Example:		
Through lanes	=	3 lanes
Basic capacity	=	6,900 pcu/h

Step	Action		
	Adjustment factor (ft)	=	0.735
	Motorway section capacity	=	6,900 × 0.735
		=	5,072veh/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.

Determining the capacity of multi-lane roads

Procedure

Follow the steps below to determine the capacity of a multi-lane road.

Table A59: Steps to determine the capacity of a multi-lane road

Step	Action
1	Obtain 'the sum of the basic free speed reductions' for the multi-lane road section, as determined in Table A57. Example: Free speed reductions for: dividing median = 0km/h lane width = 0km/h lateral clearance = 4km/h access points = 4km/h Sum of the basic free speed reductions = 8km/h **Note**: If the free speed for the multi-lane road section was measured rather than estimated, then use step 1 of the procedure in Table A57 to determine the multi-lane 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 multi-lane 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 30km/h	2,200 veh/h per lane minus 10veh/h per lane for every km/h of basic free speed reductions
above 30km/h	1,900 veh/h per lane

Example:

Sum of the basic free speed reductions	=	8km/h
Road section capacity	=	2,200 - 8 × 10
	=	2,120 veh/h per lane

Determining the capacity of two-lane rural roads

The capacity of the road section shall be calculated by adjusting the ideal capacity of 2800veh/h (total in both directions of travel) to account for the following factors:

- directional distribution of traffic during the time period

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- 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.

Table A60: Steps to determine the capacity of a two-lane rural road

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>Determine the adjustment factor for traffic directional distribution during the time period as follows:
<table>
<tr><th>If the directional distribution is …</th><th>Then use an adjustment factor of:</th></tr>
<tr><td>100/0</td><td>0.71</td></tr>
<tr><td>90/10</td><td>0.77</td></tr>
<tr><td>80/20</td><td>0.83</td></tr>
<tr><td>70/30</td><td>0.89</td></tr>
<tr><td>60/40</td><td>0.94</td></tr>
<tr><td>50/50</td><td>1.00</td></tr>
</table></td></tr>
<tr><td>2</td><td>Determine the total roadway width. The total roadway width equals the lane width(s) plus sealed shoulder width. Round to the nearest metre.</td></tr>
<tr><td>3</td><td>With the total roadway width determined in step 2 determine the adjustment factor for trafficable width as follows:
<table>
<tr><th>If the total roadway width is…</th><th>Then use an adjustment factor of:</th></tr>
<tr><td>8m or greater</td><td>1.00</td></tr>
<tr><td>7m</td><td>0.91</td></tr>
<tr><td>6m</td><td>0.82</td></tr>
<tr><td>5m</td><td>0.73</td></tr>
<tr><td>4m</td><td>0.65</td></tr>
<tr><td>less than 4m</td><td>0.60</td></tr>
</table></td></tr>
<tr><td>4</td><td>Determine the passenger car equivalent for trucks for the road section as follows:
<table>
<tr><th>If the terrain type is…</th><th>Then use a passenger car equivalent for trucks (E_t) of:</th></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>
</table></td></tr>
<tr><td>5</td><td>Calculate the adjustment factor for trucks using the passenger car equivalent for trucks (E_t) determined in step 4.

Adjustment factor (f_t) = $1/(1 + Pt \times (E_t - 1))$
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) = $1/[1 + 0.10 \times (5.0 – 1))]$
= 0.714</td></tr>
<tr><td>6</td><td>Calculate the road section capacity by multiplying the ideal two-way capacity of 2,800veh/h by the adjustment factors determined in steps 1, 3 and 5.
Road section capacity = Ideal capacity × adjustment factor for directional distribution × adjustment factor for trafficable width × f_t

Example:
Directional distribution = 70/30
Trafficable width = 7m
Adjustment factors:</td></tr>
</table>

Step	Action		
	directional distribution trafficable width trucks Road section capacity	= = = = =	0.89 0.91 0.714 2,800 × 0.89 × 0.91 × 0.714 1,620 veh/h
7	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 Peak direction capacity	 = = =	 0.7 1,620 × 0.7 1,134 veh/h

Determining whether vehicle interactions are significant

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 A61: Steps to determine whether the effects of vehicle interactions are significant

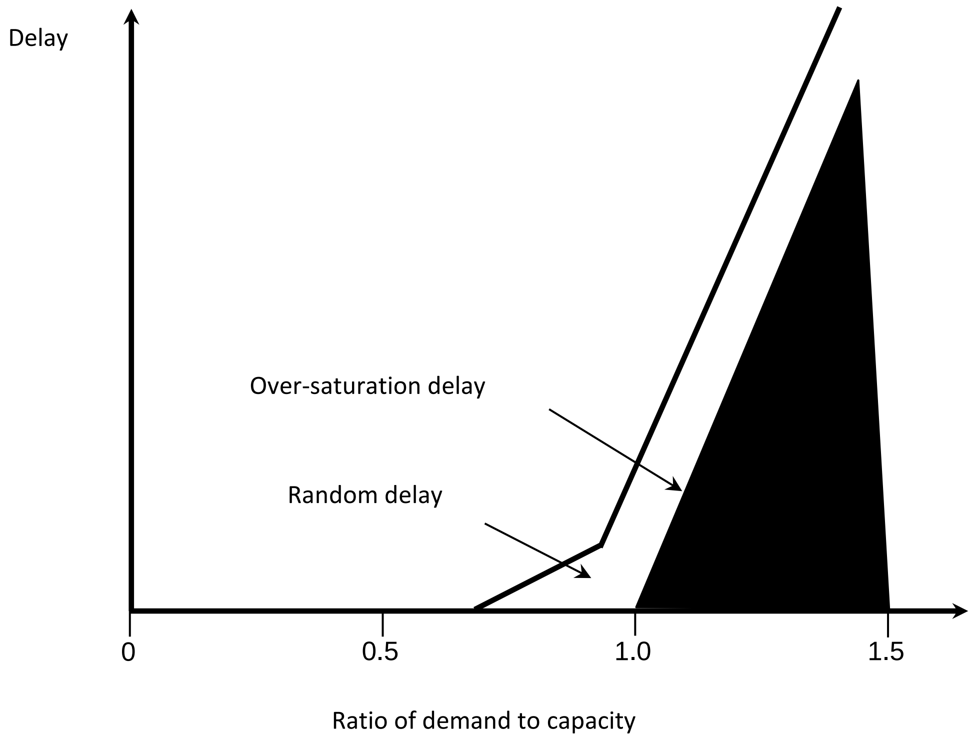
Step	Action		
1	Use the capacity for the road section determined in Table A57.		
2	Take a time period with its corresponding traffic volume (demand) as determined in Table A52.		
3	Calculate the volume to capacity ratio.		
	Example: Time period Time period traffic vol Traffic flow Capacity Volume to capacity ratio	 = = = = = = =	 0700 to 0900 6202 vehicles 6202/2 3101 veh/h 4300 veh/h 3101/4300 0.72
4	Determine whether the effects of vehicle interactions are significant as follows:		
	If the road section is a …	*And the volume to capacity ratio is …*	*Then vehicle interactions …*
	motorway section	greater than 0.7	shall be considered (continue to Types of delays)
	motorway section	0.7 or less	are not considered (go to Table A68)
	multi-lane road	greater than 0.7	shall be considered (continue to Types of delays)
	multi-lane road	0.7 or less	are not considered (go to Table A68)
	two-lane rural road	greater than 0.7	shall be considered (continue to Types of delays)
	two-lane rural road	0.7 or less	are not considered (go to Table A68)
5	Repeat steps 2 to 4 for any other time periods in which traffic volumes are likely to result in significant vehicle interactions.		

Types of delays

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.

The diagram below shows approximately when vehicle interaction (or random) delay and bottleneck (or over-saturation) delay occur.

Figure A27: Vehicle interaction delay and bottleneck delay



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 that 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.

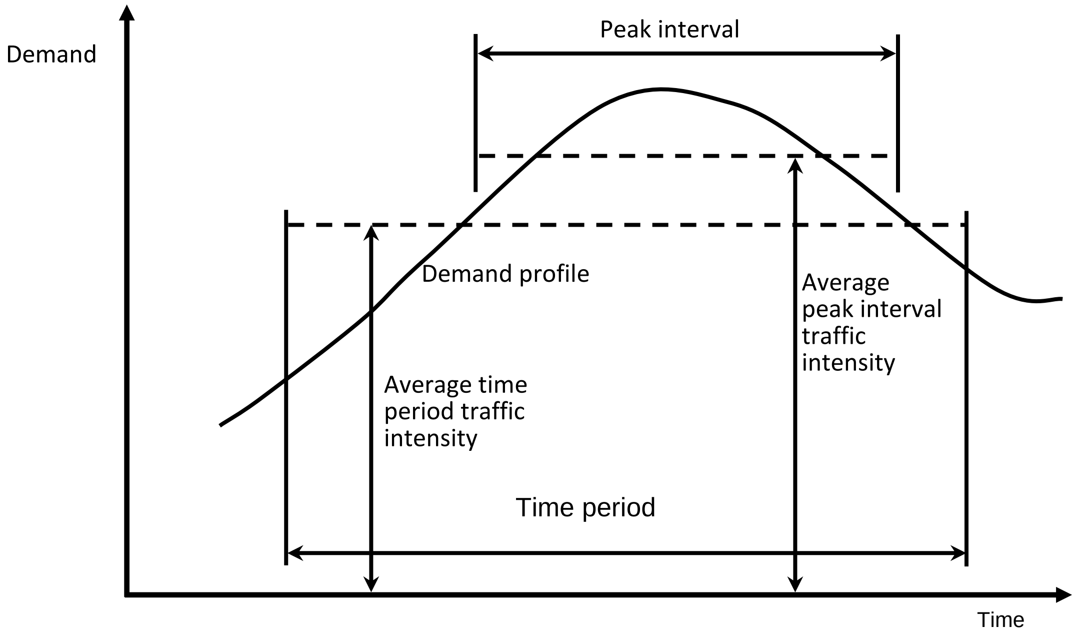
Because bottleneck delay occurs when demand exceeds capacity (ie when the volume to capacity ratio exceeds 1.0), it is also known as **over-saturation delay**.

Average peak interval traffic intensity

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 smooths 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.

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.

Figure A28: Average peak interval traffic intensity



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.

Determining the peak interval

This procedure should be used if the conclusion from the procedure in Table A61 was that vehicle interactions shall be considered.

Procedure

Follow the steps below to determine the peak interval.

Table A62: Steps to determine the peak interval

Step	Action
1	Select a time period to be analysed (usually the weekday morning or evening commuter peak). See Dividing the year into time periods. **Note:** The time period must be long enough to ensure sufficient capacity, even though for some time that capacity is exceeded.
2	Identify the time interval that traffic data for the time period has been collected (usually 5, 10 or 15 minute intervals).
3	Set out the traffic data for the time period. Example:

Step	Action	
	Time	Observed traffic volume
	7:00–7:15	800
	7:15–7:30	1,040
	7:30–7:45	1,200
	7:45–8:00	1,280
	8:00–8:15	1,240
	8:15–8:30	1,140
	8:30–8:45	1,020
	8:45–9:00	840
4	Calculate the average time period traffic intensity (F_{tp}) (see Average time period traffic intensity definition) 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	
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 = ti + (Ftp- vi-1)/vi - vi-1) × 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 (ti) = 8:30 Volume in interval (vi) = 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 + (1,140 – 1,070)/(1,140 – 1,020) × 15 = 8:38.8	

Step	Action		
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

Calculating the average peak interval traffic intensity

This procedure should only be applied after having calculated the peak interval in Table A62.

Procedure

Follow the steps below to calculate the average peak interval traffic intensity.

Table A63: Steps 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	=	1,200 vehicles
	Volume 7:45–8:00	=	1,280 vehicles
	Volume 8.00–8.15	=	1,240 vehicles
	Volume 8:15–8:30	=	1,140 vehicles
	Volume 8:30–8:45	=	1,020 vehicles
	Peak interval traffic vol	=	(7:45 - 7:32.8)/15 × 1,200 + 1,280 + 1,240 + 1140 + (8:38.8 - 8:30)/15 × 1,020
		=	5,234 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})		
		=	5,234 × 60/66.0
		=	4,758 veh/h

Calculating the volume to capacity ratio

The volume to capacity (VC) ratio is also known as the saturation ratio.

Procedure

Follow the steps below to determine the VC ratio.

Table A64: Steps to determine the volume to capacity (VC) ratio

Step	Action	
1	Determine the appropriate **capacity** for calculating the VC ratio as follows:	
	If the road section is a …	*Then use the …*
	motorway section	capacity determined in Table A58
	multi-lane highway	capacity determined in Table A59
	two-lane rural road	peak direction capacity determined in Table A60
	other urban road	capacity specified in Table A57
2	Obtain the average peak interval traffic intensity (F_{pi}) as determined in Table A63 and use this volume in step 3. **Note:** If the VC 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 VC ratio using the appropriate capacity and traffic volume determined in steps 1 and 2. Example: VC ratio	 = = =	 volume/capacity 4,758/5,072 0.938

Calculating the additional travel time

The average additional travel time above that experienced when travelling at the free speed shall be determined as a function of the VC 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.

Table A65: Steps to calculate 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
	multi-lane 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 VC ratio determined in Table A64, as follows (for motorways and multi-lane roads only):	
	If the peak interval VC 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 VC ratio determined in Table A64 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

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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

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 is the volume to capacity flow ratio

P_{NP} is 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

4	Calculate the peak interval additional travel time by multiplying the free speed travel time in Table A53 by the factor from step 2 or 3.		
	Peak interval additional	=	free speed travel time x peak interval travel time additional travel time factor (F_{dr})
	Example 1: (motorway or multi-lane highway):		
	Free speed travel time	=	0.571 mins/km
	VC 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%
	VC 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

Calculating bottleneck delay

This procedure should be used for all time periods during which demand exceeds capacity (VC ratio greater than one) at some time.

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.

Table A66: Steps 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 Table A57.
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 8:00–8:15 = 264 + 475 + 591 + 600 + 591 = 2,521
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 = 8:00–8:15 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 × (queue at end of interval + queue at start of interval)/2
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

A worked example of the bottleneck delay procedure is provided in Appendix 8: Worked examples.

Determining whether to consider peak spreading

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.

Table A67: Steps to determine whether to consider peak spreading

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td>1</td><td colspan="3">Calculate the average delay per delayed vehicle, using the time period average delay per vehicle determined in Table A66.

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 calculating bottleneck delay example in Appendix 8: Worked examples):
Average delay per delayed vehicle
= 3.37 × (3744 / (591 + 600 + 591 + 475 + 264))
= 3.37 × (3744 / 2521)
= 5.0mins/veh</td></tr>
<tr><td>2</td><td colspan="3">Determine whether peak spreading should be considered as follows:</td></tr>
<tr><td></td><td>If the average minutes delay per delayed vehicle is …</td><td>And there is …</td><td>Then peak spreading …</td></tr>
<tr><td></td><td>between 0 and 15</td><td></td><td>does not need to be considered</td></tr>
<tr><td></td><td>between 15 and 25</td><td>an alternative route</td><td>does not need to be considered</td></tr>
<tr><td></td><td>between 15 and 25</td><td>no alternative route</td><td>shall be considered, see Applying variable trip matrix with growth constraint techniques</td></tr>
<tr><td></td><td>25 or greater</td><td></td><td>shall be considered, see Applying variable trip matrix with growth constraint techniques</td></tr>
</table>

Determining the additional travel time resulting from speed change cycles

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 4: Vehicle operating cost tables 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.

Table A68: Steps to determine the additional travel time of speed change cycles from 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 Table A53 and Table A56 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	-3,892
LCV	0.97	54.51	0.4531	-3,337
MCV	0.89	51.77	0.4744	-3,245
HCVI	0.91	59.16	0.4068	-3,506
HCVII	0.91	69.57	0.3085	-3,768
Bus	0.91	59.16	0.4068	-3,506

Step	Action
1 (cont.)	Example: A horizontal curve of radius 100m exists within a road section where the free speed is estimated at 94.33km/h. Ideal approach speed = 0.89 × 94.33 For MCV = 84km/h Desired negotiation speed for MCV = 51.77 + 0.4744 × 84 – 3,245/100 = 59km/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: 1km at free speed travel time = 0.636mins/km 1km additional travel time for vehicle interactions (from Table A65) = 0.636 × 0.2 = 0.127 mins/km Initial operating speed = 1.00/(0.636 + 0.127) × 60 = 1.00/0.763 × 60 = 79km/h
3	The additional travel time associated with speed change cycles is then determined from the appropriate table in Appendix 4: Vehicle operating cost tables. **Note:** Where the desired negotiating speed is greater than the operating speed no speed change will occur. Example: Using Table A100 Initial cruise speed for all vehicles = 79km/h Curve speed for MCV = 59km/h MCV additional travel time per speed change = 2.0 seconds

Step	Action
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 Table A47) For each vehicle type: proportion in traffic from traffic composition number of vehicles = traffic volume × proportion in traffic additional travel time = number of vehicles × additional travel time for speed change cycles Sum over all vehicle types to obtain the total additional travel time.

Calculating the time period total average travel time

Use this procedure once free speed and delays caused by vehicle interactions and speed changes have been calculated.

When evaluating 'other urban roads', this procedure is used in conjunction with the procedure in Table A57.

Procedure

Follow the steps below to calculate the time period total average travel time per vehicle.

Table A69: Steps to calculate the time period total average travel time per vehicle

Step	Action
1	Use the following previously calculated values: • free speed travel time (Table A53) • time period additional travel time (Table A65) • time period average delay per vehicle (Table A66) • additional travel time due to speed changes (Table A68). **Notes:** '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 the procedures for traffic signals, priority intersections and roundabouts below. Time period additional travel time is only calculated if the VC ratio exceeds 0.7 (see Table A61). 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.

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 Akcelik R (1981) 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. For this reason, 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 2000 passenger cars units per hour of green by the factors tabulated in TableA70, Table A71, Table A73 and Table A74.

Parking movements refers to the number of such movements, in and out, within a length of 50m on either side of the intersection.

Table A70: 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 A71: Approach grade factors

Gradient %	Factor
-4	1.02
-2	1.01
0	1.00
+2	0.99
+4	0.98

Table A72: 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 A73: Locality factors

Type of street	Factor
CBD shopping	0.90
Suburban shopping	0.95
Other	1.00

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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 in Table A75. Arrival types 1 and 5, from Table A74, 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. Table A76 provides a broad guide to such effects.

Table A74: 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 A75: 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 A76: Platoon dispersal distances (m)

Platoon type	Speed environment (km/h)	
	50–64	65–105
Dense	<100	<300
Dispersed	150–500	350–1,000
Random	>1,000	>2,000

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.

A worked example of the Traffic signal procedure is provided in Appendix 8: Worked examples.

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 a procedure below.

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:

1. movements that have priority
2. movements that yield the right-of-way to the priority flows
3. movements that must give way to both the above categories.

Only priority levels 2 and 3 will experience delays.

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.

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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 is capacity
T_o is $T_g - H_m$ (H_m = 0.5 or 2.0)
H_m is minimum headway in conflicting flow
T_g is critical gap
T_f is follow-up headway
V is conflicting volume during peak interval, veh/h.

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 A77 should be used.

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.

The follow-up headway is related to the critical gap, by the expression: $T_f = 2.0 + 0.2\ T_g$

Table A77: 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

Average peak interval delay

For Table A78 the following conditions apply:

- The movement VC ratio is the ratio of the average movement traffic demand for that movement during the peak interval divided by the capacity.
- The peak interval average travel time is equivalent to the delay for each movement. This delay depends on the VC ratio as tabulated in the table on the next page.
- The total average travel for the intersection is approximated by the peak interval time period.

Table A78: Average peak interval delay

Volume to capacity ratio	Average peak interval delay (min/veh)
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

Where a traffic model has been used to calculate delays at priority intersections, the provisions of the procedure for traffic signals also apply.

Roundabouts

Roundabouts are a special case of a priority intersection. Delays at each approach can be estimated in a manner similar to that given in the procedure for priority intersections, ie each approach can be considered as an independent elemental intersection with one-way conflicting flows circulating round the central island.

Procedure

The procedures and methods of Austroads (1993) *Guide to traffic engineering practice part 6: roundabouts* shall be used to obtain the capacities of each approach lane.

The VC ratio for each approach lane shall be estimated as the expected average flow during the peak interval using that lane divided by the capacity.

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 A78 up to a maximum VC 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.

The time period total average travel time is the average delay during the time period, and shall be estimated from the peak interval delay.

Where a traffic model has been used to calculate delays at roundabouts, the provisions of the procedure for traffic signals also apply.

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Back to 4. Evaluation procedures >>

Appendix 4: Vehicle operating cost tables

Table A79: Passenger car VOC by speed and gradient (cents/km – July 2015)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	34.0	34.1	34.2	34.2	34.3	34.4	34.5	34.6	34.8	35.0	35.2	35.5	35.9
15	30.4	30.5	30.6	30.7	30.8	30.9	31.1	31.3	31.5	31.8	32.1	32.5	32.9
20	27.7	27.8	28.0	28.1	28.2	28.4	28.6	28.8	29.0	29.4	29.7	30.2	30.7
25	25.8	25.9	26.0	26.2	26.3	26.5	26.7	27.0	27.3	27.6	28.0	28.5	29.1
30	24.4	24.5	24.7	24.8	24.9	25.1	25.4	25.6	25.9	26.3	26.8	27.3	27.9
35	23.4	23.5	23.6	23.8	23.9	24.1	24.4	24.7	25.0	25.4	25.9	26.4	27.0
40	22.7	22.8	22.9	23.1	23.2	23.4	23.7	24.0	24.3	24.7	25.2	25.8	26.4
45	22.2	22.3	22.4	22.5	22.7	22.9	23.2	23.5	23.8	24.3	24.8	25.3	26.0
50	21.8	21.9	22.1	22.2	22.4	22.6	22.8	23.2	23.5	24.0	24.5	25.1	25.7
55	21.7	21.8	21.9	22.0	22.2	22.4	22.7	23.0	23.3	23.8	24.3	24.9	25.6
60	21.6	21.7	21.8	21.9	22.1	22.3	22.6	22.9	23.3	23.7	24.3	24.9	25.6
65	21.6	21.7	21.8	21.9	22.1	22.3	22.6	22.9	23.3	23.8	24.3	24.9	25.6
70	21.7	21.8	21.9	22.0	22.2	22.4	22.7	23.0	23.4	23.9	24.4	25.0	25.7
75	21.9	22.0	22.1	22.2	22.4	22.6	22.8	23.2	23.6	24.0	24.6	25.2	25.9
80	22.1	22.2	22.3	22.4	22.6	22.8	23.0	23.4	23.8	24.2	24.8	25.4	26.2
85	22.4	22.4	22.5	22.7	22.8	23.0	23.3	23.6	24.0	24.5	25.1	25.7	26.5
90	22.7	22.7	22.8	23.0	23.1	23.3	23.6	23.9	24.3	24.8	25.4	26.0	26.8
95	23.0	23.1	23.2	23.3	23.5	23.7	23.9	24.3	24.7	25.1	25.7	26.4	27.1
100	23.4	23.4	23.5	23.6	23.8	24.0	24.3	24.6	25.0	25.5	26.1	26.7	27.5
105	23.8	23.8	23.9	24.0	24.2	24.4	24.7	25.0	25.4	25.9	26.5	27.1	27.9
110	24.2	24.3	24.3	24.5	24.6	24.8	25.1	25.4	25.8	26.3	26.9	27.6	28.3
115	24.7	24.7	24.8	24.9	25.0	25.2	25.5	25.8	26.3	26.7	27.3	28.0	28.8
120	25.1	25.2	25.2	25.3	25.5	25.7	26.0	26.3	26.7	27.2	27.8	28.4	29.2

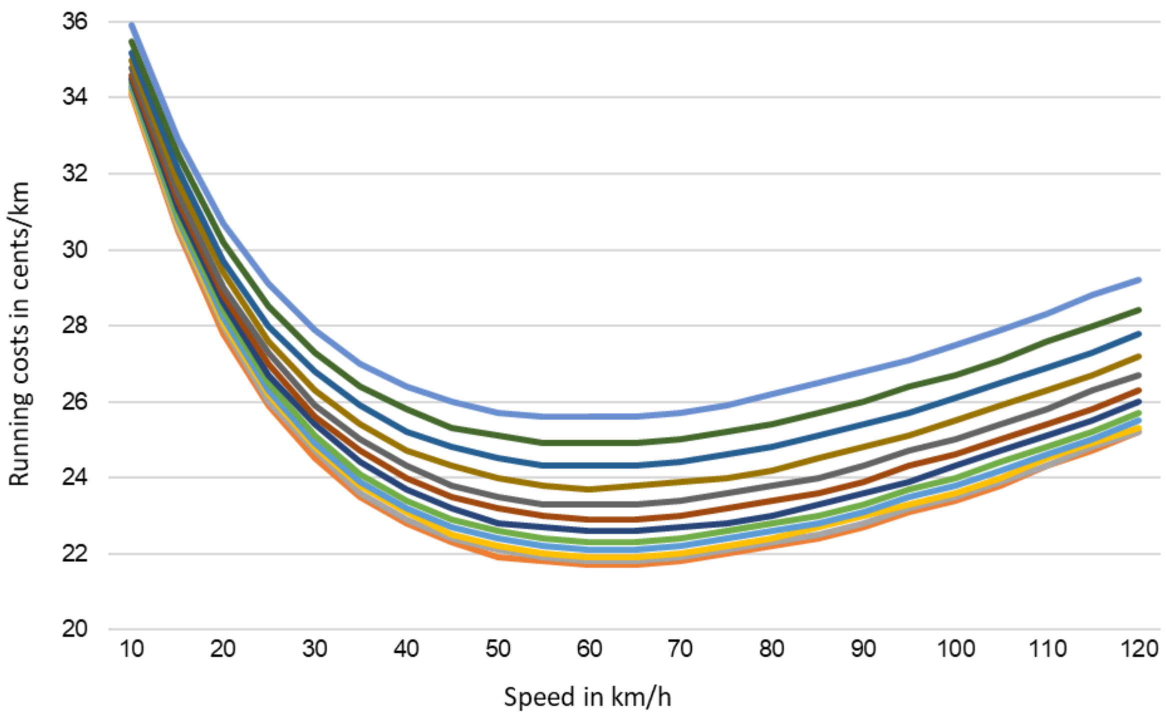

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Table A80: LCV VOC by speed and gradient (cents/km – July 2015)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	44.2	44.2	44.3	44.3	44.5	44.7	44.9	45.2	45.6	46.1	46.7	47.3	48.1
15	39.2	39.3	39.4	39.5	39.8	40.0	40.4	40.8	41.4	42.0	42.7	43.5	44.4
20	35.5	35.6	35.7	35.9	36.2	36.6	37.0	37.5	38.1	38.8	39.6	40.5	41.5
25	32.9	33.0	33.1	33.3	33.6	34.0	34.5	35.0	35.7	36.4	37.3	38.3	39.4
30	30.9	31.0	31.2	31.4	31.8	32.2	32.7	33.2	33.9	34.7	35.7	36.7	37.8
35	29.6	29.7	29.8	30.1	30.4	30.8	31.4	32.0	32.7	33.5	34.5	35.6	36.8
40	28.6	28.7	28.9	29.2	29.5	29.9	30.5	31.1	31.8	32.7	33.7	34.8	36.0
45	28.0	28.1	28.3	28.5	28.9	29.3	29.9	30.5	31.3	32.2	33.2	34.3	35.6
50	27.6	27.7	27.9	28.2	28.5	29.0	29.5	30.2	31.0	31.9	32.9	34.1	35.4
55	27.5	27.6	27.8	28.0	28.4	28.8	29.4	30.1	30.9	31.8	32.8	34.0	35.3
60	27.5	27.6	27.8	28.0	28.4	28.9	29.4	30.1	30.9	31.9	32.9	34.1	35.5
65	27.7	27.8	27.9	28.2	28.6	29.0	29.6	30.3	31.1	32.0	33.1	34.3	35.7
70	28.0	28.0	28.2	28.5	28.8	29.3	29.9	30.6	31.4	32.3	33.4	34.7	36.0
75	28.3	28.4	28.6	28.8	29.2	29.7	30.2	30.9	31.8	32.7	33.8	35.1	36.4
80	28.8	28.9	29.0	29.3	29.6	30.1	30.7	31.4	32.2	33.2	34.3	35.5	36.9
85	29.3	29.4	29.5	29.8	30.1	30.6	31.2	31.9	32.7	33.7	34.8	36.1	37.5
90	29.9	30.0	30.1	30.4	30.7	31.2	31.8	32.5	33.3	34.3	35.4	36.7	38.1
95	30.5	30.6	30.7	31.0	31.3	31.8	32.4	33.1	34.0	34.9	36.1	37.3	38.8
100	31.2	31.3	31.4	31.7	32.0	32.5	33.1	33.8	34.6	35.6	36.7	38.0	39.5
105	31.9	32.0	32.1	32.4	32.7	33.2	33.8	34.5	35.3	36.3	37.5	38.8	40.2
110	32.7	32.7	32.9	33.1	33.4	33.9	34.5	35.2	36.1	37.1	38.2	39.5	41.0
115	33.5	33.5	33.6	33.9	34.2	34.7	35.3	36.0	36.8	37.8	39.0	40.3	41.7
120	34.3	34.3	34.4	34.7	35.0	35.5	36.1	36.8	37.6	38.6	39.8	41.1	42.5

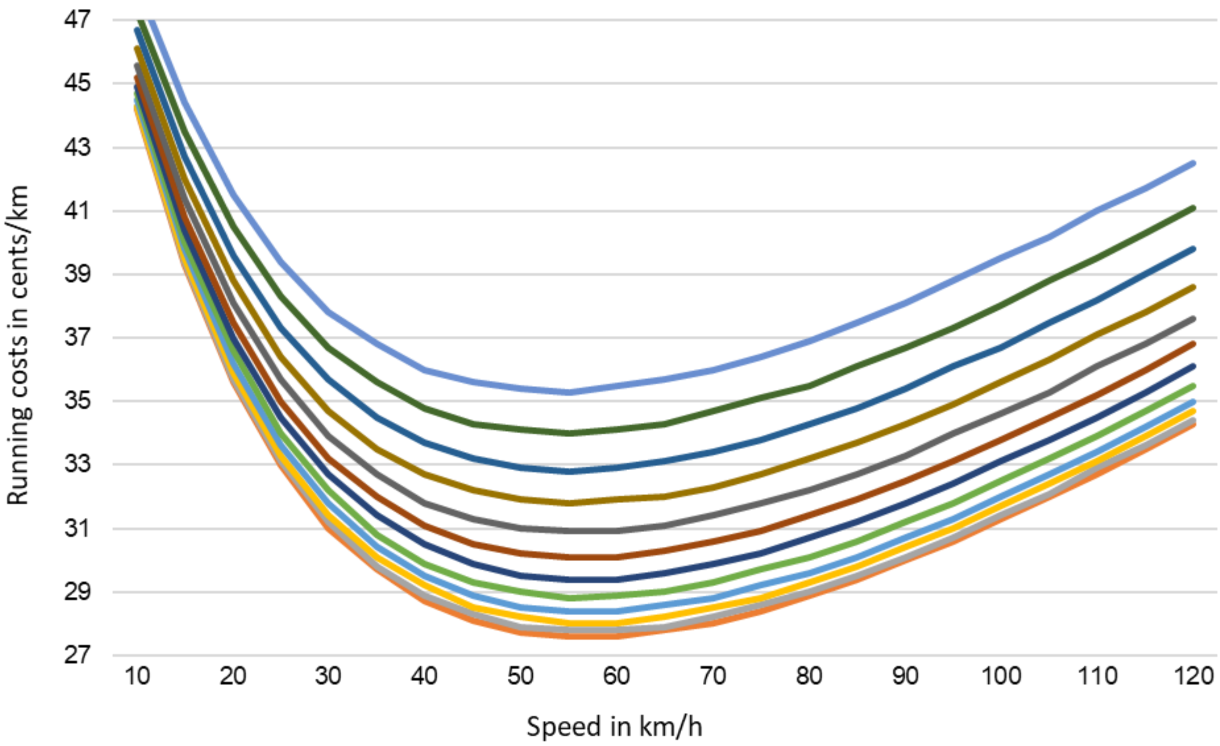

Table A81: MCV VOC by speed and gradient (cents/km – July 2015)

Speed	Gradient in percent (both directions)												
(km/h)	0	1	2	3	4	5	6	7	8	9	10	11	12
10	68.1	68.5	69.6	71.3	73.5	76.0	78.7	81.6	84.6	87.4	90.1	92.6	94.6
15	63.2	63.5	64.5	66.2	68.3	70.8	73.7	76.7	79.9	83.0	86.0	88.8	91.3
20	59.7	59.9	60.8	62.4	64.5	67.1	70.0	73.1	76.4	79.7	82.9	85.9	88.7
25	57.2	57.3	58.2	59.7	61.9	64.5	67.4	70.6	74.0	77.4	80.8	84.0	86.9
30	55.6	55.6	56.4	58.0	60.1	62.7	65.7	68.9	72.4	75.9	79.4	82.7	85.8
35	54.6	54.6	55.3	56.8	58.9	61.5	64.5	67.8	71.4	75.0	78.5	82.0	85.3
40	54.1	54.0	54.7	56.1	58.2	60.8	63.9	67.2	70.8	74.5	78.1	81.7	85.1
45	53.9	53.7	54.4	55.8	57.9	60.5	63.6	67.0	70.6	74.3	78.1	81.7	85.2
50	54.0	53.8	54.4	55.8	57.9	60.5	63.6	67.0	70.7	74.4	78.3	82.0	85.5
55	54.4	54.1	54.7	56.1	58.1	60.7	63.8	67.3	71.0	74.8	78.7	82.5	86.1
60	54.9	54.6	55.1	56.5	58.5	61.2	64.3	67.7	71.4	75.3	79.2	83.1	86.8
65	55.5	55.2	55.7	57.1	59.1	61.7	64.8	68.3	72.1	76.0	79.9	83.9	87.6
70	56.3	55.9	56.5	57.8	59.8	62.4	65.5	69.0	72.8	76.7	80.8	84.7	88.6
75	57.2	56.8	57.3	58.6	60.6	63.2	66.3	69.9	73.7	77.6	81.7	85.7	89.6
80	58.2	57.8	58.2	59.5	61.5	64.1	67.2	70.8	74.6	78.6	82.7	86.8	90.7
85	59.3	58.8	59.2	60.5	62.5	65.1	68.2	71.8	75.6	79.6	83.8	87.9	91.9
90	60.4	59.9	60.3	61.5	63.5	66.1	69.3	72.8	76.7	80.7	84.9	89.1	93.1
95	61.6	61.0	61.4	62.6	64.6	67.2	70.4	73.9	77.8	81.9	86.1	90.3	94.4
100	62.8	62.2	62.6	63.8	65.8	68.4	71.5	75.1	79.0	83.1	87.3	91.5	95.6
105	64.0	63.4	63.8	65.0	66.9	69.5	72.7	76.3	80.2	84.3	88.5	92.8	97.0
110	65.3	64.7	65.0	66.2	68.1	70.7	73.9	77.5	81.4	85.5	89.8	94.1	98.3
115	66.6	65.9	66.3	67.4	69.4	72.0	75.1	78.7	82.7	86.8	91.1	95.5	99.7
120	67.9	67.2	67.5	68.7	70.6	73.2	76.4	80.0	83.9	88.1	92.5	96.8	101.1

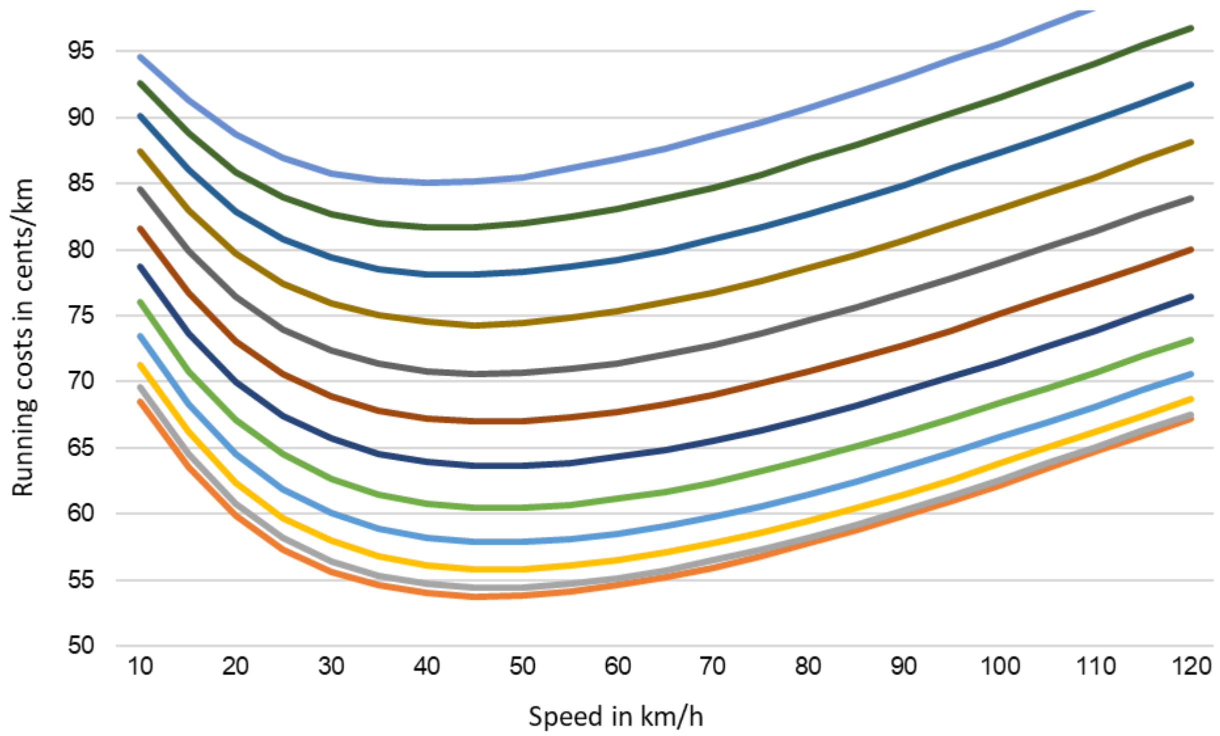

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Table A82: HCVI VOC by speed and gradient (cents/km – July 2015)

Speed (km/h)	Gradient in percent (both directions)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	118.9	118.9	120.5	123.4	127.4	132.2	137.7	143.6	149.7	155.6	161.3	166.4	170.8
15	111.5	111.4	112.9	115.8	119.9	124.9	130.6	136.9	143.3	149.7	156.0	161.7	166.8
20	105.4	105.1	106.6	109.5	113.6	118.8	124.7	131.1	137.9	144.7	151.3	157.5	163.1
25	100.8	100.5	101.9	104.8	109.0	114.2	120.3	126.9	133.8	140.9	147.8	154.4	160.4
30	97.5	97.2	98.5	101.5	105.7	111.0	117.2	123.9	131.1	138.3	145.5	152.4	158.7
35	95.3	94.9	96.2	99.2	103.4	108.8	115.1	122.0	129.2	136.7	144.1	151.2	157.8
40	94.0	93.5	94.8	97.7	102.0	107.5	113.8	120.8	128.2	135.8	143.4	150.7	157.5
45	93.2	92.7	94.0	96.9	101.3	106.8	113.2	120.2	127.8	135.5	143.3	150.8	157.8
50	93.0	92.4	93.7	96.7	101.0	106.6	113.0	120.2	127.9	135.7	143.6	151.3	158.5
55	93.2	92.6	93.9	96.9	101.2	106.8	113.3	120.6	128.3	136.3	144.4	152.2	159.6
60	93.8	93.2	94.5	97.4	101.8	107.4	114.0	121.3	129.1	137.2	145.4	153.4	160.9
65	94.7	94.0	95.3	98.2	102.6	108.3	114.9	122.3	130.2	138.4	146.7	154.8	162.4
70	95.8	95.1	96.3	99.3	103.7	109.4	116.1	123.5	131.5	139.8	148.2	156.4	164.2
75	97.1	96.4	97.6	100.6	105.0	110.7	117.4	125.0	133.0	141.4	149.9	158.2	166.1
80	98.6	97.8	99.1	102.0	106.5	112.2	119.0	126.5	134.7	143.1	151.7	160.1	168.1
85	100.2	99.5	100.7	103.6	108.1	113.9	120.7	128.3	136.5	145.0	153.6	162.1	170.3
90	102.0	101.2	102.4	105.4	109.9	115.6	122.5	130.1	138.4	147.0	155.7	164.3	172.6
95	103.8	103.0	104.2	107.2	111.7	117.5	124.4	132.1	140.4	149.1	157.8	166.5	174.9
100	105.8	105.0	106.2	109.1	113.7	119.5	126.4	134.1	142.5	151.2	160.1	168.9	177.3
105	107.8	107.0	108.2	111.2	115.7	121.5	128.5	136.2	144.7	153.4	162.4	171.2	179.8
110	109.9	109.1	110.3	113.2	117.8	123.7	130.6	138.4	146.9	155.7	164.7	173.7	182.3
115	112.1	111.2	112.4	115.4	119.9	125.8	132.8	140.7	149.2	158.1	167.1	176.1	184.8
120	114.3	113.4	114.6	117.6	122.1	128.1	135.1	143.0	151.5	160.5	169.6	178.6	187.4

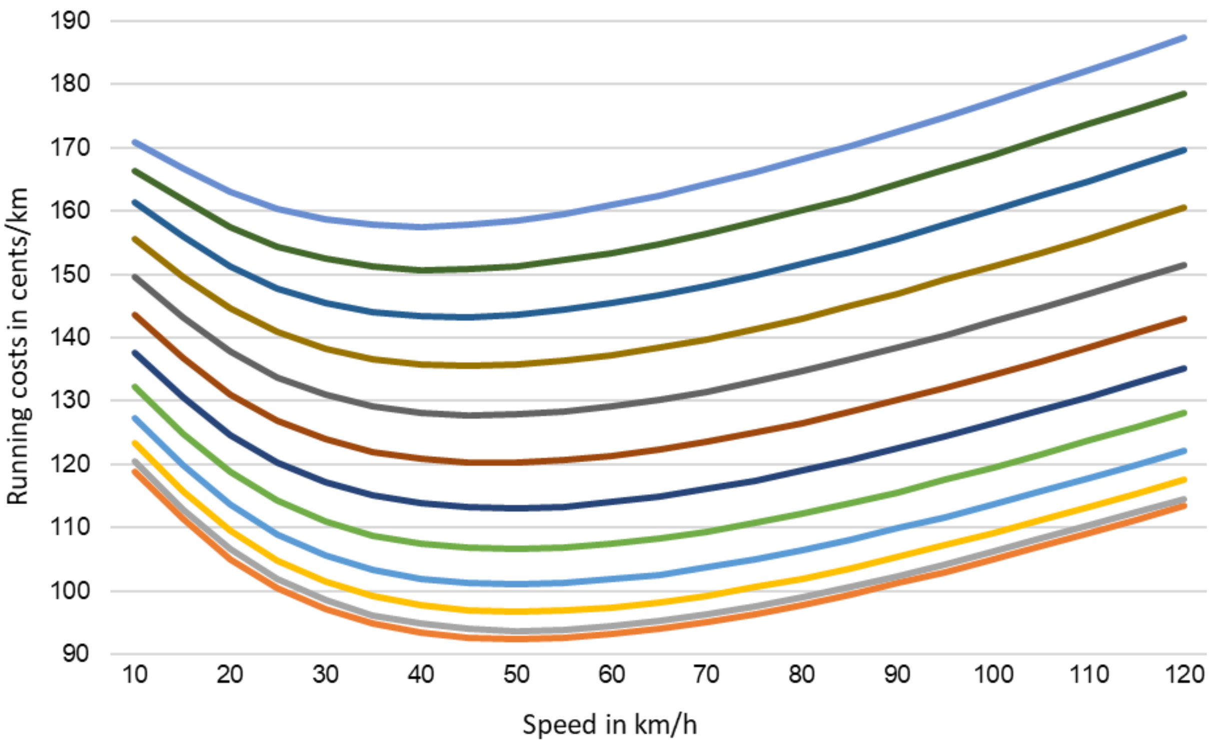

Table A83: HCVII VOC by speed and gradient (cents/km – July 2015)

Speed	Gradient in percent (both directions)												
(km/h)	0	1	2	3	4	5	6	7	8	9	10	11	12
10	172.9	178.2	186.6	197.5	210.4	224.7	239.9	255.6	271.2	286.2	300.1	312.3	322.5
15	173.1	176.8	183.9	193.7	205.8	219.6	234.7	250.5	266.5	282.1	296.9	310.4	322.1
20	169.5	172.5	178.9	188.3	200.2	214.0	229.3	245.4	262.0	278.4	294.3	309.0	322.0
25	166.0	168.5	174.6	183.9	195.8	209.8	225.3	242.0	259.2	276.4	293.2	309.0	323.3
30	163.2	165.4	171.5	180.7	192.7	207.0	222.9	240.1	257.9	275.9	293.6	310.4	325.9
35	161.3	163.4	169.4	178.7	190.9	205.5	221.8	239.5	257.9	276.7	295.2	313.0	329.5
40	160.1	162.2	168.2	177.7	190.1	205.0	221.8	239.9	259.0	278.4	297.8	316.4	333.9
45	159.7	161.7	167.8	177.5	190.2	205.4	222.5	241.2	260.9	281.0	301.0	320.5	338.9
50	159.8	161.9	168.1	178.0	190.9	206.4	224.0	243.2	263.4	284.1	304.9	325.1	344.4
55	160.5	162.6	169.0	179.0	192.2	208.1	226.1	245.7	266.4	287.8	309.2	330.2	350.2
60	161.5	163.8	170.3	180.5	194.0	210.2	228.6	248.7	269.9	291.8	313.9	335.6	356.4
65	163.0	165.3	172.0	182.4	196.2	212.7	231.5	252.0	273.7	296.2	318.8	341.2	362.7
70	164.7	167.2	174.0	184.7	198.7	215.5	234.7	256.6	277.8	300.8	324.1	347.0	369.2
75	166.8	169.3	176.3	187.2	201.5	218.6	238.1	259.5	282.2	305.7	329.5	353.0	375.9
80	169.0	171.7	178.9	190.0	204.5	222.0	241.8	263.6	286.7	310.7	335.0	359.2	382.6
85	171.5	174.3	181.6	193.0	207.8	225.5	245.7	267.8	291.4	315.8	340.7	365.4	389.5
90	174.1	177.1	184.6	196.1	211.2	229.2	249.7	272.2	296.2	321.1	346.4	371.7	396.3
95	176.9	180.0	187.7	199.4	214.7	233.1	253.9	276.8	301.1	326.5	352.3	378.1	403.3
100	179.8	183.0	190.9	202.9	218.4	237.0	258.2	281.4	306.2	331.9	358.2	384.5	410.2
105	182.8	186.2	194.2	206.4	222.2	241.1	262.6	286.1	311.3	337.4	364.2	390.9	417.2
110	186.0	189.5	197.7	210.1	226.1	245.2	267.0	290.9	316.4	343.0	370.2	397.4	424.1
115	189.2	192.8	201.2	213.8	230.0	249.5	271.5	295.8	321.6	348.6	376.2	403.8	431.1
120	192.5	196.3	204.8	217.6	234.1	253.8	276.1	300.7	326.9	354.2	382.2	410.3	438.0

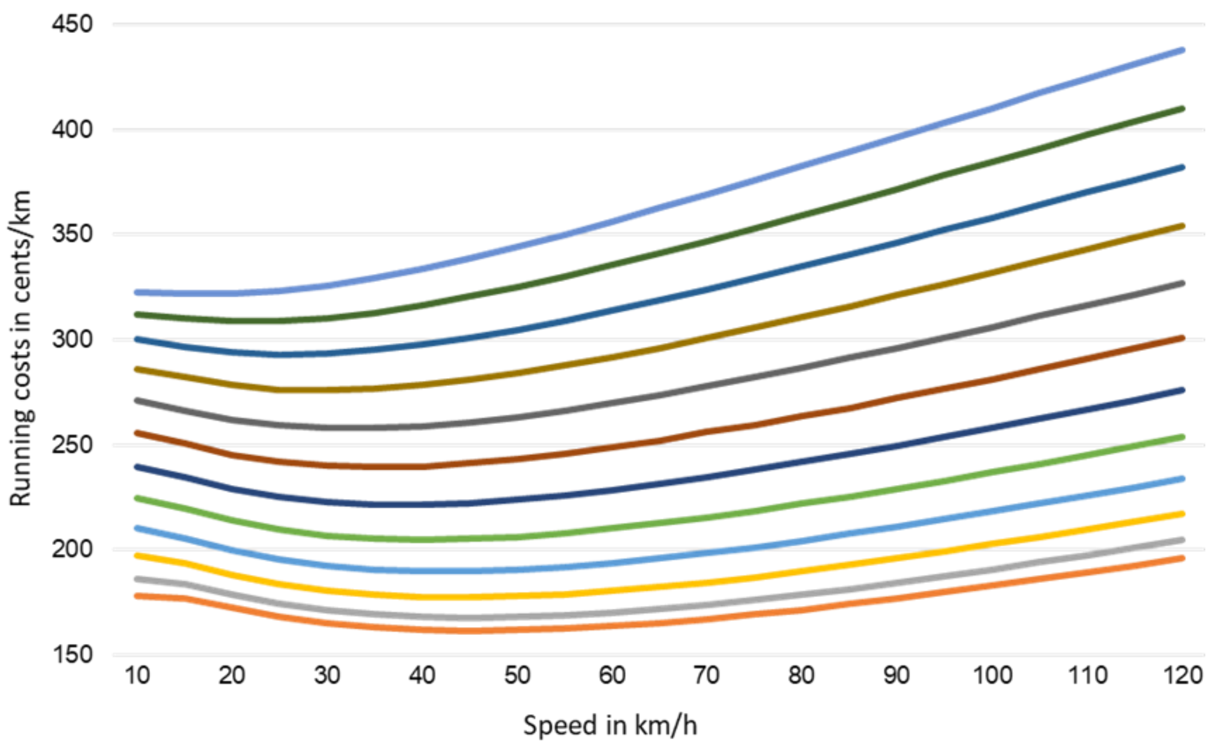

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Table A84: Bus VOC by speed and gradient (cents/km – July 2015)

Speed (km/h)	Gradient in percent (both directions)											
	0	1	2	3	4	5	6	7	8	9	10	11	12
10	79.0	80.4	82.6	85.5	88.9	92.7	96.8	101.0	105.2	109.3	113.0	116.4	119.1
15	75.4	76.5	78.4	81.1	84.5	88.4	92.6	97.1	101.6	106.1	110.4	114.4	117.9
20	72.0	72.7	74.5	77.0	80.4	84.2	88.5	93.2	97.9	102.7	107.4	111.8	115.8
25	69.5	70.0	71.6	74.0	77.3	81.2	85.5	90.2	95.2	100.1	105.1	109.8	114.2
30	67.9	68.3	69.7	72.1	75.2	79.1	83.5	88.3	93.3	98.5	103.6	108.6	113.2
35	67.2	67.4	68.7	70.9	74.1	77.9	82.3	87.1	92.3	97.6	102.8	108.0	112.9
40	67.1	67.1	68.3	70.5	73.6	77.4	81.8	86.7	91.9	97.3	102.7	108.0	113.2
45	67.6	67.4	68.5	70.6	73.6	77.4	81.8	86.7	92.0	97.5	103.0	108.5	113.8
50	68.4	68.2	69.1	71.2	74.1	77.9	82.3	87.2	92.6	98.1	103.8	109.4	114.8
55	69.6	69.3	70.1	72.1	75.0	78.7	83.2	88.1	93.5	99.1	104.8	110.6	116.1
60	71.1	70.6	71.4	73.3	76.2	79.9	84.3	89.3	94.7	100.3	106.2	112.0	117.7
65	72.8	72.2	72.9	74.8	77.6	81.3	85.7	90.7	96.1	101.8	107.7	113.6	119.5
70	74.7	74.0	74.6	76.4	79.2	82.9	87.3	92.3	97.7	103.5	109.5	115.5	121.4
75	76.8	76.0	76.5	78.3	81.0	84.6	89.0	94.0	99.5	105.3	111.4	117.5	123.5
80	79.0	78.1	78.6	80.2	82.9	86.6	90.9	96.0	101.5	107.3	113.4	119.6	125.6
85	81.3	80.3	80.7	82.3	85.0	88.6	93.0	98.0	103.5	109.4	115.5	121.8	127.9
90	83.7	82.6	83.0	84.5	87.2	90.7	95.1	100.1	105.7	111.6	117.8	124.1	130.3
95	86.1	85.1	85.3	86.8	89.4	93.0	97.3	102.4	107.9	113.9	120.1	126.4	132.7
100	88.7	87.5	87.7	89.2	91.8	95.3	99.6	104.7	110.2	116.2	122.5	128.9	135.3
105	91.3	90.1	90.2	91.6	94.2	97.7	102.0	107.0	112.6	118.6	124.9	131.4	137.8
110	93.9	92.6	92.8	94.1	96.6	100.1	104.4	109.5	115.1	121.1	127.4	133.9	140.4
115	96.6	95.3	95.3	96.7	99.1	102.6	106.9	111.9	117.5	123.6	130.0	136.5	143.0
120	99.4	97.9	97.9	99.2	101.7	105.1	109.4	114.4	120.1	126.2	132.5	139.1	145.7

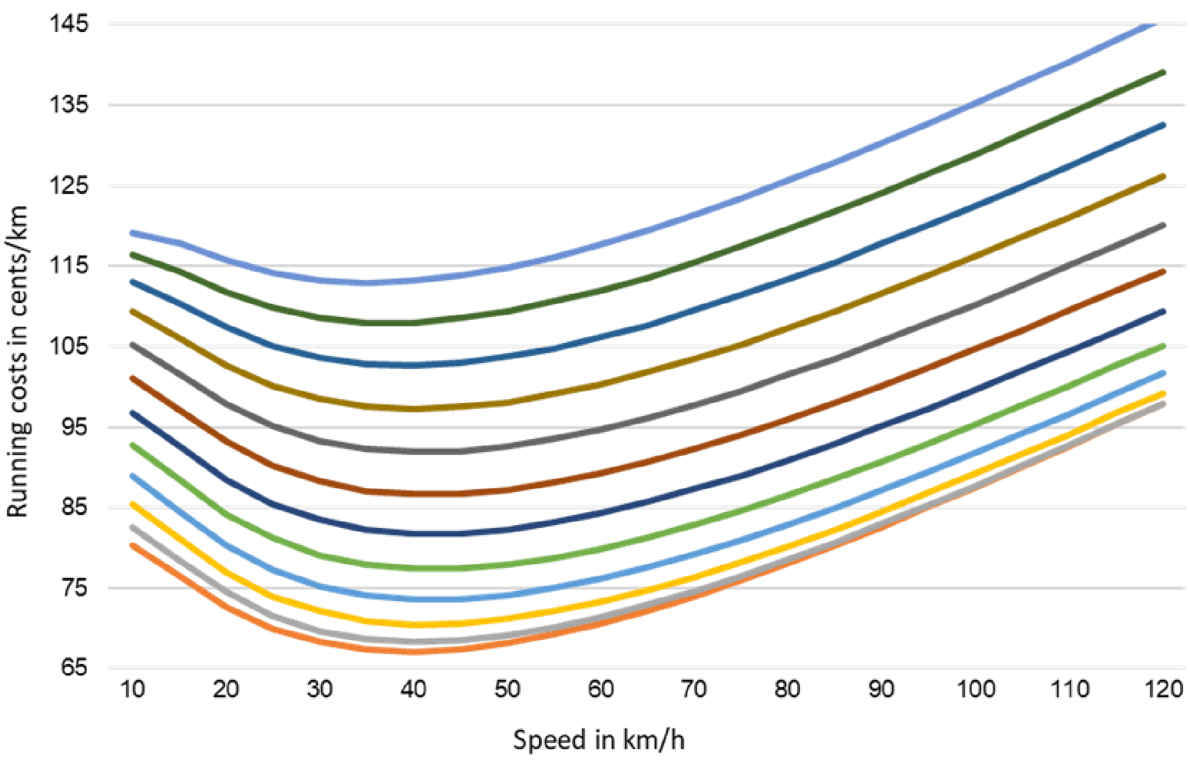

Table A85: Urban arterial VOC by speed and gradient (cents/km – July 2015)

Speed	Gradient in percent (both directions)												
(km/h)	0	1	2	3	4	5	6	7	8	9	10	11	12
10	39.4	39.5	39.8	40.1	40.6	41.0	41.5	42.1	42.7	43.4	44.0	44.7	45.3
15	35.6	35.8	36.0	36.4	36.8	37.3	37.9	38.6	39.3	40.0	40.8	41.6	42.4
20	32.8	32.9	33.2	33.6	34.0	34.6	35.2	35.9	36.6	37.4	38.3	39.2	40.1
25	30.7	30.9	31.1	31.5	32.0	32.6	33.2	33.9	34.7	35.6	36.5	37.5	38.5
30	29.2	29.3	29.6	30.0	30.5	31.1	31.8	32.5	33.4	34.3	35.2	36.2	37.3
35	28.1	28.3	28.5	28.9	29.4	30.0	30.7	31.5	32.4	33.3	34.3	35.4	36.5
40	27.4	27.5	27.8	28.2	28.7	29.3	30.0	30.8	31.7	32.7	33.7	34.8	36.0
45	26.9	27.0	27.3	27.7	28.2	28.8	29.5	30.4	31.3	32.3	33.4	34.5	35.7
50	26.5	26.7	26.9	27.3	27.9	28.5	29.3	30.1	31.0	32.1	33.2	34.4	35.6
55	26.4	26.5	26.8	27.2	27.7	28.4	29.1	30.0	31.0	32.0	33.1	34.3	35.6
60	26.4	26.5	26.8	27.2	27.7	28.4	29.1	30.0	31.0	32.1	33.2	34.5	35.7
65	26.5	26.6	26.8	27.2	27.8	28.5	29.2	30.1	31.1	32.2	33.4	34.7	36.0
70	26.6	26.7	27.0	27.4	28.0	28.6	29.4	30.3	31.4	32.5	33.7	34.9	36.3
75	26.9	27.0	27.3	27.7	28.2	28.9	29.7	30.6	31.6	32.8	34.0	35.3	36.7
80	27.2	27.3	27.6	28.0	28.5	29.2	30.0	31.0	32.0	33.1	34.4	35.7	37.1
85	27.6	27.7	27.9	28.3	28.9	29.6	30.4	31.4	32.4	33.6	34.8	36.1	37.6
90	28.0	28.1	28.3	28.8	29.3	30.0	30.8	31.8	32.9	34.0	35.3	36.6	38.1
95	28.4	28.5	28.8	29.2	29.8	30.5	31.3	32.3	33.3	34.5	35.8	37.2	38.6
100	28.9	29.0	29.3	29.7	30.3	31.0	31.8	32.8	33.9	35.1	36.4	37.7	39.2
105	29.4	29.5	29.8	30.2	30.8	31.5	32.3	33.3	34.4	35.6	36.9	38.3	39.8
110	30.0	30.1	30.3	30.8	31.3	32.0	32.9	33.9	35.0	36.2	37.5	38.9	40.4
115	30.5	30.6	30.9	31.3	31.9	32.6	33.5	34.5	35.6	36.8	38.1	39.6	41.1
120	31.1	31.2	31.5	31.9	32.5	33.2	34.1	35.1	36.2	37.4	38.8	40.2	41.7

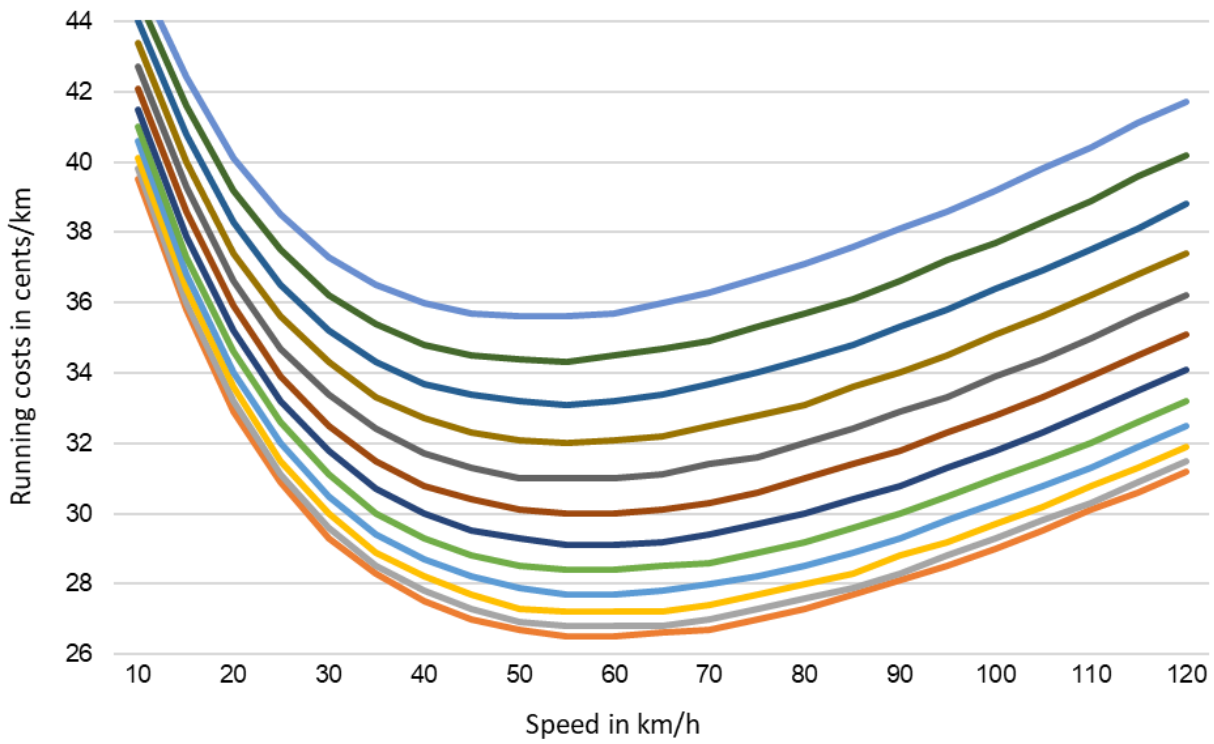

Table A86: Urban other VOC by speed and gradient (cents/km – July 2015)

Speed	Gradient in percent (both directions)												
(km/h)	0	1	2	3	4	5	6	7	8	9	10	11	12
10	39.0	39.1	39.3	39.6	39.9	40.3	40.8	41.3	41.8	42.3	42.9	43.6	44.2
15	35.1	35.3	35.5	35.8	36.2	36.6	37.1	37.7	38.3	39.0	39.7	40.4	41.2
20	32.3	32.4	32.6	33.0	33.4	33.8	34.4	35.0	35.7	36.4	37.2	38.0	38.9
25	30.2	30.3	30.6	30.9	31.3	31.8	32.4	33.1	33.8	34.6	35.4	36.3	37.2
30	28.7	28.8	29.1	29.4	29.8	30.4	31.0	31.6	32.4	33.2	34.1	35.0	36.0
35	27.7	27.8	28.0	28.3	28.8	29.3	29.9	30.6	31.4	32.3	33.2	34.2	35.2
40	26.9	27.0	27.2	27.6	28.0	28.6	29.2	29.9	30.7	31.6	32.6	33.6	34.6
45	26.4	26.5	26.7	27.1	27.5	28.1	28.7	29.5	30.3	31.2	32.2	33.2	34.3
50	26.1	26.2	26.4	26.7	27.2	27.8	28.4	29.2	30.0	30.9	31.9	33.0	34.1
55	25.9	26.0	26.2	26.6	27.0	27.6	28.3	29.0	29.9	30.8	31.9	33.0	34.1
60	25.9	26.0	26.2	26.6	27.0	27.6	28.3	29.0	29.9	30.9	31.9	33.0	34.2
65	26.0	26.1	26.3	26.6	27.1	27.7	28.4	29.1	30.0	31.0	32.1	33.2	34.4
70	26.2	26.2	26.4	26.8	27.3	27.8	28.5	29.3	30.2	31.2	32.3	33.4	34.7
75	26.4	26.5	26.7	27.0	27.5	28.1	28.8	29.6	30.5	31.5	32.6	33.7	35.0
80	26.7	26.8	27.0	27.3	27.8	28.4	29.1	29.9	30.8	31.8	32.9	34.1	35.4
85	27.1	27.1	27.3	27.7	28.2	28.7	29.5	30.3	31.2	32.2	33.3	34.5	35.8
90	27.5	27.5	27.7	28.1	28.6	29.2	29.9	30.7	31.6	32.7	33.8	35.0	36.3
95	27.9	28.0	28.2	28.5	29.0	29.6	30.3	31.1	32.1	33.1	34.3	35.5	36.8
100	28.4	28.5	28.7	29.0	29.5	30.1	30.8	31.6	32.6	33.6	34.8	36.0	37.3
105	28.9	29.0	29.2	29.5	30.0	30.6	31.3	32.1	33.1	34.2	35.3	36.6	37.9
110	29.5	29.5	29.7	30.0	30.5	31.1	31.8	32.7	33.6	34.7	35.9	37.1	38.5
115	30.0	30.1	30.2	30.6	31.1	31.7	32.4	33.2	34.2	35.3	36.4	37.7	39.1
120	30.6	30.6	30.8	31.1	31.6	32.2	33.0	33.8	34.8	35.9	37.0	38.3	39.7

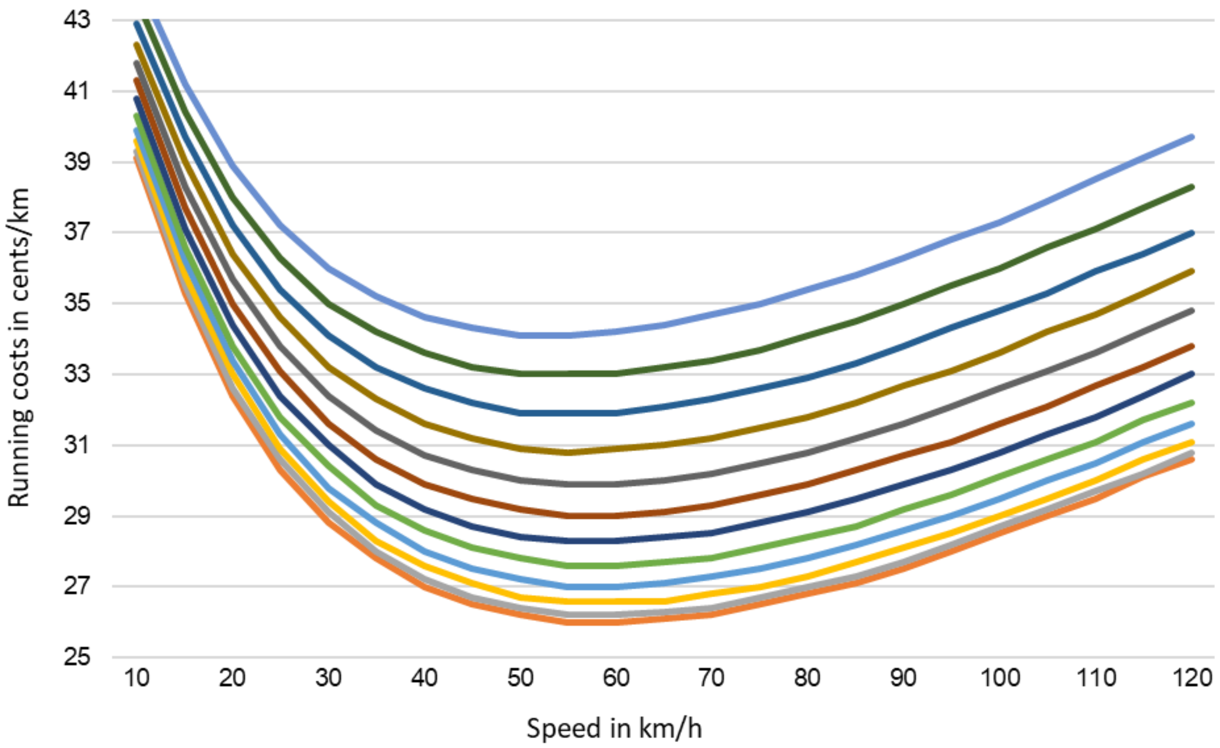

Table A87: Rural strategic VOC by speed and gradient (cents/km – July 2015)

Speed	Gradient in percent (both directions)												
(km/h)	0	1	2	3	4	5	6	7	8	9	10	11	12
10	45.4	45.7	46.1	46.8	47.6	48.6	49.6	50.7	51.9	53.0	54.2	55.3	56.3
15	41.5	41.8	42.2	42.9	43.7	44.7	45.8	47.0	48.3	49.6	50.9	52.1	53.3
20	38.6	38.8	39.2	39.9	40.8	41.8	42.9	44.2	45.5	46.9	48.3	49.7	51.1
25	36.4	36.6	37.0	37.7	38.6	39.6	40.8	42.1	43.5	45.0	46.5	48.0	49.4
30	34.8	35.0	35.4	36.1	37.0	38.0	39.3	40.6	42.1	43.6	45.2	46.8	48.4
35	33.7	33.8	34.3	34.9	35.8	36.9	38.2	39.6	41.1	42.7	44.3	46.0	47.7
40	32.9	33.0	33.5	34.2	35.1	36.2	37.5	38.9	40.5	42.1	43.8	45.5	47.3
45	32.4	32.5	33.0	33.6	34.6	35.7	37.0	38.5	40.1	41.8	43.5	45.3	47.1
50	32.1	32.2	32.7	33.4	34.3	35.5	36.8	38.3	39.9	41.6	43.4	45.3	47.1
55	32.0	32.1	32.5	33.3	34.2	35.4	36.7	38.3	39.9	41.7	43.5	45.4	47.3
60	32.0	32.1	32.6	33.3	34.3	35.4	36.8	38.4	40.1	41.9	43.7	45.7	47.6
65	32.1	32.3	32.7	33.4	34.4	35.6	37.0	38.6	40.3	42.2	44.1	46.1	48.1
70	32.4	32.5	33.0	33.7	34.7	35.9	37.3	38.9	40.7	42.5	44.5	46.5	48.6
75	32.7	32.9	33.3	34.0	35.0	36.3	37.7	39.3	41.1	43.0	45.0	47.0	49.1
80	33.1	33.3	33.7	34.5	35.5	36.7	38.2	39.8	41.6	43.5	45.5	47.6	49.8
85	33.6	33.7	34.2	34.9	36.0	37.2	38.7	40.3	42.2	44.1	46.2	48.3	50.4
90	34.1	34.3	34.7	35.5	36.5	37.8	39.2	40.9	42.8	44.7	46.8	49.0	51.2
95	34.7	34.8	35.3	36.0	37.1	38.4	39.9	41.5	43.4	45.4	47.5	49.7	51.9
100	35.3	35.4	35.9	36.6	37.7	39.0	40.5	42.2	44.1	46.1	48.2	50.5	52.7
105	35.9	36.1	36.5	37.3	38.3	39.6	41.2	42.9	44.8	46.8	49.0	51.2	53.5
110	36.6	36.7	37.2	38.0	39.0	40.3	41.9	43.6	45.5	47.6	49.8	52.0	54.4
115	37.3	37.4	37.9	38.7	39.7	41.1	42.6	44.4	46.3	48.4	50.6	52.9	55.2
120	38.0	38.1	38.6	39.4	40.5	41.8	43.4	45.1	47.1	49.2	51.4	53.7	56.1

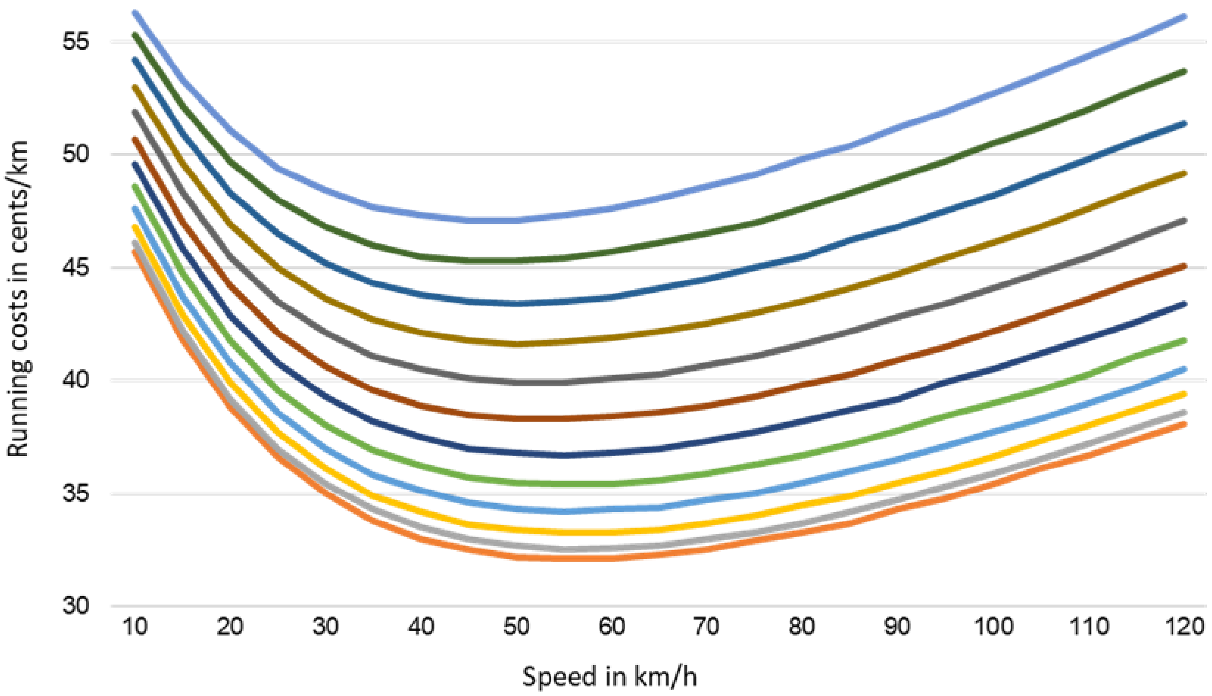

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Table A88: Rural other VOC by speed and gradient (cents/km – July 2015)

Speed	Gradient in percent (both directions)												
(km/h)	0	1	2	3	4	5	6	7	8	9	10	11	12
10	43.5	43.8	44.2	44.7	45.4	46.2	47.0	48.0	48.9	49.9	50.9	51.8	52.7
15	39.7	39.9	40.3	40.8	41.5	42.4	43.3	44.3	45.3	46.4	47.6	48.7	49.8
20	36.8	36.9	37.3	37.9	38.6	39.4	40.4	41.5	42.6	43.8	45.0	46.2	47.5
25	34.6	34.8	35.1	35.7	36.4	37.3	38.3	39.4	40.6	41.9	43.2	44.5	45.8
30	33.0	33.2	33.6	34.1	34.9	35.8	36.8	38.0	39.2	40.5	41.9	43.3	44.7
35	31.9	32.1	32.4	33.0	33.8	34.7	35.8	36.9	38.2	39.6	41.0	42.5	43.9
40	31.1	31.3	31.6	32.2	33.0	33.9	35.0	36.3	37.6	39.0	40.5	42.0	43.5
45	30.6	30.7	31.1	31.7	32.5	33.5	34.6	35.8	37.2	38.6	40.1	41.7	43.3
50	30.3	30.4	30.8	31.4	32.2	33.2	34.3	35.6	37.0	38.5	40.0	41.6	43.3
55	30.2	30.3	30.7	31.3	32.1	33.1	34.2	35.5	36.9	38.5	40.1	41.7	43.4
60	30.2	30.3	30.7	31.3	32.1	33.1	34.2	35.5	37.0	38.6	40.2	41.9	43.6
65	30.3	30.4	30.8	31.4	32.2	33.3	34.4	35.8	37.3	38.8	40.5	42.2	44.0
70	30.6	30.7	31.0	31.7	32.5	33.5	34.7	36.1	37.6	39.2	40.8	42.6	44.4
75	30.9	31.0	31.3	32.0	32.8	33.8	35.1	36.4	37.9	39.6	41.3	43.1	44.9
80	31.2	31.4	31.7	32.3	33.2	34.2	35.5	36.9	38.4	40.0	41.8	43.6	45.5
85	31.7	31.8	32.2	32.8	33.6	34.7	35.9	37.3	38.9	40.5	42.3	44.2	46.1
90	32.2	32.3	32.6	33.3	34.1	35.2	36.4	37.9	39.4	41.1	42.9	44.8	46.7
95	32.7	32.8	33.2	33.8	34.7	35.7	37.0	38.4	40.0	41.7	43.5	45.4	47.4
100	33.3	33.4	33.7	34.4	35.2	36.3	37.6	39.0	40.6	42.4	44.2	46.1	48.1
105	33.9	34.0	34.3	35.0	35.8	36.9	38.2	39.7	41.3	43.0	44.9	46.8	48.8
110	34.5	34.6	35.0	35.6	36.5	37.6	38.9	40.3	42.0	43.7	45.6	47.6	49.6
115	35.1	35.2	35.6	36.3	37.1	38.2	39.6	41.0	42.7	44.5	46.3	48.3	50.4
120	35.8	35.9	36.3	36.9	37.8	38.9	40.3	41.7	43.4	45.2	47.1	49.1	51.2

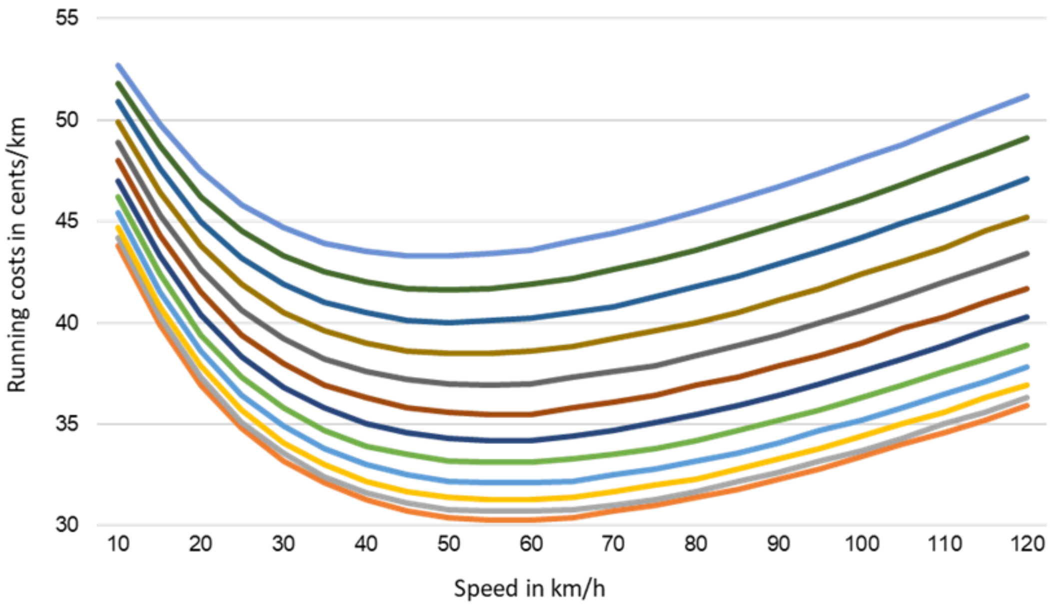

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Table A89: Urban additional VOC due to roughness by vehicle class (cents/km – July 2015)

Roughness		Additional VOC in cents/km by vehicle class					
IRI (m/km)	NAASRA (count/km)	Passenger car	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	0.7	0.9	1.4	0.8
3.5	92	0.8	0.7	2.3	3.1	4.4	2.8
4.0	106	1.6	1.4	4.7	6.3	8.5	5.7
4.5	119	2.7	2.6	7.6	10.2	13.6	9.1
5.0	132	4.0	4.2	10.9	14.7	19.3	12.9
5.5	145	5.5	6.0	14.5	19.6	25.4	16.9
6.0	158	7.1	8.1	18.3	24.7	31.9	21.2
6.5	172	8.8	10.3	22.2	30.0	38.6	25.5
7.0	185	10.5	12.6	26.1	35.4	45.3	29.8
7.5	198	12.3	14.9	30.1	40.8	52.1	34.1
8.0	211	14.1	17.2	34.0	46.2	58.8	38.5
8.5	224	15.8	19.5	37.9	51.6	65.5	42.7
9.0	238	17.5	21.7	41.8	56.8	72.2	46.9
9.5	251	19.2	23.9	45.6	62.0	78.7	51.1
10.0	264	20.8	26.0	49.2	67.1	85.0	55.2
10.5	277	22.4	28.0	52.8	72.0	91.3	59.2
11.0	290	23.3	29.0	55.0	74.9	95.4	61.7
11.5	304	24.1	29.8	57.1	77.5	99.3	64.2
12.0	317	24.9	30.6	59.1	80.1	103.1	66.6
12.5	330	25.6	31.5	61.1	82.7	107.0	69.0
13.0	343	26.4	32.3	63.1	85.3	110.8	71.4
13.5	356	27.2	33.1	65.2	87.9	114.6	73.8
14.0	370	28.0	33.9	67.2	90.6	118.5	76.2
14.5	383	28.7	34.7	69.2	93.2	122.3	78.6
15.0	396	29.5	35.5	71.2	95.8	126.1	81.0

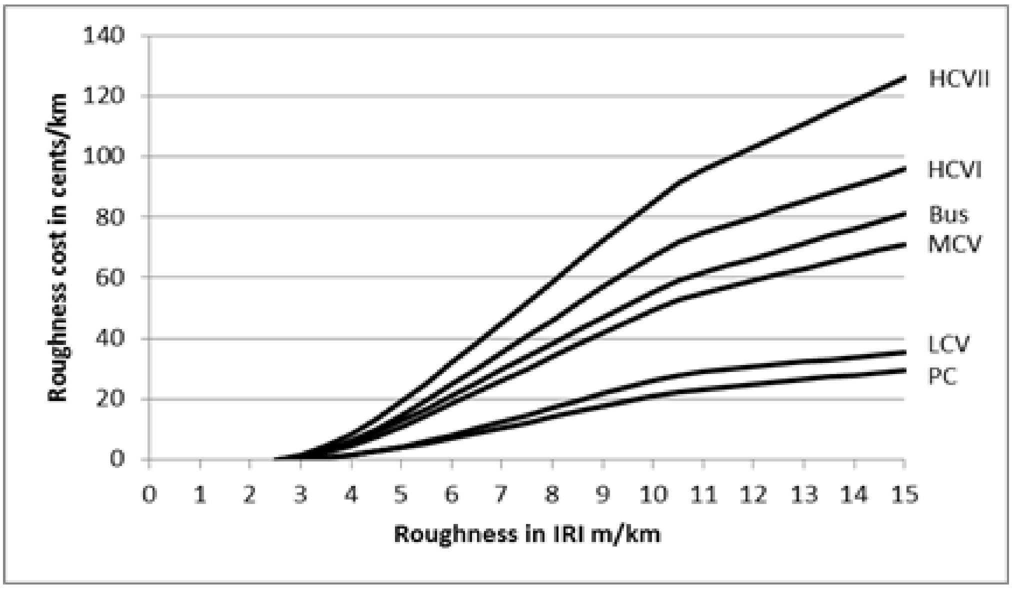

Table A90: Rural additional VOC due to roughness by vehicle class (cents/km – July 2015)

Roughness		Additional VOC in cents/km by vehicle class					
IRI (m/km)	NAASRA (count/km)	Passenger car	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	0.2	0.5	0.7	1.1	0.6
3.5	92	0.9	0.9	2.5	3.5	4.8	3.1
4.0	106	2.4	2.7	6.4	8.8	11.1	7.4
4.5	119	4.4	5.3	11.2	15.5	18.9	12.7
5.0	132	6.6	8.2	16.3	22.7	27.3	18.2
5.5	145	8.9	11.1	21.3	29.8	35.6	23.7
6.0	158	11.0	14.0	26.2	36.6	43.7	29.0
6.5	172	13.2	16.9	31.0	43.2	51.7	34.2
7.0	185	15.3	19.8	35.7	49.8	59.7	39.4
7.5	198	17.6	22.8	40.6	56.6	67.9	44.7
8.0	211	18.5	23.8	42.8	59.2	72.0	47.2
8.5	224	19.3	24.6	44.8	61.8	75.9	49.6
9.0	238	20.0	25.5	46.8	64.4	79.7	52.0
9.5	251	20.8	26.3	48.9	67.0	83.6	54.4
10.0	264	21.6	27.2	50.9	69.7	87.5	56.8
10.5	277	22.4	28.0	52.9	72.3	91.4	59.3
11.0	290	23.2	28.9	55.0	74.9	95.3	61.7
11.5	304	24.0	29.7	57.0	77.5	99.1	64.1
12.0	317	24.8	30.6	59.1	80.1	103.0	66.5
12.5	330	25.6	31.4	61.1	82.7	106.9	69.0
13.0	343	26.4	32.3	63.1	85.3	110.8	71.4
13.5	356	27.2	33.1	65.2	87.9	114.7	73.8
14.0	370	28.0	34.0	67.2	90.6	118.5	76.2
14.5	383	28.8	34.8	69.2	93.2	122.4	78.6
15.0	396	29.6	35.7	71.3	95.8	126.3	81.1

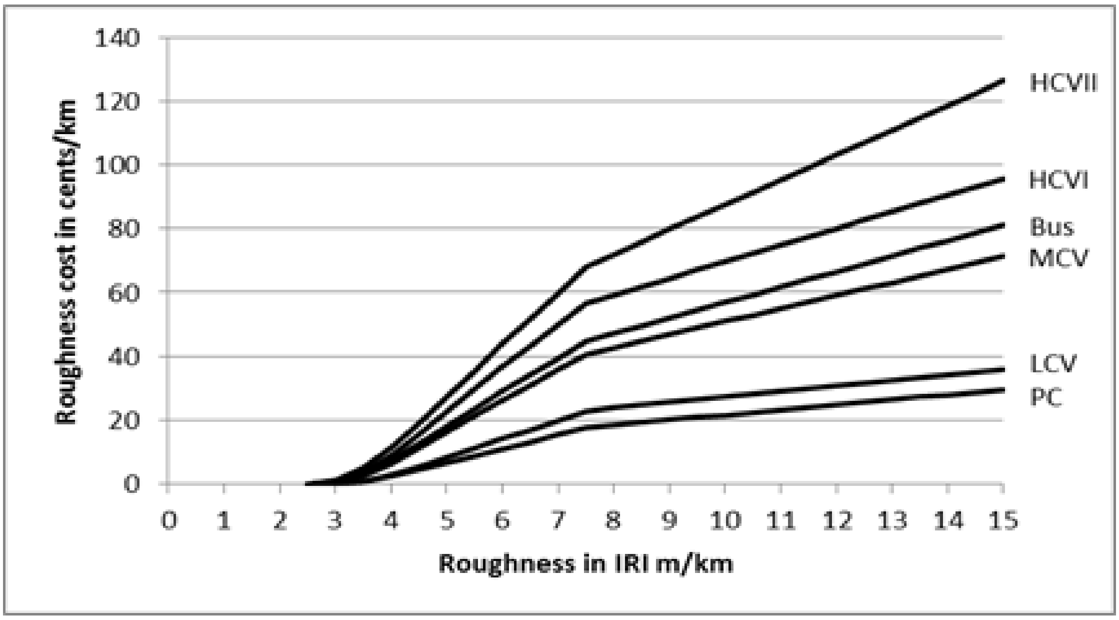

Table A91: Additional VOC due to roughness by road category (cents/km – July 2015)

Roughness		Additional VOC in cents/km by road category		
IRI (m/km)	NAASRA (count/km)	Urban	Rural strategic	Rural others
0–2.5	0–66	0.0	0.0	0.0
3.0	79	0.3	0.3	0.3
3.5	92	0.9	1.2	1.2
4.0	106	1.8	3.2	3.1
4.5	119	3.0	5.8	5.6
5.0	132	4.6	8.6	8.3
5.5	145	6.3	11.5	11.1
6.0	158	8.1	14.3	13.8
6.5	172	10.0	17.0	16.4
7.0	185	12.0	19.7	19.1
7.5	198	14.0	22.6	21.8
8.0	211	16.0	23.7	22.9
8.5	224	18.0	24.8	23.9
9.0	238	19.9	25.8	24.9
9.5	251	21.8	26.9	25.9
10.0	264	23.7	27.9	26.9
10.5	277	25.4	29.0	27.9
11.0	290	26.5	30.0	28.9
11.5	304	27.3	31.1	29.9
12.0	317	28.2	32.1	30.9
12.5	330	29.1	33.1	31.9
13.0	343	30.0	34.2	32.9
13.5	356	30.9	35.2	33.9
14.0	370	31.8	36.3	34.9
14.5	383	32.7	37.3	35.9
15.0	396	33.5	38.4	36.9

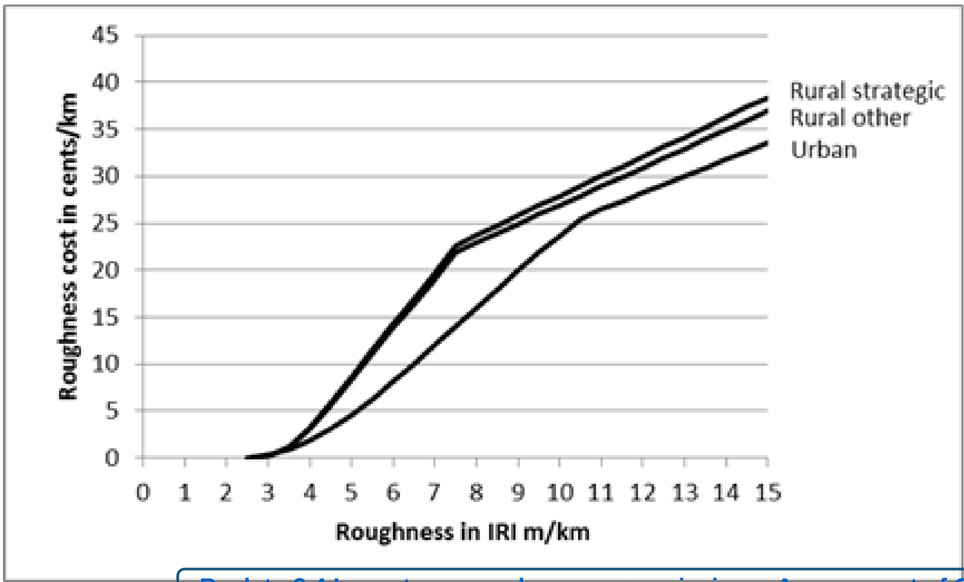

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Table A92: Urban arterial and urban other – additional VOC due to congestion by vehicle class (cents/km – July 2015)

VC ratio	Additional VOC in cents/km by vehicle class					
	Passenger car	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	0.2	0.5	0.1
0.10	0.0	0.0	0.1	0.3	1.0	0.2
0.15	0.0	0.1	0.2	0.6	1.7	0.3
0.20	0.0	0.1	0.3	0.8	2.5	0.4
0.25	0.1	0.2	0.4	1.2	3.5	0.6
0.30	0.1	0.2	0.5	1.6	4.7	0.9
0.35	0.1	0.3	0.7	2.1	6.1	1.1
0.40	0.2	0.4	0.9	2.7	7.8	1.5
0.45	0.2	0.5	1.1	3.4	9.9	1.9
0.50	0.3	0.7	1.4	4.2	12.3	2.4
0.55	0.4	0.9	1.7	5.3	15.3	3.0
0.60	0.5	1.2	2.2	6.5	18.8	3.8
0.65	0.7	1.5	2.7	8.0	23.0	4.7
0.70	1.0	1.9	3.3	9.9	28.1	5.8
0.75	1.3	2.5	4.1	12.1	34.2	7.3
0.80	1.7	3.2	5.0	14.8	41.5	9.0
0.85	2.2	4.1	6.2	18.0	50.3	11.1
0.90	2.9	5.2	7.6	21.9	60.8	13.7
0.95	3.8	6.6	9.0	26.0	69.5	16.8
1.00	4.4	7.1	9.0	26.0	69.5	16.8
1.05	4.4	7.1	9.0	26.0	69.5	16.8
1.10	4.4	7.1	9.0	26.0	69.5	16.8
1.15	4.4	7.1	9.0	26.0	69.5	16.8
1.20	4.4	7.1	9.0	26.0	69.5	16.8

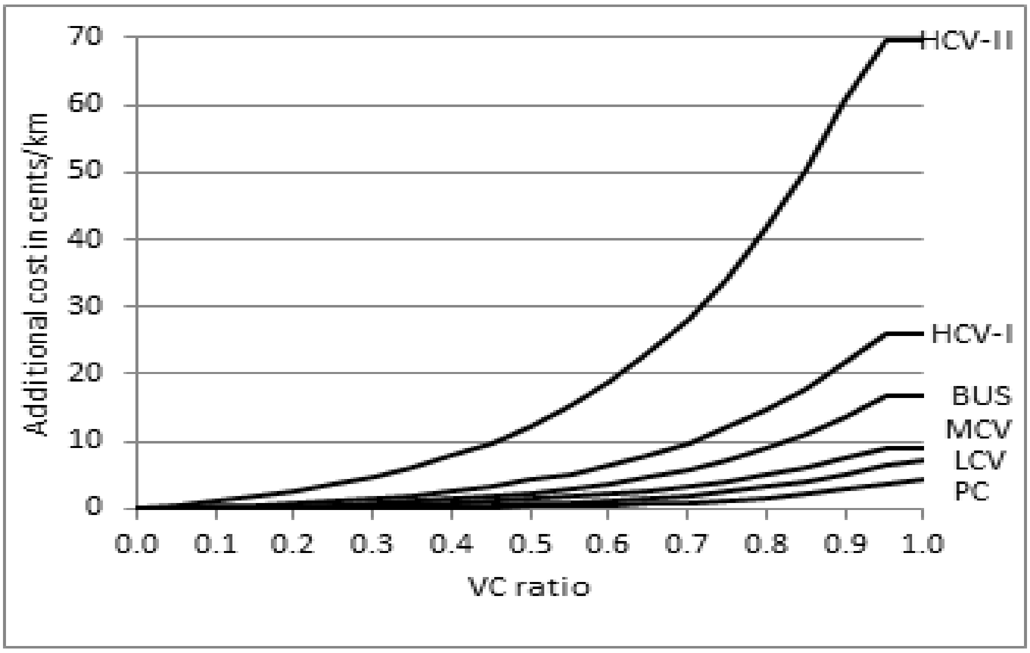

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Table A93: Rural strategic and rural other – additional VOC due to congestion by vehicle class (cents/km – July 2015)

VC ratio	Additional VOC in cents/km by vehicle class					
	Passenger car	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	0.1	0.3	1.0	0.1
0.10	0.0	0.0	0.2	0.5	2.2	0.1
0.15	0.0	0.0	0.3	0.9	3.5	0.2
0.20	0.0	0.0	0.4	1.2	4.9	0.3
0.25	0.0	0.0	0.5	1.7	6.6	0.5
0.30	0.0	0.0	0.7	2.2	8.4	0.6
0.35	0.0	0.0	0.9	2.7	10.5	0.8
0.40	0.0	0.0	1.1	3.4	12.9	1.0
0.45	0.0	0.0	1.3	4.1	15.5	1.3
0.50	0.0	0.0	1.6	4.9	18.5	1.7
0.55	0.0	0.0	1.9	5.9	21.9	2.1
0.60	0.1	0.0	2.2	7.0	25.7	2.6
0.65	0.1	0.0	2.6	8.2	30.0	3.2
0.70	0.2	0.1	3.1	9.6	34.8	3.9
0.75	0.3	0.2	3.6	11.2	40.2	4.8
0.80	0.5	0.4	4.2	13.1	46.4	5.8
0.85	0.8	0.7	4.9	15.2	53.3	7.1
0.90	1.3	1.5	5.7	17.6	61.1	8.6
0.95	2.2	3.0	6.7	20.4	69.8	10.5
1.00	3.7	6.0	7.5	23.5	70.6	12.7
1.05	3.9	6.0	7.5	24.2	70.6	13.1
1.10	3.9	6.0	7.5	24.2	70.6	13.1
1.15	3.9	6.0	7.5	24.2	70.6	13.1
1.20	3.9	6.0	7.5	24.2	70.6	13.1

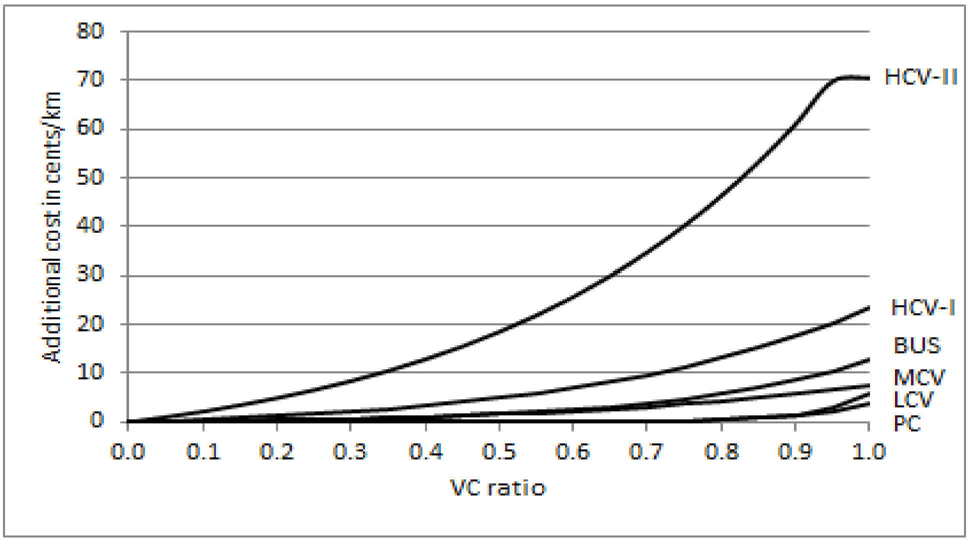

Table A94: Motorway – additional VOC due to congestion by vehicle class (cents/km – July 2015)

VC ratio	Additional VOC in cents/km by vehicle class					
	Passenger car	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	0.1	0.0
0.10	0.0	0.0	0.0	0.0	0.2	0.0
0.15	0.0	0.0	0.0	0.0	0.3	0.0
0.20	0.0	0.0	0.0	0.1	0.4	0.0
0.25	0.0	0.0	0.0	0.1	0.6	0.0
0.30	0.0	0.0	0.1	0.2	0.9	0.0
0.35	0.0	0.0	0.1	0.2	1.4	0.0
0.40	0.0	0.0	0.1	0.3	1.9	0.0
0.45	0.0	0.0	0.2	0.5	2.7	0.1
0.50	0.0	0.0	0.2	0.7	3.7	0.1
0.55	0.0	0.0	0.3	1.0	5.1	0.2
0.60	0.0	0.0	0.5	1.4	7.1	0.3
0.65	0.0	0.0	0.7	2.1	9.7	0.5
0.70	0.0	0.0	1.0	3.0	13.3	0.8
0.75	0.0	0.0	1.4	4.2	18.2	1.2
0.80	0.0	0.0	2.1	6.0	24.9	2.0
0.85	0.1	0.1	2.9	8.6	34.0	3.1
0.90	0.3	0.3	4.2	12.3	46.4	4.9
0.95	0.9	1.1	6.0	17.6	63.4	7.7
1.00	3.1	4.8	7.2	23.1	70.0	12.1
1.05	3.3	5.0	7.2	23.1	70.0	12.1
1.10	3.3	5.0	7.2	23.1	70.0	12.1
1.15	3.3	5.0	7.2	23.1	70.0	12.1
1.20	3.3	5.0	7.2	23.1	70.0	12.1

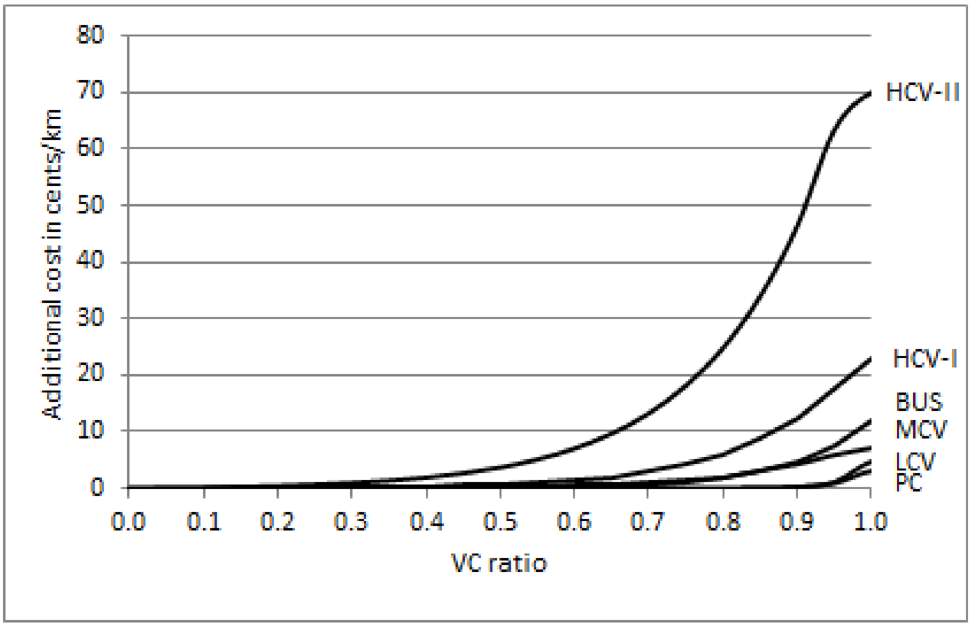

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Table A95: Additional VOC due to congestion by road category (cents/km – July 2015)

VC ratio	Additional cost in cents/km			
	Urban	Rural two-lane strategic	Rural two-lane other	Motorway
0.00	0.0	0.0	0.0	0.0
0.05	0.0	0.1	0.0	0.0
0.10	0.1	0.1	0.1	0.0
0.15	0.1	0.2	0.1	0.0
0.20	0.2	0.3	0.2	0.0
0.25	0.3	0.4	0.3	0.0
0.30	0.4	0.5	0.4	0.0
0.35	0.5	0.6	0.5	0.0
0.40	0.7	0.8	0.6	0.1
0.45	0.9	0.9	0.8	0.1
0.50	1.1	1.2	0.9	0.1
0.55	1.5	1.4	1.2	0.2
0.60	1.8	1.7	1.4	0.3
0.65	2.3	2.1	1.7	0.4
0.70	2.9	2.5	2.1	0.7
0.75	3.7	2.9	2.5	1.0
0.80	4.6	3.5	3.0	1.4
0.85	5.7	4.2	3.6	2.1
0.90	7.2	4.9	4.3	3.2
0.95	8.9	5.8	5.1	4.7
1.00	9.2	6.9	6.1	6.9
1.05	9.2	7.7	7.0	7.1
1.10	9.2	7.7	7.0	7.1
1.15	9.2	7.7	7.0	7.1
1.20	9.2	7.7	7.0	7.1

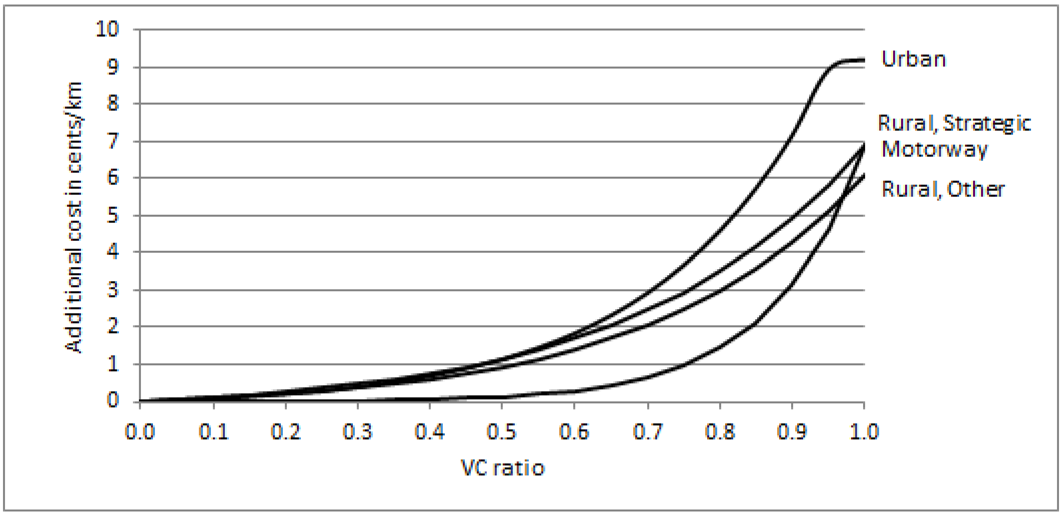

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Table A96: Passenger car additional travel time due to speed change cycles (seconds/speed cycle)

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 A97: Passenger car additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.1																							
10	0.1	0.0																						
15	0.2	0.1	0.0																					
20	0.3	0.2	0.1	0.0																				
25	0.4	0.3	0.2	0.1	0.1																			
30	0.5	0.4	0.3	0.2	0.1	0.1																		
35	0.6	0.5	0.4	0.3	0.2	0.1	0.1																	
40	0.7	0.6	0.6	0.5	0.4	0.2	0.1	0.1																
45	0.9	0.8	0.7	0.6	0.5	0.4	0.2	0.1	0.1															
50	1.0	0.9	0.9	0.8	0.7	0.5	0.4	0.3	0.1	0.1														
55	1.2	1.1	1.0	0.9	0.8	0.7	0.5	0.4	0.3	0.1	0.1													
60	1.3	1.3	1.2	1.1	1.0	0.8	0.7	0.5	0.4	0.3	0.1	0.1												
65	1.5	1.5	1.4	1.3	1.2	1.0	0.9	0.7	0.6	0.4	0.3	0.1	0.1											
70	1.7	1.6	1.6	1.5	1.4	1.2	1.0	0.9	0.7	0.6	0.4	0.3	0.1	0.1										
75	1.9	1.8	1.8	1.7	1.6	1.4	1.2	1.1	0.9	0.7	0.6	0.4	0.3	0.1	0.1									
80	2.1	2.0	2.0	1.9	1.7	1.6	1.4	1.3	1.1	0.9	0.8	0.6	0.4	0.3	0.1	0.1								
85	2.3	2.3	2.2	2.1	1.9	1.8	1.6	1.5	1.3	1.1	0.9	0.8	0.6	0.5	0.3	0.1	0.0							
90	2.5	2.5	2.4	2.3	2.2	2.0	1.8	1.6	1.5	1.3	1.1	1.0	0.8	0.6	0.5	0.3	0.1	0.0						
95	2.8	2.7	2.6	2.5	2.4	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.5	0.3	0.1	0.0					
100	3.0	2.9	2.8	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.5	0.3	0.1	0.0				
105	3.2	3.1	3.0	2.9	2.8	2.6	2.4	2.2	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.5	0.3	0.1	0.0			
110	3.5	3.4	3.3	3.1	3.0	2.8	2.6	2.4	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.4	0.3	0.1	0.0		
115	3.7	3.6	3.5	3.3	3.2	3.0	2.8	2.6	2.4	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.4	0.3	0.1	0.0	
120	3.9	3.8	3.7	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.3	1.1	1.0	0.8	0.6	0.4	0.3	0.1	0.0

Table A98: 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 A99: LCV additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.5	0.3	0.2	0.1																			
30	0.8	0.6	0.5	0.4	0.2	0.1																		
35	1.0	0.9	0.7	0.6	0.4	0.2	0.1																	
40	1.2	1.1	0.9	0.8	0.6	0.4	0.3	0.1																
45	1.4	1.3	1.2	1.0	0.8	0.6	0.4	0.3	0.1															
50	1.7	1.6	1.4	1.3	1.1	0.9	0.6	0.5	0.3	0.1														
55	1.9	1.8	1.7	1.6	1.4	1.1	0.9	0.7	0.5	0.3	0.1													
60	2.2	2.1	2.0	1.8	1.7	1.4	1.2	0.9	0.7	0.5	0.3	0.1												
65	2.5	2.4	2.3	2.1	1.9	1.7	1.5	1.2	1.0	0.7	0.5	0.3	0.1											
70	2.8	2.7	2.6	2.4	2.3	2.0	1.8	1.5	1.3	1.0	0.8	0.5	0.3	0.1										
75	3.2	3.1	2.9	2.8	2.6	2.3	2.1	1.8	1.6	1.3	1.0	0.8	0.5	0.3	0.1									
80	3.5	3.4	3.3	3.1	2.9	2.6	2.4	2.1	1.9	1.6	1.3	1.1	0.8	0.5	0.3	0.1								
85	3.8	3.7	3.6	3.4	3.2	3.0	2.7	2.4	2.2	1.9	1.6	1.4	1.1	0.8	0.5	0.3	0.1							
90	4.2	4.1	3.9	3.7	3.5	3.3	3.0	2.7	2.5	2.2	1.9	1.7	1.4	1.1	0.8	0.6	0.3	0.1						
95	4.6	4.4	4.3	4.1	3.9	3.6	3.3	3.0	2.8	2.5	2.2	1.9	1.7	1.4	1.1	0.8	0.6	0.3	0.1					
100	4.9	4.8	4.6	4.4	4.2	3.9	3.6	3.4	3.1	2.8	2.5	2.2	2.0	1.7	1.4	1.1	0.8	0.5	0.3	0.1				
105	5.3	5.1	4.9	4.7	4.5	4.2	3.9	3.6	3.4	3.1	2.8	2.5	2.2	1.9	1.7	1.4	1.1	0.8	0.5	0.3	0.1			
110	5.6	5.5	5.3	5.1	4.8	4.5	4.2	3.9	3.6	3.3	3.1	2.8	2.5	2.2	1.9	1.6	1.4	1.1	0.8	0.5	0.3	0.1		
115	6.0	5.8	5.6	5.4	5.1	4.8	4.5	4.2	3.9	3.6	3.3	3.0	2.7	2.4	2.2	1.9	1.6	1.3	1.1	0.8	0.5	0.2	0.1	
120	6.3	6.1	5.9	5.7	5.4	5.1	4.7	4.4	4.1	3.8	3.5	3.2	2.9	2.7	2.4	2.1	1.8	1.6	1.3	1.0	0.7	0.5	0.2	0.1

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Table A100: 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

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Table A101: MCV additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.4	0.2																						
15	0.7	0.4	0.2																					
20	1.0	0.8	0.5	0.3																				
25	1.5	1.3	1.0	0.7	0.3																			
30	2.0	1.8	1.5	1.2	0.8	0.4																		
35	2.7	2.4	2.2	1.8	1.4	1.0	0.5																	
40	3.4	3.2	2.9	2.5	2.1	1.6	1.1	0.5																
45	4.2	4.0	3.7	3.3	2.9	2.3	1.8	1.2	0.6															
50	5.2	4.9	4.6	4.2	3.8	3.2	2.6	2.0	1.3	0.7														
55	6.2	6.0	5.7	5.3	4.8	4.2	3.5	2.8	2.1	1.4	0.7													
60	7.4	7.1	6.8	6.4	5.9	5.3	4.6	3.9	3.1	2.3	1.5	0.7												
65	8.6	8.4	8.0	7.6	7.1	6.5	5.8	5.1	4.3	3.4	2.5	1.6	0.8											
70	9.9	9.7	9.4	8.9	8.4	7.8	7.1	6.3	5.5	4.6	3.7	2.7	1.7	0.8										
75	11.4	11.1	10.8	10.3	9.8	9.2	8.5	7.7	6.9	6.0	5.0	4.0	2.9	1.8	0.8									
80	12.9	12.7	12.3	11.8	11.3	10.6	9.9	9.1	8.3	7.4	6.4	5.3	4.2	3.1	1.9	0.8								
85	14.6	14.3	13.9	13.4	12.9	12.2	11.5	10.7	9.8	8.9	7.9	6.8	5.7	4.5	3.3	2.0	0.8							
90	16.3	16.0	15.6	15.1	14.5	13.9	13.1	12.3	11.4	10.5	9.5	8.4	7.2	6.0	4.8	3.4	2.1	0.8						
95	18.2	17.8	17.4	16.9	16.3	15.6	14.8	14.0	13.1	12.1	11.1	10.0	8.9	7.7	6.4	5.0	3.6	2.2	0.8					
100	20.1	19.7	19.3	18.8	18.1	17.4	16.6	15.8	14.9	13.9	12.9	11.8	10.6	9.3	8.0	6.7	5.3	3.8	2.3	0.9				
105	22.2	21.8	21.3	20.7	20.1	19.3	18.5	17.6	16.7	15.7	14.7	13.5	12.4	11.1	9.8	8.4	7.0	5.5	3.9	2.4	0.9			
110	24.3	23.9	23.4	22.8	22.1	21.3	20.5	19.6	18.6	17.6	16.6	15.4	14.2	13.0	11.6	10.3	8.8	7.3	5.7	4.1	2.5	0.9		
115	26.5	26.1	25.5	24.9	24.2	23.4	22.5	21.6	20.6	19.6	18.5	17.4	16.1	14.9	13.5	12.2	10.7	9.2	7.6	5.9	4.2	2.5	0.9	
120	28.9	28.4	27.8	27.1	26.4	25.5	24.6	23.7	22.7	21.6	20.5	19.4	18.1	16.8	15.5	14.1	12.6	11.1	9.5	7.9	6.1	4.4	2.6	0.9

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Table A102: 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 A103: HCVI additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.6	0.3																						
15	1.1	0.8	0.4																					
20	1.7	1.4	0.9	0.5																				
25	2.7	2.3	1.8	1.3	0.6																			
30	3.8	3.4	3.0	2.3	1.6	0.8																		
35	5.1	4.7	4.2	3.6	2.8	1.9	0.9																	
40	6.5	6.2	5.7	5.0	4.2	3.2	2.1	1.0																
45	8.3	7.9	7.3	6.6	5.7	4.7	3.5	2.4	1.2															
50	10.2	9.8	9.3	8.5	7.5	6.3	5.1	3.9	2.6	1.3														
55	12.4	12.0	11.4	10.6	9.7	8.4	7.1	5.6	4.2	2.8	1.4													
60	14.7	14.3	13.8	13.0	12.0	10.7	9.3	7.8	6.2	4.5	3.0	1.4												
65	17.3	16.9	16.3	15.5	14.5	13.2	11.8	10.2	8.6	6.8	4.9	3.1	1.5											
70	20.1	19.6	19.0	18.2	17.2	15.8	14.4	12.8	11.1	9.3	7.4	5.4	3.3	1.6										
75	23.0	22.6	21.9	21.1	20.0	18.7	17.2	15.6	13.9	12.0	10.1	8.0	5.8	3.5	1.6									
80	26.2	25.7	25.0	24.2	23.1	21.7	20.2	18.6	16.8	14.9	12.9	10.8	8.5	6.2	3.7	1.6								
85	29.5	29.0	28.3	27.4	26.3	24.9	23.4	21.7	20.0	18.0	16.0	13.8	11.5	9.1	6.5	4.0	1.6							
90	33.1	32.6	31.8	30.9	29.7	28.3	26.7	25.1	23.2	21.3	19.2	17.0	14.7	12.2	9.6	6.9	4.2	1.6						
95	36.9	36.3	35.5	34.5	33.3	31.9	30.3	28.5	26.7	24.7	22.6	20.4	18.0	15.5	12.9	10.1	7.3	4.4	1.6					
100	40.8	40.2	39.4	38.3	37.1	35.6	34.0	32.2	30.3	28.3	26.2	23.9	21.5	19.0	16.3	13.5	10.6	7.6	4.6	1.7				
105	45.0	44.3	43.4	42.3	41.0	39.5	37.8	36.0	34.1	32.0	29.9	27.6	25.2	22.6	19.9	17.1	14.2	11.1	8.0	4.8	1.7			
110	49.4	48.6	47.6	46.5	45.2	43.6	41.8	40.0	38.0	35.9	33.7	31.4	29.0	26.4	23.7	20.9	17.9	14.8	11.6	8.3	4.9	1.8		
115	53.9	53.1	52.1	50.9	49.5	47.8	46.0	44.1	42.1	40.0	37.7	35.4	32.9	30.3	27.6	24.7	21.7	18.6	15.4	12.0	8.6	5.1	1.8	
120	58.7	57.8	56.7	55.4	53.9	52.2	50.4	48.4	46.3	44.2	41.9	39.5	37.0	34.4	31.6	28.7	25.7	22.6	19.4	16.0	12.5	8.9	5.3	1.9

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Table A104: 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 A105: HCVII additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	1.1	0.6																						
15	2.2	1.7	0.9																					
20	3.7	3.2	2.3	1.2																				
25	5.8	5.3	4.4	3.2	1.7																			
30	8.4	7.8	6.9	5.6	4.0	2.1																		
35	11.4	10.8	9.9	8.6	6.9	4.8	2.4																	
40	14.9	14.3	13.3	12.0	10.2	8.0	5.5	2.8																
45	19.3	18.6	17.4	15.9	14.1	11.8	9.2	6.3	3.2															
50	24.3	23.6	22.4	20.8	18.7	16.1	13.4	10.4	7.1	3.6														
55	29.9	29.2	28.0	26.3	24.2	21.6	18.5	15.1	11.5	7.8	3.9													
60	36.2	35.5	34.2	32.5	30.3	27.6	24.5	20.9	17.0	12.7	8.5	4.2												
65	43.2	42.4	41.1	39.4	37.1	34.3	31.1	27.5	23.4	19.0	14.1	9.2	4.6											
70	50.9	50.0	48.7	46.9	44.6	41.7	38.4	34.7	30.6	26.0	21.0	15.6	9.9	4.8										
75	59.3	58.4	57.0	55.1	52.7	49.8	46.4	42.6	38.4	33.7	28.6	23.0	17.1	10.9	5.1									
80	68.5	67.5	66.0	64.1	61.6	58.6	55.2	51.3	46.9	42.1	36.9	31.2	25.1	18.6	11.8	5.4								
85	78.5	77.4	75.8	73.8	71.3	68.2	64.6	60.6	56.2	51.3	45.9	40.1	33.9	27.2	20.1	12.7	5.6							
90	89.3	88.1	86.4	84.3	81.6	78.5	74.8	70.7	66.2	61.2	55.8	49.8	43.4	36.6	29.3	21.7	13.7	5.8						
95	100.9	99.6	97.8	95.6	92.8	89.5	85.8	81.6	77.0	71.9	66.3	60.3	53.8	46.8	39.4	31.5	23.2	14.7	6.1					
100	113.4	112.0	110.1	107.7	104.9	101.4	97.6	93.3	88.6	83.4	77.7	71.5	64.9	57.8	50.2	42.2	33.7	24.8	15.6	6.5				
105	126.8	125.2	123.2	120.7	117.7	114.2	110.2	105.8	100.9	95.6	89.8	83.6	76.8	69.6	61.9	53.7	45.0	35.9	26.4	16.6	6.9			
110	141.1	139.4	137.2	134.6	131.5	127.8	123.7	119.1	114.1	108.7	102.8	96.4	89.5	82.2	74.4	66.0	57.2	47.9	38.2	28.0	17.6	7.3		
115	156.4	154.5	152.2	149.4	146.1	142.3	138.0	133.3	128.2	122.6	116.6	110.1	103.1	95.6	87.6	79.2	70.2	60.8	50.9	40.5	29.7	18.6	7.7	
120	172.7	170.6	168.1	165.2	161.7	157.7	153.3	148.4	143.2	137.4	131.2	124.6	117.5	109.9	101.8	93.2	84.1	74.5	64.4	53.8	42.8	31.3	19.6	8.1

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Table A106: 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

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Table A107: Bus additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.6	0.3																					
20	1.3	1.1	0.8	0.4																				
25	2.0	1.7	1.4	1.0	0.5																			
30	2.7	2.5	2.1	1.7	1.2	0.6																		
35	3.6	3.3	3.0	2.5	2.0	1.4	0.7																	
40	4.5	4.3	3.9	3.5	2.9	2.3	1.5	0.8																
45	5.7	5.4	5.0	4.5	3.9	3.3	2.5	1.7	0.9															
50	7.0	6.7	6.3	5.8	5.1	4.4	3.6	2.7	1.9	0.9														
55	8.4	8.1	7.7	7.2	6.5	5.7	4.9	3.9	2.9	2.0	1.0													
60	10.0	9.7	9.3	8.7	8.0	7.2	6.3	5.3	4.3	3.1	2.1	1.0												
65	11.7	11.4	10.9	10.3	9.6	8.8	7.9	6.9	5.8	4.6	3.4	2.2	1.1											
70	13.5	13.2	12.7	12.1	11.4	10.5	9.6	8.6	7.5	6.3	5.0	3.6	2.2	1.1										
75	15.5	15.1	14.6	14.0	13.2	12.4	11.4	10.4	9.2	8.0	6.7	5.3	3.9	2.3	1.1									
80	17.6	17.1	16.6	15.9	15.2	14.3	13.3	12.3	11.1	9.9	8.6	7.1	5.6	4.1	2.5	1.0								
85	19.7	19.3	18.7	18.0	17.2	16.3	15.3	14.3	13.1	11.8	10.5	9.1	7.5	6.0	4.3	2.6	1.0							
90	22.1	21.6	20.9	20.2	19.4	18.5	17.4	16.3	15.1	13.9	12.5	11.1	9.5	7.9	6.2	4.5	2.7	1.0						
95	24.5	23.9	23.3	22.5	21.7	20.7	19.6	18.5	17.3	16.0	14.6	13.2	11.6	10.0	8.3	6.5	4.7	2.8	1.0					
100	27.0	26.4	25.7	24.9	24.0	23.0	21.9	20.7	19.5	18.2	16.8	15.3	13.8	12.1	10.4	8.6	6.8	4.8	2.8	1.0				
105	29.7	29.0	28.2	27.4	26.4	25.4	24.2	23.0	21.8	20.4	19.0	17.5	16.0	14.3	12.6	10.8	8.9	7.0	5.0	2.9	1.0			
110	32.4	31.7	30.9	30.0	28.9	27.8	26.7	25.4	24.1	22.7	21.3	19.8	18.2	16.6	14.8	13.1	11.2	9.2	7.2	5.1	3.0	1.0		
115	35.3	34.5	33.6	32.6	31.5	30.4	29.1	27.8	26.5	25.1	23.6	22.1	20.5	18.8	17.1	15.3	13.4	11.5	9.5	7.4	5.2	3.0	1.0	
120	38.2	37.3	36.3	35.3	34.2	32.9	31.6	30.3	28.9	27.5	26.0	24.4	22.8	21.1	19.4	17.6	15.7	13.8	11.8	9.7	7.5	5.3	3.0	1.0

Table A108: 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

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Table A109: Urban arterial additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.2	0.1																				
25	0.5	0.4	0.3	0.2	0.1																			
30	0.7	0.6	0.5	0.4	0.3	0.1																		
35	0.9	0.8	0.7	0.6	0.4	0.3	0.1																	
40	1.2	1.1	1.0	0.8	0.7	0.5	0.3	0.1																
45	1.4	1.3	1.2	1.1	0.9	0.7	0.5	0.3	0.2															
50	1.7	1.6	1.5	1.4	1.2	1.0	0.7	0.5	0.3	0.2														
55	2.0	1.9	1.8	1.7	1.5	1.3	1.0	0.8	0.6	0.4	0.2													
60	2.4	2.3	2.2	2.0	1.9	1.6	1.4	1.1	0.9	0.6	0.4	0.2												
65	2.8	2.7	2.6	2.4	2.2	2.0	1.7	1.5	1.2	0.9	0.7	0.4	0.2											
70	3.2	3.1	2.9	2.8	2.6	2.4	2.1	1.9	1.6	1.3	1.0	0.7	0.4	0.2										
75	3.6	3.5	3.4	3.2	3.0	2.8	2.5	2.3	2.0	1.7	1.4	1.1	0.7	0.4	0.2									
80	4.0	3.9	3.8	3.7	3.5	3.2	3.0	2.7	2.4	2.1	1.8	1.5	1.1	0.8	0.5	0.2								
85	4.5	4.4	4.3	4.1	3.9	3.7	3.4	3.1	2.8	2.5	2.2	1.9	1.5	1.2	0.8	0.5	0.2							
90	5.0	4.9	4.8	4.6	4.4	4.1	3.9	3.6	3.3	3.0	2.7	2.3	2.0	1.6	1.2	0.9	0.5	0.2						
95	5.6	5.4	5.3	5.1	4.9	4.6	4.4	4.1	3.8	3.5	3.1	2.8	2.4	2.1	1.7	1.3	0.9	0.5	0.2					
100	6.1	6.0	5.8	5.7	5.4	5.2	4.9	4.6	4.3	3.9	3.6	3.3	2.9	2.5	2.2	1.8	1.4	1.0	0.6	0.2				
105	6.7	6.6	6.4	6.2	6.0	5.7	5.4	5.1	4.8	4.5	4.1	3.8	3.4	3.0	2.6	2.2	1.8	1.4	1.0	0.6	0.2			
110	7.3	7.2	7.0	6.8	6.5	6.3	5.9	5.6	5.3	5.0	4.6	4.3	3.9	3.5	3.1	2.7	2.3	1.9	1.5	1.0	0.6	0.2		
115	7.9	7.8	7.6	7.4	7.1	6.8	6.5	6.2	5.9	5.5	5.2	4.8	4.4	4.0	3.6	3.2	2.8	2.4	1.9	1.5	1.0	0.6	0.2	
120	8.6	8.4	8.2	8.0	7.7	7.4	7.1	6.8	6.4	6.1	5.7	5.3	5.0	4.6	4.2	3.8	3.3	2.9	2.5	2.0	1.5	1.1	0.6	0.2

Table A110: 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

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Table A111: Urban other additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.1	0.1																					
20	0.4	0.2	0.1	0.1																				
25	0.5	0.4	0.3	0.2	0.1																			
30	0.7	0.6	0.5	0.4	0.2	0.1																		
35	0.9	0.8	0.7	0.6	0.4	0.3	0.1																	
40	1.1	1.0	0.9	0.8	0.6	0.4	0.3	0.1																
45	1.3	1.2	1.1	1.0	0.8	0.7	0.5	0.3	0.1															
50	1.6	1.5	1.4	1.3	1.1	0.9	0.7	0.5	0.3	0.1														
55	1.9	1.8	1.7	1.6	1.4	1.2	0.9	0.7	0.5	0.3	0.2													
60	2.2	2.1	2.0	1.9	1.7	1.5	1.3	1.0	0.8	0.5	0.3	0.2												
65	2.5	2.5	2.4	2.2	2.0	1.8	1.6	1.3	1.1	0.8	0.6	0.4	0.2											
70	2.9	2.8	2.7	2.6	2.4	2.2	1.9	1.7	1.4	1.2	0.9	0.6	0.4	0.2										
75	3.3	3.2	3.1	2.9	2.8	2.5	2.3	2.0	1.8	1.5	1.2	0.9	0.7	0.4	0.2									
80	3.7	3.6	3.5	3.3	3.2	2.9	2.7	2.4	2.1	1.9	1.6	1.3	1.0	0.7	0.4	0.2								
85	4.1	4.0	3.9	3.7	3.6	3.3	3.1	2.8	2.5	2.3	2.0	1.7	1.4	1.0	0.7	0.4	0.2							
90	4.6	4.5	4.3	4.2	4.0	3.7	3.5	3.2	2.9	2.7	2.4	2.1	1.7	1.4	1.1	0.8	0.4	0.2						
95	5.0	4.9	4.8	4.6	4.4	4.2	3.9	3.6	3.4	3.1	2.8	2.5	2.1	1.8	1.5	1.1	0.8	0.4	0.2					
100	5.5	5.4	5.3	5.1	4.9	4.6	4.4	4.1	3.8	3.5	3.2	2.9	2.6	2.2	1.9	1.5	1.2	0.8	0.5	0.2				
105	6.0	5.9	5.7	5.6	5.4	5.1	4.8	4.5	4.2	3.9	3.6	3.3	3.0	2.6	2.3	1.9	1.6	1.2	0.8	0.5	0.2			
110	6.5	6.4	6.2	6.1	5.8	5.6	5.3	5.0	4.7	4.4	4.1	3.7	3.4	3.1	2.7	2.4	2.0	1.6	1.2	0.9	0.5	0.2		
115	7.1	6.9	6.8	6.6	6.3	6.0	5.8	5.5	5.1	4.8	4.5	4.2	3.9	3.5	3.2	2.8	2.4	2.0	1.7	1.3	0.9	0.5	0.2	
120	7.6	7.5	7.3	7.1	6.8	6.5	6.2	5.9	5.6	5.3	5.0	4.6	4.3	3.9	3.6	3.2	2.9	2.5	2.1	1.7	1.3	0.9	0.5	0.2

Table A112: 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

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Table A113: Rural strategic additional VOC due to speed change cycles (cents/speed cycle – July 2015)

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	0.5	0.4	0.2	0.1																				
25	0.7	0.6	0.5	0.3	0.2																			
30	1.0	0.9	0.7	0.6	0.4	0.2																		
35	1.3	1.2	1.1	0.9	0.7	0.4	0.2																	
40	1.7	1.6	1.4	1.2	1.0	0.7	0.5	0.2																
45	2.1	2.0	1.8	1.6	1.4	1.1	0.8	0.5	0.3															
50	2.5	2.4	2.3	2.1	1.8	1.5	1.2	0.9	0.6	0.3														
55	3.0	2.9	2.8	2.6	2.3	2.0	1.7	1.3	1.0	0.6	0.3													
60	3.6	3.5	3.3	3.1	2.9	2.5	2.2	1.8	1.4	1.0	0.7	0.3												
65	4.2	4.1	3.9	3.7	3.5	3.1	2.8	2.4	2.0	1.6	1.1	0.7	0.3											
70	4.9	4.7	4.6	4.4	4.1	3.8	3.4	3.0	2.6	2.1	1.7	1.2	0.7	0.3										
75	5.6	5.4	5.3	5.0	4.8	4.4	4.1	3.7	3.2	2.8	2.3	1.8	1.3	0.8	0.4									
80	6.3	6.2	6.0	5.8	5.5	5.1	4.8	4.4	3.9	3.5	3.0	2.5	1.9	1.4	0.8	0.4								
85	7.1	7.0	6.8	6.5	6.3	5.9	5.5	5.1	4.7	4.2	3.7	3.2	2.6	2.1	1.5	0.9	0.4							
90	8.0	7.8	7.6	7.4	7.1	6.7	6.3	5.9	5.4	5.0	4.5	3.9	3.4	2.8	2.2	1.6	0.9	0.4						
95	8.9	8.7	8.5	8.2	7.9	7.5	7.1	6.7	6.3	5.8	5.3	4.7	4.2	3.6	2.9	2.3	1.7	1.0	0.4					
100	9.8	9.6	9.4	9.1	8.8	8.4	8.0	7.6	7.1	6.6	6.1	5.6	5.0	4.4	3.8	3.1	2.4	1.7	1.0	0.4				
105	10.8	10.6	10.4	10.1	9.8	9.4	8.9	8.5	8.0	7.5	7.0	6.4	5.8	5.2	4.6	3.9	3.3	2.5	1.8	1.1	0.4			
110	11.9	11.6	11.4	11.1	10.8	10.3	9.9	9.4	9.0	8.4	7.9	7.3	6.7	6.1	5.5	4.8	4.1	3.4	2.7	1.9	1.1	0.4		
115	13.0	12.7	12.5	12.2	11.8	11.4	10.9	10.4	9.9	9.4	8.9	8.3	7.7	7.1	6.4	5.7	5.0	4.3	3.5	2.8	2.0	1.2	0.5	
120	14.1	13.9	13.6	13.2	12.9	12.4	11.9	11.5	10.9	10.4	9.8	9.3	8.6	8.0	7.4	6.7	6.0	5.2	4.5	3.7	2.9	2.0	1.2	0.5

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Table A114: 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

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Table A115: 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	0.2	0.1																						
15	0.3	0.2	0.1																					
20	0.5	0.3	0.2	0.1																				
25	0.7	0.6	0.4	0.3	0.1																			
30	0.9	0.8	0.7	0.5	0.3	0.2																		
35	1.2	1.1	0.9	0.8	0.6	0.4	0.2																	
40	1.5	1.4	1.3	1.1	0.9	0.7	0.4	0.2																
45	1.9	1.7	1.6	1.4	1.2	1.0	0.7	0.5	0.2															
50	2.3	2.2	2.0	1.8	1.6	1.3	1.0	0.8	0.5	0.2														
55	2.7	2.6	2.5	2.3	2.0	1.7	1.4	1.1	0.8	0.5	0.3													
60	3.2	3.1	2.9	2.7	2.5	2.2	1.9	1.6	1.2	0.9	0.6	0.3												
65	3.7	3.6	3.5	3.3	3.0	2.7	2.4	2.1	1.7	1.3	1.0	0.6	0.3											
70	4.3	4.2	4.0	3.8	3.6	3.3	2.9	2.6	2.2	1.8	1.4	1.0	0.6	0.3										
75	4.9	4.8	4.6	4.4	4.2	3.9	3.5	3.2	2.8	2.4	2.0	1.5	1.1	0.7	0.3									
80	5.5	5.4	5.2	5.0	4.8	4.5	4.1	3.8	3.4	3.0	2.6	2.1	1.7	1.2	0.7	0.3								
85	6.2	6.1	5.9	5.7	5.4	5.1	4.8	4.4	4.0	3.6	3.2	2.7	2.2	1.8	1.2	0.7	0.3							
90	6.9	6.8	6.6	6.4	6.1	5.8	5.5	5.1	4.7	4.3	3.8	3.4	2.9	2.4	1.9	1.3	0.8	0.3						
95	7.7	7.6	7.4	7.1	6.9	6.5	6.2	5.8	5.4	5.0	4.5	4.0	3.5	3.0	2.5	1.9	1.4	0.8	0.3					
100	8.5	8.3	8.2	7.9	7.6	7.3	6.9	6.5	6.1	5.7	5.2	4.7	4.2	3.7	3.2	2.6	2.0	1.5	0.9	0.3				
105	9.4	9.2	9.0	8.7	8.4	8.1	7.7	7.3	6.9	6.4	6.0	5.5	5.0	4.4	3.9	3.3	2.7	2.1	1.5	0.9	0.3			
110	10.2	10.1	9.8	9.6	9.3	8.9	8.5	8.1	7.7	7.2	6.7	6.2	5.7	5.2	4.6	4.1	3.5	2.9	2.2	1.6	0.9	0.4		
115	11.2	11.0	10.7	10.5	10.1	9.7	9.3	8.9	8.5	8.0	7.5	7.0	6.5	6.0	5.4	4.8	4.2	3.6	3.0	2.3	1.6	1.0	0.4	
120	12.1	11.9	11.7	11.4	11.0	10.6	10.2	9.8	9.3	8.8	8.4	7.8	7.3	6.8	6.2	5.6	5.0	4.4	3.7	3.1	2.4	1.7	1.0	0.4

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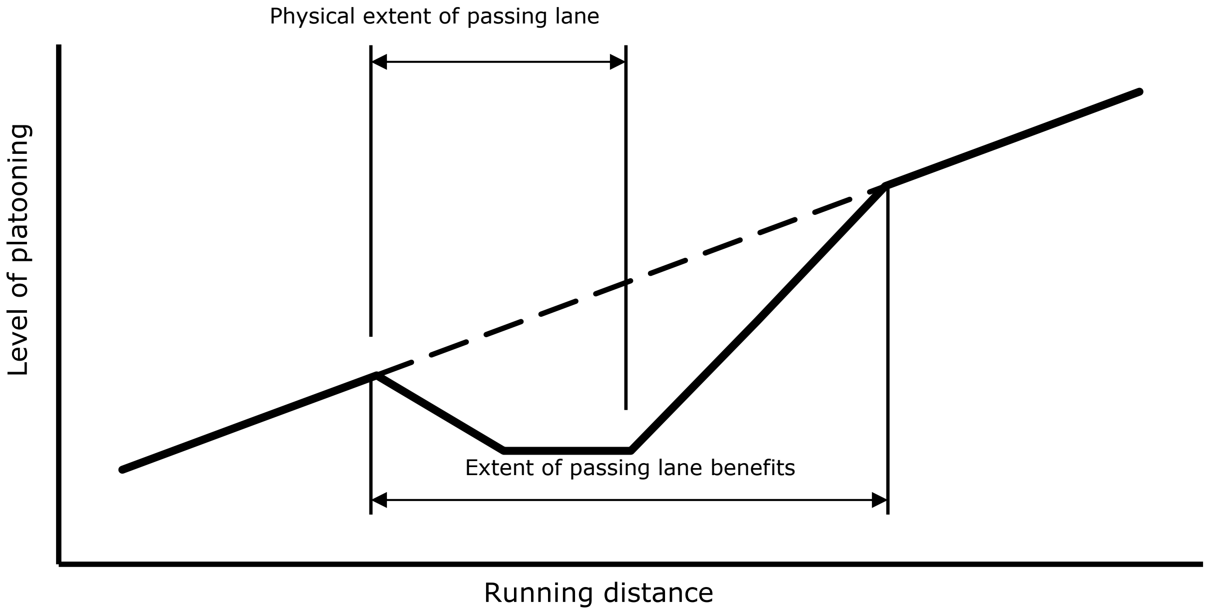
Appendix 5: Passing lanes

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.

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).

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 further than the physical length of the passing lane section itself, as shown in Figure A29 below.

Figure A29: 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.

In hilly and mountainous terrain, passing lanes (and climbing lanes) may not be viable, particularly on lower volume roads. In these situations, 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. 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 analysis procedures

There are three procedures in this appendix:

1. Passing lane strategy for determining the location of individual passing lanes
2. Assessment of individual passing lanes identified as feasible from a passing lane strategy
3. Detailed analysis of passing lane projects using rural traffic simulation software, such as TRARR.

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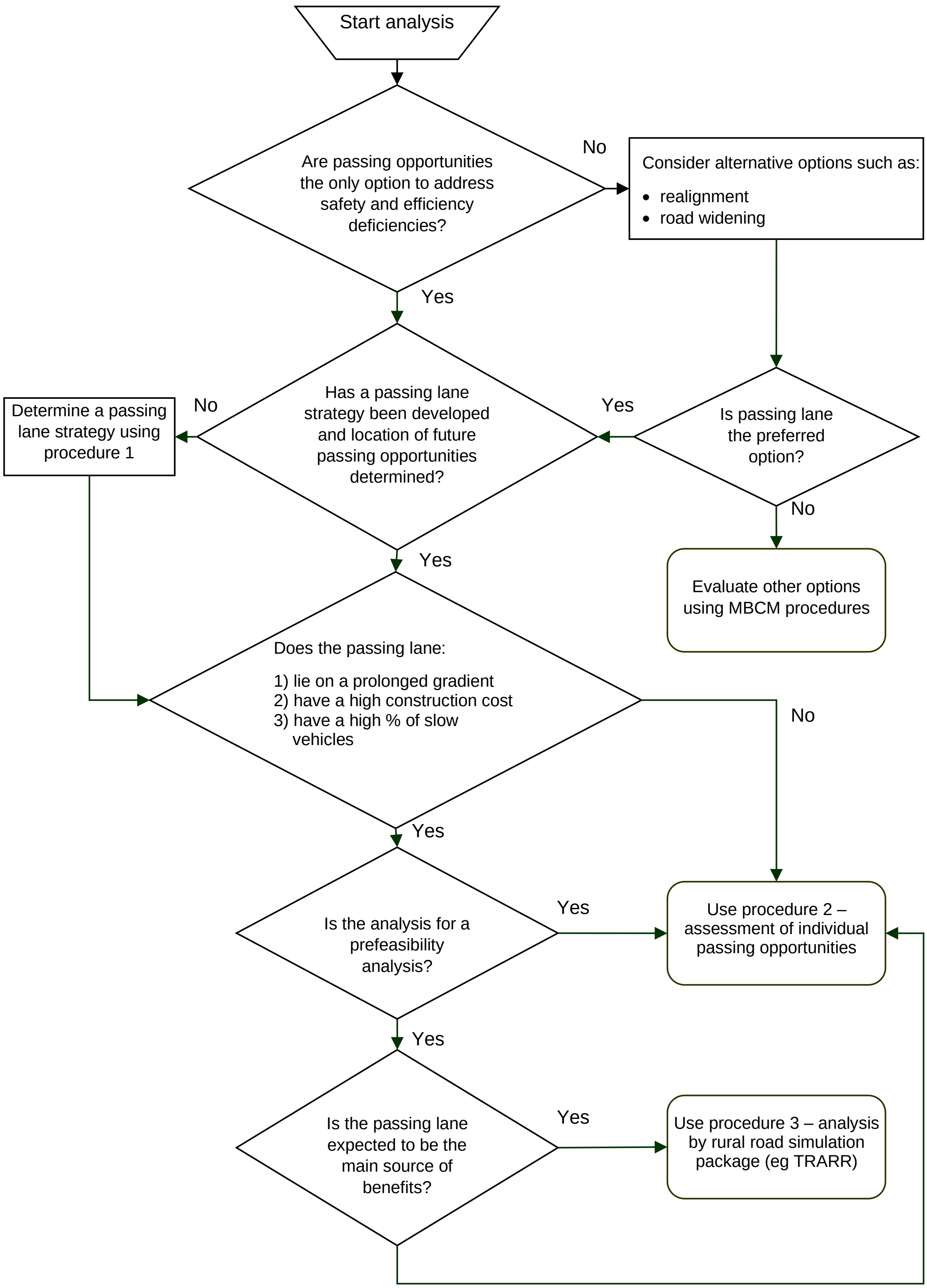
Figure A30 should be used to determine the appropriate procedure.

Figure A30: Selection of passing lane analysis procedure



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 increase. 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 Figure A37 to Figure A40. The typical crash rate by terrain type is taken from Table A36. 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 5–10km downstream), or where another passing lane begins.

Table A116 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 1km section (up to 10km downstream of the passing lane) then crash-by crash analysis may be suitable. To determine if such an analysis is appropriate refer to FigureA22.

In the majority of cases crash benefits should only be claimed up to 5km downstream of a passing lane, unless a rural simulation analysis indicates that vehicle platooning will not return to normal until more than 5km downstream. No upstream crash benefits can be included unless international or local research is produced to justify such benefits.

Table A116: 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

Passing lane length

A standard passing lane length of 1km is assumed in these procedures. When evaluating passing lanes with a length greater or shorter than 1km, the appropriate factors in Table A125 should be applied to the road user benefits.

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 A45). This assumption impacts on both the level of travel time benefits and on the value of these benefits. The adjustment in equation 1 (Table A126) 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 annual average daily traffic (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 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 A117).

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 rural simulation (eg TRARR) may be required.

Table A117: 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/year	% 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 COV will increase. In such cases the simplified model will underpredict 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 overpredict the travel time benefits. The adjustment in equation 2 (Table A126) 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 1km 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.

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 A118. Table A119 relates each of the four terrain types to the cost categories, together with the unit and total construction costs used in the analysis. All costs include the end tapers.

Table A118: 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 or three passing lanes projects in one contract Existing road 10m seal width, new passing lanes on both sides of road 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 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 Often expensive special features such as rehabilitation and intersection improvements	$800 (Estimates in this category were as high as $1,700 per linear metre)

Table A119: Passing lane average costs ($ 2005)

Terrain type	Cost category	Unit cost (per m)	Total cost (for 1km)
Flat	Easy/average	$250	$250,000
Rolling	Average	$320	$320,000
Hilly	Average/difficult	$500	$500,000
Mountainous	Difficult	$800	$800,000

Note, however, that cost estimates vary widely depending on site-specific and therefore standardised and average costs should be used with caution.

Where the estimated cost of construction differs significantly from that assumed in Table A119, an adjustment to the BCR could be made using equation 3 (Table A126).

Be aware that the analysis of data from selected passing lane sites indicated:

- 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
- significant 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 on the NZTA website. When applying an update factor to the combined travel time and vehicle operating costs, the adjustment factor for travel time costs should be used.

Passing lane strategies

This section provides a procedure for assessing passing lane strategies and is divided into two sections. The first gives a coarse analysis for identifying 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 Assessment of individual passing lanes.

The assumptions made in this procedure are affected by local conditions (refer to Background).

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.

Table A120: Steps to determine passing lane spacing strategy

Step	Action
1	**Break the network into sections,** as specified in the NZTA 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-ssections should not be shorter than: • 10km for passing lanes at 5km spacing • 20km for passing lanes at 10km 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 on 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.** This can be done 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 classifications of vertical and horizontal terrain are shown in Table A121, and are a result of analysis of 500m lengths using a 1500m moving average of these parameters. The curvature, or degrees per kilometre specified in Table A121, 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.
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 A122. 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 A122 PSD has been calculated as a moving average over 15km, with the PSD ascribed to the centre 5km. 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.
4	**Use the analysis year AADT, and % PSD to calculate a BCR**, using Figure A31 to Figure A34. If traffic growth is not 2% per year, multiply the BCR by the correction factors in Table A123. If the traffic growth is not in Table A123, 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 A121: Combined terrain classification

<table>
<tr><th></th><th colspan="4">Horizontal terrain (degrees/km)</th></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>

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Table A122: 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	–	–	–	–

Table A123: Traffic growth correction factors for BCR graphs

AADT	Traffic growth				
	0%	1%	2%	3%	4%
2,000	0.80	0.90	1.00	1.10	1.21
3,000	0.82	0.91	1.00	1.09	1.18
4,000	0.84	0.92	1.00	1.08	1.16
6,000	0.84	0.92	1.00	1.08	1.16
8,000	0.84	0.92	1.00	1.08	1.15
10,000	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 (Table A126).

Table A124: Steps to refine passing lane spacing strategy

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.

7	**Identify suitable sites**. Sites should be within 1km 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 5km in sub-section one to 10km in sub-section two, then the spacing should be increased to the higher values (10km) over the boundary.

Step	Action
	Any inbound sites in the vicinity of towns should commence at least 5km 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.
8	**Sections of prolonged gradient should be identified,** as possible opportunities for climbing lanes (or slow vehicle bays) using Table A125 below, which is adapted from Austroads (2003) and considers the length of sustained gradient necessary to reduce the speed of a heavy commercial vehicle to 40km/h. To assess the benefits of such sites a more detailed analysis is required using rural simulation software (refer to Rural simulation for assessing passing lanes).

Table A125: 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	1,000
5	200	450	
4	300	650	

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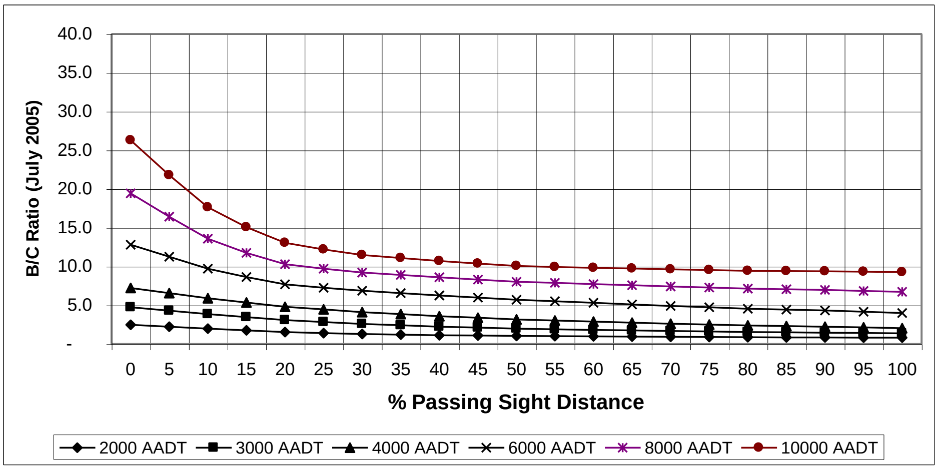
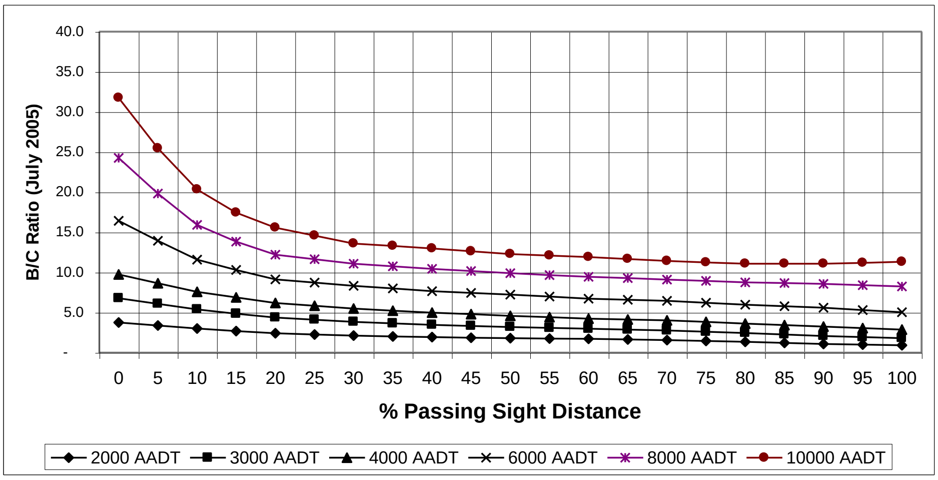
Figure A31: Graphs of strategy BCR for flat terrain

Flat terrain – 5km spacing – 2% traffic growth



Flat terrain – 10 km spacing – 2% traffic growth



Flat terrain – 20km spacing – 2% traffic growth

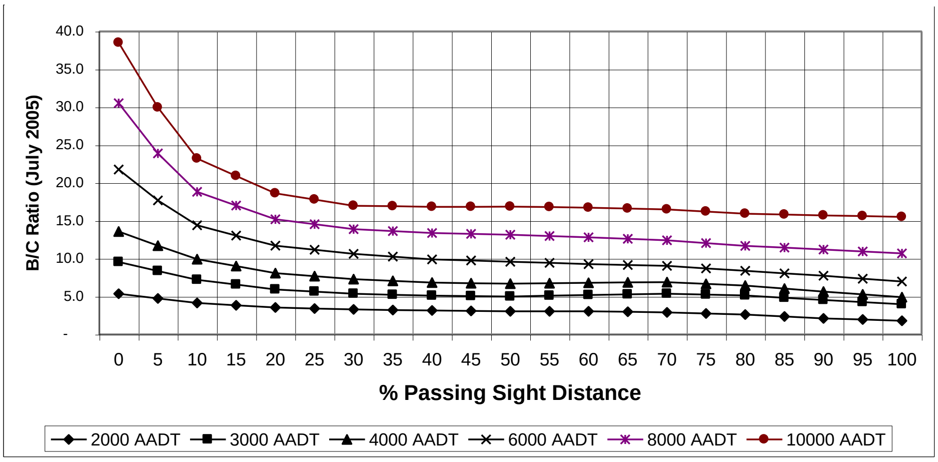


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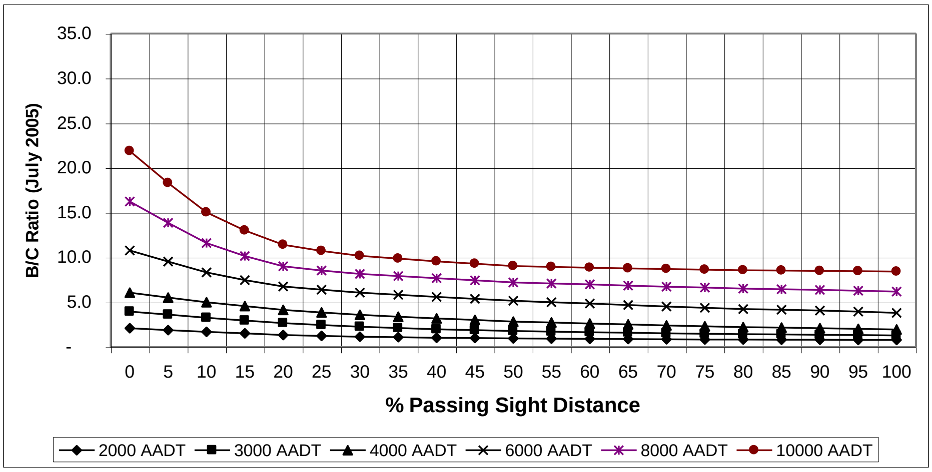
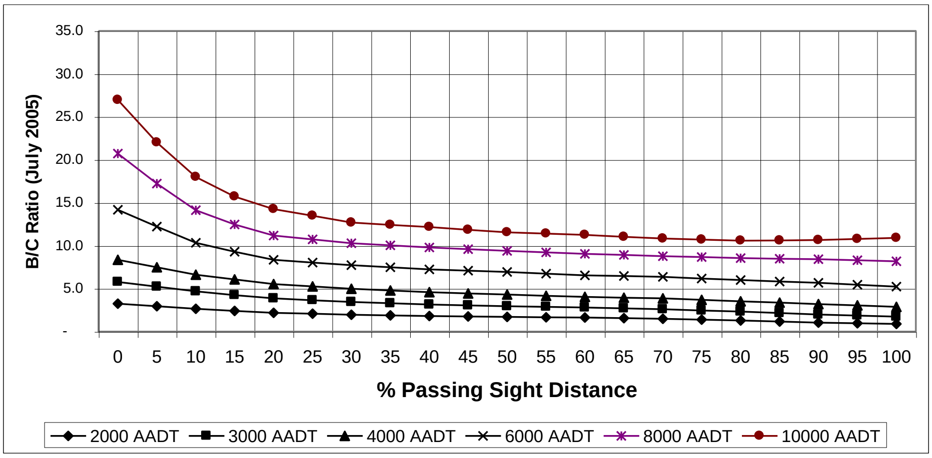
Figure A32: Graphs of strategy BCR for rolling terrain

Rolling terrain – 5km spacing – 2% traffic growth



Rolling terrain – 10km spacing – 2% traffic growth



Rolling terrain – 20km spacing – 2% traffic growth

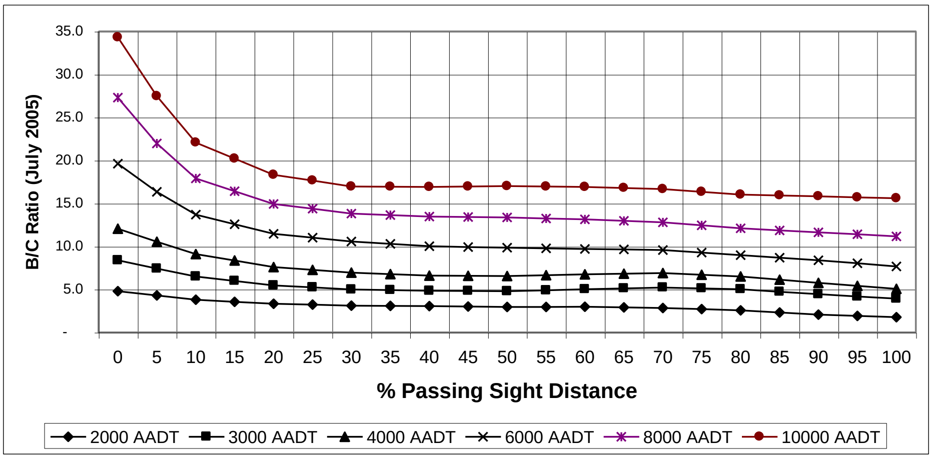


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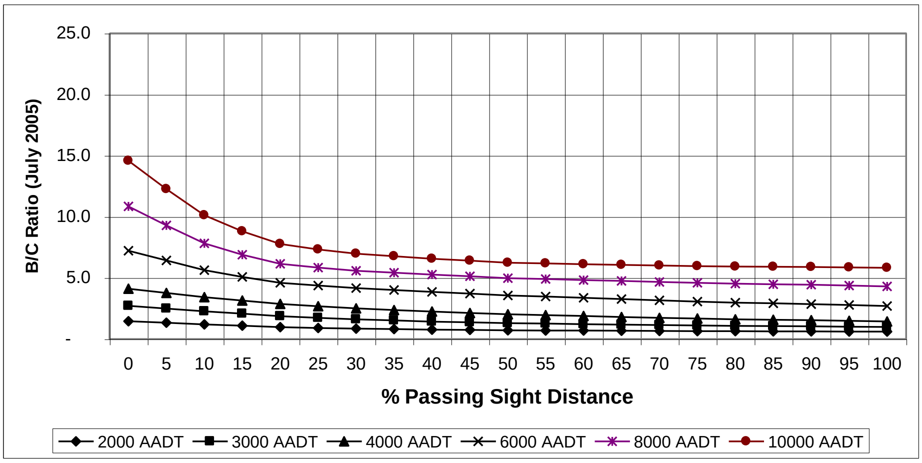
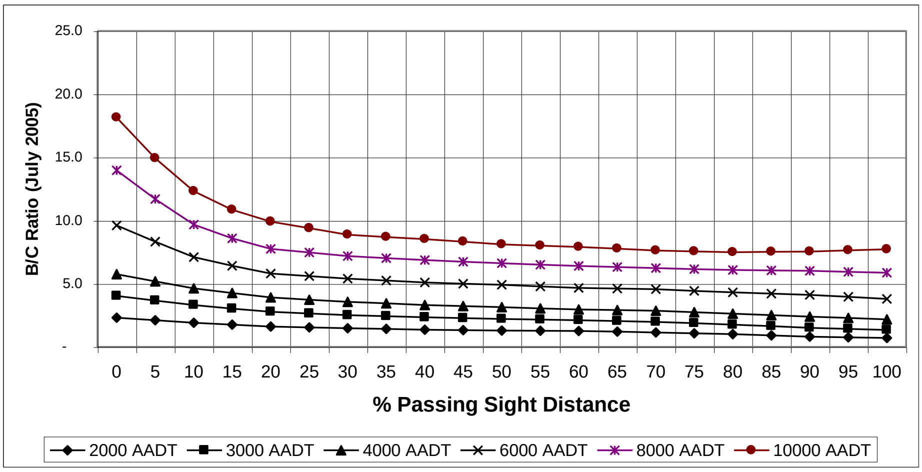
Figure A33: Graphs of strategy BCR for hilly terrain

Hilly terrain – 5km spacing – 2% traffic growth



Hilly terrain – 10km spacing – 2% traffic growth



Hilly terrain – 20km spacing – 2% traffic growth

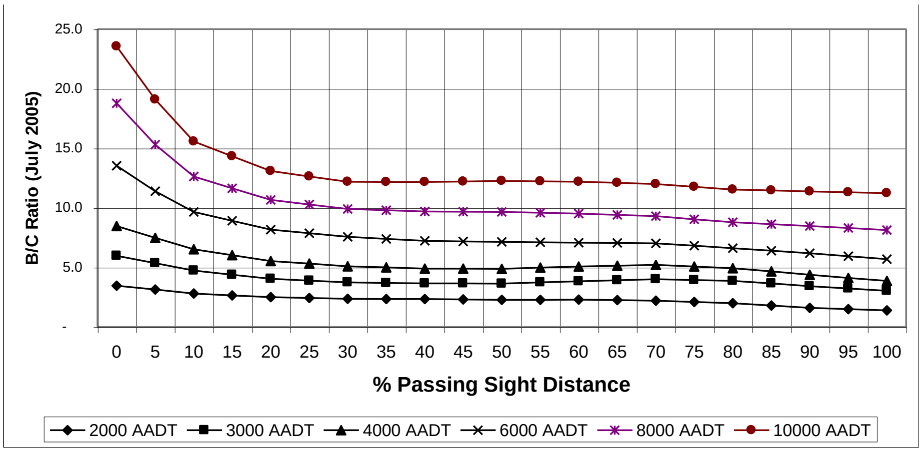
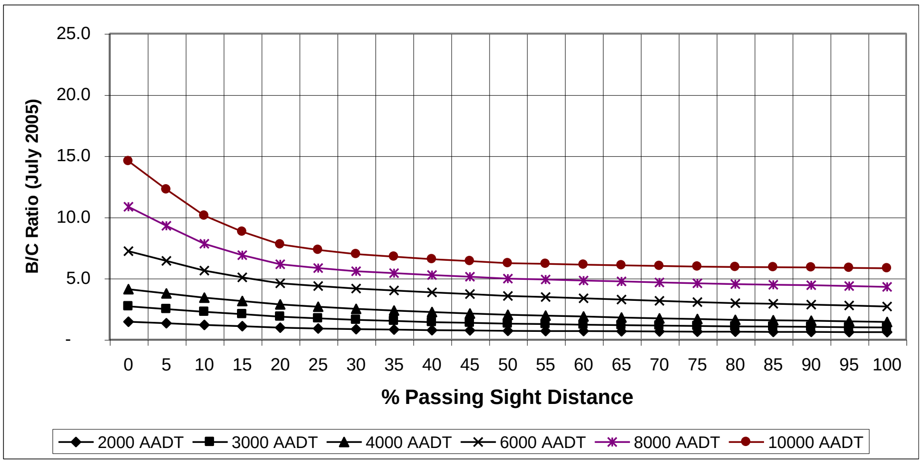
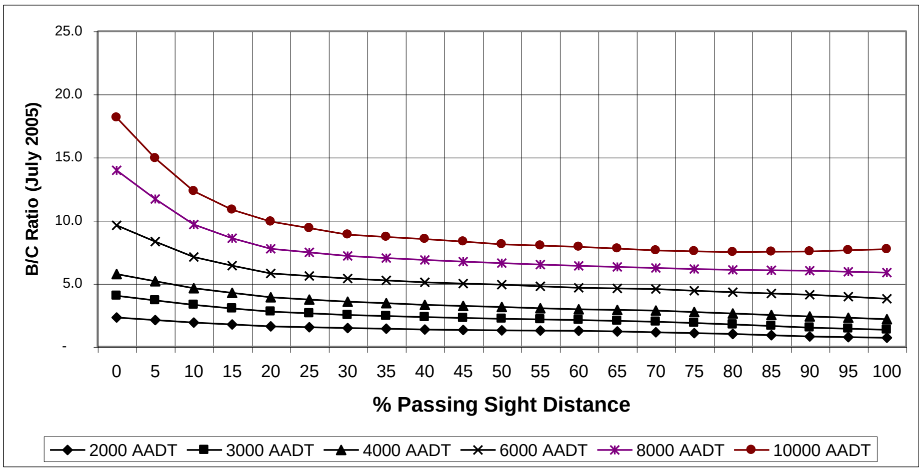


Figure A34: Graphs of strategy BCR for mountainous terrain

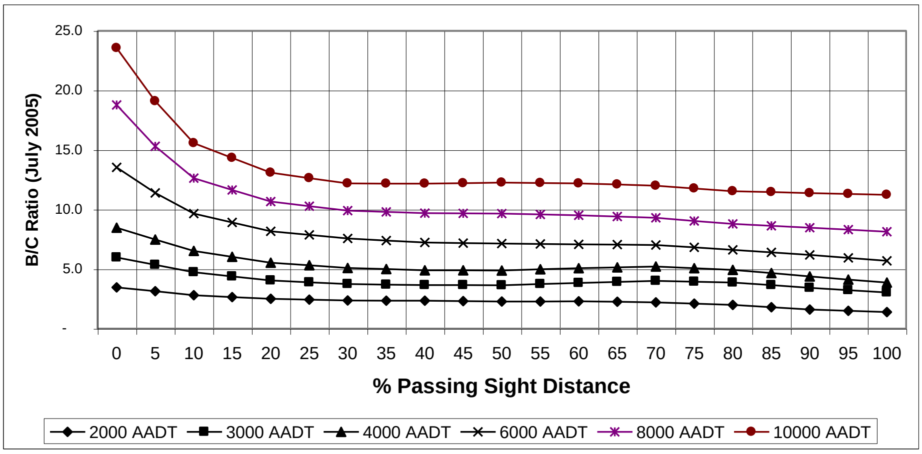
Hilly terrain – 5km spacing – 2% traffic growth



Hilly terrain – 10km spacing – 2% traffic growth



Hilly terrain – 20km spacing – 2% traffic growth



Assessment of individual passing lanes

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 is 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 (refer to Rural simulation for assessing passing lanes).

It is assumed that before using this procedure an appropriate passing lane strategy has been developed using the method in Table A120 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 Figure A31 to Figure A34 are not to be used. Instead, separate graphs for each category of road user benefits are used (Figure A35 to Figure A40), and these can be adjusted where necessary to account for local conditions.

Procedure for individual passing lanes

Table A126: Steps for assessment of individual passing lanes

Step	Action
1	**Calculate the travel time and vehicle operating savings,** using graphs in Figure A35. If necessary multiply by the traffic growth correction factor in Table A127 and the travel time update factor from the most recent update factors, available on the NZTA website. The inputs to the graphs are: • passing lane spacing (either 5, 10 or 20km – for isolated passing lanes use 20km spacing) • analysis year AADT • % PSD (to calculate see Table A120).
2	**Calculate the driver frustration savings,** using graphs in Figure A36. If necessary, multiply by the traffic growth correction factor in Table A128 and the driver frustration update factor from the most recent update factors, available on the NZTA website.
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 1km in length. Where individual passing lanes are less than 1km in length, the benefits are reduced because a lesser number of platooned vehicles will be released. Where the proposed passing lane is longer than 1km, 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 Table A129 and Table A130 below (intermediate values may be interpolated).
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 from Table A46. 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)** $= Road\ user\ benefits\ (unadjusted) \times (1 + [prop\ heavy\ vehicles - 0.12])$

Step	Action
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 COV of speed of 13.5%. Similarly reduce the road user benefits for a lower COV. **Equation 2: Road user benefits (adjusted)** $= Road\ user\ benefits\ (unadjusted) \times (1 + [COV - 0.135] \times 2.5)$
7	**Calculate crash costs savings,** using graphs in Figure A37 to Figure A40 (interpolate or extrapolate if necessary) and multiply with the appropriate traffic growth correction factors in Table A131. 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 1km section (up to 10km downstream of the passing lane), then crash-by-crash analysis can be used. To determine if such an analysis is appropriate, refer to Figure A22.
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 A119). **Equation 3:** $BCR\ (adjusted) = \frac{BCR\ (calculated\ above) \times Table\ A7.4\ unit\ cost}{Local\ unit\ cost\ (per\ m)}$

Table A127: Traffic growth correction factors for travel time and VOC graphs

AADT	Traffic growth				
	0%	1%	2%	3%	4%
2,000	0.66	0.83	1.00	1.18	1.39
3,000	0.70	0.85	1.00	1.17	1.34
4,000	0.72	0.86	1.00	1.14	1.27
6,000	0.80	0.90	1.00	1.10	1.20
8,000	0.82	0.91	1.00	1.09	1.18
10,000	0.82	0.91	1.00	1.09	1.17

Table A128: Traffic growth correction factors for driver frustration graphs

AADT	Traffic growth				
	0%	1%	2%	3%	4%
2,000	0.64	0.82	1.00	1.19	1.40
3,000	0.70	0.85	1.00	1.15	1.30
4,000	0.76	0.88	1.00	1.11	1.22
6,000	0.84	0.92	1.00	1.08	1.15
8,000	0.86	0.93	1.00	1.07	1.15
10,000	0.86	0.93	1.00	1.07	1.15

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Table A129: Passing lane length factors for travel time delays and vehicle operating cost savings

AADT (veh/day)	Passing lane length (m, excl tapers)								
	400	600	800	1,000	1,200	1,400	1,600	1,800	2,000
2,000	0.39	0.65	0.91	1.00	1.17	1.15	1.13	1.16	1.18
4,000	0.30	0.60	0.86	1.00	1.19	1.30	1.40	1.48	1.55
6,000	0.08	0.35	0.80	1.00	1.21	1.38	1.54	1.65	1.76
8,000	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

Notes:

1. Shaded values show either excluded values 1.6–2km passing lane with 2000–4000 vpd or drop-off in efficiency.
2. The values are for passing lanes on flattish gradient with 110km/h overtaking speed.
3. Refer to NZTA 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 A130: 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
2,000	0.17	0.52	0.87	1.00	1.13	1.33	1.52	1.62	1.71
4,000	0.13	0.48	0.82	1.00	1.18	1.30	1.41	1.50	1.59
6,000	0.03	0.29	0.80	1.00	1.20	1.29	1.37	1.47	1.56
8,000	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

Notes:

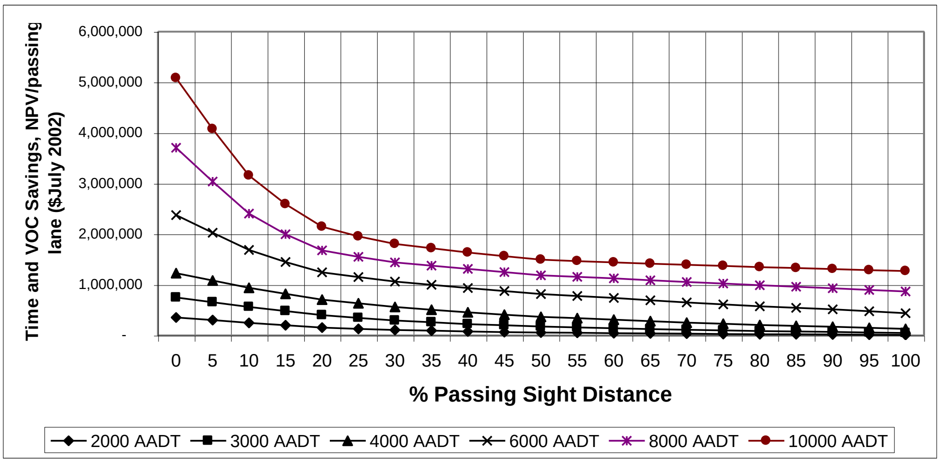
1. Shaded values show either excluded values 1.6–2km passing lane with 2,000–4,000 vpd or drop-off in efficiency.
2. The values are for passing lanes on flattish gradient with 110km/h overtaking speed.
3. Refer to NZTA for passing lanes that lie outside of the above range of values.
4. These factors 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 A131: Traffic growth correction factors for crash savings graphs

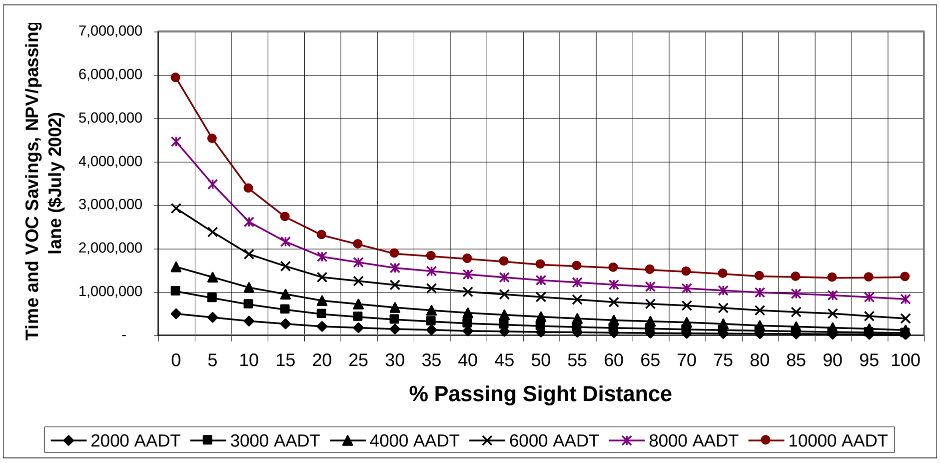
AADT	Traffic growth				
	0%	1%	2%	3%	4%
2,000	0.84	0.92	1.00	1.08	1.15
3,000	0.88	0.94	1.00	1.04	1.07
4,000	0.88	0.94	1.00	1.02	1.05
6,000	0.88	0.94	1.00	1.06	1.12
8,000	0.88	0.94	1.00	1.06	1.12
10,000	0.88	0.94	1.00	1.06	1.12

Figure A35: Graphs of vehicle operating cost and delay savings for all terrain

5km spacing – 2% traffic growth



10km spacing – 2% traffic growth



20km spacing – 2% traffic growth

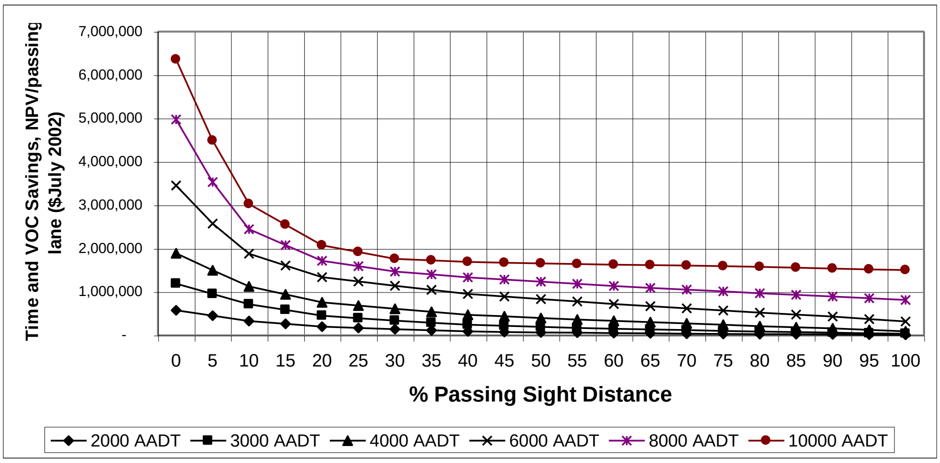


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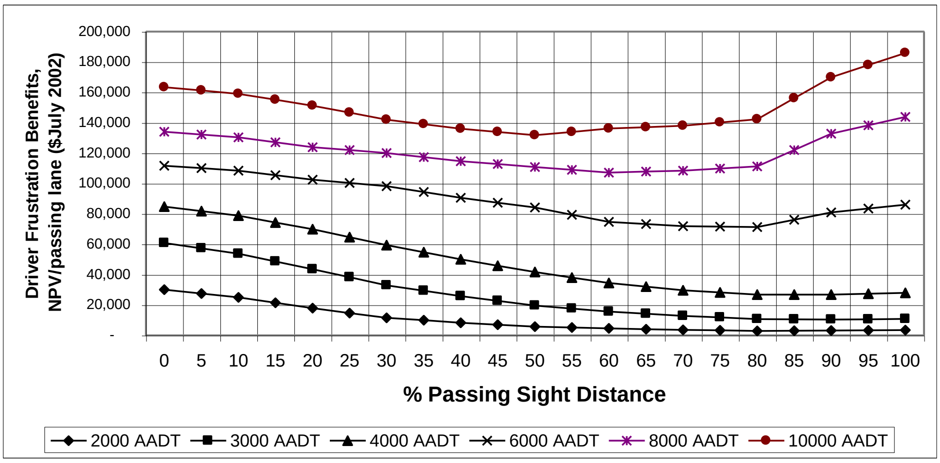
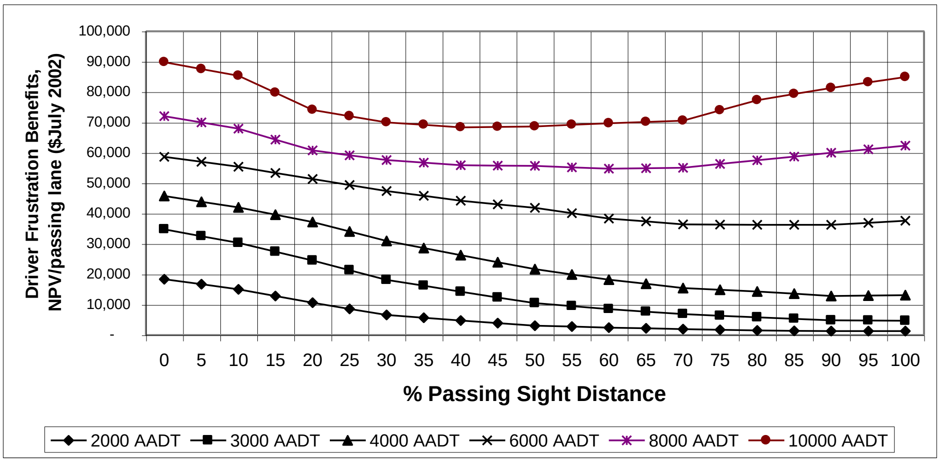
Figure A36: Graphs of driver frustration benefits for all terrain

5km spacing – 2% traffic growth



10km spacing – 2% traffic growth



20km spacing – 2% traffic growth

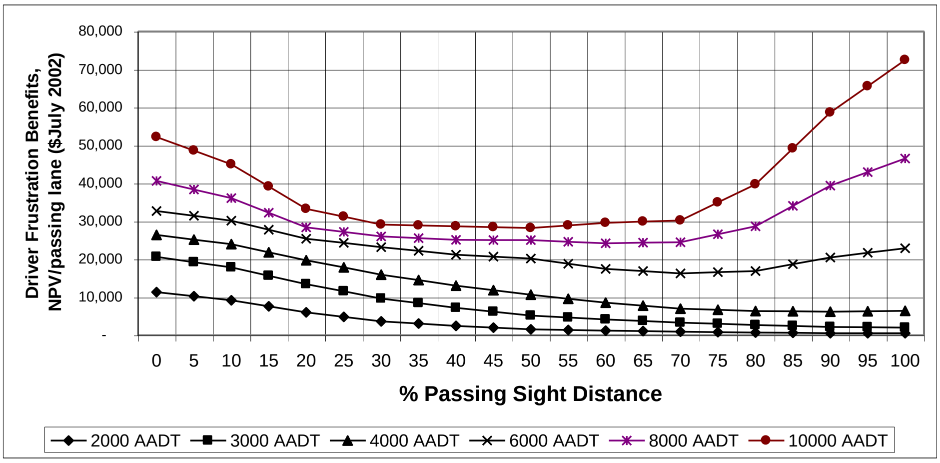


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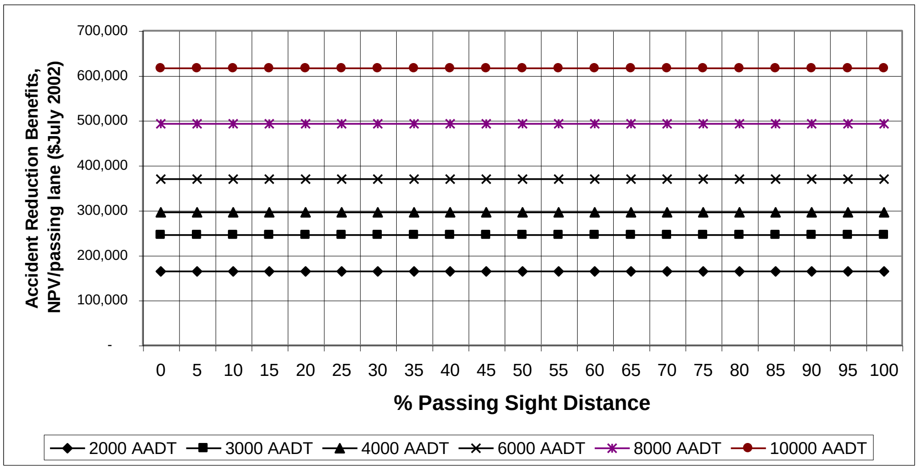
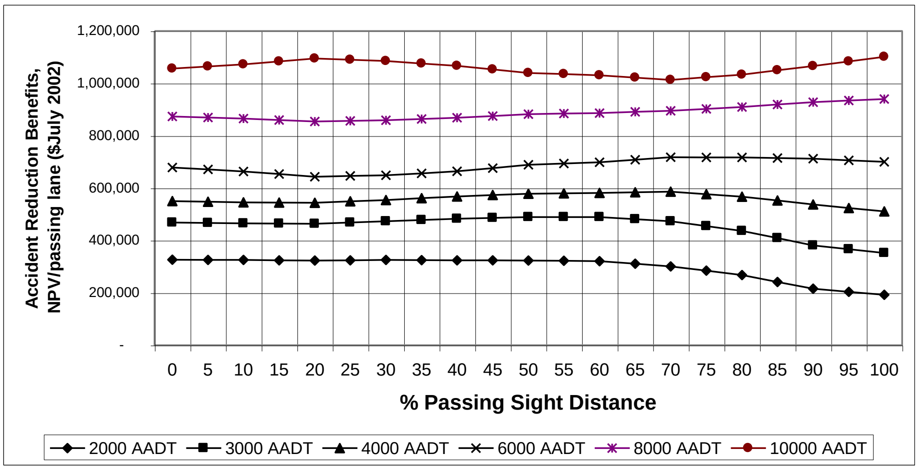
Figure A37: Graphs of crash savings for flat terrain

Flat terrain – 5km spacing – 2% traffic growth



Flat terrain – 10km spacing – 2% traffic growth



Flat terrain – 20km spacing – 2% traffic growth

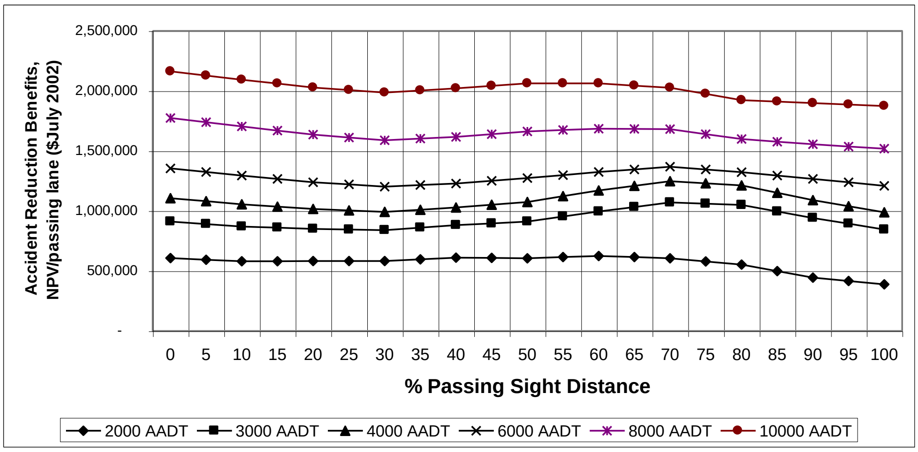


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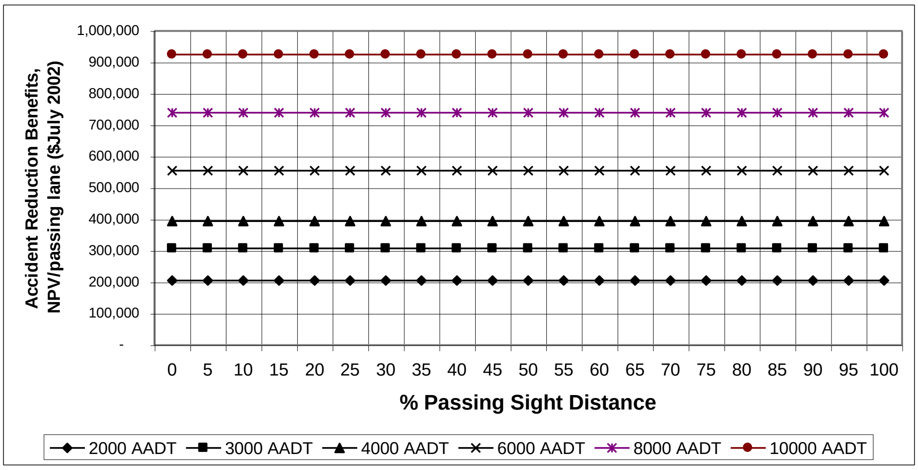
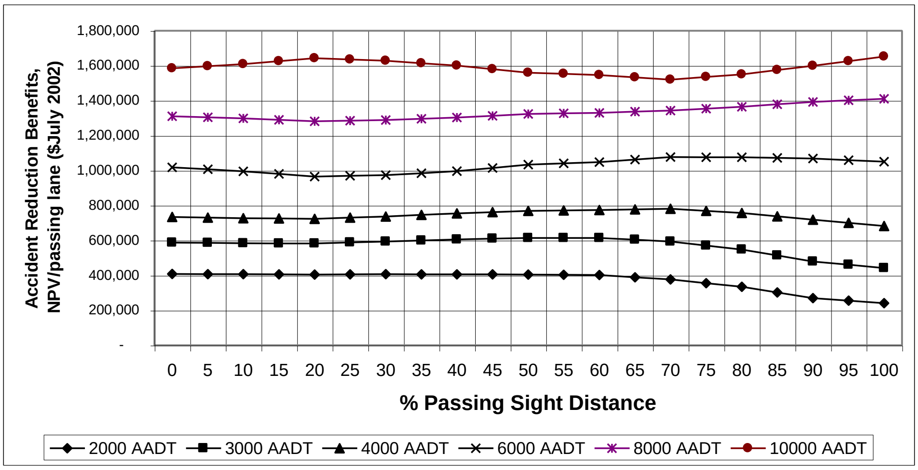
Figure A38: Graphs of crash savings for rolling terrain

Rolling terrain – 5km spacing – 2% traffic growth



Rolling terrain – 10km spacing – 2% traffic growth



Rolling terrain – 20km spacing – 2% traffic growth

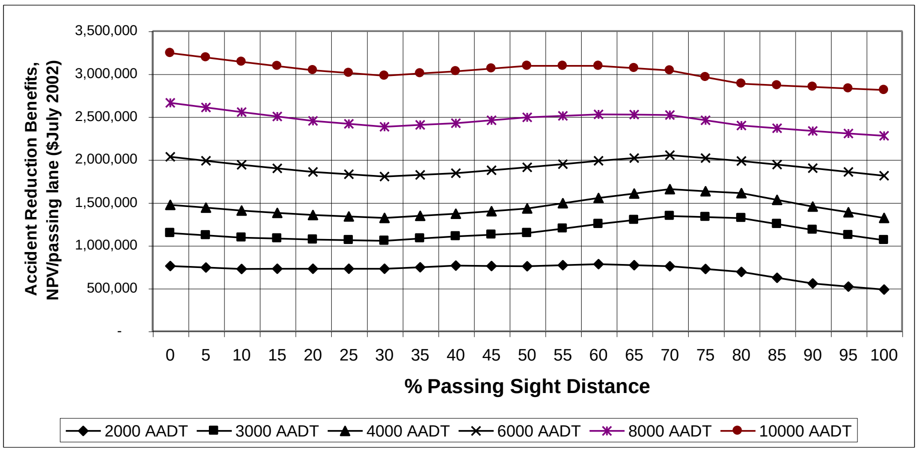


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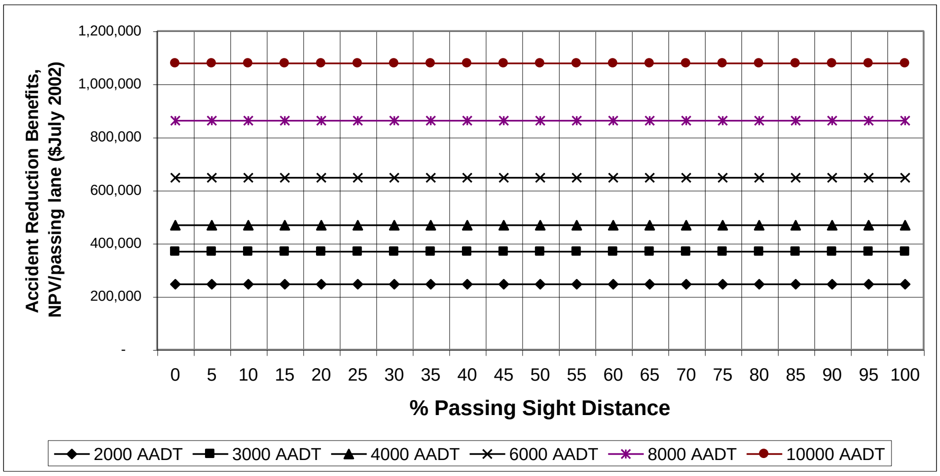
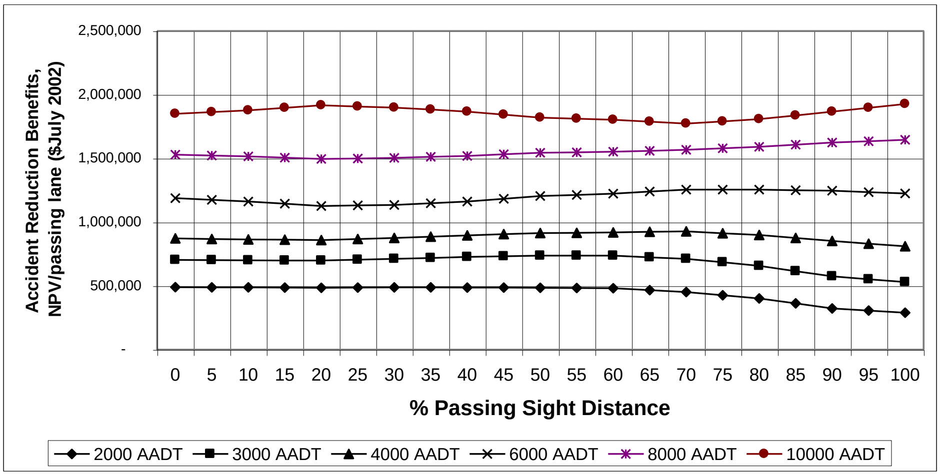
Figure A39: Graphs of crash savings for hilly terrain

Hilly terrain – 5km spacing – 2% traffic growth



Hilly terrain – 10km spacing – 2% traffic growth



Hilly terrain – 20km spacing – 2% traffic growth

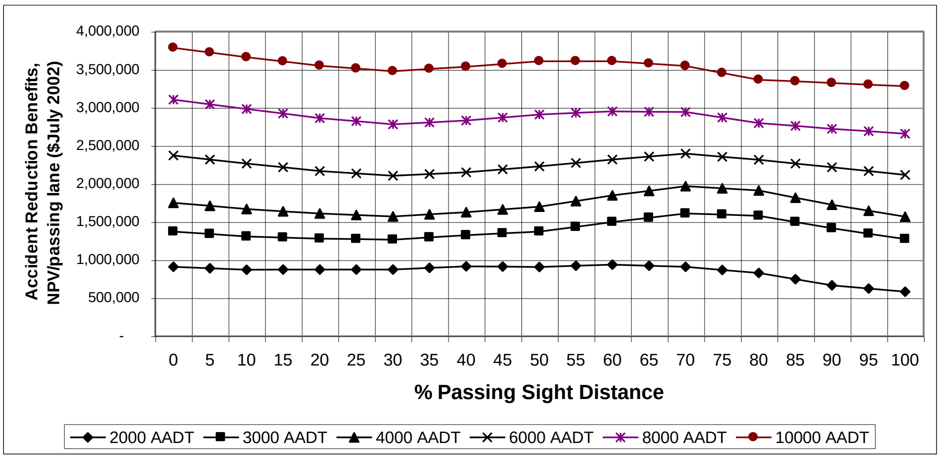
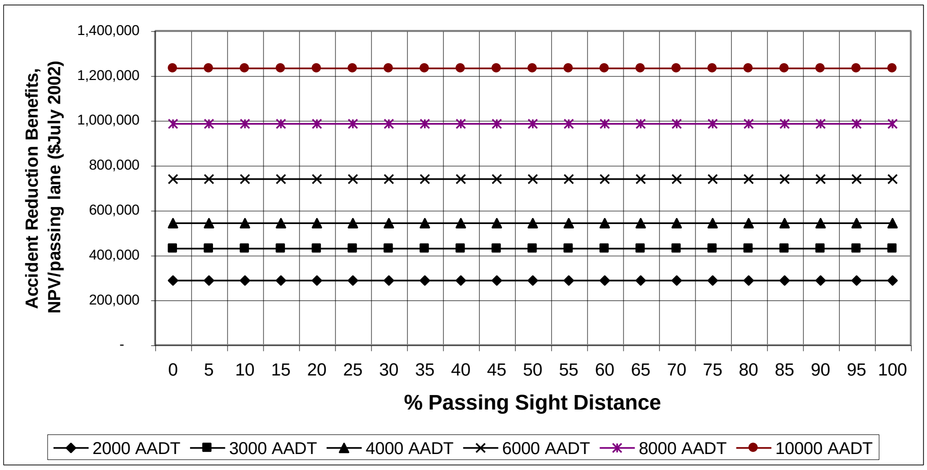
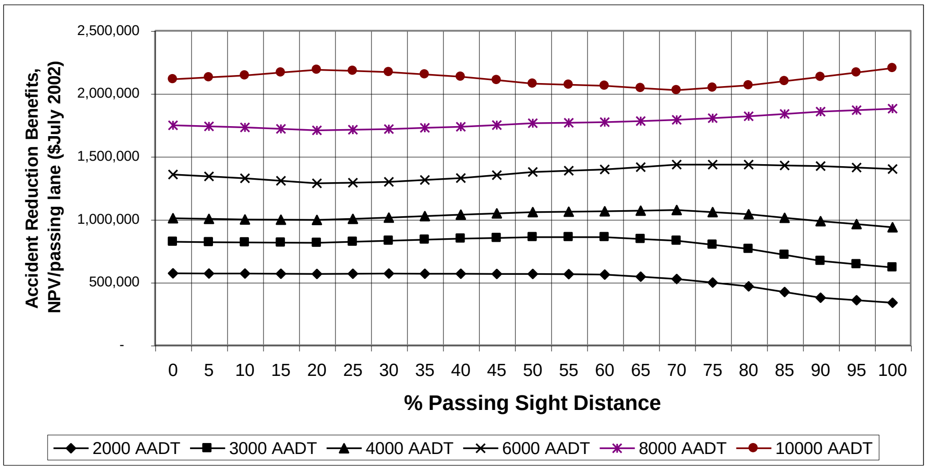


Figure A40: Graphs of crash savings for mountainous terrain

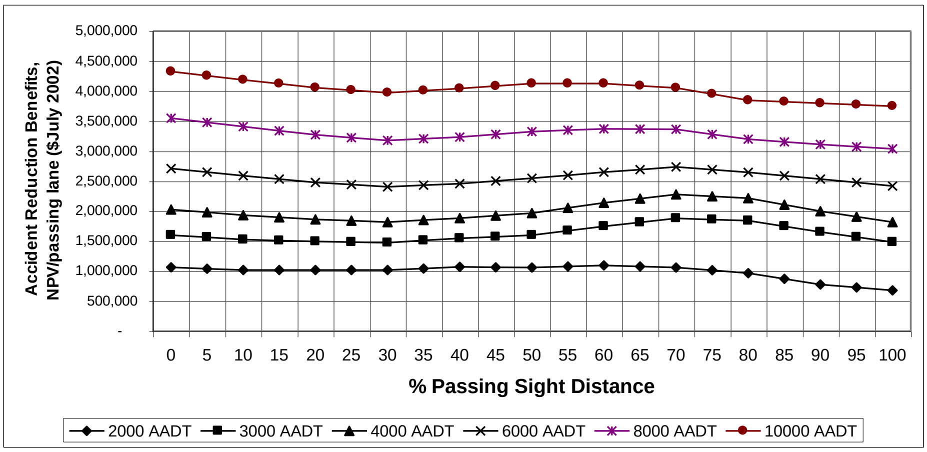
Mountainous terrain – 5km spacing – 2% traffic growth



Mountainous terrain – 10km spacing – 2% traffic growth



Mountainous terrain – 20km spacing – 2% traffic growth



Rural simulation for assessing passing lanes

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 is 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 2km 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 on the traffic volume, terrain and passing lanes downstream of the project section, this may be up to 10km.
- 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 fewer than 50 veh/h 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 and 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 veh/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 12km of road.

- For a traffic volume of 200veh/h, 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/h.
- Crash benefits should be considered up to 10km 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 flows. 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 veh/h, the models may be validated by comparing the model outputs against field measurements taken when traffic volumes were 200 veh/h.

Refer to section 4.3 for further information on checking traffic models.

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 six 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) for further information, especially with regard to object and eye heights.
Slow vehicle bay	A short section of shoulder marked as a lane for slow vehicles to move over and let other 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.

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Appendix 6: Discount factors

Table A132: Quarterly single payment present worth factors

Time (years from time zero in quarters from 1 July to 30 June)	4% discount rate SPPWF	3% discount rate SPPWF (sensitivity test)	6% discount rate SPPWF (sensitivity test)
0	1.0000	1.0000	1.0000
0.25	0.9902	0.9926	0.9855
0.50	0.9806	0.9853	0.9713
0.75	0.9710	0.9781	0.9572
1.00	0.9615	0.9709	0.9433
1.25	0.9522	0.9637	0.9298
1.50	0.9429	0.9566	0.9163
1.75	0.9337	0.9496	0.9031
2.00	0.9246	0.9426	0.8900
2.25	0.9155	0.9357	0.8771
2.50	0.9066	0.9288	0.8644
2.75	0.8978	0.9219	0.8519
3.00	0.8890	0.9151	0.8396
3.25	0.8803	0.9084	0.8275
3.50	0.8717	0.9017	0.8155
3.75	0.8632	0.8951	0.8037
4.00	0.8548	0.8885	0.7921
4.25	0.8465	0.8819	0.7806
4.50	0.8382	0.8755	0.7693
4.75	0.8300	0.8690	0.7582
5.00	0.8219	0.8626	0.7473
5.25	0.8139	0.8563	0.7365
5.50	0.8060	0.8500	0.7258
5.75	0.7981	0.8437	0.7153
6.00	0.7903	0.8375	0.7050
6.25	0.7826	0.8313	0.6948
6.50	0.7750	0.8252	0.6847
6.75	0.7674	0.8191	0.6748
7.00	0.7599	0.8131	0.6651
7.25	0.7525	0.8071	0.6554
7.50	0.7452	0.8012	0.6460
7.75	0.7379	0.7953	0.6366
8.00	0.7307	0.7894	0.6274

Table A133: Annual uniform series present worth factors

Time (years from time zero)	4% discount rate USPWF	3% discount rate USPWF (sensitivity test)	6% discount rate USPWF (sensitivity test)
0	0.0000	0.0000	0.0000
1	0.9806	0.9854	0.9714
2	1.9236	1.9420	1.8879
3	2.8302	2.8708	2.7524
4	3.7020	3.7726	3.5680
5	4.5403	4.6481	4.3375

Time (years from time zero)	4% discount rate USPWF	3% discount rate USPWF (sensitivity test)	6% discount rate USPWF (sensitivity test)
6	5.3463	5.4980	5.0634
7	6.1213	6.3233	5.7482
8	6.8665	7.1245	6.3943
9	7.5831	7.9023	7.0038
10	8.2721	8.6575	7.5787
11	8.9345	9.3907	8.1212
12	9.5715	10.1026	8.6329
13	10.1841	10.7937	9.1157
14	10.7730	11.4647	9.5711
15	11.3393	12.1161	10.0008
16	11.8838	12.7486	10.4061
17	12.4074	13.3626	10.7885
18	12.9108	13.9588	11.1493
19	13.3949	14.5376	11.4896
20	13.8604	15.0995	11.8107
21	14.3079	15.6451	12.1136
22	14.7382	16.1748	12.3993
23	15.1520	16.6890	12.6689
24	15.5499	17.1883	12.9232
25	15.9325	17.6731	13.1631
26	16.3003	18.1437	13.3895
27	16.6540	18.6006	13.6030
28	16.9941	19.0442	13.8044
29	17.3212	19.4749	13.9945
30	17.6356	19.8930	14.1738
31	17.9380	20.2990	14.3429
32	18.2287	20.6931	14.5025
33	18.5082	21.0757	14.6530
34	18.7770	21.4473	14.7950
35	19.0355	21.8079	14.9290
36	19.2840	22.1581	15.0554
37	19.5229	22.4981	15.1746
38	19.7527	22.8282	15.2871
39	19.9736	23.1487	15.3932
40	20.1860	23.4598	15.4933
41	20.3903	23.7619	15.5877
42	20.5867	24.0551	15.6768
43	20.7755	24.3399	15.7609
44	20.9571	24.6163	15.8402
45	21.1317	24.8847	15.9150
46	21.2996	25.1453	15.9856
47	21.4610	25.3982	16.0522
48	21.6163	25.6438	16.1150
49	21.7655	25.8823	16.1742
50	21.9090	26.1138	16.2301
51	22.0470	26.3386	16.2829
52	22.1797	26.5568	16.3326

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Time (years from time zero)	4% discount rate USPWF	3% discount rate USPWF (sensitivity test)	6% discount rate USPWF (sensitivity test)
53	22.3073	26.7687	16.3795
54	22.4299	26.9744	16.4238
55	22.5479	27.1741	16.4656
56	22.6613	27.3680	16.5050
57	22.7704	27.5562	16.5422
58	22.8752	27.7390	16.5773
59	22.9761	27.9164	16.6103
60	23.0730	28.0887	16.6416

Table A134: Annual arithmetic growth present worth factors

Time (years from time zero)	4% discount rate AGPWF	3% discount rate AGPWF (sensitivity test)	6% discount rate AGPWF (sensitivity test)
0	0.0000	0.0000	0.0000
1	0.4871	0.4903	0.4810
2	1.8984	1.9229	1.8512
3	4.1621	4.2426	4.0084
4	7.2105	7.3965	6.8591
5	10.9799	11.3340	10.3180
6	15.4104	16.0069	14.3069
7	20.4455	21.3688	18.7549
8	26.0321	27.3758	23.5971
9	32.1204	33.9856	28.7748
10	38.6635	41.1582	34.2343
11	45.6175	48.8550	39.9273
12	52.9410	57.0395	45.8098
13	60.5953	65.6768	51.8420
14	68.5442	74.7334	57.9883
15	76.7537	84.1777	64.2163
16	85.1919	93.9794	70.4971
17	93.8292	104.1097	76.8048
18	102.6376	114.5411	83.1162
19	111.5914	125.2474	89.4107
20	120.6663	136.2038	95.6699
21	129.8396	147.3867	101.8778
22	139.0905	158.7736	108.0200
23	148.3994	170.3431	114.0842
24	157.7481	182.0748	120.0593
25	167.1198	193.9496	125.9362
26	176.4990	205.9492	131.7068
27	185.8711	218.0561	137.3643
28	195.2228	230.2541	142.9030
29	204.5419	242.5274	148.3182
30	213.8170	254.8614	153.6061
31	223.0377	267.2421	158.7639
32	232.1944	279.6563	163.7893

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Time (years from time zero)	4% discount rate AGPWF	3% discount rate AGPWF (sensitivity test)	6% discount rate AGPWF (sensitivity test)
33	241.2786	292.0916	168.6808
34	250.2821	304.5362	173.4374
35	259.1978	316.9791	178.0587
36	268.0191	329.4097	182.5449
37	276.7401	341.8182	186.8963
38	285.3554	354.1954	191.1139
39	293.8603	366.5326	195.1989
40	302.2505	378.8216	199.1528
41	310.5222	391.0547	202.9773
42	318.6723	403.2248	206.6744
43	326.6977	415.3251	210.2463
44	334.5960	427.3494	213.6954
45	342.3651	439.2919	217.0240
46	350.0033	451.1472	220.2348
47	357.5091	462.9101	223.3304
48	364.8815	474.5760	226.3136
49	372.1196	486.1406	229.1872
50	379.2228	497.5998	231.9540
51	386.1908	508.9501	234.6170
52	393.0235	520.1880	237.1789
53	399.7209	531.3105	239.6428
54	406.2835	542.3146	242.0116
55	412.7115	553.1980	244.2880
56	419.0058	563.9583	246.4749
57	425.1670	574.5934	248.5753
58	431.1962	585.1015	250.5918
59	437.0942	595.4810	252.5273
60	442.8624	605.7305	254.3844

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Appendix 7: Risk analysis worksheets

Risk analysis worksheet 1

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 risk matrix and assign a risk rating. 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. Space is allowed for identifying other material risks in the worksheet.

Each identified risk is to be assigned a risk owner who shall be a named individual or team. A risk owner can be defined as: 'the person best placed to manage the risk, suitably qualified and experienced to do so'.

Responsibilities of the risk owner include:

- managing owner risks – definition, analysis and evaluation
- managing risk treatment – definition, effectiveness, programme requirements and conduct
- ensuring owned risk and treatment data is robust and well maintained
- participating in reviews/workshops as appropriate.

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 report on the risks for each category as a whole, and the worksheet is structured to permit this.

Table A135: Summary of benefit risks

	Risk description (risk source)	Risk owner	Risk events and consequences	Likelihood	Risk rating
	Benefit risks				
1	Base travel demand				
1.1	Age of data source				
1.2	Data scope				
1.3	Data quantity and statistical reliability				
1.4	Diversion assumption				
1.5	Travel demand validation				
1.6	Traffic composition				
1.7	Other				
2	Growth forecasts				
2.1	High city population growth				
2.2	Development-related traffic as proportion of scheme traffic				
2.3	Time series projection				
2.4	Other				
3	Assignment				
3.1	Changes in user safety – observed crash sample size				
3.2	Changes in user safety – judgemental crash reduction risk				
3.3	Changes in human health – walking and cycling tourists				
3.4	Changes in human health – environment				

	Risk description (risk source)	Risk owner	Risk events and consequences	Likelihood	Risk rating
3.5	Changes in transport costs – travel time valuation				
3.6	Changes in tourism benefits				
3.7	Changes in climate – CO_2 valuation				
3.8	Changes in access to social and economic opportunities – user experience				
3.9	Other				
4	Benefit realisation				
4.1	Tourism				
4.2	Dependency on overall economy				
4.3	Dependency on future projects or technology				
4.4	Force majeure				
4.5	Other future projects				
4.6	Diversion from private vehicle				
4.7	Supply relationships				
4.8	Routing parameters				
4.9	Other				

Table A136: Summary of cost risks

	Cost risks	Risk owner	Risk events and consequences	Likelihood	Risk rating
5	Environmental and planning				
5.1	Tangata whenua				
5.2	Emissions				
5.3	Landscape and visual				
5.4	Ecological effects				
5.5	Archaeological and historic sites				
5.6	Social networks and severance				
5.7	Economic/amenity impacts on land users				
5.8	Natural hazards				
5.9	Other				
6	Land and property				
6.1	Property acquisition				
6.2	Property economic value				
6.3	Other				
7	Earthworks				
7.1	Knowledge of ground conditions				
7.2	Complex/unpredictable conditions				
7.3	Road design form				
7.4	Extent of topographical data				
7.5	Source and disposal of material				
7.6	Other				
8	Other engineering costs				
8.1	Engineering complexity				
8.2	Signalling and communications				
8.3	Transport service operating surplus/deficit				

	Cost risks	Risk owner	Risk events and consequences	Likelihood	Risk rating
8.4	Other				
9	Services				
9.1	Existence, location and condition				
9.2	Site flexibility				
9.3	Cooperation of utilities				
9.4	Other				

Table A137: Summary of other risks

Other risks	Risk owner	Risk events and consequences	Likelihood	Risk rating
10				
10.1				
10.2				
10.3				
11				
11.1				
11.2				
11.3				
11.4				
12				
12.1				
12.2				
12.3				
12.4				
13				
13.1				
13.2				
13.3				
13.4				
14				
14.1				
14.2				
14.3				
14.4				

Risk analysis worksheet 2

In this worksheet, additional information should be supplied on the nature of the high or critical 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 in the risk treatment section.

In respect of high or critical risks identified in Table A135, TableA136, and, TableA137 additional information should be supplied under the following headings.

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. It is, however, accepted that it is the nature of some risks that reliable estimation of their potential impacts is impossible.

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).

Recommended actions and estimated costs of those actions (where relevant):
NZTA 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.

Table A138: Identified high or critical risks

Risk category (a)	Description and nature of the risk (b)	Estimated impacts on benefits and costs (c)	Implications (d)	Recommended actions (e)

The worksheet should be completed for the identified high risks. The risk categories are labelled R1 to R17. 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 on benefits, costs or the anticipated programme delay in the relevant box.

The worksheet 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.

Risk analysis worksheet 3

This worksheet allows for the calculation of relative risk indicators for a project's benefits, costs and BCR.

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.

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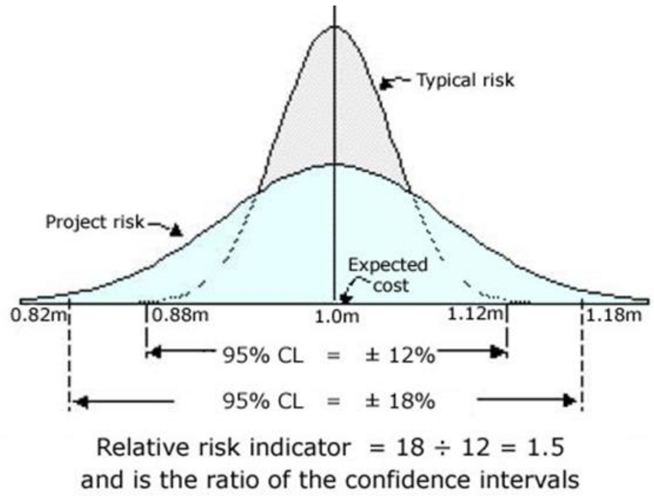
Figure A41 illustrates the concept. If, for example, we estimate the baseline cost risk of a typical project to be $1M ±12% (95% confidence limits) and the risk for a specific project is higher at ±18%, then the relative risk indicator is 1.5, the ratio of the two values. Thus the 'high' risks identified for this project increase the overall risk by 50% over what would normally be expected.

Figure A41: The relative risk indicator for project costs



As 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.

$$RBCR = [0.35 * RC^2 + 0.65 * RB^2]^{0.5}$$

After the applying risk treatments and contingency, any residual risks shall be reported and quantified to produce risk adjusted BCR. Use this worksheet along with the BCR risk tool (BCR optimism bias testing).

Table A139: Risk adjusted BCR

Risk category	Residual cost risk	Residual benefit risk	Residual programming risk
Overall relative risk indicators	(RC =)	(RB =)	(RBCR =)
			Adjusted BCR =

A worked example for Risk analysis worksheet 3: relative risk indicator calculation is provided in Appendix 8: Worked examples.

Back to 4. Evaluation procedures >>

Back to 7.4 Risk analysis procedures: Risk assessment >>

Appendix 8: Worked examples

This appendix contains worked examples of benefit quantification and monetisation procedures, discounting and incremental cost–benefit appraisal, and application of the risk procedures.

Consumer surplus and the rule of half

The basic technique for evaluating consumer impacts of price changes is to use the incremental cost to consumers who do not 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 × 2 million for existing trips, plus $1 × 1 million × 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 × 10 million for existing trips, plus 50c × two million × ½ for added trips).

Back to 1.7 Benefits: Rule of half >>

Crash cost procedure

This worked example uses methods B and C from Appendix 2: Crash analysis.

Do-minimum crash costs:

A straight and flat 3.3km section of rural state highway in a 100km/h area is identified as having a high incident of loss of control crashes. This section of road has two 3.5 metre lanes (7m width) and no sealed shoulder. The road is a rural connector with an AADT of 2800 and 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 metres in total: two 3.5 metre lanes and 1-metre-wide sealed shoulders. Time zero is 2015.

As per the thresholds described in Figure A22 (Appendix 2) with less than 3 injury crashes per kilometre (i.e. 9 injury crashes divided by 3.3km = 2.7) or 1 or more fatal and serious crash per kilometre, the weighted crash procedure is used.

Crash rates are available for the do-minimum and option(s). These are provided in the Crash estimation compendium (CEC).

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 (refer to Appendix 2 Definitions) and costs.

Site specific crash rate A_S

A_S	=	nine injury crashes/five years for the site history × 1.10
where:		1.10 is the crash trend adjustment factor from TableA21 (using 100km/h speed limit and 4% traffic growth).
A_S	=	9 / 5 × 1.10 = 1.98 injury crashes per year

Typical crash rate A_T (see Appendix 2 Definitions)

A_T = $(b_0 \times CMF) \times X$

where: coefficient b_0 = 14 from CEC table 4-2, for a rural connector with a straight alignment

X = Exposure = 3.3km × 2,800 AADT × 365 / 10^8 = 0.034

CMF = 1.21 (Crash Modification Factor from CEC table 4-5 for rural connectors (using 3.5m lane widths and no (i.e. 0m) shoulders).

This adjusts b_0 upward, because the current seal width of 7 metres is narrower than the mean seal width of 8.2 metres assumed for Road Type 2, a rural connector (refer section 4.1 in CEC).

$A_{T,dm}$ = 14 × 0.034 × 1.21 = 0.58 injury crashes per year.

Weighted crash rate (refer to Appendix 2 Definitions) A_W for the do-minimum.

The weighted crash rate equation from Weighted crash rate for the do-minimum is:

$A_{W,dm}$ = $w \times A_T + (1 - w) \times A_S$

where: $w = k / (k + A_{T\ dm} \times Y)$

and: k = 1.0 (from CEC table 4-2), and Y = number of years of data (i.e. 5)

Because k is per kilometre, and for when you are calculating for ‘w’, $A_{T\ dm}$ (0.58) needs to be divided by the site length (3.3km).

$A_{T\ dm}$ = 0.58/3.3

= 0.176

and

w = 1.0 / (1.0 + 0.176 x 5)

w = 0.53

Therefore, the weighted crash rate is:

$A_{W,dm}$ = 0.53 × 0.58 + (1 – 0.53) × 1.98

= 1.24 injury crashes per year

Do-minimum crash costs:

= 1.24 × $1,437,000 (from Table A36)

= $1,781,880 per year

Option (a) crash costs: no significant changes at site.

Typical crash rate A_T:

$A_{T,opt}$ = b_0 × exposure × CMF (cross-section)

= 14 × 0.034 × 0.71

= 0.34 injury crashes per year

where: the CMF (cross-section) from CEC table 4-5 (for 3.5m lanes and 1.0m shoulders) is = 0.71 and therefore adjusts b_0 downwards as the proposed seal width of 9 metres is wider than the assumed mean seal width of 8.2 metres (for a rural connector).

Weighted crash rate A_W for the option:

$A_{W,opt}$ = $A_{T,opt} \times A_{W,dm} / A_{T,dm}$ (from Weighted crash rate for project option)

= 0.34 × 1.24 / 0.58

= 0.73 injury crashes per year

Option (a) crash costs = 0.73 × $1,437,000 = $1,049,010 per year

Option (a) crash benefits = Do Minimum crash costs – Option (a) crash costs

= $1,781,880 - $1,049,010 = $732,870 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 × CMF (cross-section for the option)

= 14 × 0.034 × 0.71

= 0.34 crashes per year

Option (b) crash costs = 0.34 × $1,437,000 = $488,580 per year

Option (b) crash benefits = Do Minimum crash costs – Option (a) CEC

= $1,781,880 - $488,580 = $1,293,300 per year

Back to 3.1 Impact on social cost of deaths and serious injuries >>

Cycling benefits

For this example calculation, assume:

- an average (two-way) distance cycled per user: 10km
- cycling specific number of days per week for 52 weeks per year
- $4.90/km health benefit per cyclist (no e-bikes) with $6200/user/year health benefit cap
- cycleway has over 100 users per day
- health benefits capping calculations based on frequency of use as shown below.

Days cycled/week	Annual health benefits (uncapped)	Health benefits cap	Annual health benefits after capping
1	$2,548	No	$2,548
2	$5,096	No	$5,096
3	$7,644	Yes	$6,200
4	$10,192	Yes	$6,200
5	$12,740	Yes	$6,200

In this example, the health benefits are capped for new individual users cycling three or more days per week.

Back to 3.2 Impact of mode on physical and mental health >>

Vehicle emissions procedure

For a 1km 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 = 25.3km/h
Light PM_{10}	=	0.02 g/vkt
Heavy PM_{10}	=	0.22 g/vkt
Weighted PM_{10} emission rate	=	95% x 0.02 + 5% × 0.22
	=	0.03 g/vkt
PM_{10} emissions	=	weighted PM_{10} emission rate × vkt
	=	0.03 × (1km × 1,000 vehicles) = 57g

Back to 3.3 Impact of air emissions on health >>

Traffic congestion procedure

Two worked examples are provided for different road categories as defined in Table A46.

Rural highway realignment

An activity involves the realignment of a busy 2 kilometre section of rural highway, which improves sight distances, providing more overtaking opportunities for following traffic. The road is classified as rolling terrain.

From calculations in Appendix 3: Traffic data and travel time estimation, the road section carries 12,500 veh/day, with a peak interval intensity of 1000 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:

2800 × ft × fd	=	2,800 × 0.675 × 0.94
	=	1,775 veh/h
where:		2,800 is the ideal capacity of the road section;
		ft and fd are adjustment factors for directional distribution and the proportion of trucks (see Table A60).

The peak interval traffic intensity (1000 veh/h) divided by capacity gives a VC ratio of 56%.

From **Error! Reference source not found.** the PTD in the do-minimum is 79%, and 71.5% after r ealignment. The CRV for rural strategic roads is $32.33 per veh/h (from Table 16).

The incremental values for congestion for the do-minimum and project option are calculated as follows:

Do-minimum	=	32.33 × 79/90
	=	$28.38 per veh/h
Activity option	=	32.33 × 71.5/90
	=	$25.68 per veh/h

The time period total average travel time for the road section is calculated using the procedures in Table A69 (based on component values calculated in other sections of Appendix 3: Traffic data and travel time estimation). 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 options, 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 × 28.38 × 1.70/60
	=	$804.10/h
Project option	=	1,000 × 25.68 × 1.30/60
	=	$556.40/h
Congestion cost saving	=	$804.10 - $556.40
	=	$247.70/h over the peak period.

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 modelled 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:

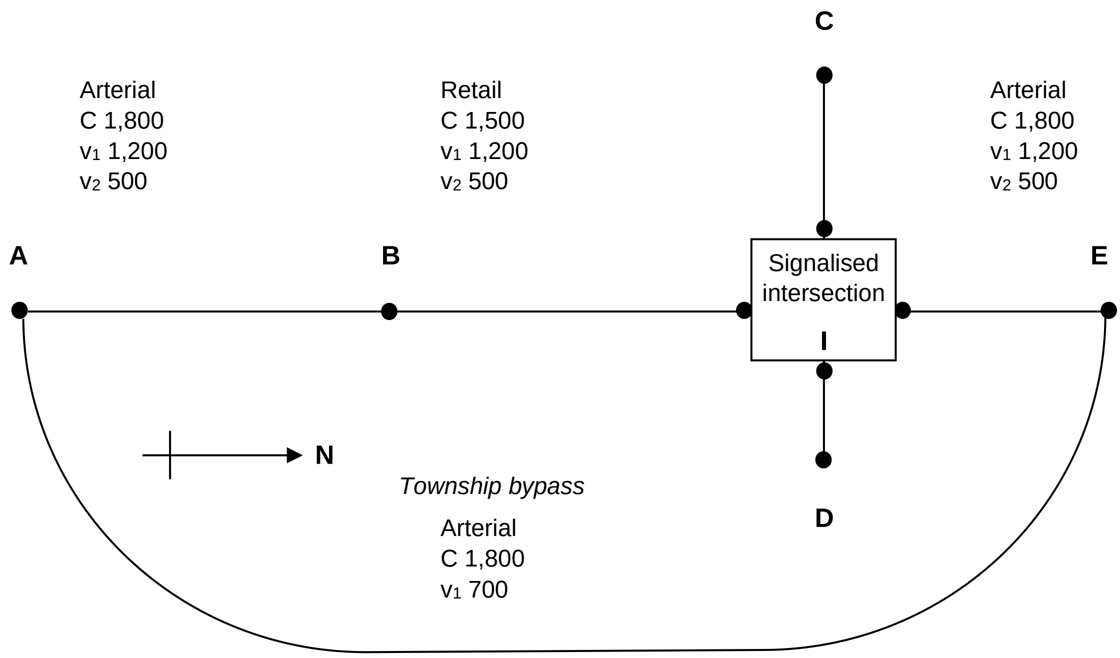
Do-minimum	= (500 × 35 + 300 × 5) / 3,600 = 5.28 veh/h
Roundabout option	= (500 × 7 + 700 × 5.5 + 600 × 6) / 3,600 = 3.04 veh/h
Reduction in bottleneck delay	= 5.28 - 3.04 = 2.24 veh/h
Congestion cost saving	= 2.24 × CRV = 2.24 × $24.79 = $55.53/h over time period.

Back to 3.6 Impact on network productivity and utilisation: Traffic congestion values >>

Trip reliability procedure

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 1,400 vehicles will use the new bypass each hour (700 in each direction).

Figure A42: Township bypass overview



Traffic volumes and VC ratios at signalised intersection I are summarised in Table A140, TableA141, Table A142 and TableA143.

Table A140: Do-minimum VC ratios

Approach	Lane no.	Movement	Traffic volume (veh/h)	VC ratio
South (B)	1	LT	1,121	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

Table A141: Option VC ratios

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

Table A142: Do-minimum flow matrices

		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0	0	1	82	1,120	0	1,203
	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	1,208
	E via bypass	0	0	0	0	0	0	0
Sum		1,200	0	12	345	1,200	0	2,757

Table A143: Option flow matrices

		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	12,03
	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		1,200	0	12	345	500	700	2,757

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 70)

For urban retail road: $S = 0.87$, $b = -16$, $a = 1$, $S_0 = 0.150$ (Table 70)

Table A144: Standard deviations of travel time (minutes)

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 70).

Table A145: Standard deviations of intersection travel times

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 $_{\text{activity option}}$ $= \sqrt{0.117^2 + 0.150^2 + 0.120^2}$

= 0.225 min

Table A146: Do-minimum matrices of standard deviations of travel times

		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

Table A147: Option matrices of standard deviations of travel times

		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

Multiply the element in the flow matrix (Table A142 and TableA143) with the corresponding element in the standard deviation matrix (Table A146 and TableA147) 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.

Table A148: Do-minimum matrices of flow × standard deviation of travel time

		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0.000	0	0.248	20.008	306.880	0	327.136
	B	0.000	0	0.000	0.000	0.000	0	0.000
	C	0.976	0	0.000	1.320	3.360	0	5.656
	D	60.756	0	0.240	0.000	10.080	0	71.076
	E via town	256.637	0	1.512	42.336	0.000	0	300.485
	E via bypass	0.000	0	0.000	0.000	0.000	0	0.000
Sum		318.369	0	2.000	63.664	320.320	0	704.353

Table A149: Option matrices of flow × standard deviation of travel time

		To A	To B	To C	To D	To E via town	To E via bypass	Sum
From	A	0.000	0	0.225	18.450	106.680	81.900	207.255
	B	0.000	0	0.000	0.000	0.000	0.000	0.000
	C	0.900	0	0.000	1.320	3.360	0.000	5.580
	D	56.025	0	0.240	0.000	10.080	0.000	66.345
	E via town	62.738	0	1.512	42.336	0.000	0.000	106.586
	E via bypass	81.900	0	0.000	0.000	0.000	0.000	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 16)

0.9 is the variability travel time factor

30% is the adjustment factor as there is only one major source of variability.

Back to full procedures for road improvement activities: Stage 4g. Impact on system reliability >>

Risk analysis procedure for resilience

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:

- The probability of an earthquake in the first year = p = 1/200 = 0.005.
- The probability of the bridge surviving for one year is therefore (1 - p) = 0.995.
- 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 (Table A150).

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.

Table A150: Example expected value calculations

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.

Back to full procedures for road improvement activities: Stage 4j. Other significant impacts …>>

Back to 7.3 Risk analysis overview: Risk reduction benefit >>

Resilience to coastal inundation

Construction of a new 4.5km shared path between Ngauranga and Petone was proposed to provide safe infrastructure for walking and cycling. Seawalls would be built along the new path to provide resilience by better protecting the rail line from flooding and futureproofing of sea-level rise between Ngauranga and Petone. The project applied a resilience adaptation strategy to protect the transport network from risk.

The economic analysis was calculated based on a 40-year analysis period and a discount rate of 4%. The economic analysis started in 2013 as year zero and construction of the project was assumed to be completed by the end of 2017. An update factor of 1.4 was also applied to the resilience benefits.

The 2013 Wellington storm was determined as the minimum magnitude of disruption that would cause closure and it was used as the baseline to determine the ARI/return period of the storm. The Ministry of Transport (MoT) calculated that the return period of the 2013 Wellington storm was 1 in 50 years.[19] Based on advice from subject matter experts, the return period was increased to 1 in 20 years as the likelihood of a similar storm will likely increase in the future due to climate change. MoT also estimated that the economic impact of transport disruption resulting from the 2013 Wellington storm was between $12m to $32m. A 50% factor was applied to the transport disruption cost as the project area only roughly overlaps 50% of the affected area. A medium cost of $11m (50% of $22m) was adopted as the base case scenario. The $6m and $16m transport disruption costs were used as sensitivity tests.

[19] Based on the transport impact of the 20 June 2013 storm: The effects of closing the Hutt Valley rail line between Petone and Wellington for multiple days report (Ministry of Transport, Appendix B).

TableA151 shows a summary of the information listed above. The subject matter expert determined that the project will have a 100% prevention success rate against flooding resulting from storms similar to the magnitude of the 2013 Wellington storm. Overall, the average annual resilience benefit of the project is $550,000.

Table A151: Te Ara Tupua – Ngauranga to Petone shared path resilience benefit

Scenario	Cost ($)	ARI/return period of the storm (year)	AEP (storm/year)	Annual transport disruption cost ($/year)	Prevention success rate (%)	Annual resilience benefit ($/year)
Low	6,000,000	1 in 20	0.05	300,000	100%	300,000
Medium	11,000,000	1 in 20	0.05	550,000	100%	550,000
High	16,000,000	1 in 20	0.05	800,000	100%	800,000

It was estimated that the project's total NPV benefit (resilience benefit + other co-benefits) was $21.3m and the total NPV cost was $5.3m. The NPV of the resilience benefits was calculated to be $8.9m, accounting for 42% of the total project benefits. The overall BCR of the project was 4.0. Several sensitivity tests were calculated to understand the uncertainty of the resilience benefits and costs, as shown in TableA152.

Table A152: Te Ara Tupua – Ngauranga to Petone shared path sensitivity analysis

Sensitivity test scenarios	Low	Base	High
The economic impact of transport disruption: • Low = annual transport disruption cost of $300,000. • Base = annual transport disruption cost of $550,000. • High = annual transport disruption cost of $800,000.	3.3	4.0	4.8
Timing of storm: • Low = Storm occurring last year of the analysis period. • Base = Using annual average resilience benefit value. • High = Storm occurring first year after construction of the project.	2.6	4.0	4.5
The return period of the storm: • Low = 1 in 50 years. • Base = 1 in 20 years. • High = 1 in 10 years.	3.0	4.0	5.7

The sum NPV of the co-benefits ($12.4m) is greater than the NPV of the total cost ($5.3m). Therefore, the resilience benefit has been isolated to determine the year of breakeven for the resilience benefits. The breakeven year for resilience benefits for this project was found to be 2031 (discount factor of 0.3053).

Breakeven BCR = (Resilience benefit x Discount factor x Update factor) ÷ NPV total cost

~1 = ($12,400,000 x 0.3053 x 1.4) ÷ $5,300,000

Resilience assessment of managed retreat

The section of State Highway 3 (SH3) through the Manawatū Gorge has been historically subject to extreme disruptive events, such as landslides and slips. As a result, the section of SH3 through the Manawatū Gorge has been closed several times. Historical data between 1985 and 2016 revealed that the average closure of the road is 1.4 times per year for a total duration of 18 days per year (AATOC).

A possible resilience adaptation strategy to address the issue of landslides and slips is to retreat from the risk and relocate the road to another less vulnerable location. For example, Table A153 shows the calculation for the daily total road user cost for three routes without the closure of the Manawatū Gorge, while TableA154Table A154 shows the calculation for the daily total road user cost for the three routes

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with the closure of the Manawatū Gorge. The total road user cost includes both the value of time cost and vehicle operating cost (which can be determined based on the length and gradient of the routes).

Table A153: Daily total road user cost without closure

	Manawatū Gorge	Saddle Road	Pahiatua Track
AADT	7,620	150	2,214
Light vehicle	6,759	150	2,214
Heavy vehicle	861	0	0
Heavy vehicle (%)	11.3%	0%	0%
Length (km)	14.1	18.0	50
Average travel time (minutes)	13.0	21.6 (light vehicle) 28 (freight)	36
Average speed (km/hr)	65	50 (light vehicle) 39 (freight)	83
Maximum gradient	Flat	16.0%	15.8%
Light vehicle total road user cost	$5.91	$8.91	$14.27
Heavy vehicle total road user cost	$16.18	$60.14	$98.53
Total road user cost for each road	$53,877	$1,337	$31,594
Total road user cost per day	$86,808		

Table A154: Daily total road user cost with closure

	Manawatū Gorge	Saddle Road	Pahiatua Track
AADT	0	6,370	3,614
Light vehicle	0	5,667	3,456
Heavy vehicle	0	703	158
Heavy vehicles (%)	0	11.0%	4.4%
Length (km)	14.1	18.0	50
Average travel time (minutes)	13.0	21.6 (light vehicle) 28 (freight)	36
Average speed (km/hr)	65	50 (light vehicle) 39 (freight)	83
Maximum gradient	Flat	16.0%	15.8%
Light vehicle total road user cost	$5.91	$8.91	$14.27
Heavy vehicle total road user cost	$16.18	$60.14	$98.53
Total road user cost for each road	$0	$92,764	$64,902
Total road user cost per day	$157,666		

Based on a transport assessment it was assumed that all vehicles would divert onto Saddle Road and Pahiatua Track during the closure of the Manawatū Gorge. Overall, the closure of the Manawatū Gorge would result in an additional road user cost of $70,858 ($157,666 - $86,808) per day or on average $1.28m per year ($70,858 x AATOC of 18 days).

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Funding gap analysis

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 years two to nine. The present value of the funding gap is $4,722,845, which does not change irrespective of how the funding gap is defined. However, this present value is at the service provider's desired rate of return, not the discount rate used in economic analysis. The cumulative amount of the funding gap is $8,518,471. This depends on how the funding gap is defined. It is smallest when all funding for the gap is provided at the start of the proposal, e.g. $5,924,337 if all paid in year two.

Table A155: Example funding gap calculation

Year	Capital cost	O&M cost	Revenue	Funding gap	Annual total	SPPWF	Net present value
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	-
			Present value = $4,722,845			**Sum of net present value = $0**	

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Discounting

Single payment present worth factor for a single period

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

Present value = $\$50,000 \times SPPWF^{6}_{15}$ (Table 83)

= $50,000 x 0.4173

= $20,865

Single payment present worth factor for multiple periods

A project costing $2 million with a implementation period of 15 months starting in the 8th month after time zero, has the following cash flow for expenditure:

Table A156: Example costs for the 2nd half of year 1

Month	7	8	9	10	11	12	**Total**
$ (000s)	0	50	50	50	100	150	**400**

Table A157: Example costs for the 1st half of year 2

Month	13	14	15	16	17	18	**Total**
$ (000s)	200	200	300	300	200	100	**1,300**

Table A158: Example costs for the 2nd half of year 2

Month	19	20	21	22	23	24	**Total**
$ (000s)	50	50	100	100	0	0	**300**

The present value of the implementation expenditure is:

Using annual SPPWF from Table 83

Present value = $(\$400,000 + \$1,300,000) \times SPPWF^{6}_{1} + \$300,000 \times SPPWF^{6}_{2}$

= $1,700,000 × 0.9434 + $300,000 × 0.8900

= $1,870,780

A more accurate calculation using quarterly SPPWF from Table A150.

Present value = $\$150,000 \times SPPWF^{6}_{0.75} + \$450,000 \times SPPWF^{6}_{1.00}$

$+ \$800,000 \times SPPWF^{6}_{1.25} + \$350,000 \times SPPWF^{6}_{1.50}$

$+ \$250,000 \times SPPWF^{6}_{1.75}$

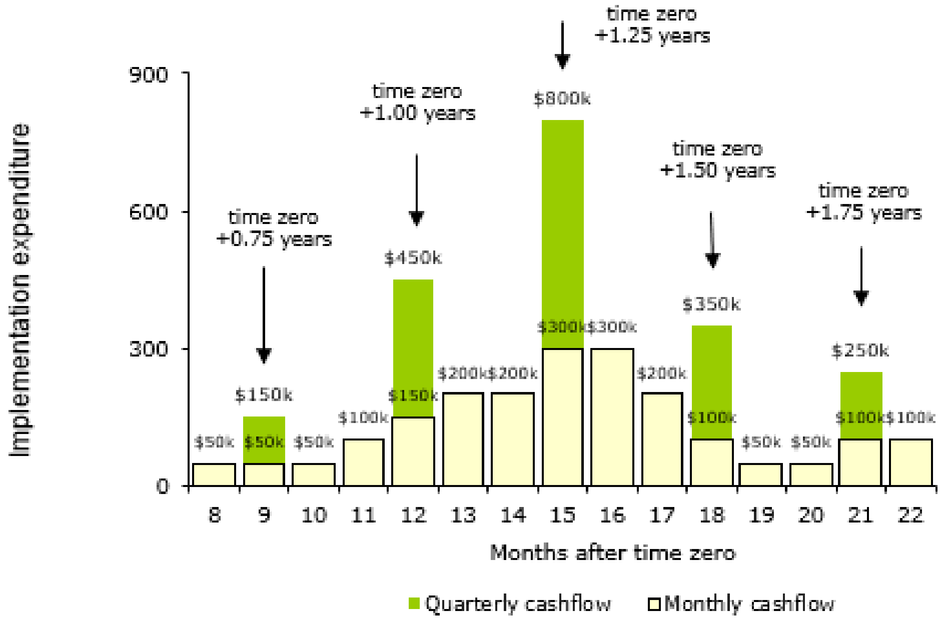
= $150,000 × 0.9572 + $450,000 × 0.9433

+ $800,000 × 0.9298 + $350,000 × 0.9163

+ $250,000 × 0.9031

= $1,858,385

Figure A42: Example cashflows



Uniform series present worth

If maintenance costs for the do-minimum are $30,000 a year over a 42-year analysis period (40 years plus two years to the start of construction), from Table A133 the present value of the maintenance costs is:

Present value	=	$\$30{,}000 \times (USPWF^{6}_{42} - USPWF^{6}_{0})$
	=	$30,000 × (15.677 - 0)
	=	$470,310

Arithmetic growth present worth factor

If vehicle operating costs are $70,000 with traffic growth of 1% at time zero, and construction finishes two years from time zero, from Table A134 the present value of the vehicle operating costs on the new construction is:

Present value	=	$\$70{,}000 \times [(USPWF^{6}_{42} - USPWF^{6}_{2}) + 0.01 \times (AGPWF^{6}_{42} - AGPWF^{6}_{2})]$
	=	$70,000 × [(15.677 - 1.888) + 0.01 × (206.674 - 1.851)]
	=	$1,108,606

Back to 5. Discounting >>

BCR_G calculations (using simplified numbers)

Toll road example

BCR_N

PV benefits	= $600m
PV costs	= $300m (including cost of toll facilities and toll collection)
BCR_N	= 600 / 300 = 2.0

BCR_G

PV benefits	= $600m
PV tolls	= $150 m (gross toll collections)
PV costs	= $300 m (including cost of toll facilities and toll collection)
BCR_G	= (600 - 150) / (300 - 150) = 3.0

PT example

BCR_N

PV benefits	= $900m
PV costs	= $300m
BCR_N	= 900 / 300 = 3.0

BCR_G

PV benefits	= $900m
PV farebox revenue	= $150m (PV of gross revenue)
PV costs	= $300 m
BCR_G	= (900 - 150) / (300 - 150) = 5.0

Private sector contribution example

BCR_N

PV benefits	= $300m
PV costs	= $200m
BCR_N	= 300/200 = 1.5

BCR_G

PV benefits	= $300m
PV private sector cont^n	= $100m
PV costs	= $200m
BCR_G	= (300 - 100) / (200 - 100) = 2.0

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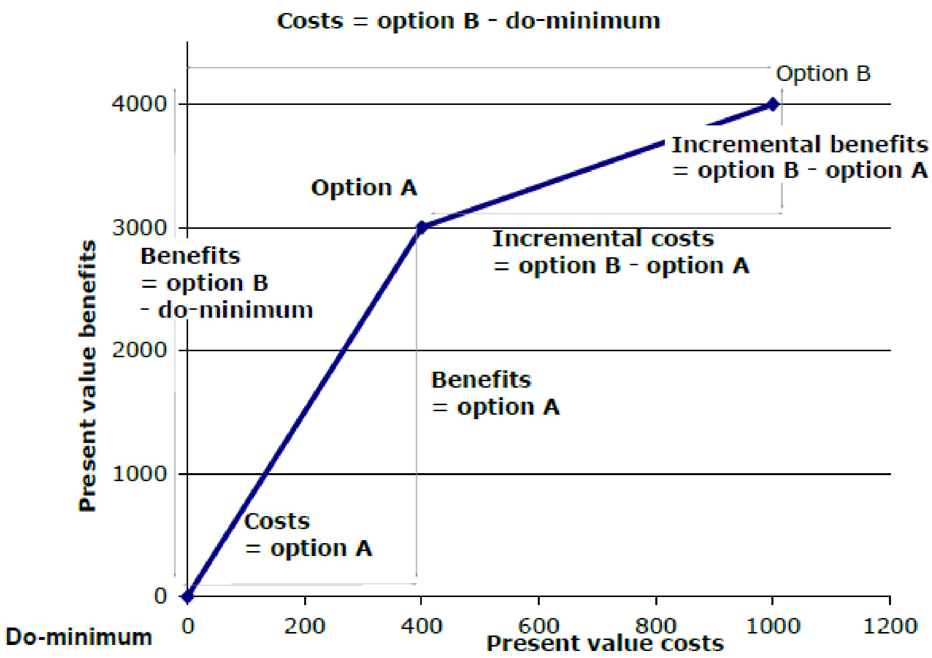
Incremental BCRs

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 (4,000/1,000). Such a value would usually result in the project receiving a *High* rating for the economic efficiency criteria considered under the NZTA funding allocation process. The less-costly option A, with a BCR of 7.5 (3,000/400), 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 ((4,000–3,000)/(1,000–400)).

Figure A43: Incremental BCR between two options



Applying incremental CBA to mutually exclusive options

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 in Table A159:

Table A159: Mutually exclusive options ranked by cost

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 in Table A160.

Table A160: Calculating the incremental BCR of mutually exclusive options

Current preferred option	Next-higher cost option	Calculation	Incremental BCR	Above/below the target incremental BCR	New preferred option
A	B	(140 - 110)/(30 - 15)	2.0	Below	A (No change)
A	C	(260 - 110)/(45 - 15)	5.0	Above	C
C	D	(345 - 260)/(65 - 45)	4.3	Above	D
D	E	(420 - 345)/(100 - 65)	2.1	Below	D (No change)

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.

Back to 6.3 Incremental cost–benefit analysis: Procedure for calculating the incremental BCR>>

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Calculating bottleneck delay

An example of the bottleneck delay calculation using the data from step 4 of Table A66 and a road capacity of 500 vehicles.

Table A161: Example data for bottleneck delay calculation

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	1,330	500	1,239	91	0	682.5
7:45	600	1,930	500	1,739	191	91	2,115.0
8:00	591	2,521	500	2,239	282	191	3,547.5
8:15	475	2,996	500	2,739	257	282	4,042.5
8:30	264	3,260	500	3,239	21	257	2,085.0
8:45	250	3,510	271	3,510	0	21	157.5
9:00	234	3,744	234	3,744	0	0	0.0

Step 11: Time period total delay

= 682.5 + 2,115 + 3,547.5 + 4,042.5 + 2,085 + 157.5

= 12,630 veh-mins

Step 12: Time period average delay per vehicle

= 12,630 / 3744

= 3.37 mins/veh

Calculating the time period total average travel time

Section length = 1km

Free speed travel time = 0.636 min/km

Time period additional travel time = 0.232 min/km

Speed change additional travel time = 0.003 min

Bottleneck delay per vehicle = 1.5 min/veh

Time period total average travel time

= $(TT_{FS} + TT_{ATT}) \times$ length + bottleneck delay + speed change

= $(0.636 + 0.232) \times 1.00 + 1.5 + 0.003$

= 2.371 min/veh

Back to Appendix 3. Traffic data and travel time estimation: Calculating bottleneck delay>>

Traffic signals

Table A162: Example traffic signal data

Basic data	
Lane width	3.3m
Number of lanes	2
Approach grade	+2%
Parking movements/h	20
Locality	CBD
Arrival type	Random
Signal type	Actuated

Lane width factor (from TableA70)	=	0.98
Approach grade factor (from Table A71)	=	0.99
Parking factor (from Table A72)	=	0.89
Locality factor (from Table A73)	=	0.90
Saturation flow rate	=	2000 × 0.98 × 0.99 × 0.89 × 0.90
	=	1554 pcu/h
Arrival type (from Table A74)	=	3
Delay adjustment factor (from Table A75)	=	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.

Back to Appendix 3. Traffic data and travel time estimation: Traffic signals >>

Risk analysis worksheet 3: relative risk indicator calculation

Estimated 95% confidence limits on quantifiable risk category (expressed as a % of the impact on TOTAL costs or TOTAL benefits).

Table A163: Example data for relative risk indicator calculation

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

The notes below illustrate the calculation of the relative risk indicators, using data from Table A163 and the methodology from Risk analysis worksheet 3.

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 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 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.