Probabilistic Risk Analysis in Transport Project Economic Evaluation

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by John Lieswyn

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Abstract

Transport infrastructure investment decision making is typically based on a range of inputs such as social, environmental and economic factors. The benefit cost ratio (BCR), a measure of economic efficiency ("value for money") determined through cost benefit analysis (CBA), is dependent on accurate estimates of the various option costs and net social benefits such as reductions in travel time, accidents, and vehicle operating costs. However, most evaluations are deterministic procedures using point estimates for the inputs and producing point estimates for the outputs. Transport planners have primarily focused on the cost risks and treat risk through sensitivity testing. Probabilistic risk analysis techniques are available which could provide more information about the statistical confidence of the economic evaluation outputs.

This research project report investigated how risk and uncertainty are dealt with in the literature and guidelines. The treatment of uncertainty in the Nelson Arterial Traffic Study (ATS) was reviewed and an opportunity to apply risk analysis to develop probabilities of sea level rise impacting on the coastal road options was identified.

A simplified transport model and economic evaluation case study based on the ATS was developed in Excel to enable the application of @RISK Monte Carlo simulation software. The simplifications mean that the results are not comparable with the ATS.

Seven input variables and their likely distributions were defined for simulation based on the literature review. The simulation of seven variables, five worksheets, and 10,000 iterations takes about 30 seconds of computation time. The input variables in rank order of influence on the BCR were capital cost, car mode share, unit vehicle operating cost, basic employment forecast growth rate, and unit value of time cost. The deterministically derived BCR of 0.75 is associated with a 50% chance that the BCR will be less than 0.6, although this probability is partly based on some statistical parameters without an empirical basis. In practice, probability distribution fitting to appropriate datasets should be undertaken to better support probabilistic risk analysis conclusions. Probabilities for different confidence levels can be reported to suit the risk tolerance of the decision makers.

It was determined that the risk analysis approach is feasible and can produce useful outputs, given a clear understanding of the data inputs and their associated distributions.

Acknowledgements

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My employers ViaStrada Ltd have made my studies possible and in particular I would like to thank Andrew Macbeth and Axel Wilke for mentoring and technical advice, Rick Houghton for GIS support, and Warren Lloyd for providing a sounding board during project selection. All my colleagues at ViaStrada have been supportive and my thanks for their patience. Graeme Belliss of the NZ Transport Agency suggested the topic and provided crucial background to get me started. Above all, I could not have put in the late nights and long weekend hours without the support and understanding of my wife Dawn Kingsbury.

The research model is a simplified version of a network detailed in the Arterial Traffic Study (ATS) project recently undertaken by MWH New Zealand Ltd. in Nelson. Thank you to David Wanty of MWH and Andrew James of Nelson City Council for permission to utilise data, which has given me a useful real-world context.

Disclaimer

This project is focused on the feasibility level case study application of risk analysis. Results of this risk analysis are based on simplified models and are not applicable to Nelson.

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Acronyms

AADT	Average Annual Daily Traffic
ANZSCO	Australian and New Zealand Standard Classification of Occupations
ATS	(Nelson) Arterial Traffic Study
BCA	Benefit Cost Analysis. In this report, BCA is used except when quoting a reference that uses reversed terms (i.e. CBA).
BCR	Benefit Cost Ratio
CB	Comfort Benefits from sealing
DfT	(United Kingdom) Department for Transport
EEM	NZ Transport Agency Economic Evaluation Manual
FHWA	(United States) Federal Highway Administration
GIS	Geographic Information System
LUTI	Land Use and Transport Integration
MCA	Multi Criteria (Decision) Analysis; some literature refers to MCDA
NZTA	NZ Transport Agency
OD matrix	Origin / Destination matrix
PPFM	NZ Transport Agency Planning Programming and Funding Manual
RA	Risk analysis
RMSE	Root Mean Square Error
TAZ	Transport Analysis Zone
TTS	Travel Time Savings
UE	User Equilibrium traffic assignment
VKT	Vehicle Kilometres Travelled
VOC	Vehicle Operating Costs
VOSL	Value of Statistical Life
VOT	Value of Time
WEB	Wider Economic Benefits

Glossary

Benefit cost analysis (BCA) is a "single objective assessment method" which reduces benefits and costs of alternatives to a common monetary unit (Meyer & Miller 1984).

Economic evaluation is the ex ante estimation of the costs and benefits which are expected to accrue from a proposed intervention. This definition is consistent with NZ practice, but opposite of UK practice where evaluation is ex post and appraisal is ex ante.

Risk analysis is the systematic use of available information to determine how often specified events may occur and the magnitude of their consequences (Palisade 2011).

Risk is the effect of uncertainty on objectives (Standards Australia & Standards New Zealand 2009) Risk is quantified as the product of the probability and consequences of an undesirable event (Dalziell et al. 1999)

Uncertainty is an unknown probability distribution, although there may be confidence in the range in which the expected value may fall (Mishan 1972)

1 Introduction

1.1 Problem

> *...we are operating in a world with many uncertainties, as evidenced by recent radical swings in both fuel prices and the economy. Uncertainties in these dimensions are compounded by what may happen with major policy decisions such as greenhouse gas policy. With such challenges it may be unrealistic to expect any model estimated from and calibrated to past behaviour to correctly predict the future 30 years out.* (Donnelly et al. 2010, p. 31)

As transport planners today are faced with ever increasing challenges, scrutiny, and financial pressure, there is a need to produce the best possible information to inform good decision making. However, measures of economic efficiency resulting from project economic evaluations are often presented as seemingly precise point estimates supported by detailed analysis which may give a decision maker a false impression of accuracy (Clay & Johnston 2006, p. 192). The decision may be made with a sense of confidence in the analysis, and few ex post evaluations are carried out to see how accurate the estimates turned out to be (Short & Kopp 2005).

Project economic ex ante evaluations depend on a set of inputs including traffic model predictions of future travel patterns and characteristics. The traffic models are themselves dependent on a range of assumptions, for example the specification of an annual traffic growth rate of 2% throughout the analysis period. Many other assumptions and exclusions are commonly made, including:

- marginal travel time savings are fully realised, and are not offset by latent or induced demand
- capital costs do not escalate significantly
- external uncertainties (e.g. fuel prices) and the decisions of others in response to the modelled changes are excluded
- costs borne by society (e.g. parking or health impacts) are excluded
- trip generation rates are the same for various urban development patterns

Uncertainty in the benefit cost ratio (BCR) output of economic evaluation is likely to increase throughout the traditional sequential four step travel demand modelling process and the subsequent economic evaluation.

Risk and uncertainty are often addressed through sensitivity testing of the BCR to changes in the input values. However, Walker and Fox-Rushby (2001, p. 441) note that the "main weakness associated with sensitivity analysis is the control that the analyst retains over three parts of the process: the choice of which variables to vary and which to treat as known or fixed; the amount of variation around the base value of the parameter that is considered...policy-relevant; and the determination of what constitutes a sensitive or robust finding."

The NZ Transport Agency *Economic Evaluation Manual* and the Austroads *Guide to Project Evaluation* provide guidance on more robust (compared to sensitivity testing) risk analysis methods to address risk and uncertainty. The Danish CBA-DK software was developed in 2011 to integrate Palisade's @RISK Monte Carlo simulation with existing (Danish) transport economic evaluation, while the Austroads Risk Explorer software has been available since 2005 (Austroads 2005a; Salling & Leleur 2011). Although @RISK and other similar software suites are commercially available, probabilistic risk analysis is rarely undertaken in New Zealand (Belliss 2011, pers. comm.). Although most experts are aware of the uncertainty problem, they may consider that the use of widely accepted deterministic procedures is better than decision making without models and economic evaluations. It may be that probabilistic risk analysis techniques are considered too time-consuming and therefore costly to apply relative to the investment being considered or the analysts themselves may not recognise the magnitude and effects of the risks and uncertainties involved. Practitioners may also feel that acknowledging uncertainty may undermine their credibility in the eyes of decision makers.

1.2 Motivation

Transport infrastructure is acknowledged to have a strong influence on the overall pattern of urban form, urban liveability, and the collective decisions of individuals with respect to mode choice. Economic evaluation is seen as an important way to ensure value for money and the correct allocation of limited resources. Initial investigations showed that the economic evaluation output BCR is heavily influenced by transport model outputs such as travel time savings. Current transport investment decision making appears to be based on evaluations which do not adequately take into account risk and uncertainty. Although guidelines exist, probabilistic risk analysis techniques designed to quantify the sources and magnitude of uncertainty are not widely applied. Risk analysis can help analysts and decision makers identify when there is a case for further investigation to reduce uncertainty or for choosing alternative courses of action.

Improving transport models is one way to reduce uncertainty, but the sources and magnitude of uncertainty should still be reported. The motivation for this project is to determine the importance and feasibility of improved treatments of uncertainty than what is currently undertaken.

This work could be combined with other areas of academic and practical research into improving transport planning. Some of these other areas where risk analysis could be used include land use and transport integration (LUTI) models to better account for strategic effects of transport infrastructure (Wenban-Smith & van Vuren 2009), developing better means of determining differential impacts and the measurement of externalities (Litman 2009a), and improving the evaluation of wider economic benefits (Lakshmanan 2010).

1.3 Objectives

The principal objective of this project is to assess the feasibility of using probabilistic risk analysis to consider the impact of uncertain inputs on the results of economic evaluation.

Specific objectives are to:

- Define and discuss the importance of risk analysis in transport project assessment
- Determine the extent to which risk analysis is required and performed in New Zealand and overseas
- Research the available literature on the sources and magnitude of risk and uncertainty in traffic models and in economic evaluation
- Apply risk analysis techniques using a case study model to determine the influence of uncertain inputs on the evaluation output BCR
- Assess the potential for risk analysis methods to be applied to transport planning

1.4 Method

The project method is summarised in Figure 1 and as follows.

The initial formulation of the research problem was undertaken through meetings with NZ Transport Agency staff and project supervisors. Initially it was hoped that a real-world example of risk analysis could be found or performed on an existing proposal. Enquiries and an initial literature review suggested that a more achievable (within the available resources) approach for the project was to extract existing data from a real-world example for application within a simplified case study.

The full literature review included searches of academic journals, textbooks and current Australian and New Zealand guidance. A major part of the review was the Nelson Arterial Traffic Study (ATS) which has a limited but perhaps representative consideration of risk and uncertainty and provides valuable context for the subsequent stage of the project.

A transport model was developed which can be run from within an Excel spreadsheet so that a commercial risk analysis package, Palisade's @RISK software, can be employed. Although very basic in comparison to what is used in practice, a simple Excel model was considered sufficient for a feasibility study.

The model development began with data collection from Statistics New Zealand and the ATS study project team, data processing in Excel to match datasets, and export to the ESRI ArcMap geographic information system (GIS). Using GIS, simplified traffic analysis zones (TAZ) were defined based on merged census meshblock areas. Next, the zones and socio-demographic data were joined. GIS also allowed a transport network to be defined and route lengths calculated.

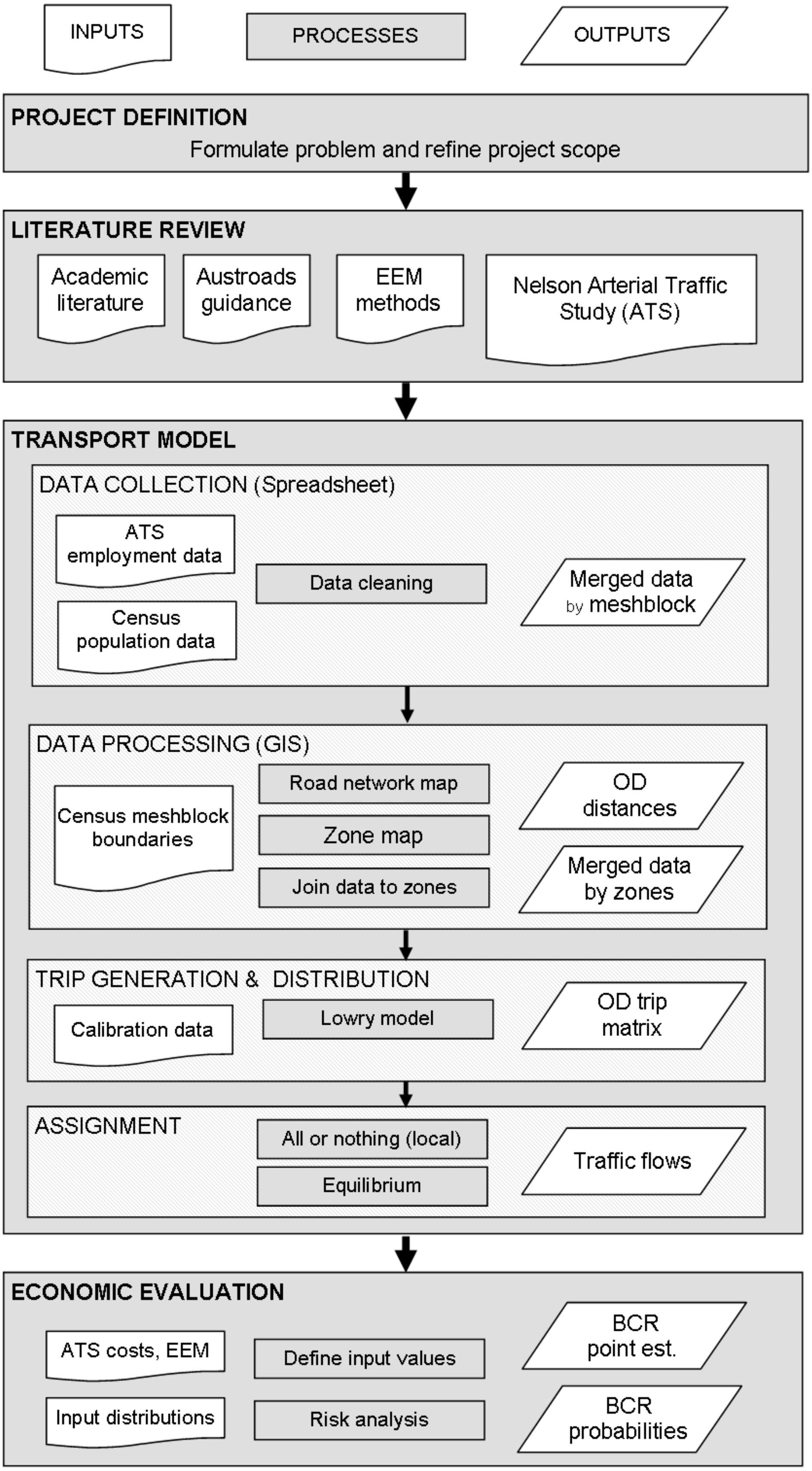


Figure 1: Project method flowchart

The next phase of the model development was the construction of a model in an Excel spreadsheet based on the Lowry formulation of economic base theory. The Lowry model concept integrates trip generation and distribution and only requires the location of employment by zone, so it was considered to be readily applied and sufficient to the study objectives. A first attempt was made to use a published Excel-based Rodrigue (2009) formulation of the Lowry model, but this model made extensive use of macros and it was considered too difficult to modify in the time available. Therefore a 16 zone model was developed from the basis of a five zone Lowry model presented in previous course notes. The model was calibrated using existing (census derived) population and employment by zone and generated an origin-destination (OD) trip matrix. A separate assignment model was needed to allocate the travel between zones by least cost. For many OD zone pairs, route choice would not likely be a factor and these trips were preloaded onto the network using the "all or nothing" assignment method. The remaining trips were allocated to the available (or proposed new) routes by use of a user equilibrium method based on the Davidson formula (Akcelik 2000). Excel Solver was used to minimise an objective function and derive flows on each route that satisfied Wardrop's first principle. The result was a traffic flow on each link and a traffic growth rate, which were then used in the economic evaluation.

The economic evaluation used the flow outputs and traffic growth rate from the transport model, ATS costs, and EEM values in a feasibility study level preliminary benefit cost analysis (BCA). The resultant deterministic outputs and input variable distributions found in the literature review were the inputs to the analysis @RISK Excel add-in module.

The preliminary method had a number of limitations and exclusions which resulted in the further development of the project method. It was decided to undertake an EEM full procedures evaluation. This process resulted in additional familiarisation with the EEM and consequently several revisions to the literature review.

2 Literature Review

The focus of this literature review was on the identification, assessment, and treatment of risk and uncertainty in transport project economic evaluation. To provide context, the review considered the role of economic evaluation in transport planning decision making. This included the available guidance and some of the relevant criticisms often levelled at BCA.

2.1 Economic evaluation

2.1.1 Decision making context

The investment in transportation systems is generally made based on planning methods commensurate with the scale of the intervention. Meyer & Miller (1984) describe two approaches to urban transportation planning:

- **Predict and provide –** the planner predicts future transport demand based on current trends, trip and/or parking generation rates and provides for that demand. This may be at the regional or city plan macro level, resulting in the construction of major infrastructure such as motorways, or at the land development level, resulting in the provision of infrastructure such as car parking and new traffic signals for a shopping centre.

- **Decision oriented planning –** after information gathering, a diagnosis of transport system issues is made to inform the selection of options. These options are then compared against a set of criteria which align with objectives. Objectives may be strategic (e.g. safety, mode choice and accessibility, economic efficiency) or problem oriented objectives such as job creation, land development, or congestion reduction.

Despite the best intentions, transport planning "is generally politicised...rarely fully transparent, and there is little ex post analysis on whether projects and policies meet expectations" (Short & Kopp 2005, p. 363). The lack of transparency is often due to a failure to engage stakeholders and a dependence on 'black box' models (Communities and Local Government 2009).

Within this context, planners and decision makers have tended to rely on BCA procedures that produce economic efficiency measures which may be seen as reproducible and incontrovertible.

The procedure of deriving a measure of value for money (economic efficiency) with regard to a proposed investment is variously known as economic analysis (USA), economic appraisal (UK), or economic evaluation (Australia and New Zealand). To compare alternative investment options which are expected to generate the same level of benefits, the analyst may use life-cycle cost analysis (FHWA 2011). Where the alternatives have different expected benefits, the appropriate tool is known as benefit cost analysis (BCA).

2.1.2 Benefit cost analysis (BCA)

2.1.2.1 Standard BCAs

BCA is a "single objective assessment method" which reduces benefits and costs of alternatives to a common monetary unit (Meyer & Miller 1984). The BCA approach generates measures of economic efficiency including:

- **BCR –** the benefit-cost ratio is a single point value based on most likely or expert "best guess" estimates of each input variable (Salling & Leleur 2011). The agency (e.g. road authority) costs are included in the denominator, with all cost reductions, benefits and negative benefits in the numerator (FHWA 2011).
- **NPV –** the net present value is the difference between the discounted present value of all benefits and costs; the project with the highest NPV is usually advanced.
- **IRR** – the internal rate of return is the discount rate necessary to yield an NPV of zero from the sum of all benefit and cost streams accruing over the analysis period (FHWA, 2011). Another way of thinking of the IRR is that a project is deemed uneconomic if the IRR calculated for it is lower than that which can be obtained in alternative social investments, such as government securities (Mishan 1972)

BCAs may be deterministic, with or without sensitivity testing, or probabilistic, using stochastic tools such as Monte Carlo simulation (Austroads 2011a). There are generally two types of BCA as outlined in Table 1 (Austroads 2009).

Table 1: Appraisal method stages (based on Figure 3, Austroads 2009b)

Stage	Planning phase	Confidence level
Strategic merit test (SMT)	Option identification	
Rapid BCA	Option short listing	Low
Detailed BCA	Final option selection	High

The method used is the same for both types; however for the rapid BCA some inputs may be omitted or estimated with less concern for accuracy. Austroads suggests a further optional step of providing an "adjusted" economic evaluation which is essentially a simple multi-criteria analysis (MCA) to provide a strategic objective overview. There is a third type of BCA which will be described in the next section.

2.1.2.2 BCAs including wider economic benefits (WEBs)

Most economic evaluations undertaken in New Zealand are of the traditional variety where only the factors which can be easily measured (such as travel time, safety impacts, and cost implications) are included. Traditional BCA, even those analyses which include externalities such as emissions, are limited to consideration of microeconomic effects (Lakshmanan 2010).

More recent advances in BCA seek to include wider economic benefits (WEBs) where the project or programme of projects is likely to have regional or national impacts (Feldman et al. 2009). WEB analysis can include more of the externalities which a given transport project may have an impact upon, such as the growth or redistribution of economic activity, environmental impacts, or energy consumption.

A recent example of including WEBs in evaluation is the Roads of National Significance (RoNS) assessment undertaken by SAHA on behalf of the NZ Transport Agency (2010). The SAHA method included the development and comparison of two approaches to including WEBs. One was a computable general equilibrium (CGE) model to estimate the magnitude of national economic impacts, and the other was a region-by-region estimation of agglomeration and land use change impacts.

Australian experience shows that inclusion of WEBs raises the benefit streams by "20-30% over above conventional BCA benefits - however it appears there has been a lack of detailed data collection, and there has been heavy reliance on one or two reference projects..." (SAHA 2010, p. 2). Yet the SAHA report finds that, for the New Zealand Roads of National Significance (RoNS) package, overall benefits (including "non-market" benefits such as lives saved through accident reduction) rise by about 80%.

2.1.2.3 <u>Risk and uncertainty in WEB analyses</u>

The UK method for estimating agglomeration benefits is "based on the observed correlation between density of employment and productivity" where density is "understood in terms of the cost of accessing other jobs both in the study zone...(and) in adjacent and more distant areas" (Feldman et al. 2009, p. 5). It is arguable as to whether such an understanding is consistent with the meaning of the word density or whether the correlated data is applicable outside the UK. A related concern is that the overall assumption of WEB analysis (where applied to highway projects) seems to exclude wider economic costs such as the higher cost of fuel per household for longer trips or the higher costs of providing more parking at destinations (due to the inability of people to access these destinations with non-car modes). The UK based DELTA LUTI model addresses the link between highway infrastructure and sprawl with a migration sub-model to estimate longer distance household movements (Simmonds & Feldman 2009). This may be because some BCA procedures are focused on agency costs rather than user (or developer) costs, and highlights the lack of joined-up thinking between government departments and the lack of consideration of all social costs at the national treasury level.

As with BCA in general (refer section 2.1.4.3), a limitation of WEBs is the inclusion of some wider benefits to the economy while excluding others. The BCR numerator should have both benefits and dis-benefits (FHWA 2011; NZTA 2010; Sinha & Labi 2007). There is a widely acknowledged correlation between vehicle kilometres travelled per capita and sedentary lifestyles, leading to relatively large health dis-benefits (Bassett et al. 2008; Pucher & Buehler 2010). On the other side of the coin, encouraging a 5% shift from motorised to active modes of transport can conservatively (only fatalities were considered) produce net savings to the New Zealand Treasury of $200M per year (Lindsay et al. 2011). Accident cost savings are monetised by transport professionals endogenously within an economic evaluation, while health care impacts are monetised by health professionals and therefore typically considered exogenous to the transport system. However, new methods to monetise the health impacts of transport infrastructure are being adopted using procedures such as the World Health Organisation HEAT tool (Sloman et al. 2009).

WEB analysis also makes a number of socio-economic assumptions. For example, the UK's Department for Transport method suggests that benefits can accrue "from improved labour supply, due to improved travel for commuters leading some people to work who would otherwise choose not to work" (Simmonds & Feldman, 2009, p.16). This seems to be a tenuous hope, and no supporting research was identified in this literature review.

Another source of uncertainty in WEB analysis is that the assumption of ever continuing economic expansion. In contrast to the WEB analysis concept of a link between transport growth and economic activity, some authors and the first New Zealand Transport Strategy suggest some decoupling must occur to achieve long run sustainability (Ballingall et al. 2003; Gray et al. 2006). Investing in new transport capacity stimulates declining marginal demand for vehicles and travel as a country becomes more developed, which may also have implications for the applicability of WEB analysis (OECD 2006). In the medium to long term, there is an economic risk of relying on the assumptions in WEB analysis to justify increased highway building, given the dependence of the New Zealand economy on motor vehicle consumption and maintenance, and the potential for transport growth to be constrained by fuel supply reductions (Krumdieck et al. 2010). Aside from identifying this risk, it is outside the scope of this project to delve further into this issue with respect to WEB analysis.

In addition to these potential risks and uncertainties, WEB analysis limitations include cost, complexity, and the risk of double counting benefits. Therefore WEB analysis is likely to be used only for major projects with regional or national significance (e.g. the RoNS). Furthermore, evaluations including WEBs can produce BCR estimates with greater uncertainty. For example, the Auckland City Rail Link business case independent review found that a standard evaluation yields a BCR between 1.0 and 1.1, while inclusion of WEBs yields a higher and more variable BCR range between 1.1 and 2.3 (Auckland Council 2011).

In summary, detailed monitoring and ex post evaluation may be required to determine the magnitude of uncertainty in WEB analysis.

2.1.3 Sources of guidance on economic evaluation and risk analysis

2.1.3.1 New Zealand guidance

The *Economic Evaluation Manual* (EEM) is the principal guideline for applying BCA in New Zealand. The EEM has replaced the Transfund (now part of the NZ Transport Agency) Project Evaluation Manual and is now in two volumes (NZTA 2010, p.1-3):

> *Volume 1 contains the basic concepts of economic efficiency evaluation and specific evaluation procedures for road activities.*
>
> *Volume 2 includes procedures to be used for evaluating transport demand management proposals, travel behaviour change proposals, walking and cycling, transport services, private sector financing, toll road activities and parking measures.*

The 685 page volume 1 is a complex document. For example, Worksheet A2.9 is in Section 5.0 on page 5-65, and it refers to Table A2.4 in Appendix A1 on page A2-7. Spreadsheets are provided for simplified procedures, while full procedures are only provided in Microsoft Word format.

The EEM addresses uncertainty in part through sensitivity testing of evaluations to "critical assumptions or estimates" including "variation in costs, future traffic volumes, particularly due to model results, growth rates, and the assessment of diverted and induced traffic..." (NZTA 2010, p. 2.21). Sensitivity and risk analysis procedures are given, with the latter requiring probability distributions of the input variables and producing probability distributions of the resulting BCRs.

The *Planning, Programming and Funding Manual* (PPFM) outlines how the results of an economic evaluation are to be used in preparation of assessments to accompany submissions to the National Land Transport Fund (NZTA 2009). The PPFM states that a single point estimate of costs without risk analysis is acceptable for projects under $4.5M ($1M for TDM activities) and indicates that the NZTA "reserves the right to request a risk analysis by Monte Carlo based simulation for any project of any value".

NZ Transport Agency research reports and the Ministry of Transport's *Surface Transport Costs and Charges Study* (Booz Allen Hamilton 2005) are also useful sources for cost and benefit valuation guidance.

Methods for identifying, assessing and treating risk and uncertainty are covered in these NZTA publications as well as the Australian/New Zealand standard *Risk management – Principles and guidelines* (2009). The standard is a brief 21 page publication setting out the definitions of risk ("the effect of uncertainty on objectives") and the characterisation of risk in terms of potential events and consequences.

2.1.3.2 Overseas guidance

This literature review identified some sources of overseas guidance on economic evaluation. These sources include the UK Department for Transport's *Transport Analysis Guidance – WebTAG*, the Canadian *Benefit-Cost Analysis Guide*[1] (Treasury Board Secretariat 1998), the Victoria Transport Policy Institute's *Transportation Cost and Benefit Analysis Techniques, Estimates and Implications* (Litman 2009b), the US Federal Highway Administration *Economic Analysis Primer* (FHWA 2011). Except for the Treasury Board document, these publications exist as recently updated web pages with extensive links to supporting documents.

Risk assessment in economic evaluation is covered in Part 2 of the Austroads *Guide to Project Evaluation* (replacing the 1996 publication *Benefit Cost Analysis Manual*) as well as in recent Austroads research reports. These publications are listed in Table 2, with abstract material sourced from the Austroads publications website.

[1] This document is referred to but not available on Canadian government websites, but a draft copy is widely available on the internet. The 1998 draft guide refers extensively to a predecessor published in 1976, of which a copy was found. Both versions are cited in this report.

Table 2: Austroads guides and Australian standards relevant to project evaluation

Guide to Project Evaluation	**Abstract**
Part 1: Introduction to Project Evaluation (2009)	Links project evaluation with the wider area of transport planning including broad outcomes such as efficiency, safety and sustainability. Recommends a three-stage evaluation process: (i) test strategic fit (ii) investigate and analyse project options that pass the strategic fit; and (iii) develop a business case for the preferred option.
Part 2: Project Evaluation Methodology (2005a)	Guidelines for conducting benefit–cost analysis and multi-criteria analysis on transport projects, policies and programs. Provides guidance on risk assessment including Risk Explorer software. Excludes specialist evaluations such as very large and complex projects and public-private partnership projects.
Part 3: Models and Procedures (2005)	Summarises the literature on the wide range of evaluation tools. Distinguishes between rural and urban project evaluation procedures.
Part 4: Project Evaluation Data (2008)	Road user unit costs (Australian 2007 dollars) for vehicle operation, travel time, crashes and environmental externalities. Calculated in resource price terms excluding indirect taxes and government charges, but including producer subsidies.
Part 5: Impact on National and Regional Economies (2005)	Describes the use of macro-economic models to capture wider economic benefits (WEBs) of major projects not fully captured by standard BCAs, e.g. the computable general equilibrium model.
Part 6: Distributional (Equity) Effects (2005)	Evaluation of distributional (equity) impacts, i.e. the winners and losers of projects, and how these impacts can be traded with efficiency gains. Aids consideration of distributional effects by comparing sets of efficiency outcomes with desired social (equity) outcomes. An Equity Explorer software tool is included.
Part 7: Post-completion Evaluation (2005)	Evaluation of completed transport projects to assess actual performance against stated objectives.
Part 8: Examples (2006)	Nine worked examples of evaluation techniques (flood mitigation, sealing and realignment, bridge maintenance, ferry upgrade, blackspot evaluation, timing of project, bus priority, town bypass and road widening), linked to an executable Excel spreadsheet.
Austroads research	**Title**
AP-R388-11 (2011a)	Improving practice in cost estimation
AP-R390-11 (2011b)	Documentation and Quality Control of Benefit-Cost Analyses
AP-R391-11 (2011d)	Valuation of Travel Time Reliability: A Review of Current Practice
AP-R392-11 (2011c)	Small Travel Time Savings: Treatment in Project Evaluations

2.1.4 Criticisms of economic evaluation

2.1.4.1 Uncertainties

The US Federal Highway Administration (FHWA) suggests that benefit cost analysis may be avoided because of concern about the uncertainty of inputs:

> *In some cases, agency personnel are skeptical about the accuracy of BCA due to perceived uncertainties in measuring or valuing costs and benefits. In reality, there is much more substance to economic analysis techniques and values than is generally understood. Where uncertainty does exist, it can usually be measured and managed. It is helpful to remember that sound economic analysis reduces uncertainty. Not doing the analysis only serves to hide uncertainty from decision makers. (FHWA 2011)*

The means of addressing this concern is an aim of this research project. Risk treatment approaches found in the literature are presented in sections 2.3 and 2.4 of this report.

2.1.4.2 Dependency on traffic forecasting

Transport evaluation practice is sometimes criticised for an auto-mobility focus, with "forecasts of future travel demand based on current travel patterns...reproducing current imbalances in transport provision" between the well-off and the transport disadvantaged (Martens 2006, p. 14). Martens recommends a change in focus to accessibility rather than travel time savings, coupled with an "inverse relationship between monetary value and people's current level of accessibility to reflect the principle of diminishing marginal benefits" (Litman 2011b). A key aspect of such a change would be to disconnect benefits from trip numbers, as the current linkage promotes a cycle of ever increasing vehicle kilometres travelled (Litman 2011b).

The trip numbers (traffic forecast) is one of the key drivers of the benefits component of economic evaluation. Many authors (Clay & Johnston 2006; Litman 2009a; Welde & Odeck 2011) note that most evaluations are presented to decision makers with point estimates for BCRs and traffic predictions accompanied by weighty and jargon rich reports to which they may ascribe an unsupported level of accuracy.

2.1.4.3 Exclusion of externalities

The typical economic evaluation excludes "parking and vehicle ownership cost savings that result when travellers shift from automobile travel to alternative modes, and generally ignores the safety benefits that result from reductions in total vehicle" travel (Litman

2011b). However, if vehicle travel reduces, the typical evaluation would generate a lower total user cost including casualty crash costs. In contrast to the train or bus stations, which usually do not attract developer contributions, parking costs are excluded from evaluation because they are usually considered to be provided by developers and landowners rather than the transport authority (Shoup 2005).

An example from the Nelson Arterial Traffic Study is the discarding of the light rail option on the basis of high cost relative to road options. The costs listed for it included stations and terminals. It would be interesting to see how the economic evaluation would look if the road options were to include the opportunity cost of road vehicle terminal capacity (i.e. parking) and vehicle ownership cost savings, as many households could reduce the number of vehicles owned by one if they had access to high quality public transport and active mode options. Such an evaluation may require new guidance in the EEM or approval from the NZ Transport Agency, as these impacts are not included in the existing procedures.

2.1.4.4 Exclusion of non-motorised user benefits

Although the non-motorised user safety impacts of a proposal are often evaluated, and procedures are available for evaluating walking and cycling schemes, the full range of non-motorised user impacts are rarely included in general transport project evaluation. A recent theoretical evaluation of removing parking and pedestrianising a principal shopping street (Macmillen et al. 2010) demonstrates how non-motorised user benefits can be monetised using the UK's NATA evaluation framework and WebTAG guidance.

However, it may be that the more impacts become available to consider, the more uncertainty and inconsistency is introduced in evaluation due to the difference in selection of which impacts to include.

2.1.4.5 Analysis period and discount rates

The length of analysis period can bias option selection towards a particular mode. The UK's online Transport Analysis Guidance (WebTAG) states that the cost and benefit streams should be "extended to cover the period of the usefulness of the assets encompassed by the options under consideration" (DfT 2011). There is some debate over whether road and rail infrastructure have the same useful life (Litman 2011a). Further discussion on the discount rate as a source of uncertainty is given in section 2.2.4.5 of this report.

2.1.4.6 *Ethical and social criticism*

Although arguing that BCA is useful for improving the quality of decision making, van Wee (2011) lists eleven categories of criticism which are summarised in Table 3. The EEM addresses some of these criticisms, such as distribution impacts and externalities, but the procedures are not uniformly well-developed or utilised in practice.

Table 3: Ethical and social criticisms of BCA (based on van Wee 2011)

Criticism	Example
Limited area of application	BCA is difficult to use for comparing different modes.
Limited objective	BCA focuses on maximising social welfare; however which trips or activities should take precedence?
Distribution effects and equity are ignored	Theoretically BCA can account for effects by income class or geographic area but in practice the winners and losers are not differentiated. Also, transport is not treated on a level playing field with other areas of government spending.
Externalities not included	Difficult to monetise and there is debate over including effects such as value of a statistical life (VOSL), social cohesion or aesthetics.
Utility is not the only evaluation theory	The duty of providing accessibility rather than simply mobility; categorical imperatives posit that it is immoral for someone to lose so another can win. Achieving Pareto optimality via the Hicks Kaldor principle (winners compensate the losers) is problematic due to high transaction costs and asymmetric information.
Values matter	Social values such as historic preservation and forced relocations are not generally included.
Not only humans matter	Although willingness to pay for nature conservation can be included in BCA, these remain phrased in terms of human perspectives.
Rich people versus poor people	As the marginal utility of one monetary unit decreases with wealth, basing the value of time (VOT) on the average income level ("equity VOT") does not address the equity impact of maximising utility.
Choices and reason	There is some (weakly supported) criticism that car use can be considered an irrational addictive behaviour and therefore not useful to describe utility or welfare.
Absolute levels ignored	BCA evaluates only changes in the system, as an economic theory maxim is that current levels are the result of previous investments.
The process matters	BCA may be seen as a "black box" whereas MCA can permit wider stakeholder involvement and ideally "social realisation" (i.e. development of mutual understanding).

2.1.4.7 Improving BCA through MCA

To address some of these shortcomings, it is argued by van Wee that BCA should be combined with multi-criteria analysis (MCA). Although BCA is relatively straightforward and widely used, it does not take into account wider objectives than economic efficiency. In response to governmental policy objectives of improving safety, protecting the environment, promoting accessibility through transport choices, and integrating land use and transport systems, economic analyses became part of a larger transport investment MCA based appraisal framework (Communities and Local Government 2009).

In New Zealand, MCA is often applied to transport infrastructure decision making (e.g. the Nelson Arterial Traffic Study reviewed in this report). Indeed, the PPFM assessment method is a MCA consisting of five criteria: readiness, strategic fit, effectiveness, economic efficiency, and funding/affordability (NZTA 2009). The first and last criteria are treated external to the MCA. The middle three criteria form an assessment profile, for example:

...an activity or combination of activities may be rated as High (H) against strategic fit, Medium (M) against effectiveness, and Medium (M) against economic efficiency. This would produce an assessment profile...of HMM. (NZTA, 2009 p.C10-3)

This allows any assessed project to be assigned a priority (there are 11 priority categories). The need for this is currently somewhat academic as experience with various regional land transport programmes shows that only the first two priority categories are funded.

However, under the PPFM approach decision makers do not have full information on the economic efficiency scoring, for example where one project scores “high” and another “medium” yet the BCR values may not be statistically significantly different (if the variances were known).

2.2 Identifying risk and uncertainty

This section begins by defining and categorising risk and uncertainty. Then, the sources of uncertainty in economic evaluation and the transport models, which produce key inputs for the evaluation, are identified. Infrastructure capital cost risks are discussed briefly, followed by a more comprehensive listing of benefit risks in line with the research project problem statement.

2.2.1 Risk versus uncertainty

Some authors distinguish between risk and uncertainty. For example, Sinha and Labi (2007) state that risk is either subjective (based on perceptions) or objective (based on theory, experiment or observation). With risk, the “range and distribution of possible outcomes are known” whereas uncertainty is the case where the input values are not known with certainty and their probability distributions are also unknown (Sinha & Labi, p.458). According to Mishan (1972), uncertainty is an unknown probability distribution, although there may be confidence in the range in which the expected value may fall. However, this distinction was not made in other literature where risk analysis is simply the process for dealing with uncertainty (Lemp & Kockelman 2009; Salling & Leleur 2011).

2.2.2 Types of risk and uncertainty

Salling and Leleur (2011) describe uncertainty as either *epistemic* uncertainty which can be reduced through further modelling or data collection, or *ontological* uncertainty with inherent variability which can be assessed but not reduced.

Uncertainty can be exogenous to the assessment, for example the price of fuel or the wider economic condition. In considering cost risks, Austroads (2011a, p. 15) defines two types of risk, with inherent risk similar to endogenous risk and contingent risk similar to exogenous risk:

> ***Inherent risk** – in the measured items (that have a 100% likelihood of occurrence) of the base estimate. This type of risk can be part of the quantity (volume) and/or rate (value) used in measuring direct project costs, indirect costs, profit margin or agency costs.*
>
> ***Contingent risk** – is the risk due to unmeasured items outside the base estimate with a less than 100% likelihood of occurrence...weather impacts, industrial issues, safety, planning approval conditions, design development, agency requirements, geotechnical investigations...are examples of contingent risk.*

Austroads further suggests that both types of risk can be assessed deterministically via sensitivity testing or probabilistically using @RISK.

The EEM defines only two types of uncertainty which can occur in a transport activity. The first is the **size or extent** of inputs to an analysis, such as growth rates, the assessment of induced or diverted traffic, and travel speeds. The second is the **timing and scale** of unpredictable events, such as those arising from natural causes (earthquakes, snow closures) or man-made (casualty crashes).

2.2.3 Cost uncertainties

Austroads (2005a) identifies six cost risks:

- Environment (severance, emissions, landscape, ecological/archaeological effects)
- Land acquisition (valuation currency, unforeseen extra land take requirements)
- Ground conditions (unknown conditions, complexity of design)
- Other engineering (remoteness of a site, programme delivery)
- Services (existence, location and condition)
- Other risks (capital cost variation)

No literature was found specifying the relative influence of cost components on economic evaluation; this is likely to be because every project is different in scope. The EEM specifies contingency amounts (to address the risk of estimation error) which are generally 10% higher for earthworks than for other cost components.

The two major issues relating to risk in cost estimation are low contingencies and lack of knowledge about probabilistic techniques (Austroads 2011a). A Best Practice Cost Estimation Standard (BPCES) developed in the UK has been streamlined by Austroads and adopted as an addendum to the *Austroads Guide to Project Evaluation*. BPCES is a set of attributes which agencies and practitioners should adhere to, rather than a formal manual or set of checklists. The guidelines include two cost estimation standards (P50 and P90) which refer to the 50% and 90% probability levels of meeting the desired project cost. Contractors using deterministic methods of cost estimation typically bid jobs around the P50 value, with a low contingency allowance. The P90 value is preferred by agencies as it represents the most conservative value and is less likely to be exceeded, but the P50 value is most often used during project evaluation. The implication is that using P90 values would lower BCRs. Austroads recommends that BCRs are reported with the cost estimation risk level included – for example BCR(P50) = 2.1 and BCR(P90) = 1.7.

2.2.4 Benefit uncertainties

2.2.4.1 Overview of benefits

According to the EEM (p.3-7) the typical benefits for a road activity include:

- Travel time savings
- Travel time reliability
- Vehicle operating cost savings
- Accident cost savings
- Comfort and productivity benefits from sealing an unsealed road
- Driver frustration reduction
- Benefits from reducing or eliminating the risks of damage
- Emissions reduction

Interestingly, driver frustration reduction in the EEM is primarily related to passing lane projects and is essentially about travel time savings. The analyst would need to be careful to avoid double counting when considering driver frustration reduction.

Austroads (2005a) identifies four benefit risks, all of which are usually derived from the transport model:

- Base travel demand forecast (age, coverage, data quantity and statistical reliability)
- Growth forecast (population and jobs growth, induced traffic)
- Assignment (network data, impact of other projects congestion levels, path derivation methods)
- Crashes (small sample sizes, high proportion of benefits)

Most of these evaluation inputs are driven by transport model traffic forecasts or outputs. Example transport model outputs as relevant to the New Zealand Transport Strategy (NZTS) objectives are listed in Table 4, which is based on a table provided in Appendix C of the ATS Stage 3 Report (MWH 2010d).

Table 4: Transport model outputs and relevant objectives

Transport model output	Relevant objective from the NZTS
Average travel time	Mobility, economic development
Average trip length	Mobility, economic development
Average network delays	Network and economic efficiency
Travel time reliability	Network and economic efficiency
Total vehicle km. travelled	Community severance, environmental noise
Emissions	Environmental air quality and climate change
Fuel consumption	Energy sustainability
Predicted crash rate (crashes/veh.km)	Safety

Most of these are monetised in the economic evaluation, while other traffic model derived measures are assigned scores in the multi-criteria analysis of options. Therefore, the traffic forecast ends up driving not just the economic evaluation but a range of decision making inputs. The various benefits have various levels of uncertainty and are often correlated to the traffic forecast or growth rate.

2.2.4.2 Travel time savings

The most influential benefit is travel time savings, which are traditionally thought to account for approximately 80% of the benefits accruing from major road schemes (Metz 2008 cited in Macmillen 2010). As the total travel time savings is a function of the per vehicle time savings multiplied by the number of vehicles, the traffic forecast is again a key uncertainty.

If all transport system users were accorded the same value of time (VOT), then the compounding effect of mode shift uncertainties could be reduced. The EEM assigns pedestrians and cyclists VOT figures 9% to 38% lower than car or motorcycle drivers. The same comparison for seated public transport users shows figures 9% to 56% lower. However, where mode shift is accounted for, the EEM states that (p.A4-2):

> *Lower travel time values are not used when evaluating the benefits of activities that encourage a change from car or motorcycle driver to shared or active modes. The travel time values pertaining to the original mode (where these values are higher) should be adopted for proposals that have a high proportion of mode switching. This includes activities which have the primary objective of changing modes or maintaining mode share.*

2.2.4.3 Traffic forecast

The number of vehicles expected for a given element of the transport system under consideration can be estimated using a transport model or a traffic growth rate. It has been estimated that “a 1% increase or decrease in traffic growth can affect the overall benefits by 6-9% when a constant rate of growth is assumed” (Koorey et al. 2000, p. 12). The EEM states that “it might not be appropriate to assume continuation of current traffic growth rates over the whole activity analysis period. The current traffic growth rate shall be adjusted, as appropriate, to account for the influences described in appendix A2.8” (NZTA 2010, p.A2-10). Appendix A2.8 describes how traffic growth rates are appropriate in the absence of capacity constraints but reminds the analyst to ensure that forecast demand is in line with supply. However, the growth rates are based on historic data which was gathered during a time of low fuel prices, rapidly increasing female participation in the labour market, and rapidly increasing car ownership. These situations are not expected to continue so it is argued by some authors that the use of traffic growth rates is not appropriate (Garrison & Levinson 2006; Litman 2010a). The accuracy of traffic forecasts is discussed in more detail in section 2.2.5.8.

2.2.4.4 Travel time reliability

Transport models often include outputs of the mean travel time for a link and/or route, but do not always have information on the variance in travel time. Some researchers have found that (Peer et al. 2009). Using an econometric model of 146 highway segments in the Netherlands which took into account segment length, density of interchanges, weather, traffic composition, speed limits, and shoulder driving lanes, Peer et al. (2009) found that travel time reliability costs can exceed mean travel time delay costs. Their results were in contrast to rules of thumb which suggest that the costs of unreliable travel times are about 10-15% of the costs resulting from mean travel time delay (Fosgerau and Karlstrom 2007, Eliasson 2009 cited in Peer et al. 2009).

Based on work undertaken for the UK SACTRA study in 1999, Austroads (2011d) suggests a very wide range of values for the benefit of improved reliability - 5-50% of the economic benefits of an arterial road scheme. The UK based Eddington Study undertaken in 2005 suggested that “...for motorway widening schemes, total value of reliability benefits are in the order of an additional 50% above the value of total time savings” (Chiang 2009). Since that study, the UK's Department for Transport has developed a more robust spreadsheet based tool called Incident Cost-benefit Assessment (INCA) to calculate delays caused by incidents, variability impacts of those queues, and residual day to day variability. The estimated variability in journey time is then multiplied by values derived from stated and revealed preference surveys of a representative sample of the public, to derive the value of time and standard deviation of daily journey time.

The EEM Appendix A4.5 provides a procedure for including improvements in travel time reliability in economic evaluation, and permits these benefits to be added to travel time savings benefits. The literature suggests that the profession is gaining an appreciation of the importance of this factor. Although it is not part of this research project model, subsequent applications of risk analysis techniques could investigate the correlations and relative influence of travel time reliability on the BCR relative to other uncertain inputs.

Travel time reliability is also a key area of research into improving trip distribution and assignment models, as will be discussed in section 2.2.5.6.

2.2.4.5 Accident cost savings

Since 1991, the monetised benefit of reducing casualty rates for a transport project in New Zealand has been based on the value of statistical life (VOSL) of $2M (in 1991 dollars) as set by the willingness to pay method (Leung 2009). A 1997/98 review recommended that the VOSL be doubled; however by 2008 the official VOSL was $3.35M (in 2008 dollars) which ranks New Zealand 9th out of 13 OECD countries compared. The quality of the willingness to pay surveys and political policy factors "can affect the validity of the VOSL" (Leung 2009, p. 6) and changes in the adopted VOSL have been found to have a "very critical" impact on the BCR (Salling & Leleur 2011, p. 239).

A source of uncertainty in quantifying safety benefits could be the impact of a project on the traffic composition. For example, a project which is estimated to result in modal shift from autos to walking and cycling would usually be undertaken with specific non-motorised user economic evaluation procedures. However, if the walking and cycling infrastructure was only a component of a larger project, the mode shift benefit may still be justifiably taken. Should the analyst then adjust the forecast modal split, the aggregate of the crash rates for the various modes would result in a reduced safety benefit (due to the slightly higher risk per unit of time or distance exposure for non-motorised modes).

However the safety unit price (VOSL) has been found to be more influential with respect to the BCR than the change in crash rate (Salling & Leleur 2011). The VOSL might be considered fixed, but if the 1997/98 review or a future review results in a large percentage change then evaluations for similar (or the same) projects undertaken before and after this change will not be directly comparable. As with the discount rate (refer section 2.2.4.8), the VOSL is not within the analyst's control but is a variable which may be influenced at the policy level.

Tai (1987, p.242) notes that a project undertaken primarily for hazard reduction is not sensitive to change in traffic volumes because the safety component is the largest part of the benefit stream, and the "basis for a reliable analysis of accident reduction (safety) measures is an adequate understanding of accident causation factors". The quality of the safety analysis is therefore a source of potential uncertainty in the BCR.

2.2.4.6 Mode shift

A safety benefit related uncertainty is the typically exogenous (to economic evaluation) health benefit of an increase in non-motorised mode share resulting from a given project; it has been shown that the health benefits (3-14 months of life gained) of cycling outweigh the costs (5-9 days of life lost) due to an increase in traffic accidents (de Hartog et al. 2010). Although the EEM simplified procedures for walking and cycling include health benefits, those active mode health benefits which are part of a larger (all-mode) transport investment are not included in a road project full procedures economic evaluation (NZTA 2010, p.2-4).

2.2.4.7 Network reliability

The benefits due to reducing the risk of road damage or road closure due to natural events (e.g. earthquake or weather) may be included as an isolation reduction benefit (Appendix 8) or a risk reduction benefit (Appendix 13 Risk Analysis). The decision to include the risk of damage or isolation can have a significant impact on the project economic evaluation. For example, Dalziell (1999) investigated the uncertainty of natural events and developed a risk assessment approach to quantify the impact of road closures for the Desert Road and alternative links on the North Island of New Zealand. This work provided an economic justification for the application of calcium magnesium acetate to reduce the number of days the highway would need to be closed.

2.2.4.8 Discount rate

The NZ discount rate (8%) is much higher than that in the US (2-6%) and the UK (1-3.5%). As previously noted, the UK's WebTAG cites the UK Treasury Green Book (2003) to advise that major road and rail projects should be appraised over a 60 year project using revised (lower) declining discount rates. These rates result in one pound 60 years from the base year being worth the same as one pound 30 years from the base year under the previously used discount rate. The declining discount rate "is assumed to fall for very long periods because of uncertainty about the future" (DfT 2011). For comparison to the New Zealand practice of a 30 year analysis period and 8% discount rate, the UK's rates are given in Table 5.

Table 5: UK's Treasury Green Book discount rate as listed in WebTAG (DfT 2011)

Years from current year	Discount rate
0-30	3.5%
31-75	3.0%
76-125	2.5%
126-200	2.0%
201-300	1.5%
301+	1.0%

Parker (2009) states that lower discount rates "increases the practical requirement to evaluate impacts more than 30 years out" but this "raises potential issues with uncertainty" (p. 12). However, stipulating a single discount rate for projects of different scales (in cost and impact) disadvantages small to medium size projects. The discount rate could be determined from the social opportunity cost rate (SOC) which reflects an assumption that government investment displaces private investment. Alternatively it could be determined from the social time preference rate (STPR) which reflects an assumption that government investment displaces consumption. According to Parker, as of 2008 the New Zealand SOC is in the range of 8-10%. The debate is rephrased by Short and Kopp (2005, p. 362):

> *The criterion for the correct level of transport investment is straightforward in principle: it should have a rate of return which is as high as the rate of return in other public or private activities. Any rate of return...that is higher indicates an underinvestment, and a rate of return that falls short of the opportunity cost of capital would signal the creation of excess capacity. How high the rate of return should be in all potential uses of capital depends on the stage of development of the country, or more precisely on the gap between the long-run transport infrastructure endowment per capita of the economy and its current value...In short, a research-*

based rational answer to the question of how much should be invested, requires capital stock figures.

As long as the discount rate is fixed for all forms of transport investment, uncertainty is limited to whether or not the BCR adequately reflects the best investment. It may be considered a somewhat academic argument as the discount rate is not within the analyst's control. On the other hand, the fixed rate is "subject to ongoing review... (and) sensitivity testing at a lower discount rate of four and six percent can be used for evaluations of activities that have long term future benefits that cannot be adequately captured with the standard discount rate (NZTA 2010, p.2-11).

2.2.4.9 Comparison of evaluation inputs

In a study of ten rural road projects comparing the influence of travel time savings, casualty cost savings, and maintenance cost savings on total benefits, Tai (1987) found that travel time savings (10-100% of the benefits) dominated the other two variables (0-82% and less than 8% of the benefits, respectively).

In developing a stochastic method for assessment of transport projects in Denmark, Salling and Leleur (2011) considered the influence of a range of input parameters on the model outcome (the BCR) as described in Table 6.

Table 6: Influence of inputs on evaluation outcome (based on Salling and Leleur 2011)

Not critical	Critical	Very critical
Traffic forecasts	Time unit prices per vehicle class	Construction costs
Maintenance cost growth	Vehicle operating costs	Maintenance costs
Air pollution	Travel time savings as concerns induced traffic	Travel time savings
Severance effects	Accident cost savings	Accident unit price
External effects growth	Length of evaluation period	
	Discount rate	

The categorisation of traffic forecasts as "not critical" is contrary to the findings of other authors as reported in this review. However, many of the critical and very critical parameters are functions of the traffic forecasts. Drawing conclusions on the potential correlations between these inputs and their influence on the evaluation would be aided if there were a number of analyses conducted with similar methods and statistically significant datasets covering a representative sample of transport projects.

2.2.5 Transport model uncertainties

In the preceding section, sources of uncertainty (including but not limited to the traffic forecast) in economic evaluation were considered. The following sections describe the sources of uncertainty in the transport model estimation of the traffic forecast itself.

It has been found that the "most common causes of error in travel models are inaccuracies in socio-economic and transportation network data" (Barton-Aschman Associates & Cambridge Systematics 1997, p. 15). These two inputs are briefly addressed first, and then uncertainties inherent in the travel demand modelling process are discussed.

2.2.5.1 Base transport network data inputs

Transport network data includes the coding of the network into the model and the volumes of traffic on the network links. Traffic counts may be out of date, statistically unreliable, or not available and hence simply estimated based on link type and professional judgement (Sinha & Labi 2007). Increasing the count durations (with a consequent cost implication) can reduce the variability in the datasets and hence the overall data input uncertainty (Wright & Hu 1997)

Aside from manual coding errors, the way that zone centroid links are accounted for in the model will have a significant impact on distance and time travelled and consequently route assignment (FHWA 1990). For example, the TRACKS travel demand model includes travel time on artificially generated centroid connectors whereas the SATURN model does not (Berdica et al. 2003).

2.2.5.2 Socio-economic data inputs

To forecast future traffic volumes on a transport network, an integrated land use and transport model generally uses historic data on trip generation rates and projected number of residents and jobs per zone. Socio-economic inputs such as population and jobs are often based on "most likely" estimates derived from trend lines adjusted for factors such as estimated net population migration. According to the FHWA (1997), the main sources of error in socio-economic data include data collection errors, matching of data source geographic level to the traffic analysis zone level, and specification errors (e.g. car ownership data is available by household size only, but the model is income based). Transport modellers can do very little to reduce uncertainties in population and jobs forecasts, but can attempt to address model specification error and account for the uncertainty through risk analysis (refer section 2.4).

Pradhan and Kockelman (2001) sought to determine the impact of uncertainty in land use and transport modelling. The study used the UrbanSim land use model, a TransCAD four step transport model of Portland, USA, and linear regression analysis. The three independent variables were (Pradhan & Kockelman 2001, p. 7):

- *population and employment growth rates*
- *mobility rates representing the probability that an individual household or job will be allowed to join the queue of locators waiting to choose locations in a particular year*
- *accessibility of the location (represented by the log of accessibility to employment for the residential location choice model, and the log of accessibility to households for the employment location choice models*

The dependent variables were vehicle hours travelled (VHT), vehicle miles travelled (VMT), land prices, occupancy density, and occupancy rates. The model was run for 1985, 1990 and 1995 forecast years (from a 1980 base). They found that the effects of uncertain population and employment growth rates had a far greater impact on land use and traffic volumes than mobility and accessibility variables. They also found that uncertainty was cumulative over forecast years as reported by the coefficient of variation (the ratio of the standard deviation to the mean) of the dependent land use and transport variables. Their results indicate statistical uncertainty with the mobility and accessibility variables, so these should be considered indicative findings only. However, their results show strong and statistically significant ($p=<0.001$) correlation between socio-economic growth rates and the transport variables. Although their study was limited to one model package (UrbanSim) and one urban area (Portland, USA), they find that it confirms the findings of other researchers.

Dewar and Wachs (2008) found large variances between forecast and actual values for population and employment as shown in Figure 2. Bars above the 0.0% line represent overestimation, and bars below the 0.0% line represent underestimation.

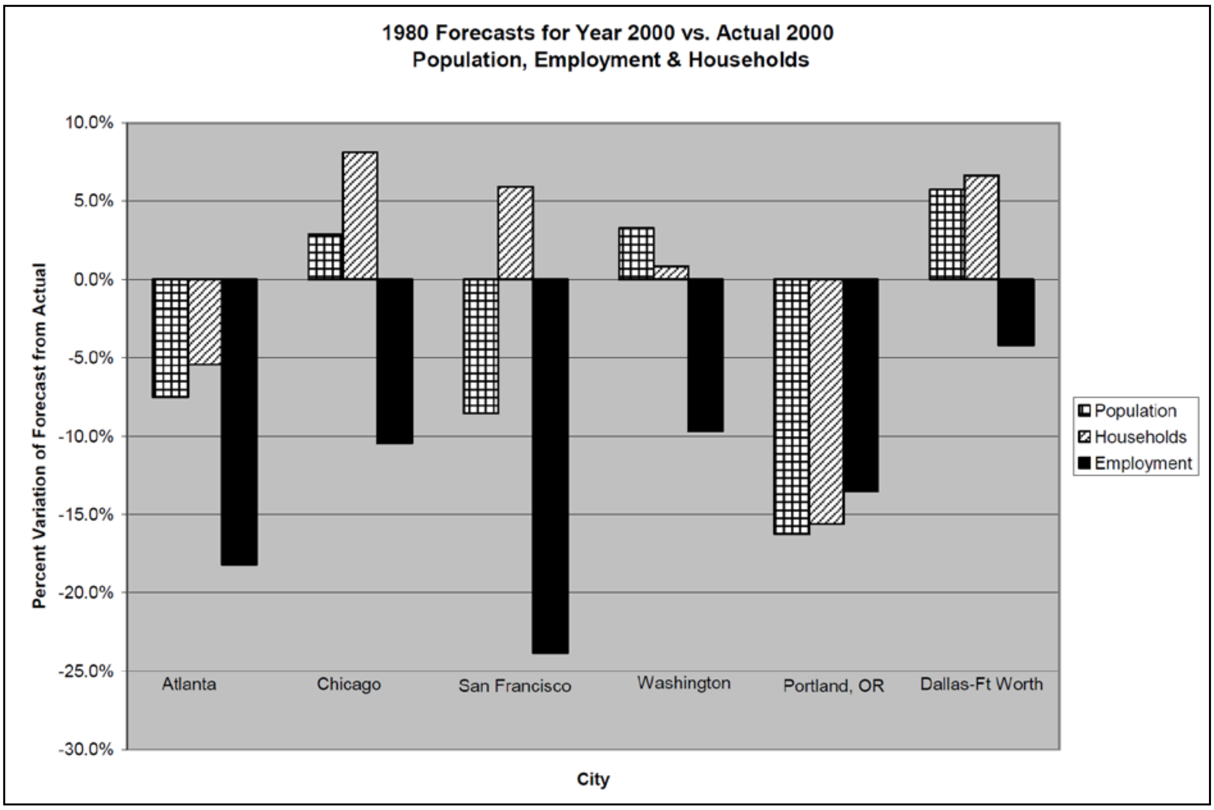


Figure 2: Socio-economic forecast inaccuracy (Dewar & Wachs, 2008)

2.2.5.3 Trip generation rates

The high cost of undertaking or updating the household travel surveys on which many models are based has led to under specification of these models and higher uncertainty levels (Clay & Johnston 2006). The surveys are used to develop trip generation rates (i.e. the number of trips produced by various household sizes and land uses). Amongst three variables tested, trip generation rates were found to have the largest influence on traffic forecasts (with socio-economic growth rates second largest) in a study using the Sacramento integrated land use and transport MEPLAN model. MEPLAN relies on Lowry's economic base theory (refer section 4.2 of this report). Like Pradhan and Kockelman, this study used linear regression to examine the influence of inputs on the dependent variable of VMT. The inputs chosen were exogenous production (derived from population and employment levels), commercial trip generation rates, and the perceived out-of-pocket costs of travel for single occupant vehicles. The base year for the model was 2000, with forecasts made each five years up to 2020. The study was limited to the morning peak period. Some key results of the study aggregated for all years are briefly summarised in Table 7.

Table 7: Sensitivity of model outputs to inputs (based on Clay & Johnston 2006)

Variable	VMT	
	β **Coefficient**	**p-value**
Constant	7,808,535	<0.001
Exogenous production (socio-economic variable)	20,164	<0.001
Commercial trip generation rates	42,138	<0.001
Cost of driving	-2,574	<0.001
Adjusted R-Squared	0.926	

The interpretation of the β coefficient is aided by the description of variable transformation and regression (Clay & Johnston 2006, p.196):

> *In order to represent these condensed inputs in the statistical tests used for this study a single number representing each needed to be generated. Further, this number needed to be readily interpretable within a regression framework. It was decided that each series would be summed and divided by the sum of the base set of numbers and then multiplied by 100. This produces a linear transformation containing numbers ranging from 50 to 150 (50, 75, 90, 100, 110, 125, and 150). These correspond to the amount of error modeled in each: 100 = the base set, 110 and 90 represent the ±10% cases, 75 and 125 represent the ±25% cases, and so on...*
>
> *The typical interpretation of the β coefficient in a regression model is that a one-unit change in the independent variable brings about a β units change in the dependent variable. The variable transformations performed here have the effect that the β units change in the dependent variable would result from a 1% change (one unit) in the independent variable (i.e. a 1% change in x_1 produces a β units change in y). Given the wide differences in initial magnitudes of the input variables, this variable transformation makes cross-variable comparisons of these βs easier...Ideally, a standardized β would be used for this type of analysis. However, the creation of standardized βs requires a known variance for each input and output. As discussed earlier, these were not available for all inputs used in this study and the method of introducing uncertainty into these input variables may not produce a representative distribution of outputs from which to acquire a variance.*

The authors also noted that the effect of the errors compounds over time as households and employers change their locations, which makes quantifying the full impact of socio-economic uncertainty difficult.

Trip generation rates are usually based on home interview surveys in places which have evolved into a car-dependent urban form (Shoup, 2005). In a study to determine whether a proposed large mixed-use development could produce and attract less motor vehicle traffic than standard trip generation rates, Walters et al (2000) used the Atlanta regional model and trip generation rates from a meta-analysis of trip generation studies. The authors attempted to match the studies to the proposed development, and aimed for studies which "attempt to isolate the true explanatory variables and to reduce or eliminate multicollinearity... (and) controlled for income, automobile ownership, or both." (p.23). They rejected studies which were based on home interview surveys which specifically excluded non-car trips for purposes other than the journey to work. The model travel demand forecast results found that for the "best" (in terms of multi-modal design and other factors) proposed site design would generate 5.8% less motor vehicle traffic than a generic development. What this study highlights is the potential error in transport models which rely on trip generation rates which are not applicable to mixed-use, rapid public transport-oriented, or central city developments (or any combination of these characteristics). This transport model error would likely manifest as overestimation of motor traffic levels (Litman 2009b).

2.2.5.4 Trip distribution

For congested networks, the effect of changes in user perceived travel costs (i.e., the elasticity of demand with respect to delay) may be incorporated into the trip matrix as well as the assignment model. Some modelling packages include growth constraint formulations based on the ME2 technique, while several general methods for constraining growth in the trip matrix are given in the EEM Appendix A11. Interestingly, the EEM states:

The final matrix produced by the elasticity formulation must reasonably represent the demand. It may be appropriate to exclude some matrix cells from the elasticity adjustments – for example, those that exhibit negative growth (generally it is undesirable to have cases where traffic volumes between an origin and destination pair decrease between successive forecast years), unreasonably high growth or those that represent external trips. (NZTA 2010, p. A11.7)

In effect, this advice to exclude the impact of a negative demand elasticity parameter upon a given OD pair may dilute the purpose of applying elasticities and the advice to apply the analyst's judgement of reasonableness introduces another uncertainty into the transport modelling process. The EEM Appendix A11.13 provides guidance on reasonableness checks of the results of applying capacity constraint methods, which if completed may reduce the potential for error and uncertainty inherent in matrix manipulation.

2.2.5.5 Mode choice

According to Walters et al (2000), "estimates of travel times and distances for intrazonal and adjoining zones vary by the greatest percentages of their true values". In other words, strategic and regional scale models are not accurate at predicting local trips. The short trips found within zones and between zones are often not captured by traffic counts and not accounted for in traffic models, so non-car journeys are under-estimated and there is a consequent potential for over-estimating or over providing infrastructure for motor vehicle travel.

2.2.5.6 Assignment

As noted previously, Austroads suggests that the uncertainties in the assignment sub-model can arise from unknown congestion levels, the degree to which induced traffic is not accounted for, and path derivation methods. An example is the uncertain response of drivers to new information about congestion (whether a result of an incident or heavy traffic flows) provided by variable message signs. Another uncertainty is inherent in trip based (e.g. home to work is one trip) models: as a greater proportion of travel involves trip-chaining, the model cannot provide information about the relationships between trips as well as the time of day and transport mode implications (Donnelly et al. 2010).

The advance of modelling techniques may reduce the level of uncertainty in assignment. One stream of work is focusing on replacing trip based models with activity (tour based) models. Another stream is addressing the impacts of congestion and travel time reliability upon location choices. For example, a reliability based integrated land use and transport model employing combined distribution and assignment model with a "genetic algorithm based solution procedure that embeds a diagonalization algorithm with an origin-based algorithm" has been proposed as a way to address transport demand uncertainty (Yim et al. 2010). Their exploratory model assumed independent O-D stochastic demand and unchanged O-D link choice proportions and they recommended further work would be needed to use this model in real-world practice.

2.2.5.7 Propagation of error in transport models

Clay and Johnston (2006) state that modelling uncertainty "is passed from submodel to submodel and across model years thus producing a propagation of error over time" (p.191)

In contrast, it has been suggested that over the long run only cumulative errors will have a significant impact on transport model outputs, and even these will be mitigated to some extent by the interaction of land use and activity systems with transport systems (Pradhan & Kockelman 2001). The 'predict and provide' approach and application of travel demand models has resulted in changes to the activity system (location choices) which are characterised by a sprawling urban form with ever increasing motor vehicle kilometres travelled. Whether or not such 'cumulative error mitigation' is desirable from the economically and environmentally sustainable urban form perspective is perhaps worthy of consideration but outside the scope of this report.

According to Zhao & Kockelman (2002), improved equilibrium assignment methods can temper the worst errors in transport models, but the greater issue is the need for the planning profession to be consistent and transparent about the assumptions and uncertainties in modelling. This could take the form of presenting outputs with an estimation and analysis of "variances and co-variances in model outputs...as a function of the variations in model inputs" – a probabilistic risk analysis as described further in section 2.4 of this report (Dewar & Wachs 2008, p. 7).

2.2.5.8 Traffic forecasting uncertainty

It is common to extrapolate historic growth rates or apply a default arithmetic growth rate (between one and three percent as listed in EEM Table A2.5) to a base traffic volume on the subject transport corridor. Traffic growth rates used in economic evaluations have been found to be very influential on the BCR, dominating virtually all other variables (Koorey et al. 2000). The use of growth rates may be accompanied by rules of thumb such as allowing for a generated traffic increase of twice the percentage decrease in total journey time. The type of growth rate used in NZ project evaluation is typically arithmetic, however there are several other approaches including geometric, declining rate, the use of a 'step' function to correspond with increases in capacity, or the use of different growth rates for heavy and light vehicles.

Flyvbjerg et al (2006) studied 26 rail and 208 road projects in 14 nations comparing forecast traffic with first year actual traffic. The authors claim that the first year of operation should be used because "it may be observed as an empirical fact that forecasters and planners typically use first-year-of-operations as the principal basis for making their forecasts" (p.5). They found average forecast inaccuracy of -51.4% (SD 28.1, 95% CI -62.9 to -39.8) for rail projects and +9.5% (SD 44.3, 95% CI 3.0 to 15.9) for road projects. Errors of 40% or more were found for 72% of rail projects (over-estimated traffic) and 25% of road projects (under-estimated traffic).

The authors identified the causes (but not the magnitude) of forecast inaccuracy from a survey of project managers for 26 rail projects and 208 road projects (Figure 3).

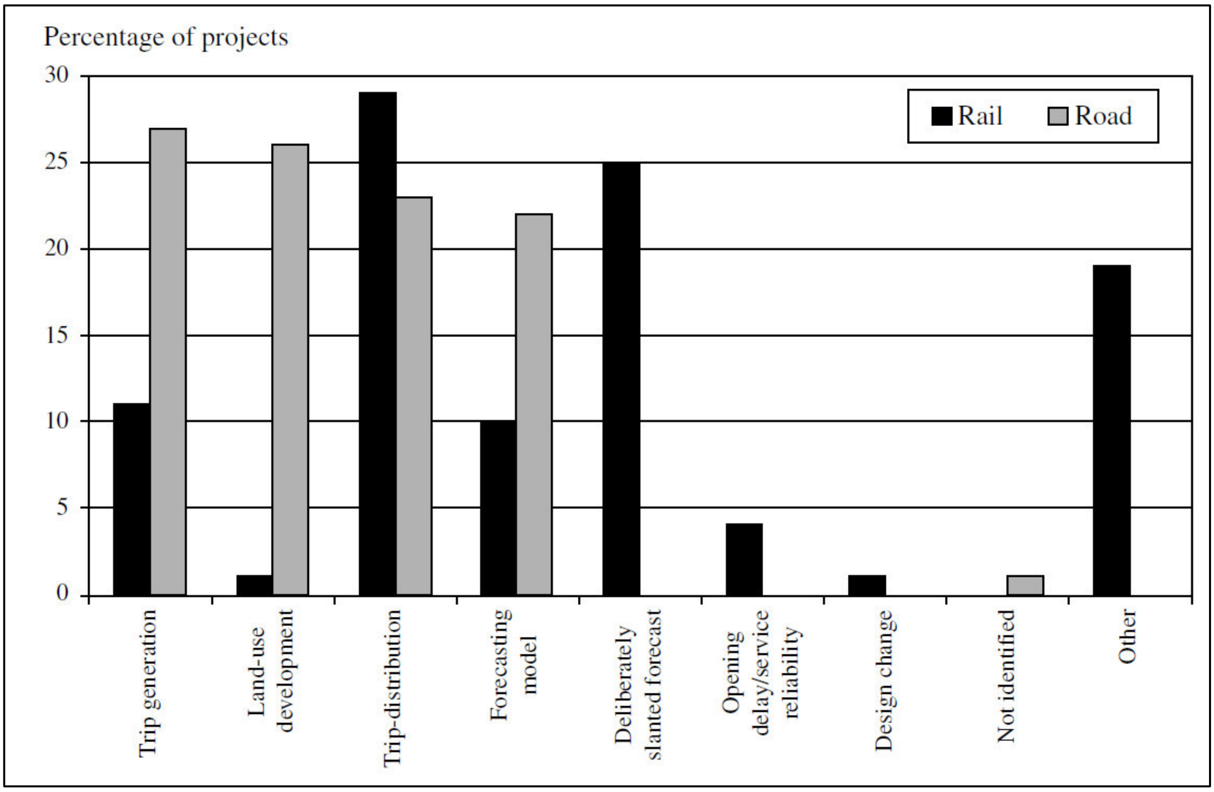


Figure 3: Stated causes of traffic forecast inaccuracy (Figure 6, Flyvbjerg et al 2006)

It can be seen from Figure 3 that the top four sources of error are trip generation rates, land-use development projections, trip-distribution assumptions and methods, and the type of forecasting model chosen. These four sources were identified by the surveyed project managers in similar proportions of projects. The authors posit that analysts may have an optimism bias or risk denial, especially in the case of public transport project forecast patronage (and hence revenues). They further allege that politics are influencing the public transport analyses and that especially rail patronage estimation does not adequately address uncertainty. Their study did not include an estimation of the magnitude of impact on any measure of economic efficiency.

However, Welde and Odeck (2011) dispute these allegations of bias. They undertook a meta-analysis of studies and found that many suffer from misleading samples while noting that some studies use first whole year of operation traffic figures, which do not account for usage increase after the first year. It may be that usage increase could take longer for some modes than others, due to the "inertia" of mode and location choices. However, they agree with other authors with respect to variability in forecast accuracy. Using data from the years 2001 to 2007 on 25 tolled and 25 toll-free road projects in Norway, Welde and Odeck (2011, p.89) found a "huge" variation in accuracies despite improved regional level 'four-step' transport models, with consequently significant impacts on project evaluation. A summary of their findings and recommendations is given in Table 8.

Table 8: Traffic forecast accuracy study recommendations (Welde & Odeck 2011)

Finding	Recommendation
High level of traffic underestimation (toll-free roads)	By using a fixed trip matrix (i.e. zero elasticity of demand), induced traffic is not accounted for. Improve transport models to reduce this variability.
Tendency towards over optimism in forecast (tolled roads)	NPV/BCR should be only one input in the decision making process, supplemented by MCA
Uncertainty in traffic forecasts has a significant impact on evaluations	Present a confidence interval illustrating the inherent uncertainty of the evaluation

In conclusion, the literature seems to agree that there are significant variations in traffic forecasting accuracy but a lack of post-opening project evaluations, location transferability (e.g. a study of forecasting accuracy in Europe may not be relevant in New Zealand) and measurement difficulties are limiting the assessment of the degree of inaccuracy.

2.3 Addressing uncertainty – ad-hoc and deterministic approaches

2.3.1 Ad-hoc approaches

This literature review has found seven general methods for addressing uncertainty. Table 9 presents the five methods which seek to reduce uncertainty in economic evaluation through ad-hoc or short cut methods. These methods and their limitations have been compiled from the work of several authors (Litman 2009a; Meyer & Miller 1984; Mishan 1972; Treasury Board Secretariat 1976).

Table 9: Ad-hoc approaches to reducing uncertainty

Method	Limitations
Assume a useful life of the project less than the economic life, commonly called adoption of a "cut-off period"	Using a shorter evaluation period is arbitrary and of limited use wherever "long cut-off periods are used in conjunction with any sizeable discount rate"
Add a risk premium to the discount rate, reducing the expected value of net benefits	Manipulating the discount rate incorrectly implies that uncertainty is compounded at a fixed rate over time
Exclude uncertain costs or benefits	Severance, urban sprawl, and health impacts of transport projects are difficult to quantify and therefore often excluded, but this results in a less conservative estimate
Increase future costs and/or decrease future benefits	Although implying caution, it is wholly arbitrary
Build flexibility into the design or delivery of the project to allow staged re-examination of alternatives	May not maximise implementation economies of scale or achieve critical mass in terms of network completion or user uptake

2.3.2 Deterministic approach

The deterministic approach is a process which considers the worst case scenario (highest costs and lowest benefits), the best case scenario (lowest costs and highest benefits), and most likely scenario (values are chosen in the middle for costs and benefits) (Butcher 1987). Future scenario planning often uses subjective expert opinion to determine the range of possible values for inputs to the decision model and undertake sensitivity testing to gauge the impact on the model outcome of a given change in one input variable, when all other variables are held constant. Based on Walker and Fox-Rushby (2001), there are several problems with this approach:

- The scenarios or ranges for the inputs to be varied are prone to subjectivity;
- It considers only a few equally weighted discrete outcomes, ignoring hundreds or thousands of others;
- Interdependence between inputs, impact of different inputs relative to the outcome, and other nuances are ignored, oversimplifying the model and reducing its accuracy;
- Doubt about how to choose which inputs to vary and which to hold constant;
- Unknown variation around the base value of the parameter considered; and
- Doubt about how to determine what a sensitive or robust finding is.

It is impractical to use sensitivity testing where it is desired to assess the impact of variability amongst several inputs where there is correlation between them (Sinha & Labi 2007). If they are not correlated, multivariate sensitivity testing for two or three variables tested simultaneously is possible (Walker & Fox-Rushby 2001).

Another limitation to sensitivity testing is that the decision maker has no information about the probability of these events occurring.

There are situations where deterministic approaches are valid. Austroads (2011a) suggests that in risk assessment of cost estimates where the contingency amounts are small relative to the total project, a deterministic method is appropriate. In addition, some uncertain costs will not be correlated with other inputs to an evaluation and therefore it may be easier to use a most likely point estimate or sensitivity test.

2.4 Addressing uncertainty – probabilistic approach

2.4.1 Description

The use of a probability distribution, describing known data about the input variable and the associated mean and standard deviation, allows the analyst to estimate the likelihood of the expected value falling within a particular range. Risk analysis (RA) can be undertaken with a simple probability of an event occurring (such as the risk analysis example of the probability of a bridge being destroyed by earthquake in section A13.10 of the EEM) or by using Monte Carlo simulation. Mishan (1972) suggested the use of a computer to select at random one 'magnitude' from the set of alternative magnitudes attributed to a particular future price, and to calculate the associated BCR for this value along with the probability of occurrence. He suggests that a run of 200 to 300 observations would be sufficient to provide a statistically reliable sample. This approach is known as Monte Carlo simulation. Monte Carlo simulation can be used for the economic evaluation and/or any multi-criteria analysis which may be undertaken; Sinha and Labi (2007) describe how the technique can be used to develop a probability that is included in the formula for computing the score for each alternative. For economic evaluation, Sinha and Labi (2007, p.475) state that:

> *It is important to consider the effect of the variability of input factors and uncertainty in the outputs. In the deterministic approach, sensitivity analysis is used for this purpose, whereas the probabilistic approach does it by using subjective risk, objective risk, and uncertainty techniques. With deterministic analysis, only a single value of each input factor is used in the analysis, and the output is also a single number. The probabilistic approach...uses a range of values for each input factor and yields a range of values for the output. In the objective risk approach...the range of values for each input factor depends on the probability distribution (and associated parameters of the distribution) for that factor.*

The general Monte Carlo simulation approach has been graphically depicted by Sinha and Labi and is reproduced with minor changes in Figure 4.

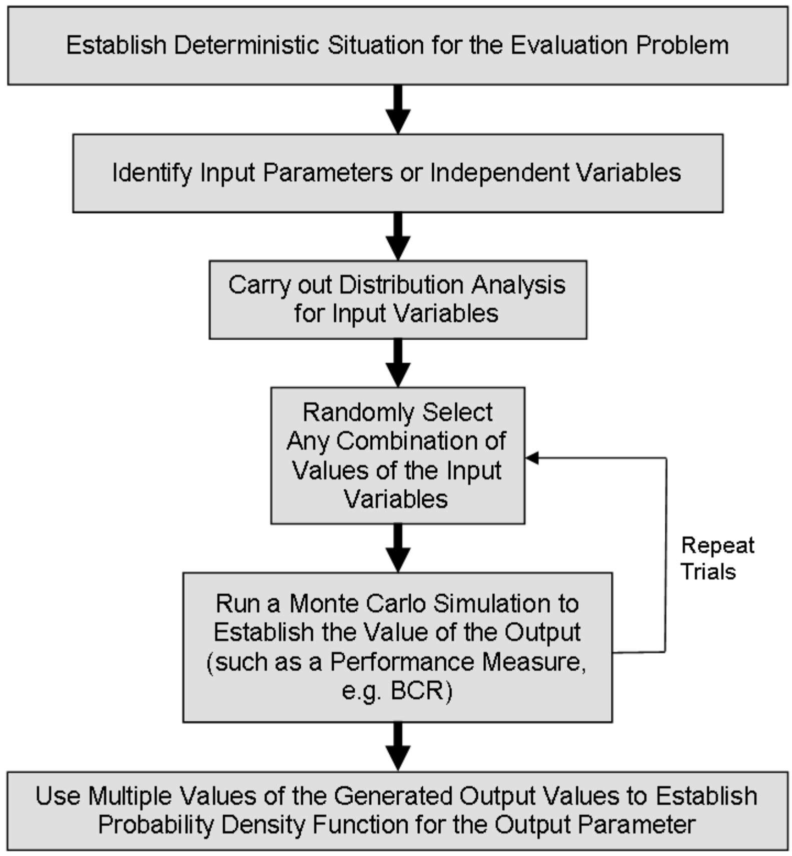


Figure 4: Monte Carlo simulation approach (based on Figure 18.9, Sinha & Labi 2007)

The determination of the number of iterations ("repeat trials") is "a function of the number of input parameters, the complexity of the situation modelled, and the precision desired for the output" (Herbold 2000, cited in Sinha & Labi 2007, p.476). This decision is less important given the advances in computing power which permit a large number of trials to be undertaken quickly. The decision on which input variable distributions to use is more difficult (refer section 2.4.3.3).

Monte Carlo simulation is generally undertaken with the aid of specialist software such as Austroads Risk Explorer or Palisade's @RISK. The result of a probabilistic RA is often represented by a probability density function (p.d.f.) and/or cumulative distribution function (c.d.f.) to graphically depict the probability of a particular outcome. Some sources refer to the c.d.f. as the "cumulative density function" however the words cumulative and density are contradictory (NIST 2010).

2.4.2 When to use risk analysis

The EEM requires a risk analysis “where the principal objective of the activity is reduction or elimination of an unpredictable event (e.g. a landslip or accident), there is a significant element of uncertainty, or the capital value of the activity exceeds $4.5 million” (p.3-15). The definition of “significant” is not given in the EEM, and is therefore subjective.

Aside from the limitations of point estimates and sensitivity analysis described previously described, there are several reasons why a RA of a given economic evaluation should be undertaken. For projects with potential large losses, a RA provides more information to enable comparison of forecast and actual benefits and/or costs as determined through any post opening project evaluation which may later be undertaken should the outcomes not meet expectations (Butcher 1987; Short & Kopp 2005).

The limitations to probabilistic risk analysis include the increase in cost and time to undertake and such analysis may not result in a change in preferred option if the economic appraisal value is not critical in the decision model. An example of the latter situation is the prioritisation of New Zealand’s Roads of National Significance (RoNS) where the economic efficiency criterion of the PPFM assessment is automatically assigned a “high” score, or the Nelson ATS multi-criteria analysis further discussed in section 3.2.4.

A further possibility is that quantifying evaluation output uncertainty may be avoided by practitioners who do not wish to sow doubt about their methods and skills in the minds of the public and decision makers (Nicholson, pers. comm.).

Austroads suggests that risks should be “adequately estimated for the project given its scope and the level of information available” (Austroads 2011a, p. 15). However this should not be seen as a “way out” for an analyst faced with either very little information or seemingly comprehensive information (e.g. detailed traffic forecasts supported by exhaustive and confident model building reports).

2.4.3 *Choosing variable distributions*

2.4.3.1 <u>Rationale</u>

Risk analysis "forces analysts to consider the distribution of parameter values about the most likely level" (Butcher 1987, p. 754). If the distribution around the mean is not normal, then the analyst may incorrectly use the most probable value when the expected value should be used. If the distribution has a large standard deviation and/or non-normal distribution, this will be a flag to use caution with regard to the final results. According to Feeney (cited in Butcher, 1987), "probability analysis is useless where the 'probabilities' are merely guesses made by engineers and others to keep an analyst happy, rather than estimates involving reasoned judgement".

2.4.3.2 <u>Types of distributions</u>

According to Sinha and Labi (2007), for each variable "the probability distribution and parameters can be derived using analysis of historical data, expert opinion, or both" (p.475). Probability distributions usually have a location and scale parameter. When describing the effect of these parameters on a p.d.f., the location parameter shifts the graph left or right on the horizontal (x) axis (NIST, 2010). A scale parameter >1 stretches out the graph, or <1 squeezes the graph. The following probability distribution figures are from various sources reviewed (NIST, 2010; Tai, 1987).

Table 10: Types of distributions

<table>
<tr><th colspan="2">Uniform</th></tr>
<tr><td>The probability distribution of a variable can be uniform or nonuniform. Uniform distributions are typically a straight line (diagonally from the origin for a c.d.f., and horizontal for a p.d.f.).

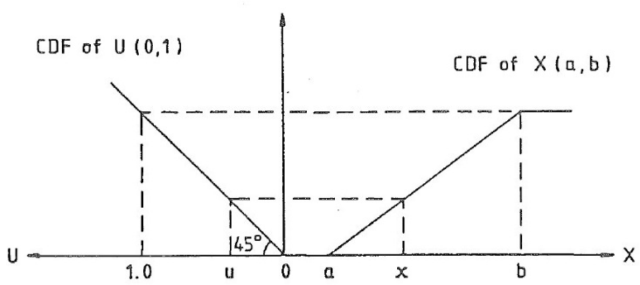
The figure at right shows the standard (left of y-axis) and general (right of y-axis) uniform distributions (c.d.f.).</td><td>

Figure 5: Uniform distributions – c.d.f.</td></tr>
</table>

Discrete - Binomial and Poisson

The binomial distribution is used when there are exactly two outcomes (success or failure) of a trial (NIST, 2010). This is also called a discrete distribution.

The binomial is also appropriate for input variables with a small range of outcomes. Examples include the traffic level of service which can be only one of six values between A and F, or casualty crash severity which is fatal, serious, or minor (Sinha and Labi, 2007).

Where the range of outcomes is larger, "the Poisson distribution is a good approximation of the binomial distribution if n is at least 20 and p is smaller than or equal to 0.05, and an excellent approximation if n>100 and np<10". Lambda (λ) is a shape parameter which indicates the average number of events in the given time interval (NIST, 2010).

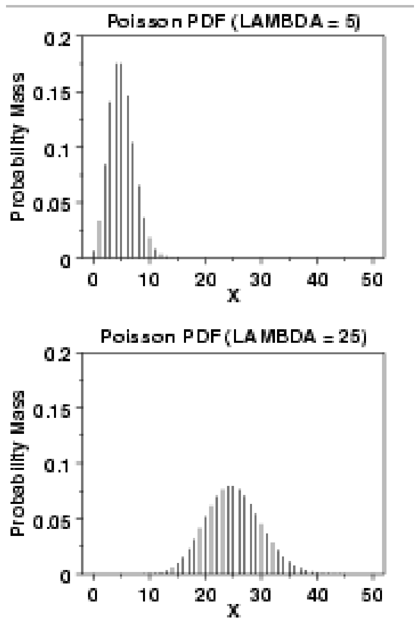


Figure 6: Examples of the Poisson distribution - p.d.f.

Continuous

Inputs such as congestion level, travel-time savings, emissions, and project costs have continuous outputs and distributions which "can be skewed or symmetric which can be modelled as a beta distribution" (Sinha & Labi 2007, p. 461).

The beta distribution includes a normalisation constant to ensure that the total probability (area under the p.d.f. curve) is one.

The upper and lower bounds are typically represented by alpha and beta. The case where alpha = 0 and beta = 1 is called the standard beta distribution. (NIST 2010)

Shape parameters are p (alternatively termed r) and q, and are estimated from formulae based on the sample mean and sample variance. The figures at right are for four different sets of shape parameters p and q (NIST 2010).

The normal distribution is not shown in a figure at right but is commonly known as the "bell-curve". It is the most common distribution. It is like the symmetric beta distribution, but unbounded at both ends.

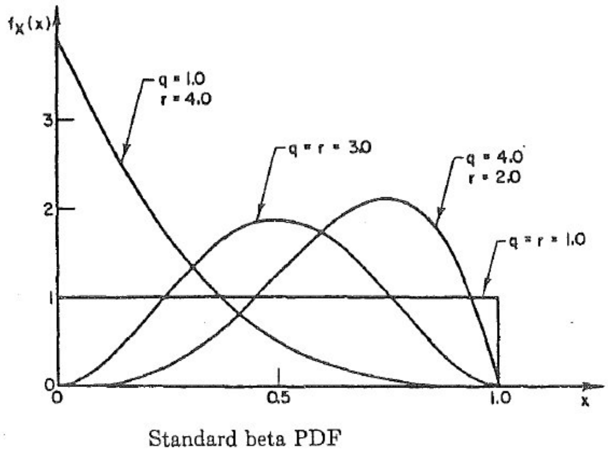


Figure 7: Standard beta distribution - p.d.f.

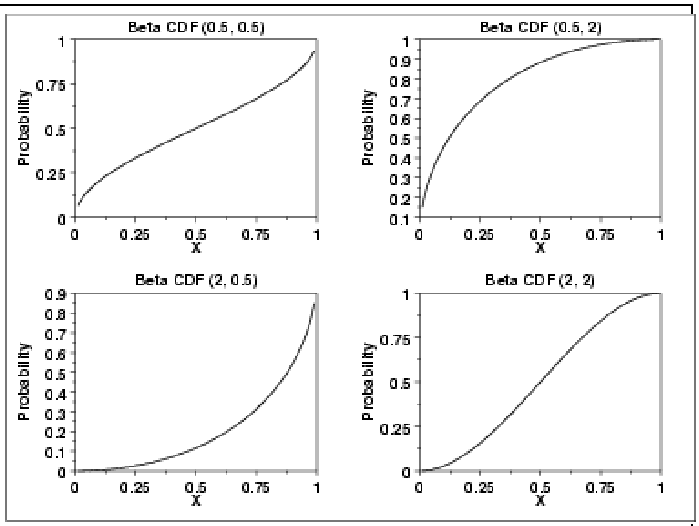


Figure 8: Standard beta distribution - c.d.f.

The log-normal distribution is thought of as having a 'fat tail'.

Log-normal distributions with identical location parameter but different scale parameters are shown at right.

Common log-normal distributions are city sizes, repair times for maintainable systems, and physiological measurements of populations (Wikipedia).

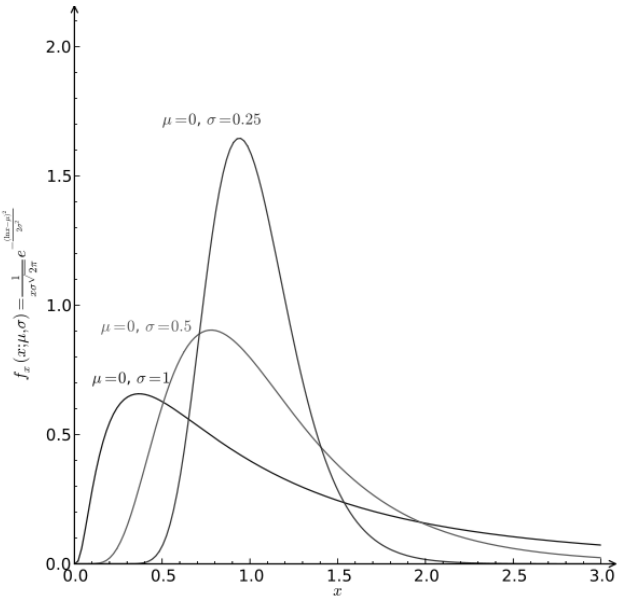


Figure 9: Log-normal distributions – p.d.f.

Distributions and uncertainty

Flatter and wider graphs indicate greater uncertainty, as shown in the figures at right (Tai 1987).

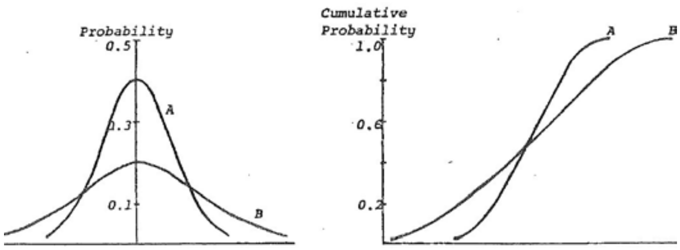


Figure 10: Two levels of uncertainty - p.d.f. (left); c.d.f. (right)

2.4.3.3 *Typical distributions for transport input variables*

A number of probability distributions and measures of variation around the expected value for various transport model and economic evaluation inputs were found in the literature review. A sample of these are summarised in Table 11.

Table 11: Input distributions and statistical measures

Variables	**Distribution**	**Mean**	**Std dev**	**Variation (%)**		**Source**
				Low	**High**	
Vehicle operating costs (VOC)	Normal	0.274[1]	0.037	-27%	27%	Berthelot
Travel time savings (TTS)	Normal			-20%	20%	Salling
Traffic flow – for TTS	Normal[2]			-10 to 20%	10 to 20%	Tai, Austroads[3]
Traffic forecast – toll free	Normal	19%	20	-15%	76%	Welde
Traffic forecast - tolled	Normal	-2.5%	22	-35%	45%	Welde
Vehicle occupancy – for flow	Normal	1.5[4]		-13%	+13%	EEM
Value of time (VoT) for TTS[5]	Lognormal	15.13		0	25%	EEM
Maintenance costs	Triangular			10%	50%	Salling
Construction costs (concept estimate stage)	Erlang			-20%	+35%	Salling, Austroads
	Lognormal					Giblett
Safety unit price	Uniform			10%	10%	Salling

Notes: 1. Value is for cars on sealed roads, quoted in 1991 Canadian cents per km
2. Refer to the text for discussion of conditional triangular distribution components
3. Variation figures from the suggested rules for sensitivity analysis in Austroads (2005a, p. 27)
4. Urban arterial – all periods (NZTA 2010, p. A2-7). Austroads suggests a variation of +/- 0.3.
5. Urban arterial – morning peak; variation based on max. congestion increment (NZTA 2010, p.A4-3).

The specification of distributions can be quite complex. For example, Tai (1987) describes the traffic flow distribution as normal. However within the overall normal distribution he applied triangular distributions to the low, middle and high flow ranges (Figure 11).

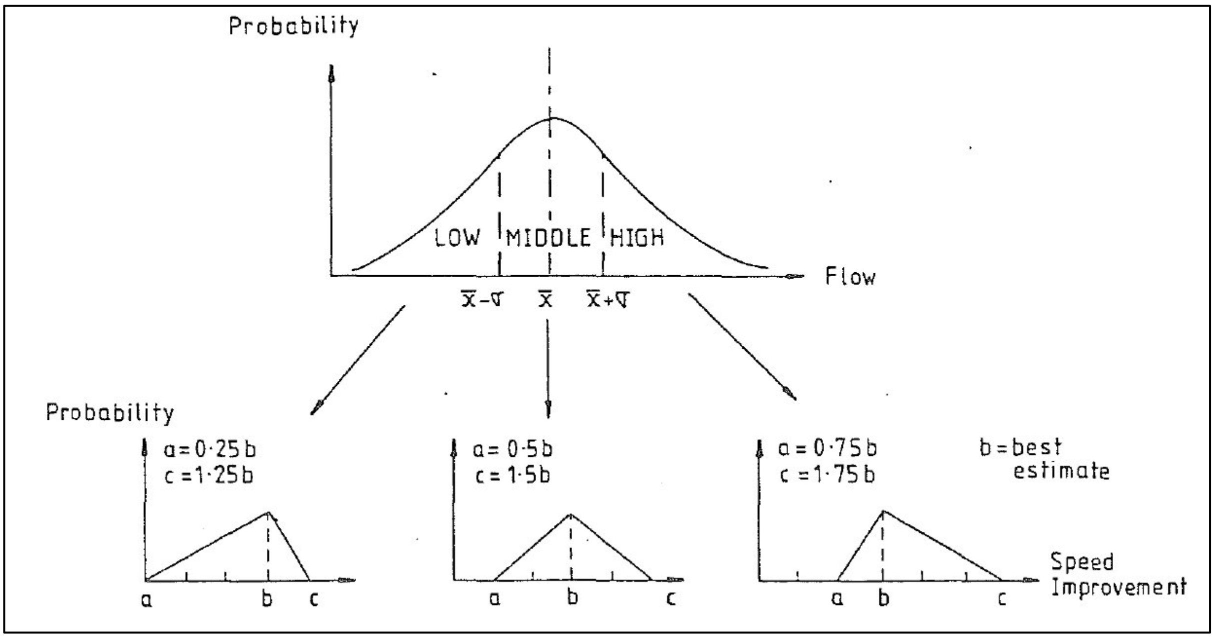


Figure 11: Traffic flow distribution (Figure 6.5 in Tai 1987)

For the low flow range, a right skewed triangular distribution was used to account for the higher probability of a small improvement in speed; for the middle flow range a symmetrical (about the mean) triangular distribution was used; and for the high flow range a left skewed triangular distribution was used to account for the higher probability of a large improvement in speed. This is how Tai allowed for correlation between flow rate and speed improvement.

Risk analysis of the traffic flow variable can improve the understanding of the variability in benefits due to travel time savings, as the potential improvement in speed is greater when addressing peak congestion periods.

2.4.4 Probabilistic risk analysis and decision making

When the decision maker is given an evaluation result accompanied by a risk analysis, the question becomes what to do with this information? Sinha and Labi (2007) describe the methods for decision making under uncertainty as follows.

Where risk analysis techniques such as Monte Carlo simulation are not feasible due to complete uncertainty about the input variables or their probability distributions, risk may be considered by approaches including:

- **Maxmin**. For risk-averse decision makers under uncertainty, the minimum (worst) outcome is determined for each alternative, and the alternative with the maximum worst outcome is selected. This approach may also be termed the **minmax regret (robust)** method.
- **Shackles model.** Rather than an expected utility (weighted average of outcomes and their associated probabilities), this model relates the expectations of gain or loss (benefits and costs) to the degree of surprise (uncertainty) by means of a three step procedure.
- **Fuzzy decision** or **possibility theory.** For projects where probability distributions cannot be reliably described and inputs are very difficult to estimate, these approaches could be applicable but are considered outside the scope of this review.

Where some knowledge of input variability ranges or implementation probabilities is present:

- **Ranking and rating (deterministic MCA).** All criteria are standardised to the same scale, weighted, and alternatives ranked. To account for uncertainty, a sensitivity test may be applied to see whether the ranking changes.
- **Impact index (probabilistic MCA)**. This variation of ranking and rating was first used for the Atlanta highway alignment project (refer section 2.4.5.1). To include uncertainty, the MCA technique multiplies the rating score for each alternative by a probability of implementation derived from Monte Carlo simulation.

Risk analysis results can be analysed by considering (Sinha & Labi, 2007, Palisade, 2011):

- **Correlation** between input variables to determine whether the variables are directly or inversely correlated.
- **Scatter** plots which show the input values versus the output values calculated in each iteration of the simulation.
- **Tornado** graphs which display a ranking of the input distributions which impact on the output, as defined by the longest bar in the graph.
- **Six Sigma** comparisons of outputs to target values. Six Sigma is a process of continuous improvement to include 99.996 of all values within three standard deviations on either side of the mean value. The @RISK programme includes the ability to specify Six Sigma functions and then produce statistics on the process output compared to the targets (Palisade 2010b). Six Sigma is commonly applied to improve supply chain logistics, but has also been used to improve the quality of transport infrastructure 'mega-project' delivery (Mudholkar 2008).

2.4.5 Probabilistic risk analysis in practice

2.4.5.1 USA (1971) – Highway route alignment

The earliest example of a probabilistic approach to transport infrastructure project evaluation found in this literature review was an evaluation of alternative alignments for Interstate 75 in the state of Georgia, USA (Sinha and Labi, 2007). The analysis combined an MCA derived "index score" and Monte Carlo simulation. Decision makers could choose the alternative with the highest index score and smallest confidence interval. Where probability distributions are not known, a rectangular distribution of -0.05 to +0.05 (e.g. +/-50%) was used.

2.4.5.2 Denmark (2011) – economic evaluation software

The Danish Centre for Traffic and Transport has developed the "CBA-DK" economic evaluation model incorporating risk analysis for the Danish Road Directorate (Salling & Leleur 2011). The model builders provide detail on the probability distributions and procedures used, and report that the software allows the analyst to report the probability that a BCR exceeds a given threshold (e.g. a 60% probability of a BCR greater than or equal to 1.1). They note that although the process is achievable, it "still lacks a generally approved way of implementation in the transport infrastructure area".

2.4.5.3 USA (2000) – Pavement Life Cycle Cost Analysis

The US Federal Highway Administration (FHWA) has used Monte Carlo simulation for pavement life cycle cost analysis (LCCA) models to provide engineers with cost estimates with probabilities based on known distributions for uncertainties including discount rate, analysis period, year of rehabilitation, future rehabilitation cost, and initial cost (Herbold 2000). Herbold goes on to say that the process of applying probabilistic methods is very easy, so it may be that at least for cost estimation it is a common practice.

2.4.5.4 New Zealand (2011) – Evaluation of pavement options

A recently concluded research project at the University of Canterbury (supported by the NZ Transport Agency, and representatives of the consulting and contracting industries) has investigated the feasibility of applying risk analysis to the evaluation of pavement construction options (Giblett 2011). The application of @RISK simulation resulted in cost estimates within 3% of existing deterministic scenario based analysis procedures. However, the probabilistic approach enables consideration of multiple uncertain input parameters not currently assessed, such as the probability of earthquake damage.

2.4.5.5 New Zealand (1999) – Risk of road closure on Desert Road

This study used a traffic assignment model to predict disruption caused by closures of the Desert Road on New Zealand's North Island due to natural hazards, and used Monte Carlo simulation to generate a probability distribution of the average annual cost of closures caused by each hazard (Dalziell et al. 1999). The cost of road closure due to snow and ice was found to be higher than earthquakes, traffic accidents and volcanic events. The economic evaluation result enabled a recommendation to apply an ice inhibitor on the road surface during cold weather to keep the road open more often.

2.4.5.6 New Zealand (1987) – Otira Viaduct, Arthurs Pass

Probabilistic risk analysis was used to calculate the NPV of a project to improve route security (the Otira Viaduct) on the highway through Arthurs Pass on the South Island (Butcher 1987). Butcher emphasises the importance of using the expected value (the sum of values multiplied by their associated probabilities) rather than the most likely value (highest probability), and notes that without a probability distribution this choice cannot be made. In evaluating a project to reduce the probability that the highway would be closed by rock fall, the point estimate NPV is -$186,000. Although with risk analysis the NPV is nearly identical at -$187,000, the NPV has a range between +$210,000 to -$490,000. The author concludes that "displaying the NPV with a probability distribution has advantages in that it shows the possibility of a disastrous loss being averted by undertaking the project" (p.760). In the case of a single road link, the decision maker will probably have a risk averse viewpoint and proceed on the basis of minimising the maximum loss (refer section 2.4.4).

2.4.5.7 New Zealand (1987) – Rural roads and the Christchurch motorway

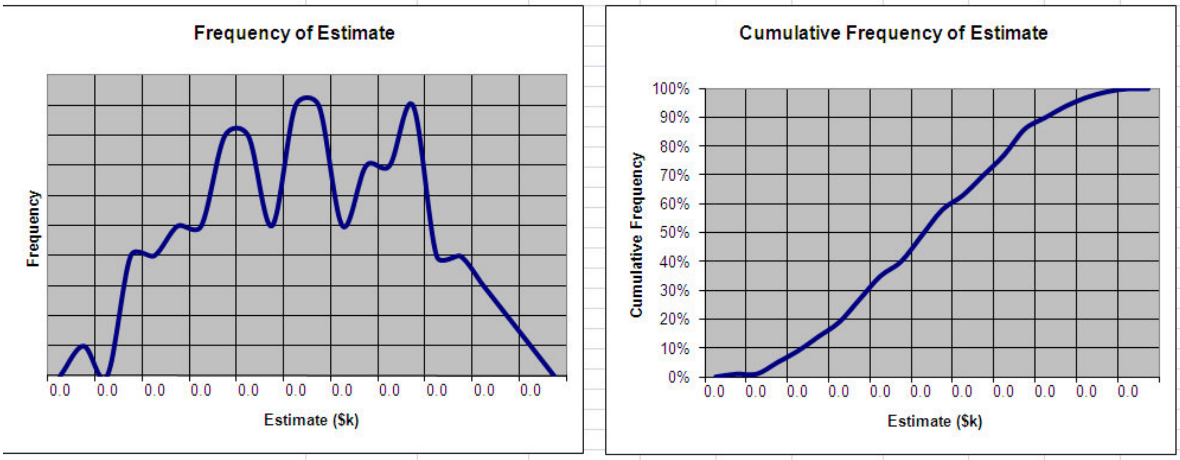
Probabilistic risk analysis was retrospectively applied to two rural road project evaluations and the proposed Christchurch Southern Motorway extension as part of a PhD thesis at the University of Canterbury (Tai 1987). The main sources of uncertainty in the economic evaluation for the motorway were all derived from specification errors in the transport model. These were the assumption that benefits accrued in the peak period could be scaled up, when in fact dis-benefits applied at uncongested times; specification of the trip matrix, and the use of link volumes as a basic measure of benefit (instead of trips). These errors were quantified as contributing to the overestimation of benefits by a factor of 2 to 4 times. For the rural roads, traffic forecasts were not required for project economic evaluations so the inputs with the most influence were traffic flow, base speed and accident reduction parameters. At the decision making stage, budget constraints (affecting the BCR cut-off level) and risk tolerance (affecting the probability of a negative outcome such as rising fatalities) were shown to have critical influence on the use of the evaluation outputs.

2.4.5.8 Australia (2005) – Risk Explorer software

The Austroads *Guide to Project Evaluation: Part 2 Project Evaluation Methodology* **Risk Explorer** software tool is an Excel spreadsheet with Visual Basic macros which run a Monte Carlo simulation. The software help file states that all input "distributions are assumed to be triangular, which will over-estimate risk compared to other distribution types". However, another supplied file (Risk Analysis Example) also includes normal and gamma distributions, although the functionality of these has not been tested as part of this research project. The user is required to enter low, likely and high estimates for all items, and may also enter the probability of occurrence if known. In comparison to Palisade's @RISK, the advantages of the Austroads spreadsheet include no requirement for a costly separate Excel add-in, a focus on transport, linkages to the Guide to Project Evaluation, potential to 'tweak' the macros and sheets as required (with a significant learning curve likely to be required) and provision of integrated standard engineering estimate forms. The project estimation forms include features such as cost price escalation. Output graphics include distributions of BCR, NPV, and the frequency and cumulative frequency of programme time and cost estimates. The disadvantages include complexity and limited statistical distributions for input variables.

An example output screen from the Risk Explorer software is shown in Figure 12.

PROJECT	Risk-based Concept Estimate		
ROAD NAME	Road A	FILE	general
LOCATION	A Rd to B Rd	DATE	01/01/01
DESCRIPTION OF WORK	Improvement	UNITS	1000
PROJECT OFFICER	Me	RUNS	100



ESTIMATE SUMMARY	Confidence Level		
	10%	50%	90%
A Project Management	$ 13,879	$ 16,212	$ 18,882
B Design and Investigation	$ 17,635,311	$ 23,841,230	$ 29,810,780
C Land Acquisition	$ -	$ -	$ -
C1 General	$ -	$ -	$ -
C2 General - Native Vegetation	$ -	$ -	$ -
D(i) PRECONSTRUCTION WORKS	$ -	$ -	$ -
D(ii) CONTRACT WORKS	$ -	$ -	$ -
D(ii)1 General	$ -	$ -	$ -
D(ii)2 Structures & Concrete Works	$ -	$ -	$ -
D(ii)3 Drainage	$ -	$ -	$ -
D(ii)4 Formation Construction	$ -	$ -	$ -
D(ii)5 Pavement Construction	$ -	$ -	$ -
D(ii)6 Surfacing	$ -	$ -	$ -
D(ii)7 Pavement Markings & Road Furnit	$ -	$ -	$ -
D(ii)8 Signal Installation	$ -	$ -	$ -
D(ii)9 Street Lighting	$ -	$ -	$ -
D(ii)10 DDA	$ -	$ -	$ -
D(ii)11 Provisional Quantities & Items	$ -	$ -	$ -
E ADDITIONAL SCOPE RISKS	$ -	$ -	$
TEC (No Price Escalation)		$ 23,856,251	$ 29,826,534

TEC PROFILE WITH PRICE ESCALATION			
Price escalation index	5%		
Year	Estimated Expenditure	Price Escalation	Required Budget
1	3		3
2	5	0.25	5.25
3	5	0.5	5.5
4	2.879	0.43185	3.31085
5	0	0	0
Total	15.879	TEC	17.06085
Check	29826.5332		

Figure 12: Screenshot of Austroads Risk Explorer output for cost estimate risk

3 Uncertainty in the Nelson ATS

3.1 Overview

The Nelson Arterial Traffic Study (ATS) has been used in this project to provide a real-world context, data, and general network form. It was considered useful to demonstrate how uncertainty is addressed in a major transportation planning study. The review aim was to identify sources of uncertainty in the decision process and the risk assessment methods employed by the ATS project team as described in the publicly available reports.

The ATS was a four stage study undertaken by MWH consultants in collaboration with the NZ Transport Agency, Tasman District Council, and Nelson City Council "to determine the best transport system configuration between Annesbrook and the QEII/Haven Rd roundabouts that will improve the city as a whole" (MWH 2010a, p. 1). The ATS study area is shown in Figure 13.

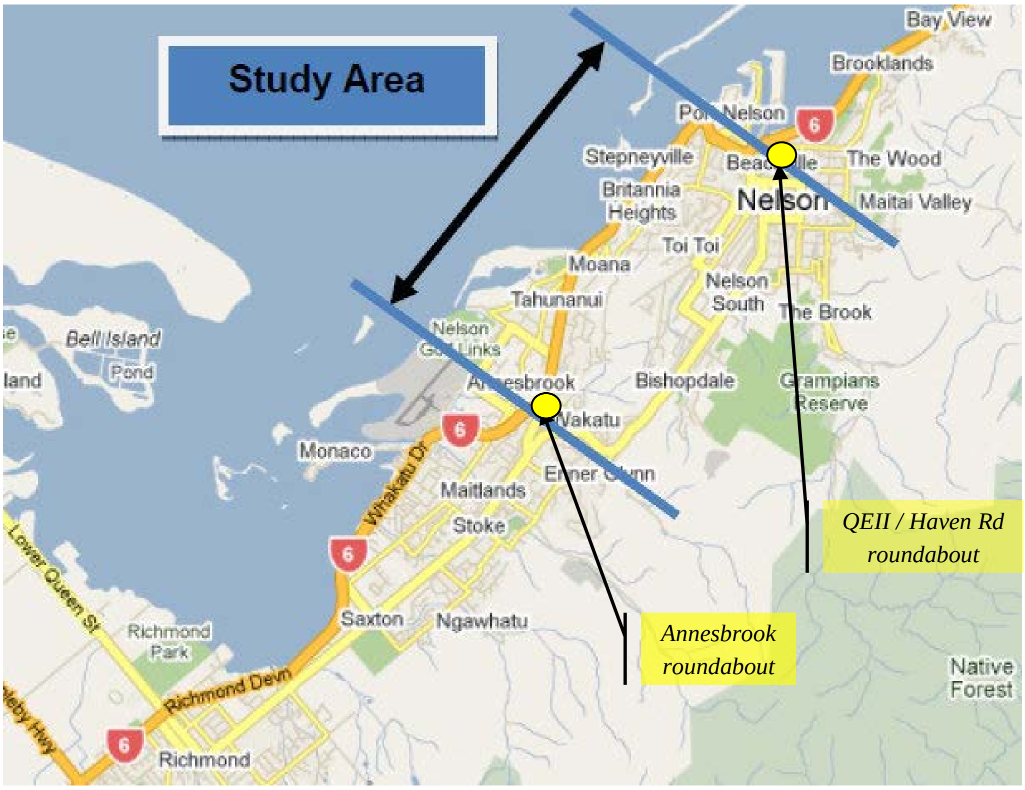


Figure 13: ATS study area (Figure 1-1 MWH 2010a)

Planning began in the 1960's for a route called the Southern Arterial. The most recent planning work undertaken prior to the ATS was the North Nelson to Brightwater study, which led into the ATS. The ATS was informed by the Tasman-Nelson Regional Transport

Model, a strategic transport demand model developed by Gabites Porter using TRACKS software. Other study inputs included expert impact analysis reports, stakeholder meetings and public consultation. The approximately two-year ATS commenced in late 2009 with the identification, development and assessment of a long list of transport options including roads, rail and travel demand management. At the conclusion of the study in 2011, the recommendations included retaining the existing arterial network configuration while preserving the ability to implement either of the top two options assessed (MWH 2011). These top two options (in rank order as determined through the Stage 4 MCA) are “Option A: Part-Time Clearways” on Rocks Road and Waimea Road and “Option B: Southern Arterial”. These options were graphically presented in the Stage 2 report (MWH 2010c) , but higher resolution versions of the same graphics are found on the Nelson City Council Stage 3 web page[2] and reproduced in Figure 14 and Figure 15.

Figure 14: ATS Option A - Part-Time Clearways

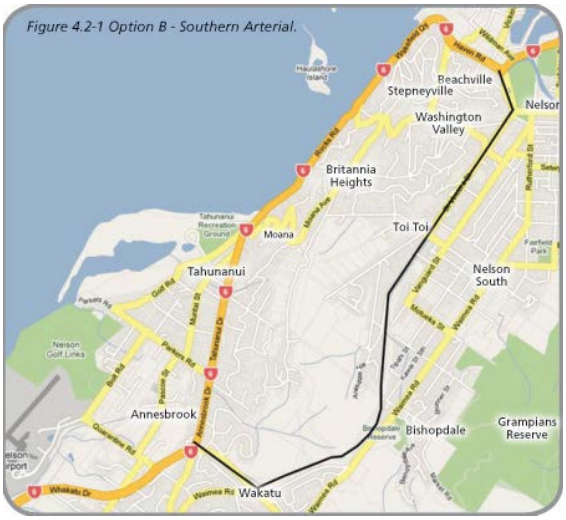


Figure 15: ATS Option B - Southern Arterial

As will be discussed further in section 4.1 of this report, only Option B has been modelled and evaluated in the case study undertaken for this research project.

The ATS included a simplified economic evaluation of options within a larger objective-oriented multi-criteria analysis (MCA) decision support model. Table 12 presents the stages, document titles, and the key sources of uncertainty as determined from a review of the ATS documents.

[2] http://www.nelsoncitycouncil.co.nz/stage-3-evaluation-of-the-four-arterial-route-options/

Table 12: ATS stages, documents and uncertainty types

Stage	Document	Uncertainties
1	**Evaluation of Existing Arterial Traffic Routes**	Traffic volumes on individual links Casualty costs Public acceptance
	Appendix D: Economic assessment	External economic factors Population and employment forecasts Policy decisions on urban growth locations
	Appendix E: Traffic noise	Valuation of noise impacts on health and property values Traffic volumes and composition (e.g. proportion of heavy vehicles) Number of dwellings in proximity to arterial routes
	Appendix F: Social impact	The degree to which transport choices will be supported
	Appendix G: Air Quality	Traffic speed and volume variability Emissions controls, vehicle technology, fuel quality
1B	**Addendum to Stage 1 report: comparison of traffic models**	Population and employment forecasts Traffic assignment model form Traffic assignment treatment of Waimea Road capacity constraint
2	**Selection of Best Arterial Route Options**	Variations on options affecting costs and benefits Land requirements Opportunity costs of designated or owned land
3	**Evaluation of Best Arterial Route Options**	Option B construction risks (e.g. water table) Traffic forecast sensitivity to fuel price
	Appendix B: Cost Estimates	Lack of detail at feasibility stage reflected in high contingency costs
	Appendix C: Traffic modelling	As per 1B modelling uncertainties
	Appendix D: Economic evaluation	Component uncertainties identified in other appendices Discount rate, funding criteria cut-off BCR, funding alternatives Project implementation timing
	Appendix F: Economic impact assessment	Port of Nelson and tourism economic activity levels Cross elasticity of demand for substitute freight modes Valuing differential impacts (winners and losers) Extent of wider economic benefit factors which may be included
	Appendix G: Noise	As per Stage 1 Appendix E
	Appendix H: Social	Valuing differential severance, accessibility, safety, amenity impacts
	Appendix I: Air Quality	As per Stage 1 Appendix G plus: Model assumptions Population densities
	Appendix J: Water Quality	Level of mitigation measures undertaken
	Appendix K: Heritage	Valuing the economic value of heritage Level of mitigation measures undertaken
	Appendix M: Sea level rise	The amount of sea level rise Mitigation costs
4	**Determination of Preferred Arterial Transport Configuration**	This concluding report summarised the uncertainties identified in earlier reports and those arising from the multi-criteria analysis decision support model

3.2 Sources of uncertainty in the ATS

NB: ATS reports which are not cited but described by stage number are the MWH reports available on the Nelson City Council website.

3.2.1 External socio-economic factors

Factors which are somewhat endogenous to the transport modelling and economic evaluation include wider economic and demographic trends (e.g. economic cycles, monetary settings and net positive migration-driven population growth) as well as home location preferences (e.g. lifestyle properties, suburban housing, and apartment dwellings).

The economic assessment undertaken by Brown, Copeland and Co. for the ATS Stage 1 (Appendix D) was focused on the outlook “without significant network upgrades”. It noted that a basic employment shift was underway from manufacturing, agriculture and fishing to construction and retail. This suggests an increasing dependence upon regional level consumption rather than export, and should increase the uncertainty with respect to employment forecasts. The assessment author concludes that if arterial route capacity is improved, more residents will be attracted to live in the wider Tasman District (e.g. Stoke and Richmond) and work in Nelson city (induced traffic in a feedback effect between land use and transport provision) and that if arterial route capacity is not improved, congestion will shift employment to the District from the city.

From this premise, the Brown, Copeland and Co. author determines that the impact of not developing arterial capacity is not only a shift in employment locations, but a reduction in overall employment for the entire region. The (uncertain) assumption is that recent trends in home location, household density, and population density continue, and that residential growth is not able to be accommodated in close proximity to the existing employment centres. In the case of Nelson, there is political uncertainty about the feasibility of promoting increased urban density. The “quarter-acre section” ideal and opposition to the perceived limitations of apartment living are largely based on a historical perspective that is fast changing not only overseas but also in New Zealand (Betanzo 2011; Lilley 2006; Litman 2010b).

3.2.2 Transport model

The basis of transport modelling for the ATS are typical inputs such as future population, land use patterns, employment, educational institution locations, freight volumes, and modal split (MWH 2010d). All of these have various degrees of uncertainty.

3.2.2.1 Socio-economic forecasts

The modelling forecasts produced by the Gabites Porter TRACKS model for the North Nelson to Brightwater study included poor level of service indicators in future years and suggested a need to provide additional capacity. When re-run for the ATS, the same model produced less dire congestion forecasts. The ATS Stage 1B report explained that earlier model used 2001 socio-economic data for the base year calibration, while the updated model used 2006 data.

In a presentation to the public and decision makers made during Stage 3 of the ATS, the authors noted that:

> *The modelling done for this study is best practice for such studies;*
>
> - *there are uncertainties, but they do not undermine the results;*
> - *the greatest sources of uncertainty are the population & employment forecasts;*
> - *Statistics NZ forecasts are the most reliable available.* (MWH 2010d)

As noted in section 2.2.5.2 of this report, the socio-economic forecast can be the dominant source of uncertainty in modelling and evaluation.

3.2.2.2 Trip generation rates

To establish trip generation rates, the Gabites Porter model for Nelson uses household category curves obtained from the Auckland Home Interview Survey 1991. This survey is quite dated, however it was claimed to be "readily transported from one area to another within New Zealand" (Gabites Porter 2009, p. 23). In addition, the coefficient of determination, r^2, for these curves are as low as 0.14 at the zone level, which indicate considerable uncertainty in predictions using these data. In addition, Nelson has the highest proportion (6.8% in 2006 census) of cycling to work trips in the country in contrast to Auckland (under 1%). The model building report notes the high accuracy of the model predictions for each category at the area wide level (i.e. the sum of all zones for each category). However, users and decision makers should not assume that the model has a similar level of accuracy at the zone or link level.

Trip generation studies are often based on very low sample sizes and the ITE has cautioned users about the transferability of data with very low coefficients of determination (Shoup 2005), however transportation planners seem to prefer a reliance on questionable data rather than no data.

3.2.2.3 Model calibration and validation using traffic counts

In "Worksheet 8 – Transport modelling checks", the EEM acknowledges the systematic or sampling error in traffic counts and therefore stipulates that individual links with greater than 15,000 vehicles per day in one direction are permitted errors of about +/- 20%. For the required scatter plot of modelled versus observed flows, the coefficient of determination is suggested to be at least 85% (95% for plots in the vicinity of a particular project scheme under consideration). The Gabites Porter model building report states that the study model is validated against traffic count data and shows a strong predictive capability, with many of the correlation coefficients (between predicted and observed traffic counts) very near to one. However as noted by Batty (1971), "goodness of fit...measures provide only a narrow interpretation of performance; such tests reflect the ability of the model-builder to achieve a good fit rather than any fundamental validation of the model's structure" (p. 165).

3.2.2.4 Fuel prices

Fuel prices are usually treated as resource cost factors external to the evaluation. The original ATS modelling (by Gabites Porter, using Tracks software) was based on the premise of no major fuel price changes in future and no TDM measures such as parking pricing (MWH 2010b). However, given that a source of uncertainty in traffic forecasts is the elasticity of demand with respect to fuel price, the ATS Stage 3 report included a sensitivity test of low (50%) and high (100%) increase in the price of fuel for the 2036 future year. This was undertaken by using a cross elasticity of demand to vehicle ownership and external trip variables in the transport model. Not all other inputs were held constant: public transport improvements were added to the low sensitivity scenario but not the high sensitivity scenario.

Table 13: Sensitivity of traffic forecasts to fuel price (based on MWH, 2010)

Output	**2006**	**2036**	**2036 +100% fuel cost**
Trips (whole model)	37,000	46,000	41,000
VKT (study area)	110,000	144,000	115,000
Average trip length (study area)	6.96	6.85	6.18
Percentage change in traffic volumes 2036 compared to 2006			
Route	**Time period**		
	AM peak	**Inter peak**	**PM peak**
Rocks Road Northbound	-34%	-31%	-18%
Rocks Road Southbound	-32%	-31%	-22%
Waimea Road Northbound	-14%	-19%	-11%
Waimea Road Southbound	-24%	-19%	-9%

The ATS report does not provide a sensitivity analysis of the BCRs to the fuel price; however considering the forecasts given above and using the 100% increase scenario, it is likely that the BCR for the Option B Southern Link road (stated to be 1.3 on page 22 of the Stage 4 report) would have been less than one if this had been undertaken.

The ATS transport model predicts that the impact of a 100% increase in fuel prices (Table 13) is that rather than VKT increasing by 26% from 2006 to 2036, VKT increases by 4%. However, a probabilistic risk analysis of fuel supply based on expert consensus by Krumdieck et al. (2010) suggests that there is a 97% chance of a 60% reduction (compared to 2005) in transport fuel supply by 2035. The authors suggest that while some efficiency gains and alternative fuels may be found, the majority of this decrease in supply will be reflected in reduced VKT. When oil producer spare capacity is low, the inelasticity of demand means that transport fuel prices increase a proportionally larger amount (“spike”) than supply reductions (Donovan et al. 2008; Smith 2010). Although these spikes have been temporary and are predicted to continue in a cycle of volatility, the linkage between oil supply and transport fuel price is well documented (Barker 2010; Energy Information Administration 2009).

In addition to addressing the assumptions inherent in the transport model trip generation, the subjective upper (+100%) and lower (+50%) bounds could be replaced by probability risk analysis techniques to enable the consideration of fuel price impacts in the economic evaluation.

3.2.3 Economic evaluation

3.2.3.1 Evaluation method

The evaluation method used by the ATS consultants appears to be based on the full procedures given in the Transfund 2004 Project Evaluation Manual (PEM), which has since been superseded by the EEM. There is some uncertainty as to whether the PEM procedure produces different values than the EEM. The approach taken for the evaluation was necessarily high level and excluded many potential impacts which could be assessed and monetised in a detailed full procedures evaluation. Such simplifications may be considered appropriate for a preliminary evaluation in contrast to one performed for a funding application. However the method used is not as simplistic as the EEM preliminary feasibility method. This is a key distinction as will be further discussed in section 3.2.3.1 of this report.

The economic evaluation of the alternatives undertaken considered only capital costs, network operating costs, travel time savings, vehicle operating cost savings, and carbon dioxide emissions (MWH 2010d). A summary table of the economic evaluation undertaken for the ATS top four shortlisted options is reproduced in Figure 16.

COST-BENEFIT ANALYSIS OF PROJECT OPTIONS **WORKSHEET 4**

All Projects in Strategy Options

1 Project Options	Do Minimum	Option A	Option B	Option H	Option I	Do Minimum	Option A	Option B	Option H	Option I
COSTS:							Net Costs of the Project Options ($)			
2 Capital Costs		$23,967,091	$30,161,923	$76,959,803	$43,589,448	$2,021,081	$21,946,010	$28,140,842	$74,938,722	$41,568,367
3 Maintenance Costs										
4 Operating Costs		$24,544,071	$23,003,819	$23,437,853	$23,437,853	$21,701,716	$2,842,356	$1,302,103	$1,736,137	$1,736,137
5 Costs (2) to (4)							$24,788,366	$29,442,945	$76,674,860	$43,304,504
BENEFITS:							Net Benefits of the Project Options ($)			
6 Travel Time Costs	$1,893,186,871	$1,901,857,704	$1,859,858,717	$1,907,522,052	$1,882,629,250		-$8,670,833	$33,328,155	-$14,335,180	$10,557,622
7 Vehicle Operating Costs	$1,257,699,738	$1,261,040,909	$1,253,346,022	$1,258,567,520	$1,260,632,999		-$3,341,171	$4,353,716	-$867,783	-$2,933,261
8 Accident Costs										
9 Seal Ext. / Passing Lane										
10 Carbon Dioxide	$62,884,987	$63,052,045	$62,667,301	$62,928,376	$63,031,650		-$167,059	$217,686	-$43,389	-$146,663
11 Benefits (6) to (10)							-$12,179,063	$37,899,556	-$15,246,352	$7,477,697
12 B/C Ratio (11) / (5)							-0.5	1.3	-0.2	0.2

Figure 16: ATS economic evaluation summary table (Stage 3 report Appendix D)

The input values are not rounded to the nearest thousand dollars and the output values (BCRs between -0.5 and 1.3) are presented as point estimates, which suggest a level of accuracy that is probably not warranted.

Transport model derived benefits were discussed in the preceding sections. The excluded benefit uncertainties and included cost uncertainties are addressed in the next sections.

3.2.3.2 Cost estimates

There is uncertainty inherent in capital cost feasibility estimates, and this is reflected by the inclusion of 20% contingency and 33% funding risk components within the total 95th percentile estimate for each option.

Although it appears from Figure 16 that maintenance costs were excluded, the network operating costs were derived from the annual costs of public transport ($2.5M for both ATS options A and B) and road maintenance. No explanation was apparent for the higher annual road maintenance cost for Option A ($300K) relative to Option B ($150K), even though the latter involves more lane-kilometres of road to maintain.

3.2.3.3 Environmental health and home location impacts of traffic noise

The noise assessment by Malcolm Hunt Associates for the ATS Stage 1 report (Appendix E) notes that traffic noise can cause relocation of noise sensitive persons away from road corridors. Concurrent with the provision of new road infrastructure, to what degree is the choice to live in a new (more distant) suburb influenced by the lower perceived cost of travel versus the environmental impacts of that road on existing suburbs? The indirect impacts of road noise, perhaps in terms of property values, network statistics such as vehicle kilometres travelled, and social costs (including identification of differential impacts i.e. winners and losers) would be difficult to quantify, however a GIS based technique was developed by the UK Department of Transport as early as 1988 by Lake et al (2001). Although further refined and used for direct impacts on affected residents within the noise contour or road frontage, it does not appear to have been used for the indirect impacts described above.

Techniques for estimating direct impacts of road noise have been developed (Austroads 2005c; McCallum-Clark et al. 2006; Ton et al. 1998). Applications of these techniques for economic evaluation include:

- The UK's "New Approach to Appraisal" includes provisions for inclusion of noise impacts in economic evaluations, including the Transport Analysis Guidance (TAG) Noise Spreadsheet (DfT 2011). The legislation provides that compensation can be claimed by owner occupiers whose property has been reduced in value by more than £50 by physical factors caused by the use of a new or altered road. The Highways Agency policy is to reduce noise with all new road projects through quieter pavements, noise walls or bunds, or mitigate noise through insulation and double glazing (Highways Agency undated).

- The EEM section A8.2 provides an NPV per dB(A) per affected person of $1500. However, evaluation using worksheet A8.3 may be difficult as existing contours and noise levels would have to be compared to forecasts of traffic volumes, traffic composition and number of households affected. The EEM simplifies evaluation by limiting affected properties to those along the frontage rather than within the unacceptable noise contour. This simplification removes the incentive to avoid noise impacts on the wider community.

Despite the presence of these methods, it has not been established by this research whether noise impacts have been internalised for any previous transport economic evaluations, and it is clear that it has not been included in the economic evaluation undertaken for the ATS. It should be noted that the ATS evaluation was a preliminary approach, and any consideration of noise impacts that might be undertaken would be more likely in a detailed evaluation.

3.2.3.4 Air and water quality

As with traffic noise, there are provisions in the EEM and established methods for including the value of changes in air and water quality in any economic evaluation. The ATS stage 1 report Appendices G and H describe the current situation and note the uncertainties with respect to predicting future values for these environmental measures. The air quality report did not mention the uncertainty of potential government regulation of vehicle imports or vehicle technology improvements which may reduce the impact of emissions.

The water quality assessment notes that the cumulative effects of urbanisation are far larger than the impacts of a particular corridor. It would be more accurate for the report to use *sub*-urbanisation in describing the effect of roads and parking on water quality. The potential for increased road capacity to accelerate sprawl resulting in a higher level of impermeable surfaces (roads and parking areas) is unknown.

3.2.3.5 Safety

Safety was considered in the option planning, but was not included in the ATS economic evaluation. However, the Stage 3 report states that "it is considered that Nelson's biggest opportunity to reduce crashes lies in undertaking safety improvements consistent with the Regional Land Transport Strategy, rather than relying on an arterial traffic solution" (MWH 2010d, p. 54). As noted in the literature review, safety benefit unit costs (based on the value of a statistical life) have been observed to have a more significant impact on the BCR than the actual reduction in crashes. Were safety to be included, an uncertainty in predicting safety benefits would be the modal split and hence non-motorised user exposure to risk as described in section 2.2.4.5 of this report.

3.2.3.6 Funding

The PPFM and the Government Policy Statement (Ministry of Transport 2010) set out the current economic efficiency ranking as High (BCR≥4), Medium (BCR≥2 and BCR<4) and Low (BCR<2). Projects with a low BCR are unlikely to be funded (unless the project has a special national significance). The ATS stage 4 report (MWH 2011) suggests that even with higher than anticipated traffic volumes, future economic evaluations of any of the current options are not likely to result in a BCR over 2. With respect to funding, the report concludes that: "...as current indications are that no national funding is available for the foreseeable future (and Nelson City Council is unlikely to fully fund any options), implementation of any arterial transport option will need to be delayed until funding is likely to become available..." (MWH 2011, p.24). Therefore, any changes in the BCR cut-offs outlined above and/or the establishment of alternative funding sources (e.g. road tolling or regional taxes) are uncertainties which will affect the timing of any options reconsidered in future years.

3.2.4 Multi-criteria analysis

Aside from the economic efficiency criteria, several other criteria were considered uncertain and addressed in various ways as discussed in the following sections.

3.2.4.1 Climate change

The ATS Stage 4 report acknowledges that there is uncertainty with respect to potentially stronger and critical climate change impacts on Option A (the clearway on the coastal road, SH6-Rocks Road). Should sea levels rise by amounts at the higher range of current estimates, the probability of road closure would increase and would likely make improvements to that road uneconomic. The project team considered that the analysis has included the most likely sea rise scenario from current expert advice, but that the climate change science was continuing to be refined. In essence, the uncertainty approach taken is a "watch this space" recommendation. The ATS economic evaluation approach was not exhaustive in inclusion of uncertainties. A more detailed evaluation that would be required for a funding application could utilise probabilistic risk analysis to include the costs of road closure based on sea level rise probabilities.

3.2.4.2 Social impacts

Some members of the community will find the ongoing uncertainty with respect to the alternative routes difficult. The ATS Stage 4 (MWH 2011, p. 24) report states that: "Uncertainty within the community was discussed in the Social Impact Assessment as having a particular affect on those people who live in areas which would be subject to considerable additional impacts with one or more of the options. This uncertainty could lead to adverse effects related to "urban blight" and under-investment, difficulty in community development and health issues in some parts of the city". The study authors consider that this uncertainty is tempered somewhat by the study recommendation of a 25 year no-build window, as forecast traffic volumes are not predicted to require any of the options during this period.

3.2.4.3 Weighting

The ATS MCA scored four options against ten criteria developed in earlier stages of the project (Figure 17). These scores were multiplied by base weights and five alternative weighting schemes to test the sensitivity of the rankings to changes in the weights (Figure 18). The ATS project team used this approach to show that the top ranking of Option A was unaffected by various weighting schemes. Rather than use Monte Carlo simulation to assign implementation probabilities to each option (refer section 2.4.1), the weighting scheme testing may be more readily understood by the key stakeholders and more economical to undertake.

Table 2-1: Multi Criteria Analysis, Scores for Criteria (1=performs well, 5=performs poorly)

Option	Cultural/ Heritage	Natural Environment	Co-Benefits	City Future	Community Impacts – Physical	Community Impacts - Social	Community Impacts - Economic	Robustness/ Future-proofing	Degree of Difficulty	Economic Efficiency
Option A: Peak Hour Clearways	3	2	3	2	1	3	2	2	2	5
Option B: Southern Arterial	2	4	3	3	4	4	2	2	3	4
Option H: SH6 Four Laning	4	2	3	3 (4)	2	4	2	4	5	5
Option I: Waimea / Rutherford 4L	3	2	4	4	3	5	4	4	5	5

Figure 17: MCA scoring (MWH 2011)

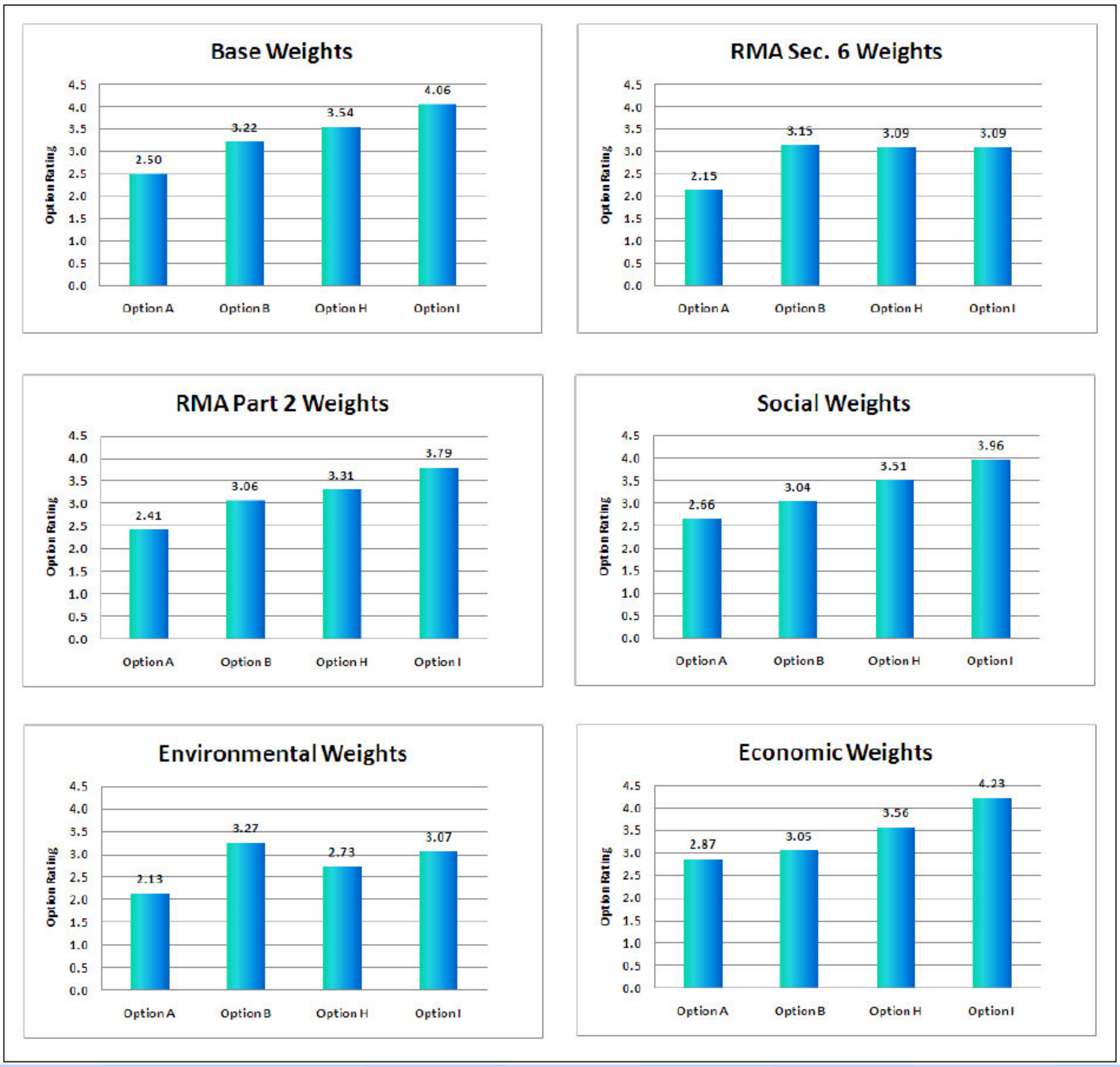


Figure 18: MCA weighted scores under six weighting schemes (MWH 2011)

3.3 Summary of uncertainty assessment in the ATS

The ATS project team applied a range of simple methods to account for uncertainty including analysis of the sensitivity of the traffic model to changes in fuel price and the sensitivity of the multi-criteria analysis to changes in criteria weights. Not enough information was found on the detailed economic evaluation to determine how uncertainty was addressed in the BCA.

The principal risk assessment methods applied to uncertainty in the ATS at various decision making stages are summarised in Table 14.

Table 14: Summary of ATS uncertainty assessment methods

Decision making process stage	Risk assessment method
Traffic forecasts	Sensitivity to fuel price Sensitivity to modal split
Economic evaluation (BCA)	Cost and funding risk contingencies
Multi-criteria decision analysis	Impact of climate change on options Sensitivity of rankings to changes in criteria weights

The Stage 4 report concludes by recognising the “significant amount of uncertainty associated with a number of factors” (MWH 2011, p. 3). At least in terms of the BCR factor, it is possible that providing a measure of that uncertainty was considered but not undertaken in light of the relative importance of other factors in the MCA.

Finally, it is interesting to note that the southern corridor (Option B) BCR as calculated by the North Nelson to Brightwater study team in 2006 was 3.7 and the BCR as calculated by the ATS team in 2011 was 1.3. Although cost estimates will have changed in the interim, the ATS authors attributed most of the 65% decrease in BCR to the revised traffic forecasts.

4 Transport Model

4.1 Study area, zones and transport network

The case study area is loosely based on the ATS study area, consisting of two urban areas (Richmond and Nelson) linearly arranged at the ends of two parallel transport corridors (SH6 Rocks Road and Waimea Road). These urban areas are close enough to one another to create a sizeable transport demand between them. The general ATS transport and land use system is considered representative of typical planning situations.

Traffic analysis zones (TAZ) and a simplified route network were developed in the ESRI ArcMap Geographic Information System (GIS). The zones selected for the project are aggregations of census meshblocks, with boundaries along roads. A map showing the zones developed for this project is shown in Figure 19.

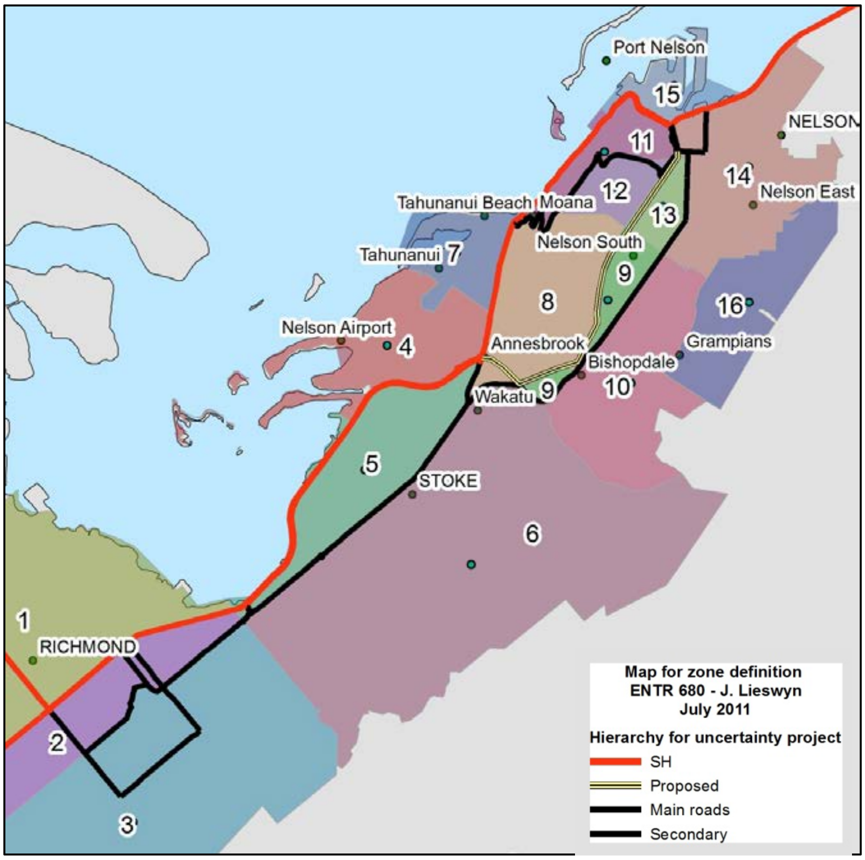


Figure 19: Study area zone map

It is a slightly larger scale than the “Figure 4 Nelson Zones” (MWH 2010a) in order to include the effect of Richmond. Areas with very low population (and therefore low traffic demands) were excluded and marked with a zero. The GIS function used to assemble the zones is "dissolve" (adds together all data in the zones being combined), instead of "merge" (keeps only the data in one shape).

4.2 Trip generation and distribution model

Although commercial traffic forecasting software packages would have far greater predictive accuracy, a simplified spreadsheet based model has been developed to easily integrate with Palisade's @RISK. As noted previously, @RISK is a stochastic risk analysis software add-in for Excel spreadsheets. The model simplifications mean that the results cannot be compared to the Nelson ATS, from which some data has been sourced.

A Lowry model was chosen for its simplicity, its ability to represent the relationships between land-use and transport, and it's being based on two of the most uncertain parameters of modelling (employment and population). The data inputs required for a Lowry type model, principally location and number of basic sector employees, are easily available from the census. The structure of the Lowry model is presented in Figure 20.

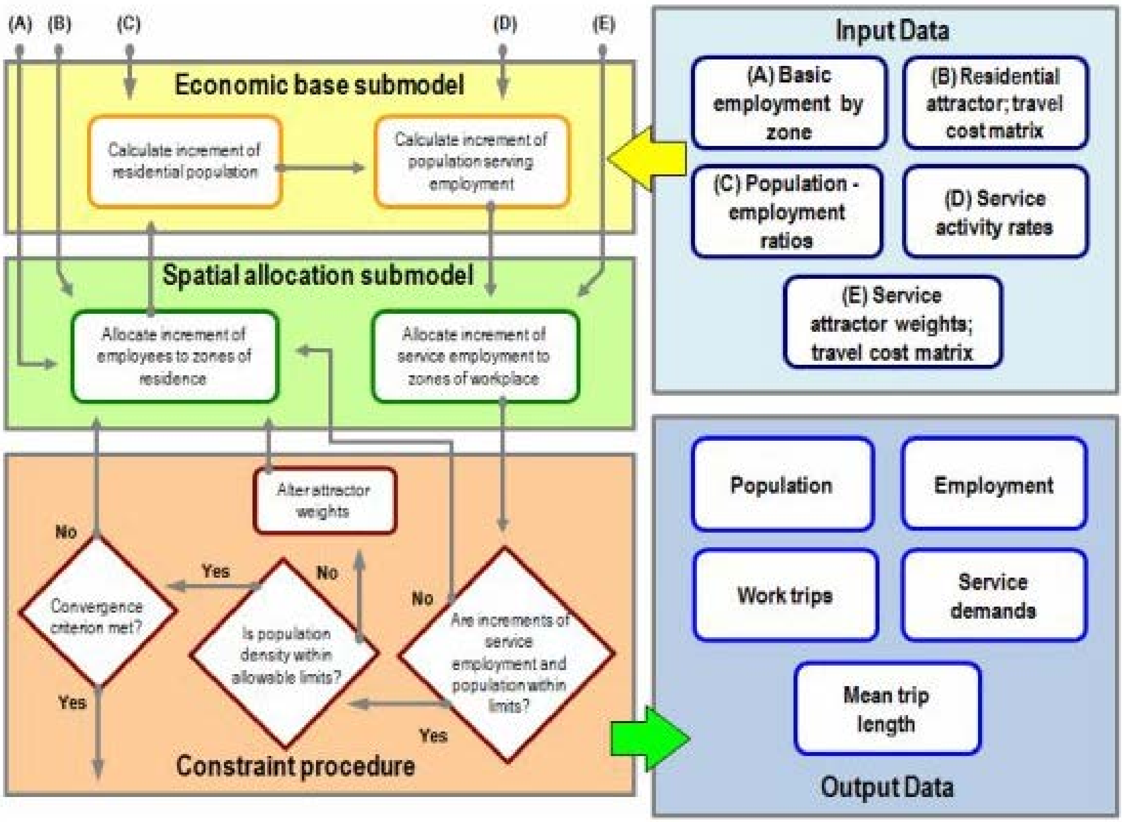


Figure 20: Structure of the Lowry model (Rodrigue et al. 2009)

The Lowry model performs the trip generation and distribution stages of the conventional four step travel demand model, with mode choice not explicitly considered. Although future mode split and vehicle occupancy parameters are important, the focus of the feasibility case study was on the impact of uncertainty in socio-economic variables upon traffic forecasts and the BCR for the alternative option. A separate assignment model was required and is described in section 4.8 of this report.

According to Rodrigue et al (2009), the “Lowry model was one of the first transportation / land use models to be developed” and was applied to the Pittsburgh region in 1964. The central premise (now called economic base theory) is an assumption that “regional and urban growth (or decline) is a function of the expansion (or contraction) of the basic sector”. The basic sector refers to employment which meets non-local demand. As described in the structure diagram, the outputs include all employment (basic and “service”) along with population by zone and trips between zones.

There are four principal limitations to the Lowry model.

- It is a “static model, which does not tell anything about the evolution of the transportation / land use system” (Rodrigue et al. 2009) This limitation was also noted by Batty (1971, p. 171) who states that “the principal limitation of the Lowry model is that it treats the spatial systems as if it is in static equilibrium... (i.e.,) the model is fitted to one cross-section in time, which is assumed to be an equilibrium condition of the system.” However, the intention of this project is not to provide rigorous assessment of alternative future scenarios but to use the simplified model to investigate the feasibility of including uncertainty.
- If the traditional definitions of basic and non-basic (service) employment are applied, it does not accurately represent many service oriented economies. This is typically addressed by expanding the classes of basic employment to include more service occupations. If such a model were applied to Queenstown, for example, one might categorise the tourism industry as basic.
- It does not consider freight movements, which for principal inter-zonal arterial routes have a major impact on traffic flow characteristics and consequently the total generalised cost of travel.

- The price of buildings and land is assumed to perfectly adjust according to the law of supply and demand irrespective of geographic and agglomeration factors.

Despite these limitations, many land use and transport models incorporate Lowry's economic base theory (Clay & Johnston 2006; Meyer & Miller 1984). For example, MEPLAN is an integrated (demand and supply of land use and transport) software package derived from the Lowry model which compares the effects of changes in various public policies and helps explain interaction of land use and transport as posited by Manheim (1976).

Unlike the typical three or four step transport model, the Lowry model does not explicitly consider trip generation rates for defined classes of land use. As discussed in section 3.2.2.4, trip generation rates themselves may be a significant source of uncertainty. Although simplistic, a Lowry type model avoids the potential pitfall of the use of uncertain trip generation rates in conventional sequential transport models. However, in the development of the trip matrices, the service trips per capita and commute trips per employee parameters may be varied to test scenarios such as what if more trips were local (intra-zonal).

4.3 Source data

The ATS future year 2036 modelling is based on land use assumptions including the number of employees by the Australia New Zealand Standard Classification of Occupations (ANZSCO) category per Gabites Porter zone. These assumptions are based upon the Tasman Growth, Supply-Demand Model (stage 1 report section 4.3) and expert projections from Tasman District Council, Nelson City Council, Boffa Miskell, and Brown Copeland & Co. (MWH 2010a).

As this research could be extended to analyse the impacts of uncertainty in the land use forecasts and the resultant impact on the Lowry model output trip matrix, the Gabites Porter zone to census meshblock lookup table was transcribed from the ATS transport model building report to an Excel spreadsheet.

Data on usually resident population, employee home and workplace addresses by ANZSCO category at the most detailed level (meshblock) was sourced from the Statistics New Zealand website and joined to the case study 2006 existing and 2036 forecasted land use data. A sample of zones was chosen at random and the sum total of persons in each of the

Gabites Porter employment categories was compared to the ANZSCO06 statistical divisions, which showed general agreement. Therefore the Gabites Porter category data was selected and aggregated into the basic / non-basic categories required by the Lowry model formulation as shown in Table 15.

Table 15: Definition of basic and non-basic employment data

Gabites Porter categories	For the project Lowry model
AGRI_JOBS	Basic
MANUFACTURING_JOBS	
WHOLESALE_JOBS	
RETAIL_JOBS	Non-basic (service)
OFFICE_JOBS	
EDUCATION_JOBS	
COMMUNITY_JOBS	
OTHER	

The join was performed using the Gabites Porter transport zone to meshblock lookup table. These data were first “cleaned” to eliminate instances where more than one Gabites Porter zone was assigned to one meshblock or vice versa as follows:

- For each Gabites Porter zone in the dataset, obtain existing and future estimates of basic employment by summation of agricultural, manufacturing and wholesale category employment categories and non-basic (service) employment by summation of retail, office, education and community employment categories
- Import, sort and cross check Gabites Porter zone lookup table
- Use a lookup function to associate a census meshblock for each Gabites Porter zone and cross check
- Identify duplicate Gabites Porter zones and create rows for proportioning data
- Proportion Gabites Porter population and employment totals by census population
- Identify duplicate meshblocks and sum data with the aim of obtaining just one meshblock with the Gabites Porter data in it

The combined data were then imported into the GIS. The final dataset which was used as an input to the project model is presented in Appendix 2.

4.4 Lowry model development

4.4.1 Lowry model setup and inputs

A prebuilt, 14 zone, Excel-based (with formulae written in Visual Basic) Lowry model has been published (Rodrigue et al. 2009) and was tested for suitability within the aims of this project. The Rodrigue model uses friction factors (impedances to travel or costs of travel) based on simple Euclidean distances between zone centroids, which was an available output from the project GIS data. The “find_distances” Visual Basic sub-model could have been replaced with a matrix of whatever travel impedances are desired (e.g. shortest path and likely alternative path). However, a model was developed in Excel to enable more direct manipulation of all formulae and parameters for calibration.

The model set-up phase was fairly detailed as it was unknown how predictive the model would be, how comprehensive the risk analysis could be in terms of testing the various inputs, and whether the research could be extended in future.

The Lowry model inputs were the basic employment per zone, default values for the population and employee ratios, and travel costs. At this stage, the travel costs are “zero flow” (i.e. uncongested situation where all vehicles can maintain their desired free speed). Only in route assignment is flow taken into account. The travel costs were calculated from the EEM Table A4.1 “value of time for the composite urban arterial morning period” ($15.13), GIS calculated route distances, 50 km/h local road speeds, and 70 km/h arterial interrupted speeds (Akcelik, 2000). It was assumed that local speeds were applicable to zones which did not have an arterial option. There are a number of simplifications in this approach, especially the treatment of longer trips as entirely done on interrupted arterials when a large proportion of many zone pairs were actually likely to be on local roads.

4.5 Lowry model formulation

The Lowry model is comprised of nine equations and three constraints (Lowry 1964, cited in Meyer & Miller 1984, p.190). The principal exogenous input required is the basic employment per zone. In this formulation, retail is synonymous with non-basic or service sector employment.

Table 16: Lowry model equations (Lowry 1964, cited in Meyer & Miller 1984)

Land use

$$A_j = A_j^U + A_j^B + A_j^R + A_j^H \qquad \textit{Equation 1}$$

Employment sector

$$E^k = a^k N \qquad \textit{Equation 2}$$

$$E_j^k = b^k \left(\sum_{i=1}^{n} \frac{c^k N_i}{T_{ij}^k} + d^k E_j \right) \qquad \textit{Equation 3}$$

$$E^k = \sum_{j=1}^{n} E_j^k \qquad \textit{Equation 4}$$

$$E_j = E_j^B + \sum_{k=1}^{m} E_j^k \qquad \textit{Equation 5}$$

$$A_j^R = \sum_{k=1}^{m} e^k E_j^k \qquad \textit{Equation 6}$$

Household sector

$$N = f \sum_{j=1}^{n} E_j \qquad \textit{Equation 7}$$

$$N_j = g \sum_{i=1}^{n} \frac{E_i}{T_{ij}} \qquad \textit{Equation 8}$$

$$N = \sum_{j=1}^{n} N_j \qquad \textit{Equation 9}$$

Constraints

$$E_j^k \geq Z^k \text{ or } E_j^k = 0 \text{ for all } j,k \qquad \textit{Equation 10}$$

$$N_j \leq Z_j^H A_j^H \qquad \textit{Equation 11}$$

$$A_j^R \leq A_j - A_j^U - A_j^B \qquad \textit{Equation 12}$$

Variables

A	=	area of land
E	=	employment (number of persons)
N	=	population (number of households)
T	=	index of trip distribution

Superscripts and subscripts

U	=	unusable land
B	=	basic sector
R	=	retail sector
H	=	household sector
k	=	class of establishments in retail sector
i,j	=	zones

Exogenous functions and coefficients

f	=	ratio of population to employees
c^k	=	relative importance (homes) as origins for shopping
d^k	=	relative importance (workplaces) as origins for shopping
a^{k1}	=	ratio non basic employment to population

For the case study application, equations 1 and 6 related to land area were not used as it was assumed to be unbounded. A screenshot of the tenth and final iteration showing the model application in Excel is shown in Figure 21.

			Zone				
Equation	Variable	Description	1	13	14	15	16
	$E^B{}_j$	Given the basic employment per zone	740	369	552	1045	15
Iteration 10							
eq. 7	N	population of all zones = f * sum employment		50827			
eq. 8	N_j	population per zone where g is not yet determined	2045102	6816335	26051247	3248154	1297723
eq. 9	N	population of all zones without g		188247061			
	g	determine g, population balancing (scale) factor		0.00027			
	N_j	population per zone using new g	552	1840	7034	877	350
eq. 2	E^k	non basic employment all zones = $a^k * N$ as last calculated		21018			
eq. 3	$E^k{}_j$	non basic employment where b is not yet determined	2636855	2591113	19044878	1107796	629399
eq. 4	E^k	non basic employment of all zones without b		60678668			
	b	determine b, employment balancing (scale) factor		0.00035			
	$E^k{}_j$	final eq. 3: non basic employment per zone using b	913	898	6597	384	218
eq. 5	E_j	total employment per zone $E_j = E^B{}_j + E^k{}_j$	1653	1267	7149	1429	233
		total employment		26883			
eq. 7		convergence achieved when $N = f$ * (sum all E_j)	$f * E_j$	52058	% change	1231	2.4%

Figure 21: Screenshot of Lowry model iteration

Ten iterations were sufficient to achieve a 2.4% percentage change between the current iteration total population and the previous iteration total population (households). A higher level of convergence (i.e. the output between iterations no longer changes more than a given convergence value, say 1%) may have been achieved through additional iterations, but the iterations were not automated and hence were time consuming. For the feasibility study purposes, ten iterations were considered adequate.

4.6 Calibration and validation

Calibration is the process of estimating the model's parameters. Calibration involves adjusting model parameters to ensure adequate agreement between the observed (base year) trip distribution and the predicted (base year) distributions; this is not the same as model validation, which involves checking predicted future distribution against actual future distribution (Ortuzar & Willumsen 2011). In New Zealand practice, validation is used interchangeably with calibration (Gabites Porter 2009; NZTA 2010). For the case study, the term calibration is used by MWH and validation is used by Gabites Porter to mean the same process – adjustment of the model parameters to produce outputs which closely match 2006 year observations.

Calibration is adjustment of the model parameters to ensure adequate agreement between the model outputs and the values from known survey data (census 2006). In the case of the Lowry model, this means agreement between the model output values (population and non-basic employment per zone) and the census 2006 figures. Validation would be to check how well the model predicts values for future years – base year say 2010 (Barton-Aschman Associates & Cambridge Systematics 1997).

The project model was calibrated using Excel Solver by varying the parameters of attractiveness per zone and overall employment ratios to minimise the average root mean square error (RMSE) of a comparison between predicted and observed (2006 census) employment and population per zone. Constraints were set to ensure non-negativity of target cells. RMSE is a NZTA recommended network-wide transport modelling check and values should be less than 30% (NZTA 2010, p.5-36). Typically, the values will be traffic volumes but in this case the study method was adapted to the model outputs (employment and population). The formula for RMSE is given in Equation 1:

$$RMSE\% = \frac{\sqrt{\frac{\Sigma(q_{mod}-q_{obs})^2}{number\ of\ counts-1}}}{\left(\frac{\Sigma q_{obs}}{number\ of\ counts}\right)} * 100$$ ***Equation 13***

where

q_{mod} = employment and population per zone as modelled; and

q_{obs} = employment and population per zone as per Census 2006 data.

Including the population and employment ratios in the variable range improved the model performance, and ratios remained similar to the actual census ratios as shown in Table 17.

Table 17: Modelled and census population and employment ratios

Modelled	Census	Ratio	Description
1.94	2.01	f	ratio of population to employees
0.41	0.38	a^k	ratio non basic employment to population

The model could be forced to predict employment or population with greater accuracy (RMSE% as low as 2%) but this was accompanied by a decrease in accuracy for the other output. As total employment is comprised of basic and non-basic employment per zone, and the known (2006 census) basic employment is used as the principal input for model construction, the average of the RMSE% for non-basic employment and population are used for calibration. The key calibration statistics and zones not modelled well are shown in Table 18, with a full summary table given in Appendix 1.

Table 18: Summary of calibration

Model output	Mean RMSE%	Zones with prediction error > 30%
Non – basic employment	25%	overestimates 6, 8, 11, 12, 16
Population	17%	underestimates 1, 16

These calibration results mean that the model has met the EEM transport modelling check for mean RMSE.

The Lowry model output includes trips from each zone to all other zones (an 'origin destination matrix') for residence/work commute trips and service trips. This matrix was adjusted by ATS values for car mode share (71%) and car occupancy (1.2). This assumption is probably biased towards the automobile, as many local trips (e.g. a walk to the dairy or to the sports field) are not accounted for in travel surveys and the census journey to work mode splits. Only the single direction, home to work (basic and service employment) trip matrix was used for the next project steps. This assumption means that inter-peak and shopping trips are not considered further. A full real world evaluation should include potential lower benefits or dis-benefits at off-peak times of day (Tai 1987).

Some estimate of recreation and other non-commute/non-shopping trips could have been made and a total-trips output generated. This would then have been assigned to the network assuming a 24 hour capacity instead of a peak period per lane capacity.

4.7 Lowry model results

The Lowry model basic employment inputs and results are summarised in Table 19. This table presents the following information:

- Census 2006 population used for model calibration
- ATS forecast basic jobs figure used to run the Lowry model for the 2036 future year
- Proportion of population and basic jobs located in Richmond/Stoke zones 1 to 6 (south of the Annesbrook roundabout)
- Tidal flow proportion southbound (from Nelson zones 7-16 to Richmond/Stoke zones 1-6)
- The arithmetic annual growth rate over a 30 year period for each total value

Table 19: Socio-economic inputs, spatial distribution, and Lowry model outputs

Year	Source	Population		Basic Jobs		AM peak period trips	
		Total	Proportion zones 1-6	Total	Proportion zones 1-6	Tij (A,B,C)	Tidal flow % southbound
2006	Census	51603	54%	5865	59%	13446	47%
2036	ATS forecast	65382	59%	9935	74%	22458	73%
Average annual arithmetic growth rate (30 years)		0.89%		2.31%		2.23%	

Perhaps reflecting assumptions relating to location preferences and land availability, the ATS forecast suggests that by 2036 a slightly higher proportion of the total population will be living in Richmond and Stoke. The proportion of basic employment in Richmond and Stoke is forecast to rise from 59% to 74%, which would require that 96% of the basic employment *growth* occurs there. The Lowry model predicted morning peak period trips increase by a 2.23% average annual growth rate from 13,446 to 22,458. This is slightly lower than the 2.50% growth rate advised in the default growth rates (Table A2.5) given in the EEM. This case study includes a risk analysis of the uncertainties inherent in the forecast basic employment growth rates and spatial distribution (refer section 5.4).

4.8 Assignment model

4.8.1 Assignment model step 1: defining the travel costs

According to Ortuzar and Willumsen (2011), the factors affecting route choice include travel time, travel distance, generalised cost (weighted sum of time and distance), safety, reliability, and taste (including aesthetics). Models often use additional measures within the total generalised cost such as cost of fuel, public transport fares, and parking charges. For simplicity, the assignment was undertaken using the travel cost based on the EEM value of time and distance values from the ATS (5.9 km for SH6, 5.1 km for Waimea Road, and 4.9 km for the new road option). The cost function employed is shown in Equation 14.

$$c = \frac{d}{v} \times VOT$$ ***Equation 14***

where

c = cost of travel;
d = distance (in kilometres);
v = speed (in kilometres per hour) from the Gabites Porter link types; and
VOT = value of time (in dollars per hour) from the EEM.

4.8.2 Assignment model step 2: defining the routes

To include the impact of socio-economic forecasts for Richmond, the Lowry model forecast trips on the main roads between Richmond and Annesbrook (routes D and E in Figure 22). In the assignment model, these trips are included as external flows, with only routes A, B, and C (between the roundabouts) endogenously varied.

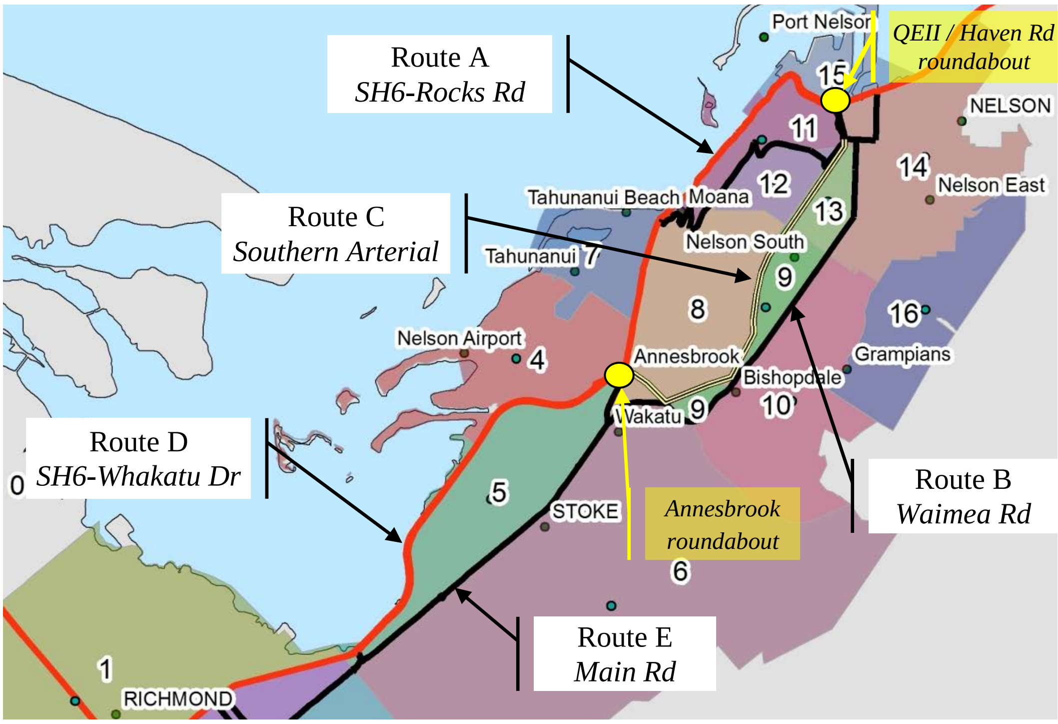


Figure 22: Division of main routes into segments for assignment

For the purposes of this project, the assignment model uses only the morning peak trips from the Lowry model. The morning period was chosen as it was considered to be the period when congestion may be a factor in the user equilibrium assignment model and in the justification for building a new road.

Centroids were simply assigned using GIS spatial tools completely independent of the actual land use distribution or transport network and linked to the road network by drawing the shortest path. As noted previously, in practice the construction of the network and links to the centroids will have a significant impact on assignment (FHWA 1990).

The ArcMap software used did not have the route analyst module which would have automatically generated shortest paths between centroids. Therefore, a “most likely / most direct” rationale was used to link the centroid of each zone to the centroid of all other zones with manual drawing of lines along the predefined routes and a statistical spatial geometry query of line length. Any errors arising from this method are unlikely to be material for the given project aims. In addition to the most likely (shortest) route, any alternative route for each pair was also coded. The resultant table of centroid pairs, possible paths, and distances was used in the traffic assignment step. It was assumed that the intra-zonal distance was 1 km.

4.8.3 Assignment model step 3: all-or-nothing assignment

For local trips, the all-or-nothing assignment method (which assumes that all trips will go on the shortest path irrespective of flow) was used. The FHWA states: "Equilibrium and capacity restraint assignments are beneficial if congestion exists. For small urbanized areas with minimal congestion, an all-or-nothing assignment may be more appropriate and give adequate results" (1990, p. 28). The all-or-nothing assignment rationale was that a trip was considered local only if the zones are adjoining and perpendicular to the long axis of the urban settlement (along the main highways). For example (refer to Figure 19), zones 1, 2 and 3 are locally adjoining but 2 and 5 are not. If the centroid can be connected without using the highways as determined from inspection of a more detailed network map, the trip was considered local. A screenshot of part of the Excel spreadsheet used for the all-or-nothing assignment is shown in Figure 23.

Indexed to Lowry model OD matrix - home to work trips each way			Trips preloaded to main routes (no choice)				Trips preloaded to main routes		Not preloded	Meets criteria for no route choice?					Meets criteria for route choice?	
Zone no. from i	Zone no. to j	Trips total	A	B	D	E	A/B	D/E	Local	Local	A	B	D	E	A/B	D/E
	Sums	15906	3457	3708	1822	1101	6281	9445	1145							
1	1	1	0	0	0	0	0	0	1	Y						
1	2	4	0	0	0	0	0	0	4	Y						
1	3	8	0	0	0	0	0	0	8	Y						
1	4	196	0	0	196	0	0	0	0				Y			
1	5	116	0	0	0	0	0	116	0							Y
1	6	114	0	0	0	114	0	0	0					Y		
1	7	95	95	0	0	0	0	95	0		Y					Y
1	8	98	98	0	0	0	0	98	0		Y					Y

Figure 23: Screenshot extract from OD matrix and all-or-nothing assignment

The total number of trips (15,906) comes from the Lowry model home to work (each way) matrix. Some trips are not made on routes A or B. Because the simplified network does not have sufficient capacity for the Lowry model output trips, a capacity constraint factor of 0.7 has been applied to reduce the total number of trips made on A or B (13,446) to 9412 for the next assignment step. The all-or-nothing (AON) trips representing those which were judged to have no route choice and the trips for the following user equilibrium (UE) assignment are shown in Table 20.

Table 20: Trips reduced by capacity constraint factor

Trips total (Lowry model output)	**15906**
A (AON)	3457
B (AON)	3708
A or B (UE)	6281
Sum A and B	**13446**
Constraint factor	0.7
Trips to UE model	**9412**

4.8.4 Assignment model step 4: user equilibrium assignment

For the longer trips (i.e. those between the two urban areas) an equilibrium function is used based on Davidson's travel time formula (Akcelik 2000):

$$t = t_o \times \left[\frac{1+(J_A \times x)}{(1-x)}\right] \qquad \textbf{\textit{Equation 15}}$$

where

t = average travel time per unit distance;

t_o = minimum (zero-flow) travel time per unit distance;

J_A = a delay parameter;

x = q/Q = degree of saturation;

q demand flow rate (in vehicles per hour); and

Q capacity (in vehicles per hour).

In User Equilibrium traffic assignment, all used routes between a given OD pair have the same travel time. This is based on Wardrop's first principle which states "under equilibrium conditions traffic arranges itself in congested networks in such a way that no individual trip maker can reduce his path costs by switching routes" (Ortuzar & Willumsen 2011, p. 367). A transformation of Davidson's formula is used to calculate the demand flow rate per road link as shown in Equation 16.

$$q_L = \frac{(c - c0_L) \times Q_L}{c - (1 - J_a) \times c0_L}$$ ***Equation 16***

where

q = flow (in vehicles per time period);

L = road link or segment identifier;

c = equilibrium cost of travel (as defined in ***Equation 14***);

$c0$ = minimum (zero-flow) cost of travel;

Q = capacity of a road link or segment (in vehicles per time period).

Using link capacity, speed and delay parameters from the Gabites Porter transport model building report and Akcelik (2000), Excel Solver was used to vary the equal cost (travel time) to minimise the difference between the total demand flow (t_{ij}) from the OD matrix and the sum of the flows on the available routes ($q_a + q_b + q_c$). This process and the results of the assignment are shown in Table 21. The relatively low number of trips assigned to the routes by user equilibrium is due to the simplified transport network.

Table 21: Assignment results (2006 base year)

	Assignment model inputs	Source or equation	Inputs			2006		
1	Value of time, VOT ($/hr)	EEM Table A4.1 composite urban arterial AM peak no CRV	15.13					
2	Trips, tij (morning period)	Lowry model output (capacity constrained)	9412					
3	Peak period length (hours)	Assumed	1.5					
4	Route identifier	Case study method	A	B	C			
5	Number of lanes, two way	Existing; ATS reports	2	2	2			
6	Capacity, Q (veh/h)	Gabites Porter 2010, Akcelik 2000	1700	1700	1900			
7	Level of service, Ja		0.86	0.54	0.54			
8	Free flow speed (km/h)	EEM Table A3-11	55	55	65			
9	Road class		II	II	I			
10	Length (km)	ArcGIS	5.9	5.1	4.9			
	Equilbrium assignment model - base year (2006)		**Do-minimum**			**Option**		
			A	B	C	A	B	C
11	Capacity, Q (veh/peak period)	*=3 * 5 * 6*	5100	5100	0	5100	5100	5700
12	= ABS(Tij-SUM(path flows))	Excel Solver target	0.000			0.000		
13	Equilibrium cost, c	Wardrops 1st, Solver varied	$1.88			$1.71		
14	Cost zero volume, c0 ($)	*= 10/8*1*	$1.62	$1.40	$0.00	$1.62	$1.40	$1.14
	Results - vehicles per peak period							
15	Total flow, qs (s=A,B,C)	*=(13-14s*11s)/(13-(1-7s)*14s+18s*	**4255**	**5157**	**0**	**3768**	**2898**	**2747**
16	User equilbrium (UE)	*= 15 - 18*	798	1449		310	1044	893
17	UE % of total	*= 16 / 15 * 100*	19%	28%		8%	36%	33%
18	All-or-nothing (AON)	Manual matrix	3457	3708		3457	1854	1854

5 Economic Evaluation

Note: It is not appropriate to compare the BCR estimates from this case study to the ATS Option B: Southern Arterial BCR because the transport network and modelling have been simplified and the do-minimum scenarios are likely to be substantially different.

5.1 Assumptions

5.1.1 Alternatives and costs

The options considered were the do minimum and new road (option B: Southern Link component of the Southern Arterial Link in the ATS). The option capital (\$31M) and annual maintenance cost (\$150K per annum) values were used from the ATS reports. The do-minimum has been assumed to be maintenance of the existing network only. For the do-minimum, no maintenance cost estimate was available. The ATS Option A (clearways on Rocks Road) had a \$300K annual maintenance cost without explanation. Therefore it was assumed that although there would be less network kilometres to maintain, the higher density of traffic on the existing network would result in a similar level of maintenance. This assumption effectively removes the annual maintenance cost from the evaluation. The ATS also included significant network operating costs (primarily public transport subsidies) in the denominator of the BCR calculation which have been excluded here.

5.1.2 Periods of day

A key input to the economic evaluation was the transport model outputs of morning peak period flows on each link (A, B in both alternatives and C in the option, as previously described). As noted in the discussion of the assignment model (section 4.8), the morning period was chosen as it was considered to be the period when congestion may be a factor in the user equilibrium assignment model and in the justification for building a new road.

The EEM full procedures can be based on various time periods (e.g. morning peak, full day, or other options). The EEM states that “if there are only very low levels of vehicle interaction throughout any day, no division of the day is necessary” (NZTA 2010, p.A2-5). Traffic count data was not reviewed, so the level of interaction (higher levels result in congestion) was not ascertained. Rather than divide the day into periods and assess each period, the evaluation was simplified by the use of one (full day) period.

The full day average daily traffic (ADT) can be estimated from the peak period traffic volume by applying a K-factor derived from full day traffic surveys (Dykstra et al. 2011). No Nelson-specific full day surveys or K-factors were available, so a K-factor of 10 was assumed (i.e. there are 10 times as many trips in a typical 24 hour period as during the morning peak hour). The 90 minute transport model output was divided by 1.5 to obtain an hourly peak flow, and then multiplied by 10 to obtain the ADT.

5.2 Feasibility report – preliminary evaluation method

As a first step, the economic evaluation was undertaken using EEM feasibility report – preliminary procedures. These procedures are a one page, simple analysis which “assumes that activity costs are incurred in time zero...The maintenance cost savings occur in years 2 to 30, and benefits occur in years 2 to 32. Growth rates are assumed to be two percent per annum across the board” (NZTA 2010, p.14-2). However, the growth rate does not appear to be included and cannot be varied. Therefore the analysis uses the base traffic volume for the entire analysis period, and the only way to include risk analysis of the uncertainty in socio-economic inputs is to consider the transport model traffic forecast output variability.

A number of impacts are excluded by the preliminary method including externalities such as noise, severance, and emissions. The focus was on the uncertain variables with the largest impact on the BCR as described in the literature review. Accordingly, accident cost savings and roughness cost benefits (which are a very small proportion of the total vehicle operating cost benefit in cents per kilometre) were excluded.

The preliminary evaluation does not allow separate road segments to be individually assessed within the worksheet. As the alternatives are comprised of several component road segments of varying lengths and characteristics, a single vehicle operating cost (VOC) unit value was developed using a flow dependent average calculation. These values were used in the short (1 page) spreadsheet, a screenshot of which is shown in Figure 24.

The first BCR calculation resulted in a BCR of 5.6 and an unreasonably high (in comparison to other benefits) undiscounted comfort sealing benefit (CB) of over $12M. Therefore this function was disabled in the worksheet.

The evaluation was completed and a point estimate of 0.8 for the BCR resulted. Variables selected for risk analysis were vehicle operating cost savings, travel time unit cost, construction cost and maintenance cost. The results of the @RISK simulation showed that variability in the EEM default base vehicle operating cost (VOC) unit values had a dominant influence on the BCR, when a 10% standard deviation and normal distribution was applied to these inputs. Although this range of variability is supported by the literature review, the small difference between the do minimum and option VOC unit values means that the result was logical. However the literature review shows that variability in travel time savings are usually the dominant influence on the BCR.

1	Evaluator	John Lieswyn
	Reviewer	Alan Nicholson
	AO	n/a - research study only
	Activity/package	n/a
	Your reference	ENTR 680
	Activity description	Uncertainty analysis using monte carlo simulation on BCR of a theoretical new road
	Describe problem to be addressed	Predicted employment and population growth leading to congestion on strategic network
	Brief description of location	Existing SH6 Rocks Rd and Waimea Rd between Nelson and Richmond
	Describe the do-minimum	Do nothing
	Summarise the options assessed	Build new third highway (Option B of the Nelson ATS)

2	Time zero (assumed construction start date)	1 July	
	Expected duration of construction (months)		
	Date economic evaluation completed (mm/yyyy)		10/2011
	Base date for costs and benefits	1 July	

Road type (tick one)	Urban arterial	Y	Urban other		Rural strategic		Rural other	
TTC from table 1	16.27	$/h			Posted speed limit		km/h	
AADT at time zero	46796	veh/day						

Variable	Do-min (M)		Option (P)		
PV cost	A		B	31,000,000	
Length	LM	5.5	LP	5.3	km
Average vehicle speed (VS)	VSM	70	VSP	72.6	km/h
Base cost (CB) - from table 2	CBM	32.20	CBP	32.6	c/km
Average roughness (IRI or NAASRA counts)					
Roughness cost (CR) - from table 3	CRM		CRP		c/km
Annual maintenance costs (MC)	MCM	100,000	MCP	150,000	$/yr

3	Calculations				
	VOC savings - ((LM*(CBM+CRM))-(LP*(CBP+CRP)))*AADT*3.6	3.6	=$	694,399	C
	Travel time savings = (LM/VSM-LP/VSP)*AADT*TTC*365		=$	1,539,919	D
	Comfort benefits from sealing = LM * 0.10 * AADT * 365	0.00	=$	-	E
	PV accident cost savings		=$		F
	Maintenance cost savings = (MCM-MCP)*10.7	10.7	=$ -	535,000	G
4	Benefits = (C+D+E)*11.4 + F	11.4	=	25,471,230	Y
	Costs = B - A - G		=	31,535,000	Z
	Provisional BCR = Y / Z		=	0.8	

Figure 24: Screenshot of preliminary method economic evaluation spreadsheet

Overall, the preliminary evaluation procedure is probably not the method that would be undertaken in conjunction with probabilistic risk analysis, at least while risk analysis techniques remain nascent in the profession. Because of the limitations of the preliminary method, the EEM's full procedures were undertaken.

5.3 Full procedures

This section describes the EEM full procedures and the principal assumptions used in developing the case study.

5.3.1 Key assumptions

The key assumptions made to develop this case study economic evaluation are listed as follows.

- In the absence of high congestion levels, induced traffic impacts on the travel demand model and traffic congestion benefits were not considered. Improved trip reliability benefits were not included.
- Construction was assumed to take one calendar year, beginning in 2012.
- Severance, air pollution and accessibility have not been considered.
- Benefits accrue for 245 (working) days per year as per the EEM method; however holiday and weekend benefits (or dis-benefits, in the case of some schemes targeting peak period issues such as traffic signals) would be omitted by this assumption.
- As in the preliminary feasibility evaluation procedure, benefits are assumed to accrue equally for all time periods (i.e. the full day was used rather than assessing peak periods separately from inter-peak and off-peak periods). As noted by Tai (1987) this can result in a substantial overestimation of benefits where peak period travel time savings benefits are assumed to apply to other periods. In this case study, the transport model simplifications and assumptions resulted in low levels of congestion even during the morning peak period, so travel time savings did not end up having as much of an influence on the BCR as might occur in a more heavily congested network.
- For travel time savings, trips were not disaggregated by trip purpose. Bottleneck, intersection delay, and speed changes were not included.
- Default and combined values were used in the absence of project and network specific data, including the default traffic compositions (e.g. light cars and trucks were aggregated).

- Accident cost benefits were included to test the variability in casualty crash unit rates, however the calculations were simplified by the use of the 70 km/h speed limit area for all road links.

5.3.2 Using the EEM full procedures

As with the preliminary evaluation, calculations were undertaken in a spreadsheet to integrate with the @RISK software. There are no full procedures spreadsheets available from the NZ Transport Agency, so this process identified a number of inconsistencies and errors in the EEM. Given the size of the manual (nearly 700 pages in volume 1 alone) this is not unexpected. Undertaking the full procedures also contributed to improving the project literature review, as some of the previously identified uncertainties have been acknowledged by the EEM with specific guidance.

5.3.3 Deterministic point estimate results

The full procedures evaluation summary results for the BCA are shown in Table 22. This indicates a point estimate BCR of 0.8 for the assessed option. A project is considered economically efficient if it has a BCR exceeding 1.0, and would require a BCR over 2.0 to achieve a "medium" efficiency score in the Planning, Programming and Funding Manual (NZTA 2009).

Table 22: Full procedures BCR summary – deterministic approach

Worksheet 3 - Benefit cost analysis				
	Benefits	PV of benefits as calculated		PV of net benefits (PV option - PV do min benefits)
		Do-min	Option A	Option A
1	TTC	24837945	23383589	1,454,356
2	VOC savings	370211591	352305209	17,906,382
3	Accident cost savings	8480307	8030543	449,764
4	Vehicle emission reduction	370212	352305	17,906
7	PV total net benefits			19,828,408
	Costs	PV of costs as calculated		PV of net costs (PV option - PV do min costs)
11	Construction/implementation		26577503	26,577,503
12	Maintenance	1393452	1393452	-
18	PV total net costs	1,393,452		26,577,503
19	BCR = (7) / (18)			**0.75**

5.4 Probabilistic risk analysis

5.4.1 Choosing the number of iterations and simulations

According to Palisade (2010a, p. 30), the "selection of values from probability distributions is called sampling and each calculation of the worksheet is called an iteration." Higher numbers of iterations require more computing power. Increasing the number of iterations will produce a wider range of output values (in this case, BCRs).

If some of the model parameters are under the analyst's control, then the value of that parameter can be set as an argument for a simulation (Palisade 2010). An example might be in the case where transport investment options have similar outcomes but different costs. A simulation using the appropriate cost can be run for each option, while holding all other uncertain variable parameters (e.g. distributions) constant. The selected number of iterations is run for each simulation, and the results of each can be compared against simulations using different assumptions. The default number of simulations is one. For this case study, ten thousand iterations and one simulation were run on a PC with a dual core 2.0GHz processor and Windows XP.

5.4.2 Presentation of results

Risk analysis allows the analyst to answer multivariate "what-if" questions and compare correlations between inputs and between inputs and outputs. The following pages present a range of potential scenarios as well as the BCR probability density function (p.d.f.), cumulative distribution function (c.d.f.), correlations between the input variables and the BCR, and sensitivity analysis graphs.

A correlation tornado graph illustrates inputs that have the largest impact on the distribution of the output; the longer the bar, the greater the impact. The @RISK user manual explains how to read the two types of correlation tornado graph presented on the following pages:

- ***regression coefficients****: a regression value of 0 indicates that there is no significant relationship between the input and the output, while a regression value of 1 or -1 indicates a strong relationship between the input and the output.*
- ***mapped values****: the length of the bar, shown for each input distribution, is the amount of change in the output due to a +1 standard deviation change in the input.*

> *Thus, when the input changes by +1 standard deviation, the output will change by the X-axis value associated with the length of the bar.* (Palisade 2010)

5.4.3 Transport model uncertainty

5.4.3.1 Variables

As noted previously, the principal input of the Lowry model is basic sector employment per zone. Population per zone, service employment per zone, and trips between zones are the outputs. The average annual (arithmetic) traffic growth rate can be derived by comparing the forecast trips with the base year trips. This growth rate is a key economic evaluation input, as most benefits in the numerator of the BCR are products of traffic volumes. Three uncertain variables which are factors in the vehicle trip forecast are explained below.

5.4.3.2 Basic employment forecast growth rate

Section 4.7 of this report presents the key population, basic jobs, and Lowry model traffic forecasts for 2006 and 2036. Region-wide, the basic employment forecast is for 9935 (in the year 2036) versus 5865 (in the year 2006 census) basic sector jobs, with the new jobs principally located around Richmond (zone 1) and the airport (zone 11).

Region-wide basic employment average annual growth rate (estimated by the ATS as 2.31% average annual growth over 30 years). Dewar and Wachs (2008) found an employment forecast mean overestimation of 12.8% with a standard deviation of 7%. A 1.69% growth rate produces a basic jobs forecast 12.8% below the ATS basic employment forecast. A normal distribution has been used to model this uncertainty in the absence of data for distribution fitting.

5.4.3.3 Basic employment spatial distribution

The second uncertainty is the spatial distribution of this growth. The ATS forecast is for 96% of the growth in basic jobs to occur in zones 1 to 6. These zones are south of the Annesbrook roundabout in the Richmond and Stoke areas.

The counterpoint to this growth assumption might be that the majority of basic employment growth occurs in the Nelson zones (7 to 16), primarily the central city (zone 14) and port (zone 15). The proportion of basic employment growth in zones 1 to 6 was counter-balanced in the Lowry model by using the remainder (i.e. one minus the variable proportion) to represent the growth in zones 7 to 16. A sensitivity test using the two extreme scenarios is shown in Table 23.

Table 23: Sensitivity test of change in basic employment spatial distribution

Basic employment growth assumption	2036 Population		2036 Basic Jobs		2036 AM peak period trips	
	Total	Proportion zones 1-6	Total	Proportion zones 1-6	Tij (A,B,C)	Tidal flow % southbound
96% in zones 1-6	86095	69%	9935	74%	22458	73%
96% in zones 7-16		59%			23099	63%

The morning peak period tidal flow proportions for 2006 (given in Table 19 as a nearly balanced 47% southbound) is somewhat counter-intuitive given the observed substantially heavier northbound morning peak period traffic flows. This difference is due to the transport model simplifications and calibration to population and jobs data but not to traffic count data (refer section 4.6). For the 2036 forecast year, the slight northbound bias changes to a heavy southbound bias (73% as given in Table 19 and Table 23). This is consistent with nearly three-quarters (74%) of the basic employment forecast to be located in Richmond zones 1-6 instead of the roughly half (59%) as reported in the 2006 census.

As this sensitivity test shows that even a large change in the spatial distribution variable has a minimal effect on the trips and tidal flow, it is not likely to have a statistically significant influence on the traffic forecast or the BCR. If the Lowry model had included the area of land constraint equations (refer section 4.5), the results of the sensitivity test may well have been different.

However, this variable has been included in a transport model risk analysis using a beta distribution skewed towards the expected value of 96%.

5.4.3.4 Motor vehicle mode share of all trips

The motor vehicle mode share of all home-based work trips has been set at 59%, based on 1.2 persons per vehicle occupancy and a 71% car mode share as used in the ATS modelling. A normal distribution around the 59% mode share with a 10% standard deviation has been chosen in the absence of data for distribution fitting.

This standard deviation may be regarded as somewhat radical; however the 30 year time period under consideration may be characterised by substantial transport system changes as noted by Krumdieck and others in the literature review.

As the motor vehicle mode share is a multiplier in the Lowry model OD matrix, it will be highly correlated to the trips forecast and therefore the traffic growth rate. @RISK has a correlation specification facility where such correlations can be defined for more complex models, but this has not been used for this case study. Any future extensions of this work should attempt to define all correlations to improve the usefulness of the risk analysis outputs.

5.4.3.5 *Transport model risk analysis results*

The simulation required 29 seconds to run. The tornado graph shown in Figure 25 presents the key influences on the traffic growth rate.

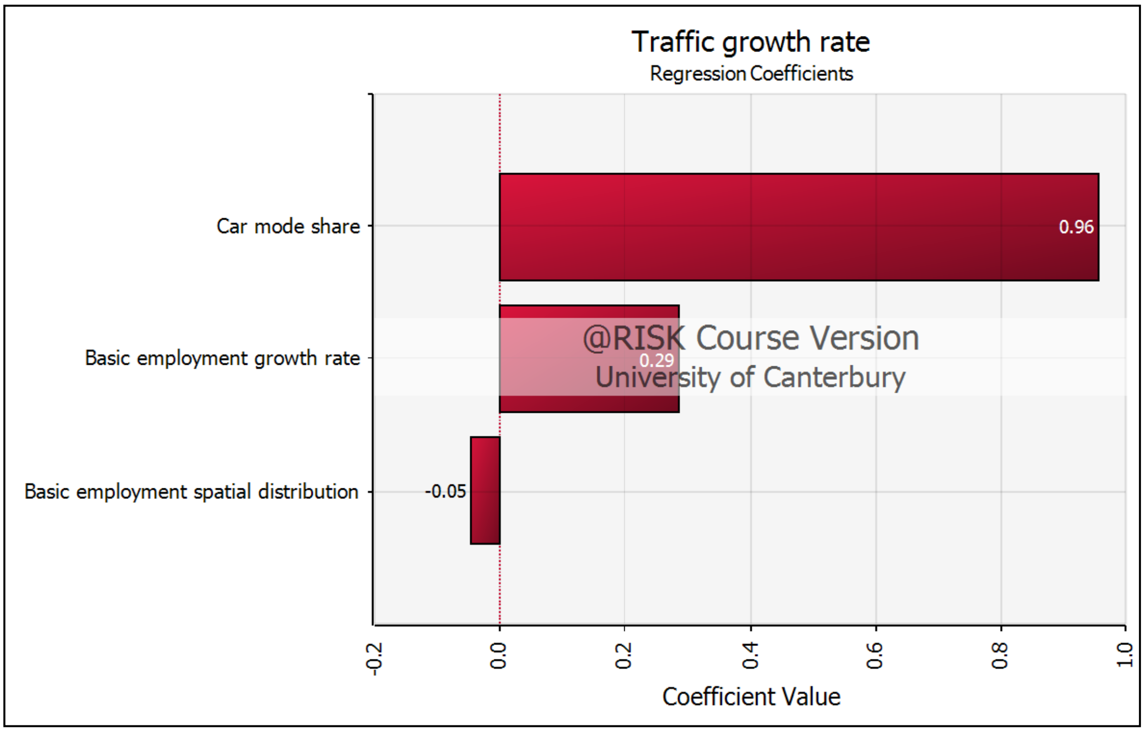


Figure 25: Traffic growth rate regression coefficients

This graph indicates that the car mode share is nearly perfectly correlated with traffic growth rate, as may be expected from an input which is a multiplication factor in the output OD trip matrix. The basic employment growth rate is also influential. As expected from the sensitivity test (Table 23), the spatial distribution of the basic employment is not influential for the limited case study as developed for this project.

The transport model risk analysis undertaken was fairly simplistic. Future work could include assignment model uncertainties such as travel cost variables or outputs such as volumes on particular links.

5.4.4 *Economic evaluation uncertainty*

5.4.4.1 Variables

Following on from the literature review findings (Table 11), a number of economic evaluation uncertain variables were also considered alongside the basic employment growth rate and car mode share variables from the transport model analysis.

For all economic evaluation benefit variables, the unit values were selected instead of the total values which comprise the final BCR calculation. This is because the total values are derived from the unit values multiplied by the traffic volumes. The variables chosen are as follows.

- Travel time savings unit value – the value of time unit was varied using a normal distribution with a 20% equal variance.

- Vehicle operating cost (VOC) savings unit value – the vehicle operating cost (cents/kilometre) was included using a normal distribution with a 27% equal variance as roughly indicated by Berthelot et al. (1996).

- Accident cost savings unit value – the static expected value used (from the EEM) is the aggregated cost of a casualty crash on a 'urban-other' road classification. There is a recognised high uncertainty in benefits arising from rare events, but relatively strong support for the existing value of statistical life. As discussed in the literature review, any change will likely be a substantial rather than incremental change to a higher value. Therefore, a uniform distribution with a minimum value equal to the existing value has been chosen. As accident cost savings are a relatively small part of the case study benefits, variability in the crash cost unit price is not expected to have statistically significant influence on the BCR.

- Vehicle emissions savings unit value – Emissions reduction benefits are a relatively small component of the deterministically derived evaluation results, perhaps due to the monetisation methodology and the free-flow characteristics of the alternatives. Therefore, CO_2 unit price was not considered in the risk analysis.

- Construction cost – an Erlang distribution has been chosen with default scale and no shift parameters, in consideration of the relatively large contingencies already included. Further scenario testing could be undertaken in subsequent work to test a wider variation in the cost estimates and inclusion of the network operating costs that the ATS identified.

- Maintenance cost – a triangular distribution has been chosen based on the work of Salling and Leleur (2011). The influence of this cost is not likely to be strong because of a low relative magnitude and equal values for the do minimum and option alternatives.

These variables and their distributions are summarised Table 24. Where different from the mean value (such as in a skewed distribution), the static expected value is presented in parentheses next to the mean value.

Table 24: Risk analysis variables chosen

Variables	Distribution	Mean	Std dev or limits	Source
Basic employment growth rate	Normal	1.69% (2.31%)	.31%	Dewar & Wachs
Car mode share	Normal	59%	5.9%	
Vehicle operating costs (VOC)	Normal	$0.268	0.04	Berthelot
Value of time (VoT) for TTS	Lognormal	$16.27	$4.06	EEM
Safety unit price	Uniform	$401K ($365K)	$21K	Salling
Maintenance costs	Triangular	$150K	$135K min $225K max	Salling
Construction costs	Erlang	$37M ($31M)	$4.4M	Salling

5.4.4.2 BCR risk analysis results

The BCR risk analysis required 31 seconds to run. The tornado graph presented in Figure 26 indicates that the largest influence on the BCR is the capital cost. The relatively large influence of the vehicle operating cost (VOC) base unit value is in part due to the 27% variance suggested in the literature (Berthelot et al. 1996). As previously noted, the car mode share and the basic employment growth rate are key influences on the traffic forecast but have a lesser influence on BCR than capital cost.

As noted previously, the transport model simplifications and assumptions made for this case study resulted in low levels of congestion even during the morning peak period, so travel time savings (as driven by the value of time unit cost) did not end up having as much of an influence on the BCR as might occur in a more heavily congested network.

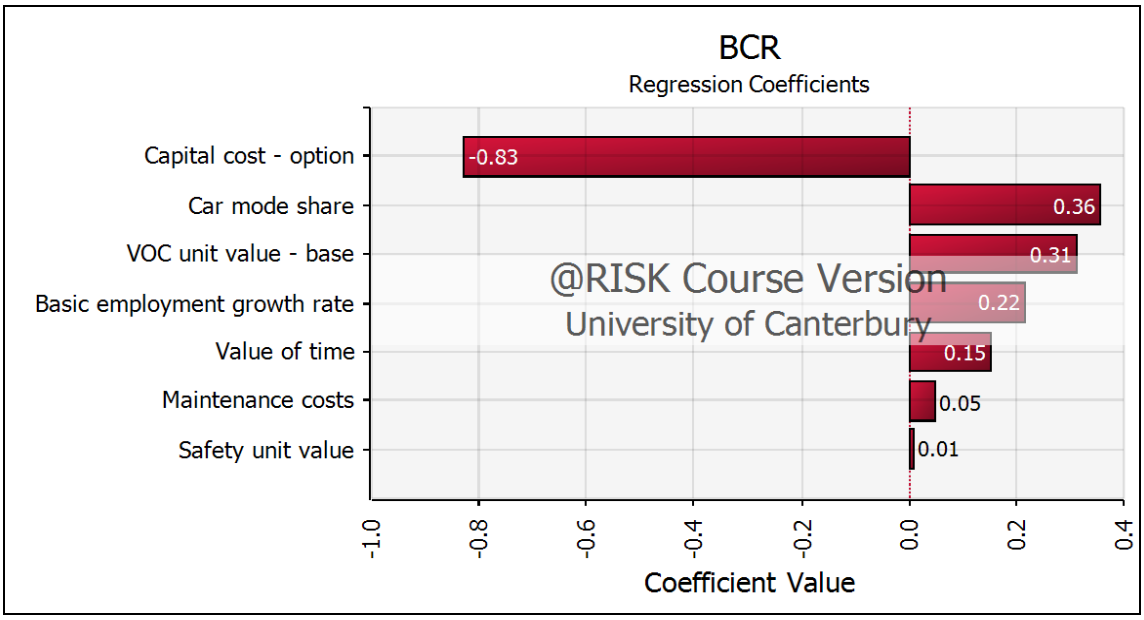


Figure 26: BCR regression coefficients

A tornado graph showing regression mapped values (Figure 27) indicates that for a one standard deviation change in capital cost, the BCR can be expected to change by slightly more than 0.06.

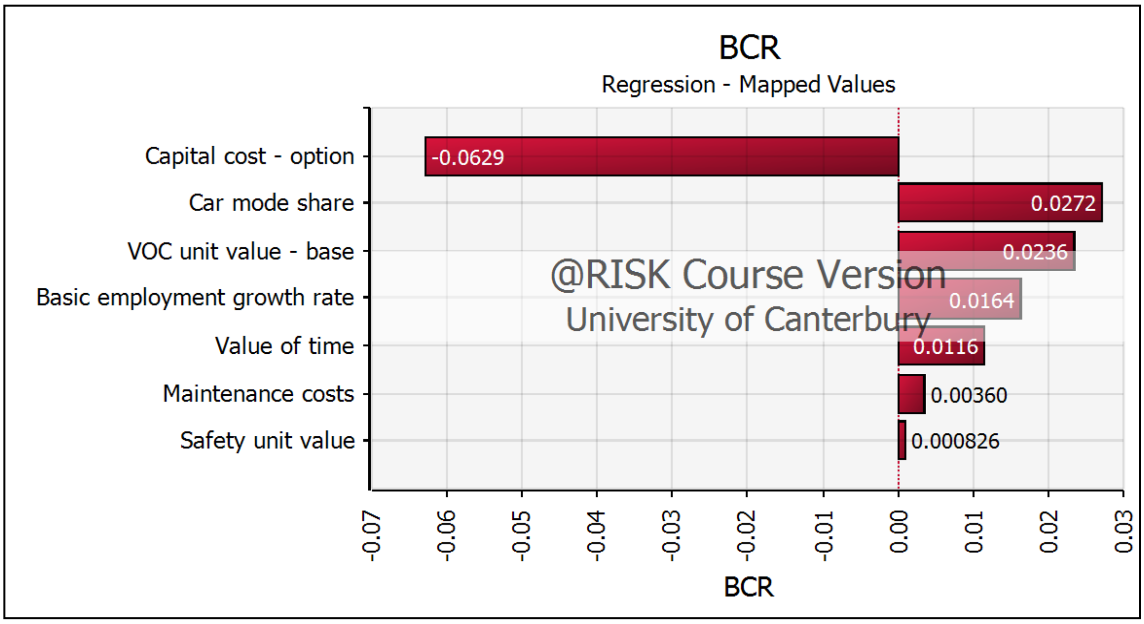


Figure 27: BCR regression mapped values

The capital cost c.d.f. (Figure 28) indicates a 90% probability that the project would come in between $32M and $46M, with a mean of $37M and standard deviation of $4.4M. An Austroads P90 estimate would be 42M, and P50 estimate would be $36M.

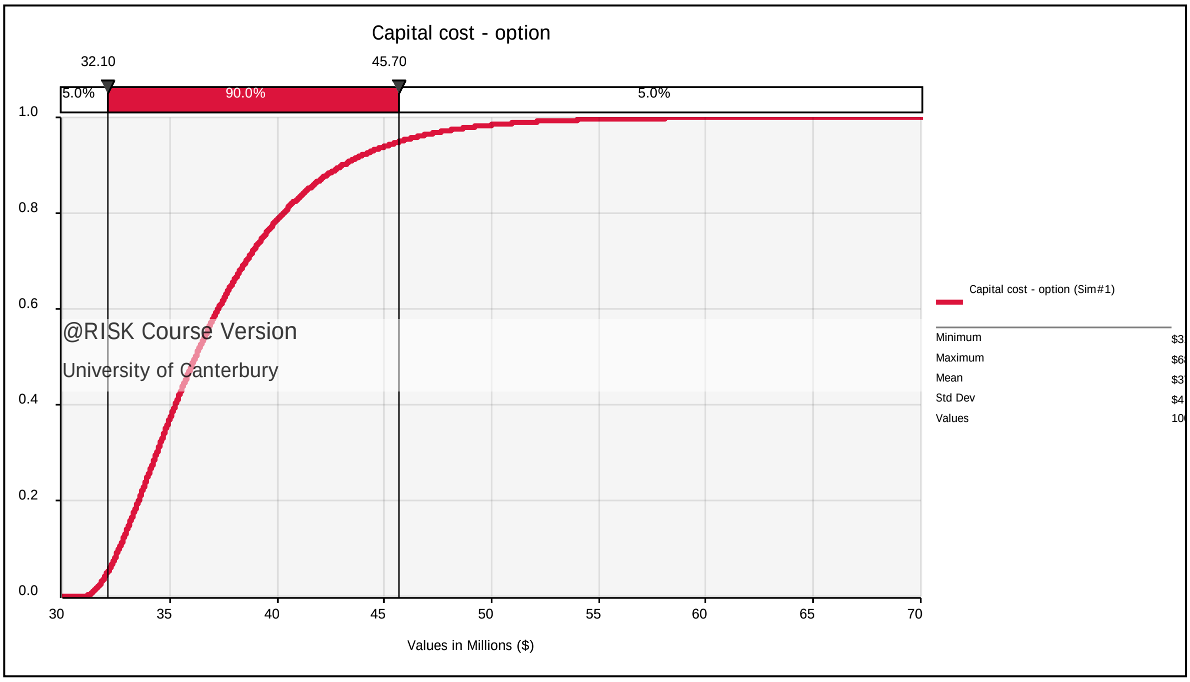


Figure 28: Capital cost c.d.f.

This probability is based on reasonably robust empirical research into the appropriate distribution and associated statistical parameters. Stronger support for the probabilities could be derived from distribution fitting to similar projects rather than an aggregation of projects.

Although the deterministically derived point estimate BCR is 0.75, a c.d.f. graphic from the risk analysis (Figure 29) shows that:

- There is a 50% probability of a BCR below 0.6
- There is a 90% probability of a BCR between 0.47 and 0.72
- The minimum and maximum estimated BCRs are 0.31 and 0.87, respectively

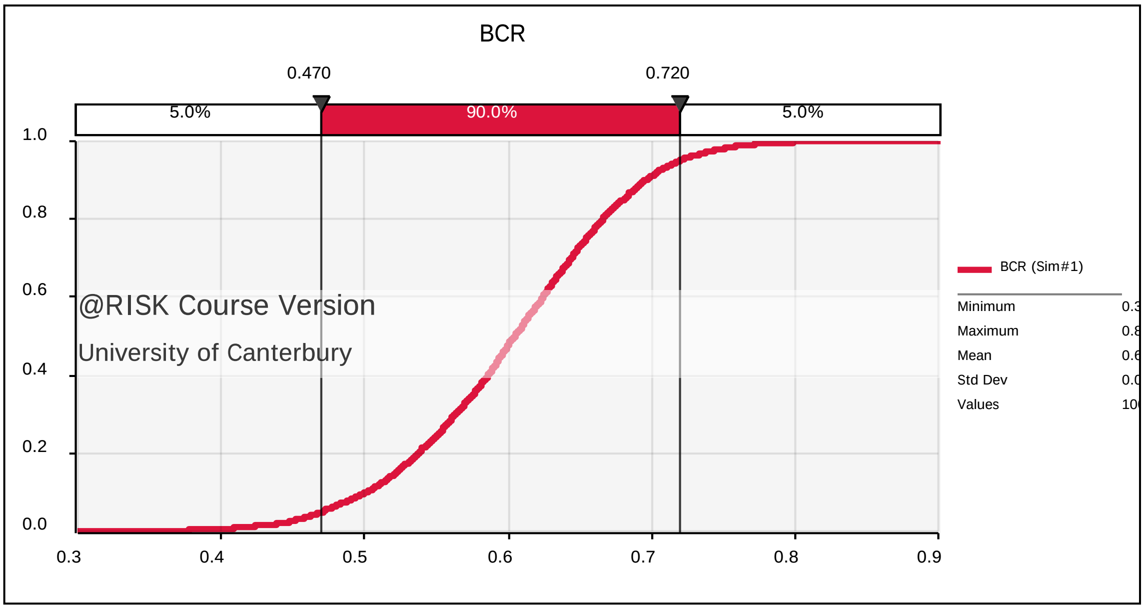


Figure 29: BCR cumulative distribution function

It should be reiterated that these probabilities are based on a risk analysis which includes some statistical parameters with little or no empirical basis.

5.4.4.3 Advanced analyses

Other analyses are possible, such as “Goal Seek” which enables the analyst to set a target value and identify the risks and inputs which must be overcome to “get a project over the line”. This could be useful to identify where reducing the uncertainty in input variables would yield an increased BCR. It should not be used to unethically manipulate the BCA procedures (sometimes euphemistically called “optimism bias” as briefly noted in section 2.2.5.8).

An “advanced sensitivity analysis” was undertaken and these outputs are provided on the following page. The sensitivity tornado (Figure 30) shows the minimum and maximum values that the specified spreadsheet cell (containing the BCR output) acquires as the values of these inputs vary during simulation (Palisade 2010).

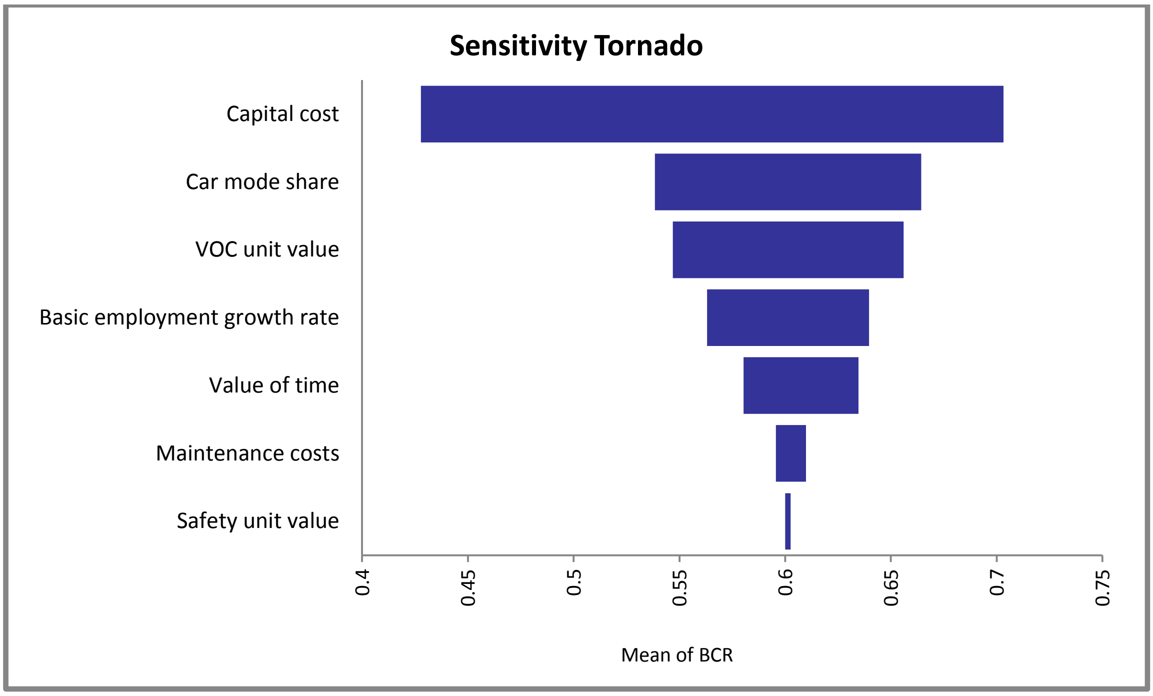


Figure 30: Sensitivity analysis tornado graph

The sensitivity percent change graph (Figure 31) illustrates at a glance via line slope which factors are most influential on the BCR. The legend series names were edited for other graphs to remove spreadsheet cell references but this graphic was not editable.

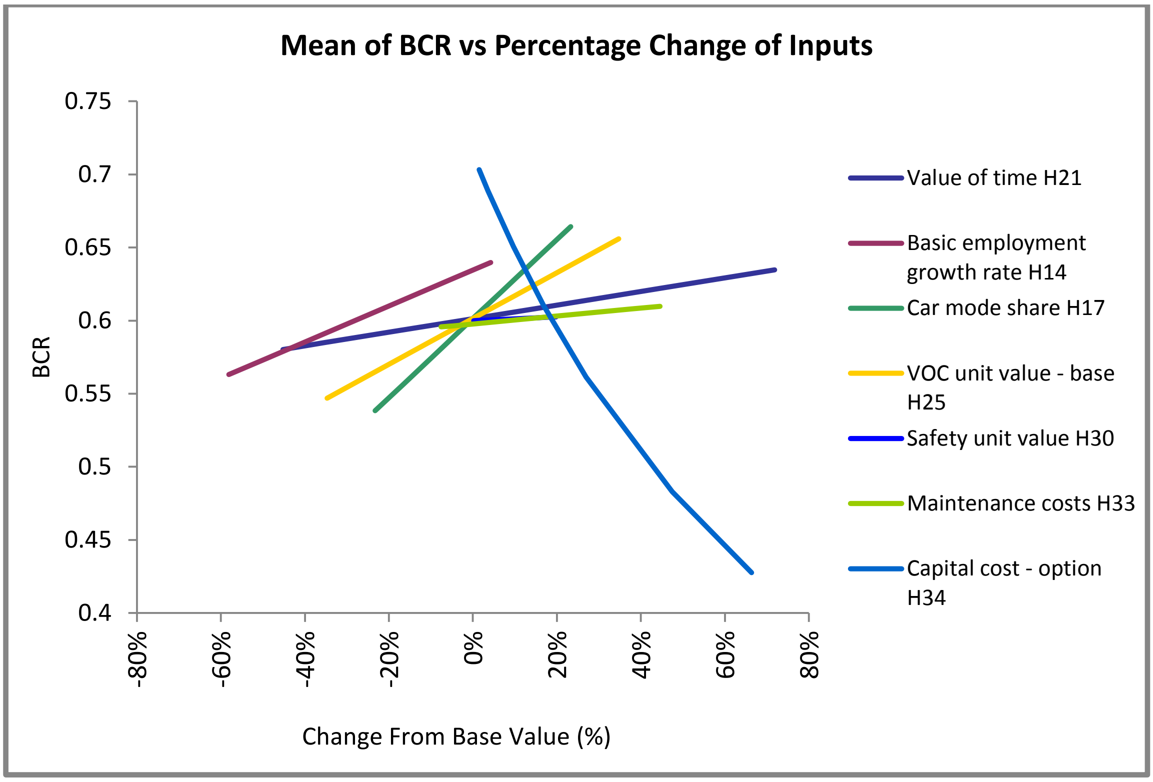


Figure 31: Sensitivity analysis percent change graph

6 Conclusions

6.1 Literature review

The literature indicates that input value uncertainty propagates through transport model stages, forecast years, and economic evaluation. Uncertainty is typically treated deterministically by univariate sensitivity analysis.

The literature shows that the inputs with the most impact on traffic volume forecasts are socio-economic variables (e.g. population and employment forecasts) and trip generation rates.

The traffic volume forecasts are then multiplied by monetary unit values for travel time, accident cost, and vehicle operating cost (amongst others). Reductions in the costs for each of these impacts are summed as benefits and used in the numerator of the benefit – cost ratio (BCR). Of these impacts, travel time savings can account for roughly 80% of the benefits of major arterial road schemes.

The literature emphasises the need for the uncertainty in these procedures to be recognised and quantified. Increased computing power and probabilistic risk analysis tools, such as Palisade's @RISK and the Austroads Risk Explorer Excel templates, are available to undertake Monte Carlo simulation. Use of these risk analysis techniques can provide decision makers with a probability distribution of outputs rather than a precise (but uncertain) point estimate, along with identification of the critical inputs which contribute the most to the evaluation uncertainty.

6.2 Uncertainty in the Nelson ATS

The Nelson Arterial Traffic Study (ATS) included transport modelling which found traffic forecasts significantly lower than earlier modelling, largely due to lower socio-economic growth forecasts. The ATS included economic evaluation as component decision support tools within a wider multi-criteria analysis (MCA) framework. The BCR for the Southern Arterial (option B) was found to be 65% lower than the BCR resulting from earlier studies, again largely due to the traffic forecasts being lower.

The uncertainties in many inputs and assumptions were recognised by the ATS project team and highlighted in various project stage reports. Within the transport model, uncertainty with respect to fuel price was addressed through sensitivity testing of the traffic forecasts to two scenarios – a 50% increase in fuel price by 2036 and a 100% increase in fuel price by 2036. The ATS transport model predicts that the impact of a 100% increase in fuel prices is that rather than VKT increasing by 26% from 2006 to 2036, VKT increases by only 4%. This estimate does not appear to have been used in further analysis, but the uncertainty is reiterated in general terms in the final ATS report (Stage 4).

The potential that sea level rise caused by a warming climate might have a critical impact on those options which depend relatively more heavily on the coastal Rocks Road was identified as a key concern by the ATS reports. A critical impact could result in a substantial change in the MCA option scoring and the possible advancement of Southern Arterial planning. With climate science generally working with the probabilities of outcomes, a risk analysis considering the probability of route closure due to tides and storm surges could be useful for future planning.

The ATS project team also undertook scenario analysis of various criteria weights within the MCA, which showed that the preferred option was ranked first regardless of the chosen scenarios. Other uncertainties were considered to be areas for further investigation, monitoring, or mitigation through the ATS study recommendation that no option was needed within the 25 year time frame because traffic conditions were not expected to require capacity expansion before then. As the economic evaluation was not the only factor in the decision model, risk analysis might not have been a critical factor in the final recommendations. However, future planning or evaluations may benefit from risk analysis.

6.3 Application of risk analysis

As part of a case study application of risk analysis, this research project developed a transport model and a feasibility level economic evaluation based on a highly simplified version of a real-world case study, the Nelson Arterial Traffic Study (ATS). This project used an urban transportation planning model based on two components, rather than the typical four stage model. The first component was an integrated trip generation and distribution sub-model based on the Lowry economic base theory formulation and two types of employment; base and service. The traffic analysis zones were based on agglomerations of the Statistics NZ meshblock boundaries relevant to the principal highways identified in the simplified transport network. Mode split and vehicle occupancy ratios were adopted from the Nelson ATS. The resultant trip matrix was manually factored down by 30% to represent the excluded local road network. This simplification was due to the modelling approach taken; in practice this kind of transport planning assumption would have effects in terms of local area traffic management.

A separate traffic assignment model was developed based on a user equilibrium method derived from a time dependent Davidson model and subsequent refinements by Akcelik. The model used link capacities and delay functions specified in the ATS transport model building report. The 90 minute morning peak period was used exclusively for the purposes of this study. The resulting traffic flows per road link were then factored up by 10 to represent an AADT and this product entered into the economic evaluation.

An initial attempt to use a preliminary evaluation method was limited by numerous exclusions. Only the Lowry base year traffic volumes were developed at this point, given that the preliminary evaluation method documentation indicated a fixed 2% arithmetic annual growth rate was assumed. However, this growth rate was not actually part of the method. As the evaluation was completed, a risk analysis using the Palisade @RISK software package was undertaken. This showed that the deterministic point estimate BCR (0.76) is highly uncertain, with a standard deviation of 1.96. Probabilistic risk analysis techniques are not likely to be employed with preliminary evaluations in the near term as these techniques remain nascent in the profession.

The limitations of the preliminary method prompted an evaluation using the EEM full procedures. The deterministic point estimate BCR was very similar at 0.75, even though many more benefit streams were included. The inputs analysed were capital cost, maintenance cost, benefit unit values, basic employment growth rate, and car mode share. For the relevant inputs, both do minimum and option project values were used.

The purpose of the risk analysis was to determine the influence of uncertain inputs on the evaluation output BCR. One of the measures used was the regression correlation coefficient, where a value of 0 indicates that there is no significant relationship between the input and the output, and a value of 1 or -1 indicates a strong relationship between the input and the output.

For this case study, the largest influence on the BCR (as measured by the regression correlation coefficient) was determined to be the capital cost (-0.83). Car mode share (0.36), vehicle operating cost unit value (0.31) and basic employment growth rate (0.22) were also important.

The literature suggests that travel time savings often have the largest influence on the BCR. In this case study, the value of time unit cost (which drives the total travel time savings) was only ranked fifth in order of influence on the BCR with a coefficient of 0.15. This may be because the transport model simplifications and assumptions resulted in low levels of congestion even during the morning peak period. Travel time savings would likely have a greater influence on the BCR for projects applying to more heavily congested transport networks.

The risk analysis indicated that there is a 50% chance that the BCR will be less than 0.6 (Figure 29). It should be noted that this probability is partly based on some statistical parameters without an empirical basis. In practice, probability distribution fitting to appropriate datasets should be undertaken to better support probabilistic risk analysis conclusions.

Risk analysis shows that the transport model and economic evaluation case study include highly correlated inputs as a result of the simplifications made in the network and the similarity between the benefits accruing to each alternative. It was determined that the risk analysis approach is feasible and can produce useful outputs, given a clear understanding of the data inputs and their associated distributions. The @RISK software has a simple user interface providing access to many sensitivity analysis tools, only a few of which were interrogated for this feasibility study.

6.4 Limitations and areas for further research

As described in section 4.2, the model employed is a static model. The principal limitation is the lack of a feedback loop between flow dependent travel cost and the location of residence and employment locations, resulting in a static trip distribution matrix. In other words, the Lowry model uses a single set of travel cost inputs with all iterations focused on convergence of the number of residents and jobs per zone. This is not to say that the Lowry model cannot be further developed; in fact the underlying economic base theory is still used in some current commercial models. As developed in Excel for this project, a partly dynamic upgrade is potentially feasible with forecasts generated at set future time intervals and iteratively developed trip matrices. However, more advanced transport models as used today will not have this limitation and the research focus is on the application of risk analysis techniques, regardless of the model form chosen. This project has not investigated @RISK integration with proprietary modelling software; however most models have the ability to import and export Excel files. Computation time may be a limitation.

The area of land constraint has not been applied in this case study, although the ATS indicates that land availability is an important location choice factor for the Tasman region. The inclusion of land constraints would influence the modelled trip forecasts and tidal flows, with potential implications for congestion during peak periods.

Another approach to more accurately define a probability distribution for the traffic forecast variable in economic evaluation could be to retrospectively analyse the economic and/or behavioural assumptions used in the modelling (Short & Kopp 2005). This could be undertaken together with a post-opening project evaluation and expanded traffic counting on the completed project and nearby links such as the A34 Newbury Bypass ‘Five Years After’ Evaluation (Atkins 2006). The *Guide to Project Evaluation Part 7: Post-completion Evaluation* (Austroads 2005b) could be used to inform such work. Results may help to improve the knowledge of traffic forecast variability to inform risk analyses.

The correlation of input variables with each other and with the BCR could be better established if the risk analysis method was applied to real networks using commercial modelling packages. The results of the risk analysis are based on a simple single example rather than a meta-analysis of transport projects. Therefore, the correlations found should not be considered to be conclusively supporting or adding to the findings of the literature.

6.5 Implications

Dewar and Wachs (2008, p. 4) contend that "incorporation of uncertainty into travel demand analysis will demand entirely new approaches to the analytical representation of travel".

As a large part of the economic benefits tend to derive from travel time savings which are "illusory because of feedback to the transport system from outside transport" (i.e. travel time savings may be overwhelmed by land use change), it has been suggested that the transport models alone will not accurately inform economic evaluation in the near future and that "models are to be used, not believed" (Wenban-Smith & van Vuren 2009, p. 15).

Improvements to modelling practice (e.g. using variable matrices) and presentation of probabilistic estimates for forecasts and BCRs should assist planners and decision makers to make better investment decisions. The public are often presented with survey and poll results including a 'margin of error'; such measures of statistical reliability should be straightforward to understand. In New Zealand, the application of risk analysis is already required by the NZ Transport Agency for projects over $4.5 million. However the procedures for application are not a 'cook-book'. The incentive for acquiring risk analysis skills and developing industry training may not eventuate until the requirement threshold is lowered and / or the software costs are reduced.

In addition to addressing uncertainty in the economic evaluation itself, the transport models which generate a substantial proportion of the economic benefits (in terms of travel time and vehicle operating cost savings) could also be improved. For example, the use of assignment algorithms which are activity based would help reflect the changing nature of transport patterns as well as identify the potential dis-benefits of projects at off-peak times.

This research has revealed that risk analysis techniques are available and appropriate to apply to transport project economic evaluation. However, these techniques and the step-by-step evaluation procedures set out in various guides are not the key to providing the best advice to decision makers. Perhaps the Canadian Treasury Board (1998, p. 8) in introducing benefit-cost analysis models, states this caveat most clearly:

> *It is important to keep in mind that techniques are only tools. They are not the essence. The essence is the clarity of the analyst's understanding of the options.*

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Appendix 1: Model Calibration

The following screenshot from the project model spreadsheet shows the root mean square error (RMSE) values comparing the modelled and observed employment and population. Please refer to section 4.6 for a full description.

Calibration																	
Modelled			Census		Rodrigue												
1.94	pop / employees	f	2.01		2.08												
0.41	non basic / pop	a^k	0.38		0.19												
2.4%	Lowry convergence after 10 iterations																
11	number zones unvaried																
		Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Non-basic (service) employment																
21,018	*Modelled*	913	2088	1248	1216	1687	1324	748	875	1152	476	634	560	898	6597	384	218
19,802	*Observed* census 2006	847	2288	970	1492	1835	753	585	282	1267	397	326	141	1154	6719	709	37
25%	RMSE%																
	Total employment																
26,883	*Modelled*	1653	2498	1395	2315	2550	1514	847	1004	1180	506	723	621	1267	7149	1429	233
25,667	*Observed* census 2006	1587	2698	1117	2590	2698	943	684	411	1295	427	415	202	1523	7271	1754	52
19%	RMSE%																
	population per zone																
50,827	*Modelled*	552	5088	7148	1697	6964	6579	2333	3295	2738	1293	1520	1517	1840	7034	877	350
51,603	*Observed* census 2006	1284	4734	7365	771	6777	7053	2502	3948	2502	1425	2103	2262	1209	6630	96	942
17%	RMSE%																
22%	**Weighted sum of RMSE for each (target cell for Solver)**																

The following explanations of the difference between calibration and validation were found during the literature review and although not of direct relevance to the project scope have been reproduced here as they were found to be a useful addition to the modelling guidance given in the EEM. The model development process has three related steps:

- Estimation: Using statistical methods to determine the model coefficients that best fit observed data.
- Calibration: Tweaking model coefficients to better match aggregate targets.
- Validation: Comparing model results to observed data independent of what was used for estimation or calibration.

Model calibration adjusts parameter values until the predicted travel matches the observed travel within the region for the base year. For purposes of forecasting it is assumed these parameters will remain constant over time. Calibration is conducted in all four steps of the modelling process and normally occurs after establishing model parameters.

Model validation tests the ability of the model to predict future behaviour. Validation requires comparing the model predictions with information other than that used in estimating the model. Validation is typically an iterative process linked to calibration. The model is considered validated if the output and the independent data are in acceptable agreement based on two types of validation checks:

- Reasonableness checks are tests that include the comparison of rates, checking of the total regional values and logic tests, etc. The analyst evaluates the models in terms of acceptable levels of error, ability to perform according to theoretical and logical expectations, and consistency of model results with the assumptions used.

- Sensitivity checks are tests that check the responses to transportation system, socio-economic, or political changes. Sensitivity often is expressed as the elasticity of a variable. For example, one might examine this impact on travel demand if parking or toll fees are doubled.

Sources: Donnelly et al (2010), Pedersen & Sandahl (1982), Wegmann & Everett (2008).

Appendix 2: Zone data

Zone number	Locality	Pop 06	Basic 06	Non Basic 06	Pop 36	Basic 36	Non Basic 36
0	External zones - primarily rural / agriculture	26931	3746	4855	30221	4171	6009
1	Richmond	1284	740	847	2227	3234	2655
2		4734	410	2288	5399	647	2722
3		7365	147	970	10630	147	1290
4	Nelson airport	771	1098	1492	823	1970	2403
5	Stoke	6777	863	1835	6831	1172	2286
6		7053	190	753	12422	190	927
7	Tahunanui	2502	99	585	2264	99	643
8	Nelson western suburbs	3948	129	282	4420	129	306
9		2502	28	1267	2272	28	1678
10		1425	30	397	1692	30	550
11		2103	89	326	2108	203	464
12		2262	61	141	2148	61	148
13		1209	369	1154	1097	407	1286
14	Nelson city centre	6630	552	6719	10062	558	7650
15	Port of Nelson	96	1045	709	85	1045	721
16	Grampians	942	15	37	903	15	39
SUMS		**78534**	**9611**	**24657**	**95603**	**14106**	**31777**