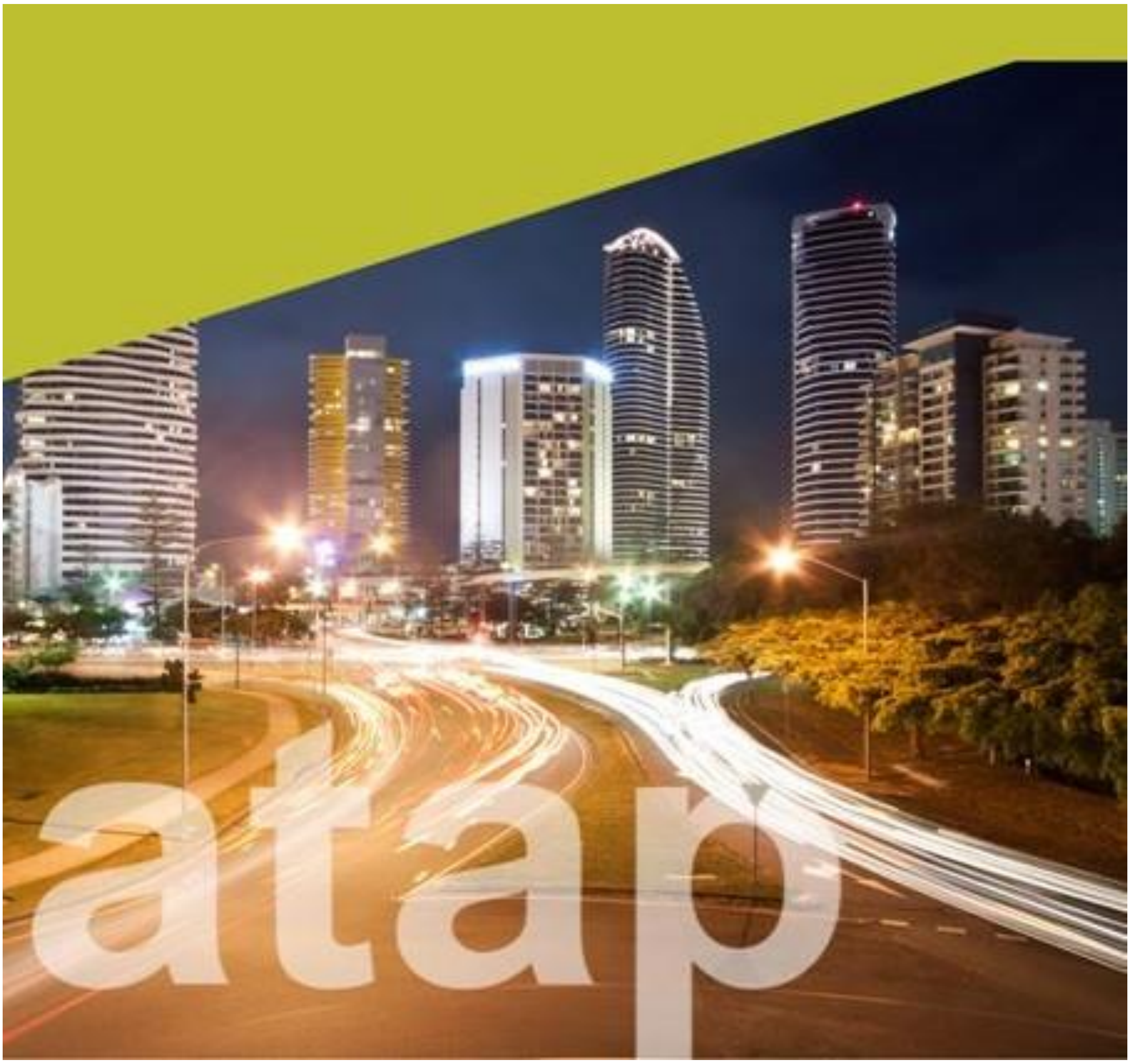
INFRASTRUCTURE AND TRANSPORT MINISTERS

Australian Transport Assessment and Planning Guidelines

T7 Risk and uncertainty assessment

August 2021



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At a glance

- In transport planning and assessment, future outcomes and events, and related assessment input variables and outputs, all involve uncertainty and risk. These need to be accounted for in assessments and subsequent decision-making.
- Risks are defined as outcomes or events that have measurable probabilities.
- Uncertainty involves outcomes or events with no measurable probability.
- Risk and uncertainty arise from a range of sources. Various methods are available for identifying risks and uncertainties: risk workshops; comparison with similar cases; research and investigation of contextual factors and trends; use of checklists.
- Assessing risk and uncertainty involves both qualitative and quantitative assessment.
- A qualitative assessment is generally simpler and less costly to undertake. As a result, the assessment of risk and uncertainty often begins at a qualitative level. In some cases, it will be sufficient to guide decision-making about a plan or initiative. In other cases, it can be used as an initial screening of low, medium and high risks, allowing subsequent, more detailed risk assessment to focus on the higher risk variables or options, and allowing more targeted monitoring into the future.
- Qualitative risk assessment involves assigning scores or ratings to the likelihood and consequence of events, combining those into an overall risk score, rating or category. Rating tables can be used as a means of developing consistency in assessments, as well as encouraging transparency. Rating tables can be tailored for particular contexts.
- Sensitivity testing is a type of quantitative risk and uncertainty assessment. It consists of selectively changing quantitative variables in an assessment to test the sensitivity of results to variation in any given variable. Sensitivity analysis has the advantage of being easy to use, requires limited information and offers a quick turnaround of results. It is therefore an attractive form of quantitative risk assessment, especially for smaller, less complex assessments.
- As far as possible, sensitivity analysis should be tailored or targeted to the specific assessment being undertaken. Testing should focus on the input variables that are considered most risky.
- Probability-based assessment provides a more advanced type of risk assessment. It requires the use of probability distributions to represent the value for the variables of interest. Assigning probability distributions to the variables is a difficult step, and the subjective judgement of experienced professionals is useful to define the form or shape of the distribution.
- Modern statistical sampling and simulation techniques (for example Monte Carlo sampling and simulation) are useful to analyse probability distributions. These techniques can use probability distributions for a number of input variables to determine the probability distribution of outputs variables. They can be applied using software programs such as @Risk.

- Scenario analysis is an important technique used in cases of uncertainty. Scenario analysis involves: describing a number of different plausible future scenarios, usually a small set, then assessing how an option or initiative performs under each of those futures. This allows the analyst to test how robust options are in the face of uncertainty about the future, and to assist the decision-maker in choosing robust options.

- The existence of risk requires consideration of risk management options: risk mitigation options and real options. Risk mitigation options increase costs, or reduce benefits, in exchange for a reduction in the probability or consequences of an adverse outcome. Real options assessment can assist in finding solutions to a transport problem in the face of future uncertainty. It does this by assessing options that contain flexibility in their nature and timing that allow them to change over time as the future becomes more certain. Probabilistic analysis is used in the assessment of both risk mitigation options and real options.

- Probabilistic assessment can also be used in a cost-benefit analysis. The Monte Carlo simulation approach is typically used, with probability distributions defined for key input variables. The usual outputs are probability distributions for net present value (NPV) and benefit cost ratio (BCR). This approach is illustrated here with summaries from a number of published case studies. There is limited published information on the application of this methodology, but practitioners are encouraged to apply it, with caution. At this stage, full use of the method is likely to be most justified on the largest project proposals where funds are available for a detailed assessment, including consultation with risk assessment specialists with practical application experience. For other projects, the method could be used at the strategic assessment and rapid appraisal stages to provide an indicative guide to probability-based CBA results. Further research and sharing of experiences in application would enhance this aspect of risk assessment.

1. Introduction

This Part of the Guidelines provides guidance on risk and uncertainty in transport planning and assessment for use by ATAP practitioners. The consideration of risk and uncertainty of outcomes and events is a central part of transport planning and assessment and subsequent decision–making.

Transport systems and transport initiatives are subject to significant risk and uncertainty. Yet, transport planning and assessment have often been based on the assumption that outcomes and events in the transport system and the broader environment in which it sits, and related assessment input variables, are known with certainty (deterministic). The natural extension of those assumptions is that outputs from assessments are also known with certainty. In reality, however, these factors, input variables and outputs are *not* known with certainty — instead they involve uncertainty and risk that need to be accounted for.

Consideration of risk and uncertainty allows risks and uncertainties: to be identified; to influence investment decisions; and for ways to be found to avoid and manage them.

For example, consider a large toll road project:

- It will be subject to risk and uncertainty from sources such as macroeconomic developments that impact, for example, the price of fuel and real interest rates
- These in turn impact the cost of travel and household incomes, exposing toll road investors to risk of patronage demand falling
- There is also exposure to the risk of cost overruns, for example due to the geotechnical risks involved when planners opt for tunnels, that manifest themselves in added expenses
- In a planning context, the identified risks and uncertainties can be accounted for in the cost-benefit analysis, enabling the robustness of a decision to proceed with the project to be tested
- In the project design context, having identified the tunnel risks, different design or construction options could be explored, such as cut-and-cover tunnels or even elevated highways. Similarly, the geotechnical risks could be managed through investment in more testing and/or by procuring the services of more skilled constructions contractors — those with a proven record of delivering projects in similar environments or projects.

Definition

In practice, the terms risk and uncertainty are sometimes used interchangeably and at other times with precise differences. Here we adopt the definitions adopted by IA (2018), namely:

- Risks are defined as outcomes or events that have measurable probabilities
- Uncertainty involves outcomes or events with no measurable probability.

Drawing this distinction is important. In transport planning and assessment, some phenomena that we wish to model and assess produce probabilities that are observable, measurable, and relatively predictable. In these cases, probability-based assessment can be applied. However, many phenomena we wish to model and assess do not present probabilities that are observable, measurable, and predictable — creating a high level of uncertainty, and making decision-making more difficult. In these cases, we are more reliant on techniques such as scenario analysis and real options assessment.

For example, consider the cost-benefit analysis of a proposed initiative. If probabilities of inputs are known, probability-based analysis can determine the most likely benefit-cost ratio and the range of benefit-cost ratio values for a certain level of confidence (such as a 90% confidence). In contrast, if the input probabilities are not known, one may need to rely on simple sensitivity testing, or the use of scenario analysis, to test the robustness of the benefit-cost ratio to uncertainties. While these analyses will still aid decision-making, they will generally provide a lower level of confidence of results than when probabilities are known.

Link to other parts of the ATAP Guidelines

The parts of the ATAP guidelines where risk and uncertainty may play a key role are:

- F2 Problem identification and assessment
- F3 Options generation and assessment, especially in cost–benefit analysis (CBA)
- T1 Demand modelling
- T2 Cost-benefit analysis
- O1 Cost estimation
- Parameter values in models
- T8 Real Options Assessment.

Structure of this guidance

Chapter 2 provides the context for assessment, discussing: sources of risk and uncertainty; and listing methods for their identification.

Chapter 3 outlines the broad types of risk and uncertainty assessment.

Chapter 4 discusses qualitative risk assessment, including types of ratings for the likelihood and consequence of an outcome and their combination into a risk rating.

Chapter 5 discusses sensitivity testing.

Chapter 6 provides an overview of probability-based risk assessment, discussing: probability distribution types; sampling and simulation techniques for combining probability distributions of input variables to produce probability distributions of output decision variables; and using those outputs in decision–making.

Chapter 7 discusses the generation of possible future scenarios and their use in scenario analysis to test the robustness of options.

Chapter 8 identifies real options analysis as another important assessment tool when faced with risk and uncertainty, and refers to a separate ATAP paper on the technique.

Most fundamentally, effective transport assessment and planning requires critical thinking and the ability to assess and interpret appropriate information. However, given the future is never fully known, approaches to account for the effects of risk and uncertainty are also required, as set out below. The approach chosen by the analyst will depend on their context and setting:

- For the assessment of smaller and less complex problems and initiatives, practitioners may find that a qualitative risk assessment may be sufficient to help guide their decision making. In those settings, a qualitative assessment is better than not undertaking any risk and uncertainty assessment.
- The larger and more complex the problem or initiative, the greater the justification for moving to quantitative assessments of different degrees of sophistication.

2. Sources and identification

2.1 Sources

In transport planning and assessment, risk and uncertainty of varying degrees exist about future socio-demographic, economic, technological and environmental trends.

With respect to the assessment of initiatives, the main sources of risks include (IA 2018):

- Investment cost risks created by unforeseen construction, technical or other project scope issues.
- Operating cost risks (including maintenance) created by unforeseen market impacts/changes and technical issues.
- Demand forecast risks driven by changes in factors such as unforeseen population growth or cost of living.
- Environmental impacts driven by unforeseen circumstances.
- Network effects caused by unexpected and inter-related network projects/changes.
- Technological risk related to changes in technology. The impacts of changes in technology are difficult to predict but can be significant, including: making existing products and assets obsolete or less competitive; creating 'lock-in' effects; and changing the relative prices of existing and new technologies, for example relative prices of transport modes.

2.2 Identification

As many major transport assets and networks are subject to significant risk and uncertainty, it is important to identify risks and uncertainties in transport planning and assessment, allowing them to then be proactively managed. Various methods of identifying risks may be useful in transport planning and assessment (Austroads 2012):

- Brainstorming in a group environment: that includes a variety of stakeholders to cover risks across different areas. This would include undertaking risk workshops and scenario analysis involving experts from different disciplines and backgrounds (see ATAP Part O1 Cost estimation, section 2.3).
- Comparison with similar cases: the risks experienced in other similar, recent situations may provide a good indication of potentially risky areas. Post-implementation evaluations of past planning and assessment processes and projects may provide valuable information.
- Undertaking research and investigations of relevant contextual factors and trends.
- Use of comprehensive checklists that contain many areas of potential risk common to transport applications.

3. Broad assessment features

Various approaches are available for the assessment of risk and uncertainty. This and subsequent chapters provide an overview of those that are relevant to the ATAP Guidelines.

Risk and uncertainty are associated with the following variables in an assessment:

- Parameter values: For example, the unit value of travel time savings, or the unit cost of emitting greenhouse gases. The impact in an assessment of risk and uncertainty in parameter values can be addressed using sensitivity testing and /or use of probability distributions for those variables

- Events: For example, flooding, breakdown of critical system infrastructure elements, or major climatic events. The risk associated with an event is assessed as the product of two components:

  – The likelihood, or probability, of the event occurring.

  – The consequence, or impact, of the event if it occurs.

Practitioners should investigate all potentially risky variables that input into their assessments to gain a better understanding of their effects on the results of their assessment.

3.1 Qualitative and quantitative assessment

The assessment of risk and uncertainty can involve both:

- Quantitative data, and

- Qualitative information based on experience and informed opinion.

A qualitative assessment is generally simpler and less costly to undertake. As a result, the assessment of risk and uncertainty often begins at a qualitative level,

A qualitative assessment can determine which risks are likely to be of greatest significance, and hence those that are a priority and/or will require the most attention. In some cases, it will be sufficient to guide decision-making about a plan or initiative. In other cases, it can be used as an initial screening of low, medium and high risks, allowing subsequent, more detailed risk assessment to focus on the higher risk variables or options, and allowing more targeted monitoring into the future.

Quantitative analysis then follows to describe the impact of the selected variable in more detail using a quantitative process. The following quantitative assessment approaches are discussed in this guidance:

- Sensitivity analysis: Selectively changing input variables to test the sensitivity of results.

- Probability-based analysis: The use of probability distributions to represent the risky variables of interest, and computer simulations to produce probability distributions of assessment output results.

- Scenario analysis: Creating a number of different plausible futures and assessing outcomes under each one.

- Assessment of risk management options:

- Risk mitigation options: Assessment of options that increase costs, or reduce benefits, in exchange for a reduction in the probability or consequences of an adverse outcome
- Real options assessment: Assessment of options that contain flexibility in their nature and timing (deferment and staging), allowing investment decisions to be changed over time when future uncertainties are resolved, called ‘real options’.

Both qualitative and quantitative assessment rely on good data being available.

As noted at the end of Chapter 1, the choice of approach will be influenced by the nature of the problem and initiative being assessed.

3.2 Objective and subjective assessment

The assessment of a risk can be subjective or objective.

The assessment can be undertaken objectively when observations, statistical data, or previous experience have been recorded and are available.

If, however, there is a lack of quantifiable information to work with, the situation is more difficult to assess. The assessment then becomes subjective, and the decision-maker has to rely on informed opinions instead of data, to assess risk.

In these cases, well informed subjective views about probabilities of outcomes and input variables, along with sensitivity testing, can still be of value to the decision-maker.

4. Qualitative risk assessment

4.1 Process

As stated above, risk is assessed as the product of two components:

- Likelihood, or probability
- Consequence, or impact

The process for a qualitative assessment consists of:

- Assigning numerical scores or ratings to likelihood and consequence.
- Determining the overall risk score or rating by combining the likelihood rating with the consequence rating.
- The overall risk score or rating is then judged to be either extreme, high, medium or low based on agreed rating ranges.

Rating tables, as illustrated below, can be used as a means of developing consistency in rating likelihood, consequence and risk, as well as encouraging transparency. Qualitative rating tables can be tailored for particular contexts.

4.2 Rating likelihood, consequence and risk

4.2.1 Category approach

Table 1 to Table 3 below (Austroads 2012) illustrate risk assessment using a qualitative category approach. Table 1 to Table 3 guide the rating of likelihood and consequence, with those ratings then combined in Table 3 into overall risk.

Table 1 Categorised measures of likelihood – example

Level	Descriptor	Description
A	Almost Certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Could occur
D	Unlikely	Could occur but not expected
E	Rare	Occurs only in exceptional circumstances

Source: Austroads 2012

Table 2 Categorised measures of consequence – example

Level	Descriptor	Description	Example description-impact on project costs
1	Catastrophic	Catastrophic impact	>$75,000
2	Major	Major impact	$50,000-$75,000
3	Moderate	Noticeable/ concerning impact	$25,000-$50,000
4	Minor	Slight/tolerable impact	$10,000-$25,000
5	Insignificant	Unnoticeable impact	<$10,000

Table 3 Categorised measures of risk (combining likelihood and consequence/impact) – example

	Levels of consequence/impact				
Level of likelihood	Catastrophic	Major	Moderate	Minor	Insignificant
Almost Certain	E	E	E	H	H
Likely	E	E	H	H	M
Possible	E	E	H	M	L
Unlikely	E	H	M	L	L
Rare	H	H	M	L	L

Note: E = extreme risk; H = high risk; M = medium risk; L = low risk

Source: Austroads 2012

4.2.2 Numerical score approach

An alternative approach is to assign numerical scores to likelihood and consequence, with a risk score then calculated by multiplying the likelihood score by the consequence score. Table 4 below shows an example of a template that could be used for the purpose of listing and rating risks.

Table 4 Risk identification and rating table

Risk	Likelihood (0-5)	Consequences/ severity (0-5)	Risk rating: likelihood * consequence	Mitigation strategy
Risk of ecological damage to plant life surrounding creek. This may result in additional costs to solve issues that may not have yet been identified.	3	3	9	Understand all issues and incorporate affordable solutions to preserving ecology into project design.
Risk of project delay due to dealing with community concerns.	2	2	4	Maintain close working relationship with community groups to resolve issues early and effectively.

Source: Austroads 2012

Note that this approach may be misleading when consequence or probability are not defined in roughly linear terms. Unlike the qualitative ratings in Table 3, the numerical quality of the ‘risk rating’ invites scalar (magnitude) comparisons of different risks or projects, which might be misleading impacts are non-linear. So care is required in application.

4.2.3 Use of ratings descriptions tables

Rating description tables are also necessary to guide the selection of a rating. Table 5 below provides an example for travel demand uncertainties. The rows of the table present different aspects of demand uncertainty, the columns list the possible ratings, and the descriptions in cells assist in selecting a rating. The table also infers how risks may be reduced, for example, how to reduce a risk rating from ‘high’ to ‘medium’.

Table 5 Example of rating descriptions table for Base Travel Demand uncertainties

	1 (Low)	2 (Medium)	3 (High)
Age of data	Counts < 1 year old Household < 5 years old	Intercepts/counts 2-3 years. Household 5-10 years	Intercepts/counts >3 years. Households > 10 years.
Data scope	Count and intercept sites in project corridor.	Acceptable data coverage.	Count and intercept sites not in close vicinity of project and thus not encompassing most (>80%) of the relevant traffic.
Data quantity and statistical reliability	5 or more years’ continuous count data. Intercept data. Strategic model: one-day household travel diary with either a sampling rate greater than 3% of population or a sample of at least 5,000 households.	Count data providing 95% confidence levels ± 10%. Household one-day travel diary with sampling rate of 1.5-3% or 2,500-5,000 households.	A few weeks’ count data in context of seasonal traffic patterns, such that the 95% confidence level for annual traffic exceeds ±10%. Strategic model based on one-day household travel diary with either a sampling rate less than 1.5% of population or a sample of less than 2,500 households.
Travel demand validation to counts	Very comprehensive count program with close fit of matrix to counts.	Reasonable coverage and fit to counts.	Limited scope count program, no more than adequate fit of matrix.
Traffic composition (models based on counts alone)	Derived from classified vehicle counts for an adequate sample of annual traffic.	Standard values used with local validation.	Standard values used without local validation.

Source: Austroads 2012

5. Sensitivity testing

Sensitivity testing is a type of quantitative risk and uncertainty assessment. It consists of selectively changing quantitative variables in an assessment to test the sensitivity of results to variation in any given variable. It allows analysts to:

- Acknowledge that there is always a degree of uncertainty and ultimately risk in an assessment.
- Understand the key variables that influence the outcomes of an assessment.

A standard example of a sensitivity test is to vary the assumed growth rate in travel demand. The expected (most likely) growth rate might be considered to be 2.1% per annum, but some degree of uncertainty exists about it. The sensitivity test would typically consist of running the assessment with a low and high growth rate, the values of which would depend on best available information on the likely variation around the most likely value. For example, the sensitivity testing may run a low value of 1.7% per annum and a high value of 2.5% per annum.

Sensitivity analysis has the advantage of being easy to use, requires limited information and offers a quick turnaround of results. It is therefore an attractive form of quantitative risk assessment, especially for smaller, less complex assessments.

There are no universally applicable rules for selecting which variables and their values to subject to sensitivity analysis. A standard approach often promoted is to run a standard set of tests, e.g. costs +/- 20%, benefits +/-20%, etc. This can provide a simple starting point. However, these tests are often too generic, and may be of limited value.

It is therefore recommended that, as far as possible, sensitivity analysis should be tailored or targeted to the specific assessment being undertaken. In general, the testing should focus on the input variables that are considered most risky – which would be those that are simultaneously of high impact and also most uncertain (Austroads 2012, IA 2018). Such critical interrogations of major 'risky' variables, assessed and interpreted by way of more focused sensitivity testing, would enhance the quality of most assessments.

In the ATAP Framework, sensitivity testing can be used as follows:

- **Demand modelling** – Demand modelling and forecasting are a central part of transport planning and assessment. Sensitivity testing is therefore important. ATAP Part T1 Travel Demand Modelling section 6.4 discusses a series of tests that should be undertaken to test the robustness of demand model outputs and projections
- **Problem assessment** – Sensitivity tests assess how sensitive problem assessment (see ATAP Part F3) is to changes in key variables, such as:
  - Growth rates in population and travel
  - Changes in policy settings
- **Cost–benefit analysis (CBA)** – Sensitivity testing is a standard part of a rigorous CBA. Practitioners are directed to ATAP Part T2 section 11.1 and IA (2018) sections D4.2 to D4.4 for more details on their application in CBAs.

6. Probability-based assessment

A more advanced type of quantitative risk assessment is probability-based assessment. It requires the use of probability distributions to represent the value for the variables of interest.

Assigning probability distributions to the variables is a difficult step, and the subjective judgement of experienced professionals is important to define the form or shape of the distribution.

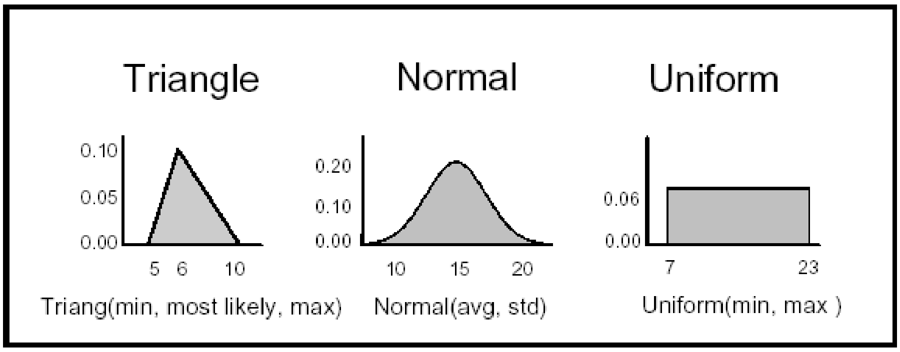
With respect to its use in cost-benefit analysis (CBA), ATAP Part T2 Chapter 11 outlines the steps for probability-based CBA. The chapter here provides supporting detail.

6.1 Probability distributions

In working with probability distributions, two types of representation are used:

- **Probability density function (PDF):** Probability distributions of continuous uncertain variables can be represented in terms of probability density functions (PDFs). A range of probability distribution functions can apply in risk assessment. The choice of the distribution function and the key parameters that determine its shape will be based on experience. Examples of common distribution functions include triangular and normal distributions as shown in Figure 1 below. The horizontal axis shows a range of possible values and the vertical axis shows the relative frequency weighting of the occurrence of a particular value. In all cases, the total area under a PDF equals 1.0. The skewed distribution shown in Figure 2 is another example.

Figure 1 Example probability distributions

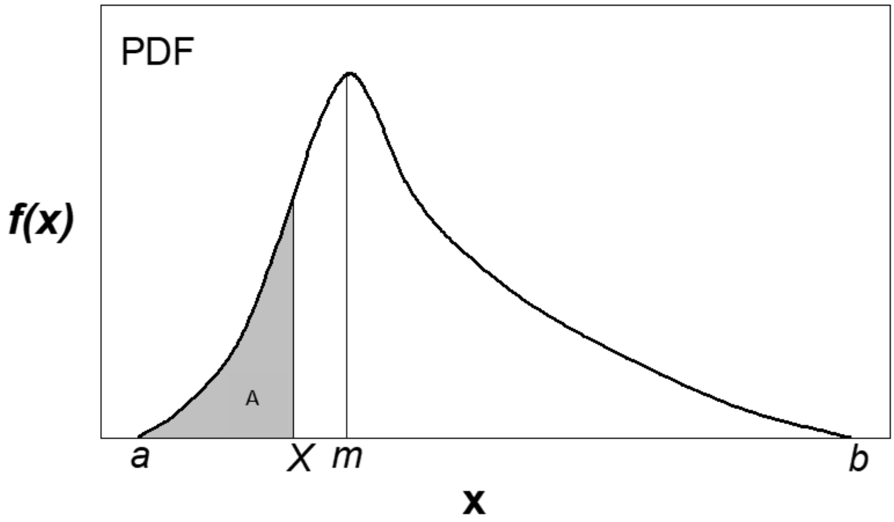


Source: Austroads (2012, citing FHWA 1998)

A normally distributed PDF has a symmetrical bell curve shape, has a central peak indicating the most likely value (or mode) of the uncertain quantity and has low-probability 'tails' on either side of the peak stretching out to the upper and lower extremes.

The PDF for an uncertain generic variable *x* is conventionally denoted by *f (x)*. Figure 2 below shows an indicative distribution, with a minimum value of *a*, a maximum value of *b* and with a mode at *m*. In this case the distribution is skewed. The area under the PDF curve measures the probability that the value of the uncertain quantity *x* will lie in the range from *a* to *b*. For example, the shaded area A shows the probability that *x* will lie in the range of *a* to *X* (Austroads 2002).

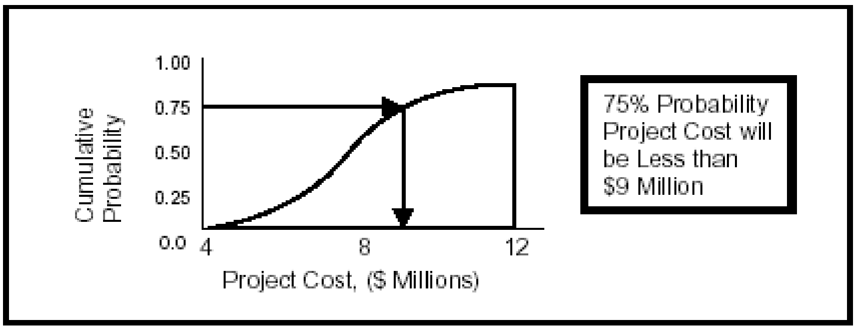
Figure 2 Probability density function (PDF)



Source: Austroads (2012, citing Hardaker et al 1997)

- **Cumulative distribution function (CDF):** Another way to represent probability is by using a cumulative distribution function (CDF). Figure 3 shows an indicative CDF. CDFs illustrate the cumulative probability of an x-axis value along the y-axis. The CDF in Figure 3 shows that there is a 75% probability that project costs will be less than $9 million.

Figure 3 Cumulative distribution function

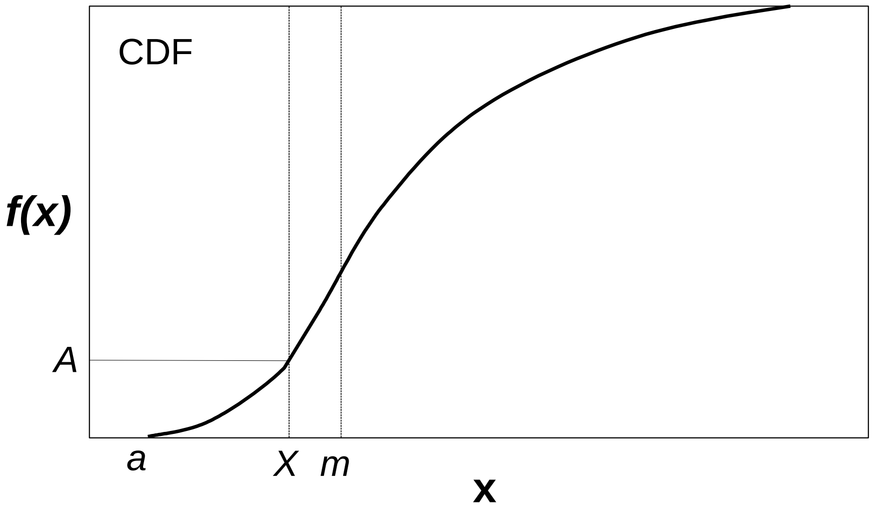


Source: Austroads (2012, citing FHWA 1998)

Figure 4 shows the CDF corresponding to the PDF in Figure 2. A few points to note about the relationship between a PDF and the associated CDF are:

- The CDF point of inflection corresponds to the mode of the PDF.
- The shaded area A shown in Figure 2 shows the probability that *x* will lie in the range of *a* to *X*. The probability A is shown in Figure 4 as point A on the Y-axis.

Figure 4 Cumulative distribution function (CDF) corresponding to PDF



Source: Austroads (2012, citing Hardaker et al 1997)

Triangular distributions

In situations where a particular distribution function is unknown, a triangular distribution may be selected for simplicity. The triangular distribution function has the advantage that it can be fully specified using only three distinctive values of a distribution (the minimum value, the maximum value and the most likely value). The minimum and maximum values represent the lowest and highest values conceivable. The minimum, maximum and most likely values of uncertain variables can be set objectively from either hard data (such as historical information) or subjectively from expert opinion.

6.2 Sampling and simulation techniques

Modern statistical sampling and simulation techniques (for example Monte Carlo sampling and simulation) are useful to analyse probability distributions (Belli et al, 2001). These techniques can use probability distributions for a number of input variables to determine the probability distribution of outputs variables. They can be applied using software programs such as @Risk.

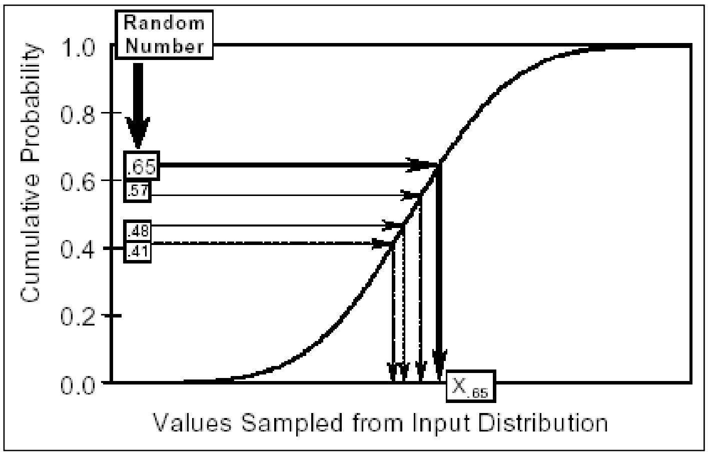
A good example of its use is how Monte Carlo simulation is now widely used in project cost estimation. All the input variables that influence project cost are first identified. A probability distribution is then specified for each input variable. The simulation process then produces a resulting output probability distribution for project cost. See ATAP Part O1 Cost Estimation for a fuller discussion.

In Monte Carlo simulation, the simulation software acts as if the same event were implemented hundreds or thousands of times under specified conditions. Since the values of the input variables are uncertain, the simulated output results are different each time. This allows probability distributions for a number of different input variables to be assessed concurrently, resulting in a probability distribution of output variables.

6.2.1 Sampling

As shown in Figure 5 below, the Monte Carlo technique uses a uniform distribution to generate random numbers. This means all values on the y-axis have an equal probability of being selected. It also means that x-values corresponding to the steeper portion of the distribution curve are more likely to be sampled than those on the flatter parts of the curve. If a small number of iterations are performed, low probability outcomes are not sampled sufficiently as sampled values are clustered around mid-range probability outcomes. Techniques like Monte Carlo require a large number of iterations to avoid clustering of sampled values around particular probability outcomes.

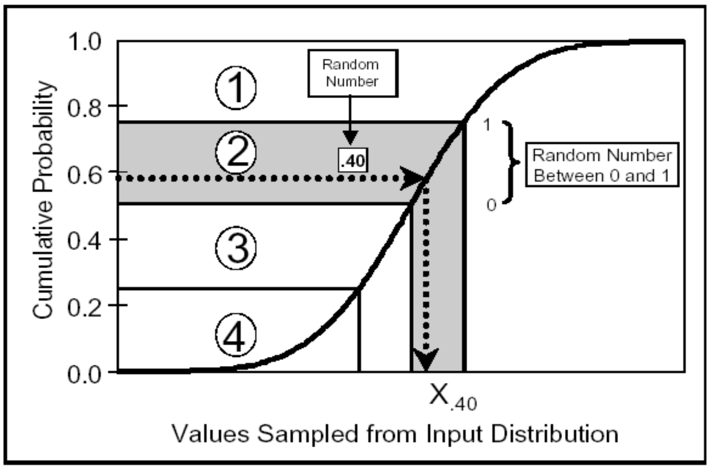
Figure 5 Monte Carlo sampling



Source: Austroads (2012, citing FHWA 1998)

On the other hand, stratified sampling techniques such as Latin Hypercube force a more representative sampling with a smaller number of iterations (FHWA, 1998). This is achieved by dividing the cumulative probability scale into equal intervals and a sample is randomly taken from each interval of the distribution, as shown in Figure 6 below. Convergence is also achieved much more quickly than with Monte Carlo sampling.

Figure 6 Latin Hypercube sampling



Source: Austroads (2012, citing FHWA 1998)

6.2.2 Combining input variables using computer simulation

Once input variables have been described with probability distributions, the next step is to use a computer software package such as @Risk to generate a probabilistic description of results using the input distributions. Probability distributions for input variables can be directly incorporated into spreadsheet models using custom distribution functions available with the software program. Separate 'what if' scenarios can be calculated by drawing a sample from each input distribution, normally based on several thousands of simulation executions.

6.2.3 Assessment outputs

The simulation produces a probability distribution for each output variable. For a given output variable, the resulting probability distribution describes the range of possible outcomes and their probability of occurrence. Consider, for example, output distributions in a cost-benefit analysis (CBA).

Distributions would be produced for:

- <u>Decision variables</u>: In a CBA, probability distributions would be produced for net present values (NPV) and benefit–cost ratios (BCR).
- <u>Component variables</u>: In a CBA, component variables would include project costs and project benefits, or particular sub-sets of variables representing benefits and costs. Having probability distributions for the component variables is helpful in gaining an understanding of what is affecting decision variable results.
- Figure 7 below illustrates the BCR output from a CBA simulation. It shows the BCR probability distribution (in the form of a histogram), showing the possible range of BCR values that could occur and the estimated probability of each outcome occurring. It shows that the BCR is most likely to be around 3. However, there is a possibility, albeit less likely, that the BCR could be as high as 8 or even negative. The BCR of an initiative needs to be greater than 1.0 for the initiative to be economically justified. Figure 7 provides the decision-maker about the level of confidence one can assign to the project being economically justified.

6.2.4 Deeper assessment

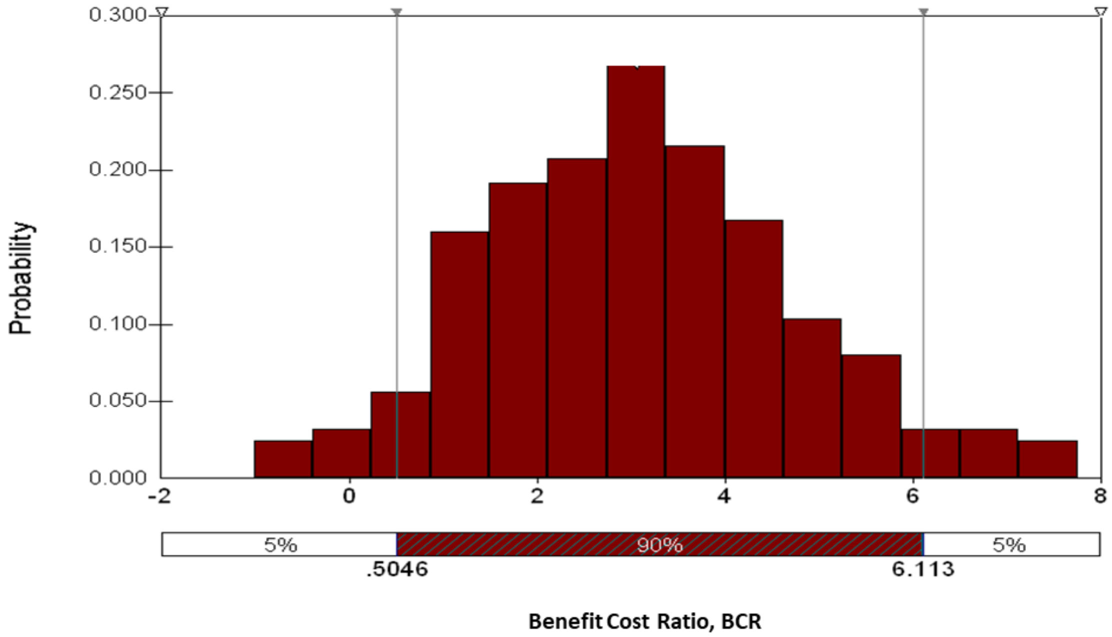
The analyst would then get a deeper understanding by looking at the probability distributions for each of the following:

- Each benefit component, for example travel time savings, operating cost savings, crash cost savings and environmental benefits.
- Capital investment cost and recurrent costs.
- The input variables, for example the unit value of travel time savings, unit crash costs.

This type of breakdown will assist the analyst to understand which variables most affects the BCR results. That knowledge in turn provides insight on which input variables may require better quality data, and how options might be best refined.

Software programs such as @Risk produce other outputs, such as a 'tornado chart', that assists the analyst to determine which risk variables have the greatest influence on the outcomes.

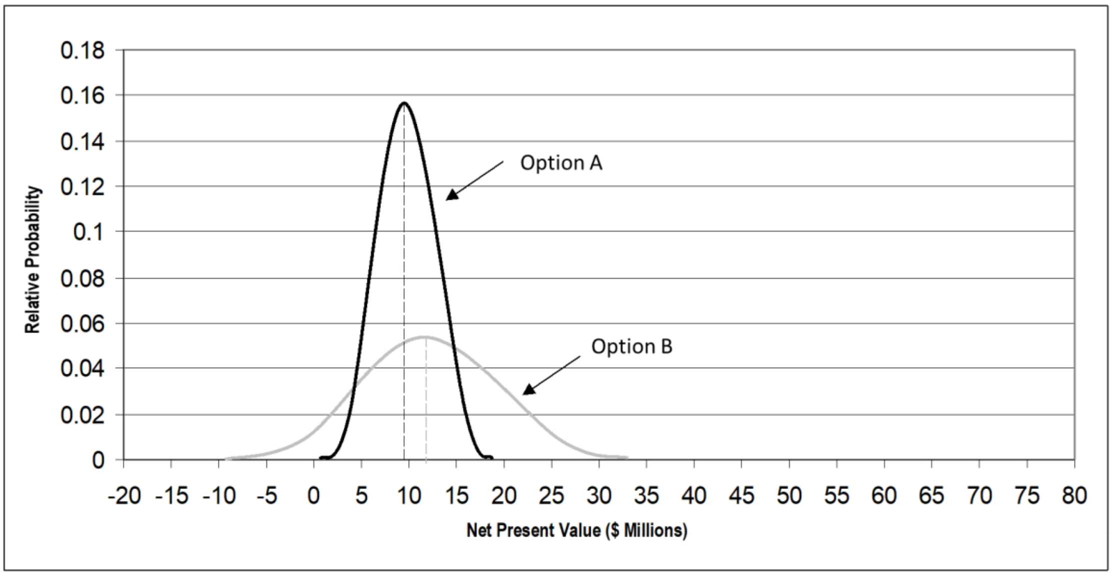
Figure 7 Example of an output probability distribution from a computer simulation



Source: Austroads 2012

Another type of assessment in a CBA is comparison of alternative project options. Figure 8 below illustrates how the results of the simulation analysis for different project options can assist decision-making, again using application in a CBA as an example. It shows the NPV results of two alternative Options A and B within an initiative. Option B has a higher mean NPV than Option A. However, the NPV for Option A has a tighter range of potential values than that of Option B, and unlike Option B, is not at significant risk of having a negative NPV value. If the decision-makers were happy to take the risk, Option B would be preferred, as it has a slightly higher NPV and possibility of upside outcomes. If the decision-makers were more risk averse, Option A, with its slightly lower NPV but lower range of downside outcomes, might be preferred Austroads (2012).

Figure 8 Probabilistic Outcome Distributions



Source: Austroads (2012, citing FHWA 2003)

7. Scenario analysis

An important technique used in cases of uncertainty is scenario analysis (ATC 2006 Vols 3 & 5, Austroads 2012, ATAP 2015 Part F0.1, IA 2018).

Scenario analysis involves:

- Describing a number of different plausible future scenarios, usually a small set.
- Assessing how an option or initiative performs under each of those futures.

This allows the analyst to:

- Test how robust options are in the face of uncertainty about the future.
- Assist the decision-maker in choosing robust options.

A scenario should (Austroads 2012, IA 2018):

- Be a coherent, internally consistent, set of assumptions describing all the characteristics of a 'possible future' describing key features of each future, such as population levels and distribution, growth rates, assumptions about climate change, assumptions about technological changes.
- Be evidence-based, wherever possible.
- Reflect variations in key drivers.
- Have a probability assigned to it, based on perceptions about the likelihood those future assumptions in the scenario will eventuate.

Scenario analysis involves the following features (ATC 2006, Austroads 2012, ATAP 2015, IA 2018):

- Because the future is hard to predict, it is sometimes desirable to analyse options under more than one future scenario.
- Scenario analysis provides a framework for exploring the uncertainty about future consequences of a decision. It is especially useful for decision-makers faced with forms of uncertainty that are uncontrollable or irreducible (for example future technology change or increased climate variability) (IA, 2018).
- Scenario analysis is a potentially useful tool when major change is occurring and the future is highly uncertain. Scenarios can describe a range of possible future circumstances and outcomes. In contrast, the traditional approach to forecasting focuses on a single forecast (typically based on one set of assumptions), which is unlikely to accurately predict 'the' future.
- The alternative futures will typically involve significantly different challenges, risks and opportunities for individual activities and organisations. Scenario analysis helps transport practitioners and decision-makers to avoid the trap of thinking (and planning on the assumption) that the future is going to be the same as the present, only a little bit more.

- Scenario analysis makes the assumptions used in transport planning more explicit and facilitates better management of risk. It can contribute to improved understanding of factors likely to significantly affect transport and the interplay between these factors. Transport practitioners can then more effectively consider the implications for transport planning, increasing the likelihood that resulting strategies and initiatives will effectively address future demands on the transport system.

- Extrapolation of current trends does not recognise the possibility of major discontinuities or one-off events. Scenario building is a tool that has attracted attention in recent years and should be applied where there is a reasonable probability of futures that differs markedly from the present. Probabilities, whether explicit or implicit, can be attached to each scenario to focus attention on the more likely scenarios. Hedging involves making plans that yield reasonable pay-offs under more than one scenario. However, hedging comes at a cost, because the chosen plan may not be the best for the scenario that is actually realised. A balance should be struck between planning based on a single view of the future and hedging for a variety of futures. Erring too much on one side or the other can be costly. The probabilities of different scenarios need to be balanced against the costs of hedging.

- In some circumstances, it may be possible to assign subjective guesses of the probability of alternative scenarios occurring. Whilst indicative only, it may sometimes assist in decision-making.

IA (2018) includes scenario analysis throughout its assessment framework. Readers are directed to IA (2018) for further details on scenario analysis, including sections: B1.3 (problem assessment), D3.3 (demand forecasting) and D4.6 (climate change).

8. Risk management strategies

When faced with risks, it is important to consider risk management strategies. Risk management can be defined as the process of assessing exposure to risk and determining how best to handle this exposure, with the aim of minimising risk and optimising the risk–benefit balance. Risk management is an ongoing process throughout transport planning, the planning and construction of initiatives, and the operation of transport facilities and services.

The twin aims of risk management are:

- Risk minimisation: This means taking any actions that reduce the probability or the cost of undesirable outcomes, where actions involve little or no cost. Risks also have to be minimised where required by law or by community expectations.

- Optimising the risk–benefit balance: Attaining the optimal balance requires determination of how much net benefit to sacrifice in order to reduce risk.

Decisions about risk management options can be guided by use of probabilistic risk assessment to calculate the expected NPV. Part T2 Cost–Benefit Analysis chapter 11 recommends the use of expected NPV for comparing options and choosing the best option.

A given option is economically viable if the expected NPV > 0. In most cases, attaining the optimal risk–benefit balance is a matter of determining the option with the highest expected NPV.

8.1 Risk mitigation

One way that risk can be managed is through risk mitigation options. For example, a bridge could be built to have greater strength, or, if the initiative was a tunnel, more extensive geological studies could be undertaken to better understand the risks and to devise actions to reduce the probability of major technical difficulties during construction.

Risk mitigation options can be identified by considering changes to proposals that reduce either the probabilities or the costs of adverse events. Often, these changes will involve expending additional resources with certainty (for example, building a stronger bridge).

The two tables below and the associated discussion illustrate how expected NPV can be used to assess risk mitigation options involving first, a reduction in the probability, and second, the cost of an adverse event.

Table 6 shows two options with different risk–benefit trade-offs. Spending an additional $50 million reduces the probability of technical failure from 20 per cent to five per cent and generates a net gain in expected NPV of $25 million after reducing the NPVs for both states of nature by $50 million. The gain comes about because of the change in probabilities.

Another option might leave the probabilities unchanged, but reduce the cost of failure. This is the case for measures taken to lessen damage in the event of a disaster. In Table 7, spending an additional $50 million reduces the NPV in the event of failure to zero, so that the NPV in this state of nature becomes –$50 million after allowing for the additional spending. The net benefit is an increase of $10 million in the expected NPV.

Table 6 Comparison of risk mitigation options using expected NPV: changing probabilities

NPV	Probability	Probability x NPV	Expected NPV
Without extra spending to reduce the probability of failure			
$200	0.8	$160	
–$300	0.2	–$60	
			$100
With extra spending to reduce the probability of failure			
$150	**0.95**	**$142.5**	
–$350	0.05	–$17.5	
			$125

Table 7 Comparisons of risk mitigation options using expected NPV: reducing costs of failure

NPV	Probability	Probability x NPV	Expected NPV
Without extra spending to reduce the cost of failure			
$200	**0.8**	**$160**	
–$300	0.2	–$60	
			$100
With an extra $50 spent to reduce the cost of failure			
$150	**0.8**	**$120**	
–$50	0.2	–$10	
			$110

8.2 Real options

Real options assessment can assist in finding solutions to a transport problem in the face of future uncertainty. A real option is a special type of option, containing a degree of flexibility in its design to allow changes in the nature or timing of investment as the future becomes more certain. ATAP Part T8 provides discussion and guidance on use of real options assessment in transport.

Appendix A – Probabilistic cost-benefit analysis

Chapter 6 above discusses the role of probability-based assessments of transport initiatives. It discusses how computer simulation methodologies can be used to produce a probability distribution of the factors under investigation. Sections 6.2.3 and 6.2.4 discussed how the approach can be used in cost-benefit analysis (CBA) to provide a richer level of information for the decision maker.

Tsai et al. (2018) notes the general lack of step by step technical guidance. Building on guidance by TfNSW (2018), this appendix provides an extended discussion of probabilistic CBA, outlining the process to be followed, and illustrates with a worked example (A.2), and refers to two case studies (A.3 and A.4). Given the limited amount of published material on this topic, the material provided here is more illustrative than comprehensive. It is limited by what has been reported in each reference. However, the material presented is considered adequate to provide an introduction to the topic for practitioners. It is hoped that the guidance can be expanded over time as more case studies are published.

A.1 Methodology

Chapter 6 discussed probability-based assessments, with section 6.2 introducing sampling and simulation techniques such as Monte Carlo simulation, including for probabilistic cost-benefit analysis (CBA). This appendix demonstrates probabilistic CBA using Monte Carlo simulation. Using the software @Risk, a Monte Carlo simulation can be undertaken by inputting probabilistic distributions for benefits and cost of the project rather than single numbers. These are then used to generate the probabilistic distribution outputs — for net present value (NPV), benefit cost ratio (BCR) and other decision criteria.

The following are specific steps to follow in applying Monte Carlo risk analysis to conduct a probabilistic CBA (adapted from TfNSW (2018)).

1. Determine the associated cost and benefit drivers and risks: These variables reflect potential risks and uncertainties that would impact on the CBA results BCR and NPV. All possible risks to a project should be identified and quantified to be able to adequately capture the uncertainty associated with the project. These variables are usually based on professional judgement. The candidate risk variables may include cost estimate, transport demand elasticity, travel time reliability, economic life of the asset, crash reduction rate, etc.
2. Specify plausible ranges of values and statistical distributions to all risk items: Statistical distributions can be:
    a. Discrete (e.g., Poisson, Binomial) or
    b. Continuous (e.g., Normal, Logistic, Weibull, Gamma, Beta, Rectangular).

    @Risk provides 71 mostly used statistical distributions. In practice, it is important to determine which distribution a variable may follow as the different specification will change the simulation result. If there are observations or historical data, the Distribution Fitting function in @Risk can be used to discover the most appropriate distributions. As a rule of thumb, the number of observations should be 30 as a minimum for use of the Distribution Fitting. If there are insufficient observations, professional judgement and guided assumptions can be used to decide the probability distribution.
3. Account for correlation between risk elements: When modelling associated cost and benefit drivers and risks, it is important to consider the impact of inter-relationships between risk items to generate accurate and sensible output. Failure to suitably account for correlation between project risks can result in artificially tight project cost and benefit distributions and an incorrect assessment of true project risk.
4. Decide on the simulation settings: Specify the number of simulations and number of iterations. @Risk allows the maximum number of simulation of 100 and the maximum number of iterations of 10,000. The selection of the settings is to balance the accuracy and simulation time. A normal simulation can be done within 1-2 minutes with an average modern computer thus the maximum number of iterations can be used in most situations.

5. Run the specified simulations. During the simulation, values are sampled at random from the input probability distributions of the risk items. These results are combined to obtain an outcome for each iteration. This process is repeated hundreds or thousands of times.
6. Generate the outputs: The result of a simulation is a probability distribution of possible outcomes for each output variable of interest. The resultant probability distribution of possible outcomes indicates not only what could happen, but also the likelihood of it happening. In the CBA, the most used simulation outputs are NPV and BCR. The simulation will calculate the mean, median and percentile values of the BCR and NPV. It will also be able to generate the distribution of the outputs including the probability of BCR≥1 or NPV≥0 that provide additional information on economic viability for decision making.
7. Check the simulation results: The full set of outputs from a simulation include the probability density, cumulative ascending and tornado charts. For each simulated output variable, it generates the minimum, maximum, mean, median, standard deviation, skewness, kurtosis and percentiles. The simulated output can also be readily fitted into a distribution. If the simulated results are strange, the user should check and revise the input specifications, and redo the simulation.

Note that the worked example in section A.2, and the case studies in sections A.3 and A.4, do not show all of the steps outlined above. As explained above, the discussion below illustrative.

In the discussion below, the results of the CBA without simulation are referred to as 'point estimates'.

A.2 Worked example

This section presents a worked example of a probabilistic CBA of a life jacket use campaign illustrating the use of @Risk simulation (TfNSW 2018).

Over the last 10 years, there were on average 17 fatalities annually on New South Wales' waterways, of which a large proportion was as a result of drownings which could have been prevented by wearing a lifejacket. The most common characteristic of the majority of the fatalities on waterways is the failure to wear a lifejacket. A lifejacket safety campaign was proposed to promote lifejacket wearing and to reduce drowning fatalities.

The target groups for the campaign are males aged 35-54. The campaign is aimed at reaching this demographic as they are the most over-represented group in recreational boating fatalities in New South Wales. The total cost of the campaign is estimated at $1,400,000 over one year. Of this, $1,100,000 is for the media cost covering the advertisements across channels such as television, print, radio, out of home and online/digital.

The remaining $300,000 is for administration, production costs and agency fees.

The CBA point estimate results are: NPV of $4.73 million and BCR of 4.4 (see Table 9 below).

A.2.1 Identify @Risk input variables

@Risk Input Variable 1: Fatality reduction

Statistical modelling shows that the preventable fatalities are 11.79 per annum without the campaign reduced to 10.98 with the campaign (see Table 8 below). The estimated preventable fatality reduction is subject to certain level of statistical confidence, which is set as the first input variable.

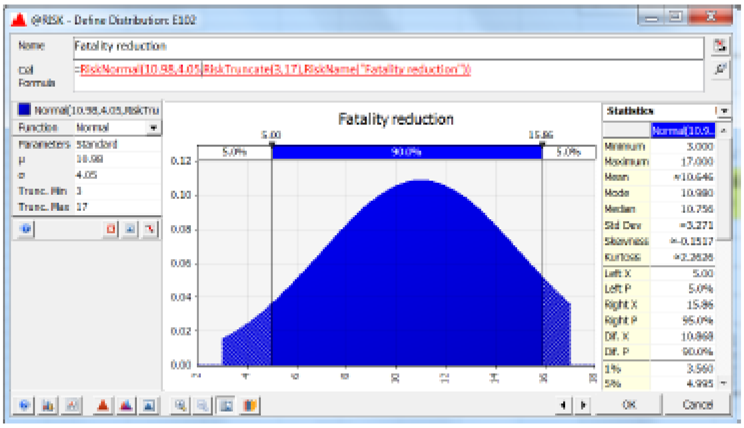
Table 8 Forecasting preventable fatalities in the base case and option

Financial year	Preventable fatalities Base Case: NO campaign	Preventable fatalities Option: With the campaign
2003/04	5	5
2004/05	5	5
2005/06	6	6
2006/07	8	8
2007/08	8	8
2008/09	9	9
2009/10	15	15
2010/11	6	6
2011/12	12	12
2012/13		17
2013/14		3
2014/15		10
2015/16 (forecast)	11.79	10.98 **@Risk Input Variable 1**

Source: TfNSW (2018)

The historical preventable fatality data from 2003/04 to 2014/15 roughly follow a normal distribution, with the standard deviation of 4.05, minimum value of 3 and maximum value of 17. As such, the @Risk input variable is specified as the normal distribution, STD 4.05 and truncated for the range of 3 to 17. This specification is shown in the Figure 9.

Figure 9 Probability distribution for risk input variable 1 – fatality reduction

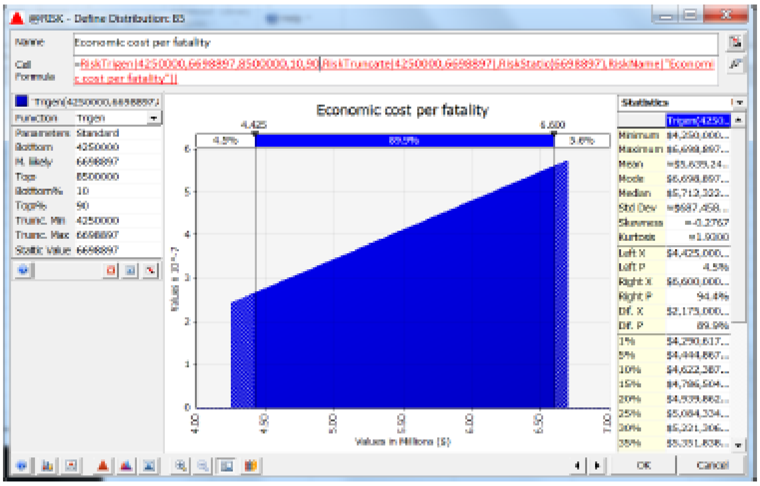


Source: TfNSW (2018)

@Risk Input Variable 2: Economic cost per fatality

The economic cost per drowning fatality is estimated based on the Willingness-To-Pay (WTP) approach. The TfNSW economic appraisal guidelines estimated the value at $6,698,897 as at 2014/15. The Commonwealth Better Regulation Office estimated the economic cost of a statistical life at $4,250,000. While the WTP value is used in the core CBA, it is reasonably assumed that the economic cost per drowning fatality is in the range of $4,250,000 to $6,698,897. In the @Risk, this is specified as shown in Figure 10. In effect, an average of the two numbers is used.

Figure 10 Probability distribution for risk input variable 2 – economic cost per fatality

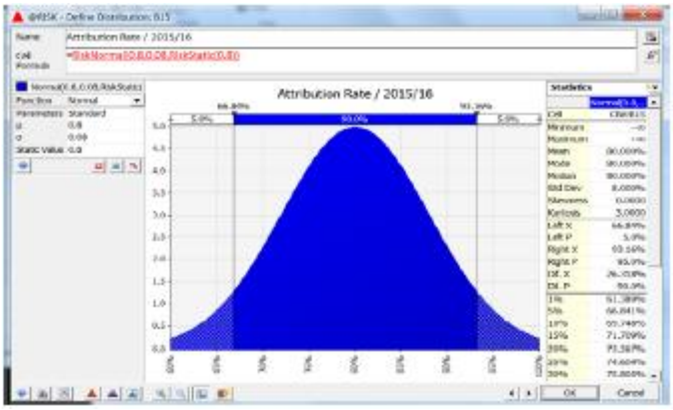


Source: TfNSW (2018)

@Risk Input Variable 3: Attribution rate

A statistical analysis was undertaken to estimate the fatality reduction attributable to the campaign. However, it was difficult to isolate the effect of the campaign and other factors. For example, fast rescue response could also reduce the drowning fatality. It was assumed that at least 80% drowning fatality could be attributed to the lifejacket wearing. This input variable is specified as a normal distribution as shown in Figure 11.

Figure 11 Probability distribution for risk input variable 3 – attribution rate

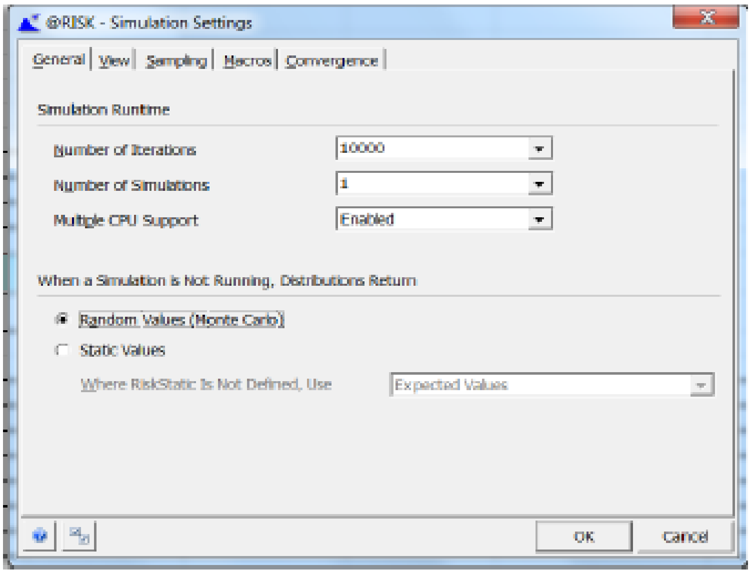


Source: TfNSW (2018)

A.2.2 Run @Risk Simulation for identified risk elements

In the Simulation Settings, specify the number of iterations and number of simulations (Figure 12). When a simulation is running, @Risk randomly draw values from the specified input variables. A typical simulation will run 1-2 minutes depending on model complexity, number of input variables and simulation specification.

Figure 12 Simulation settings input box



Source: TfNSW (2018)

The CBA will generate point estimates of PV Cost, PV Benefit, NPV and BCR as shown in Table 9 below. The purpose of @Risk analysis is to investigate how three input variables affect the outputs in terms of NPV and BCR.

Table 9 CBA point estimate summary results (7% discount rate)

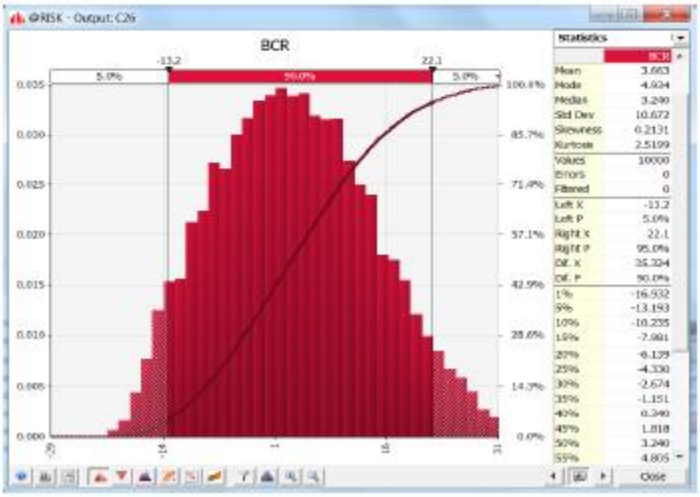
Item	Result
PV cost ($m)	1.40
PV benefit ($m)	6.13
NPV ($m)	4.73
BCR	4.40

Source: TfNSW (2018)

A.2.3 Check the simulation outputs

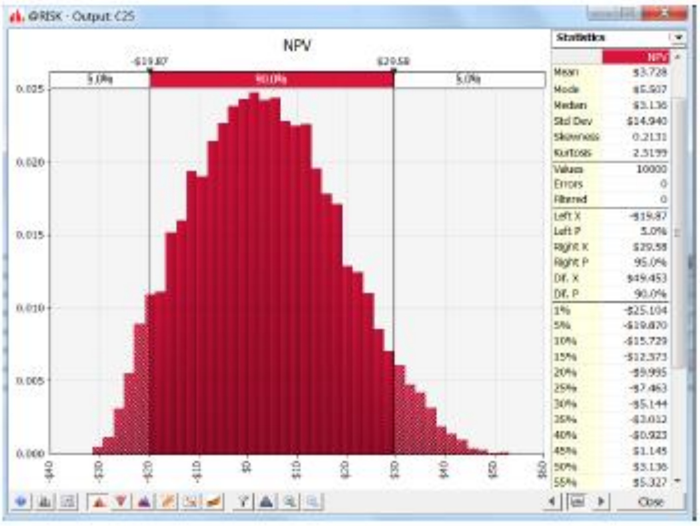
The simulation outputs are shown in Figure 13 and Figure 14. They show that the mean BCR is 3.66 and the median BCR is 3.24. The mean and median diverge a bit because the distribution is left-tilted. The probability of BCR ≤ 1 is 39% and BCR ≥ 1 is 61%, suggesting a certain risk that BCR will be less than 1 although the core BCR is 3.66. The NPV follows the same pattern, with the mean of $3.72m and median $3.14m. At 90% confidence level, the NPV ranges from -$19.87m to $29.58m. The same as BCR, the probability than NPV ≤ $0m is 39%.

Figure 13 BCR probability distribution output



Source: TfNSW (2018)

Figure 14 NPV probability distribution output



Source: TfNSW (2018)

The @Risk analysis provides a richness of possible outcome to assist decision making. In the worked example, the point estimates give a BCR of 3.66 and NPV of $3.72m, indicating the proposed campaign is economically viable. However, there is a 39% probability that the campaign will not be economically viable.

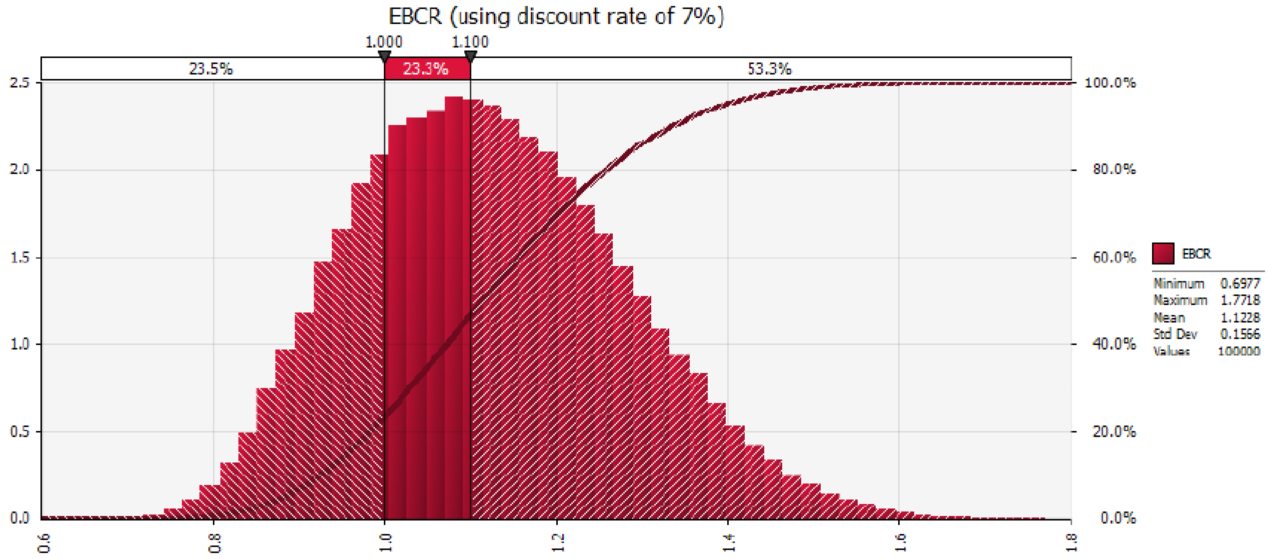
A.3 Case study 1: High speed rail initiative

Prakash and Mitchell (2015) reported on use of the results of the Australian Government high speed rail study (DIT 2013) to illustrate the potential outputs and the benefits of generating a probabilistic distribution of BCR. The DIT (2013) study reported a point estimate BCR of 1.1 using a 7% discount rate. Prakash and Mitchell took as inputs from the DIT (2013) report the probabilistic cost estimates and point estimate of benefits. It then postulated probability distributions for user benefits, operator benefits, externalities and residual values in order to generate a probability distribution for BCR.

Figure 15 shows from the simulation results the probability density and cumulative distribution function for the BCR using the 7% real discount rate. Prakash and Mitchell concluded that:

- The probability of the BCR being less than or equal to the value of 1.1 in the DIT (2013) report was 47%
- The BCR figure could be as low as approximately 0.7 if all risks are realised
- The likelihood of the BCR figure being less than the breakeven point of 1 was 23.5%.

Figure 15 High speed rail example — Probabilistic benefit cost ratio



Source: Prakash and Mitchell (2015)

A.4 Case study 2: Road and bus priority initiative

Tsai et al (2018) presents as a case study a road improvement project in an Australian capital city, involving road re-alignment and bus priority upgrades to improve traffic flow and road safety. The monetised project benefits include travel time savings, improved journey time reliability, reduced vehicle operating cost and reduced accident cost, and reported a point estimate BCR of 1.4.

The study identified three key risk factors:

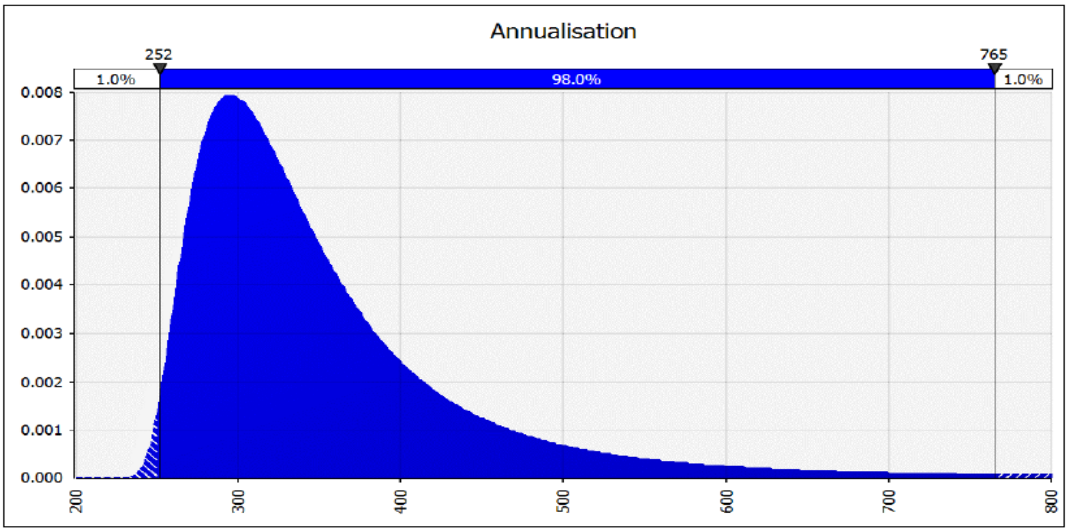
- Annualisation factor: The input probability distribution used is shown in Figure 16. Several considerations were taken into account in selecting this probability distribution:
  - The primary benefit of the project is reduced congestion. Reduced congestion benefit estimates were based on peak period demand modelling. So the lower bound of the annualisation factor was determined as the number of weekdays (excluding public holidays) in a year, at 252 days
  - Observed all-day traffic volume were 2.1 times higher than modelled volumes. The upper bound of the annualisation factor was 766 (the product of 365 days and 2.1)
  - Congestion outside of peak periods is lower, so weekend days make a lower contribution to annual benefits. The distribution will therefore be skewed to the left.

The above points, and use of the statistical distribution 'fit' procedure in the simulation software, suggested use of the Lognormal form shown in Figure 16. The distribution is skewed to the left, with the mean being 328.

- Capital costs: The preferred approach is to develop a capital cost probability distribution using professional quantity surveyors and cost estimators. For their investigation, Tsai et al. did not have access to such information. Instead they used indicative low and high cost estimates, and superimposed a normal probability distribution form on the range. Figure 17 shows the probability distribution used.

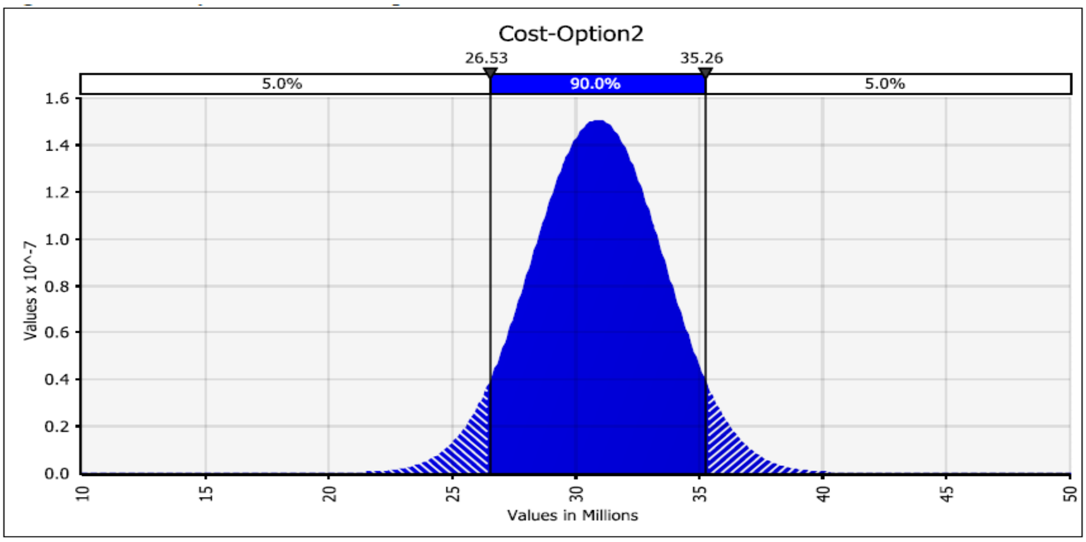
- Crash reduction rates: Using potential crash reduction factors from Austroads, and assuming a normal probability distribution form, the distribution shown in Figure 18 was used.

Figure 16 Input probability distribution — annualisation factor



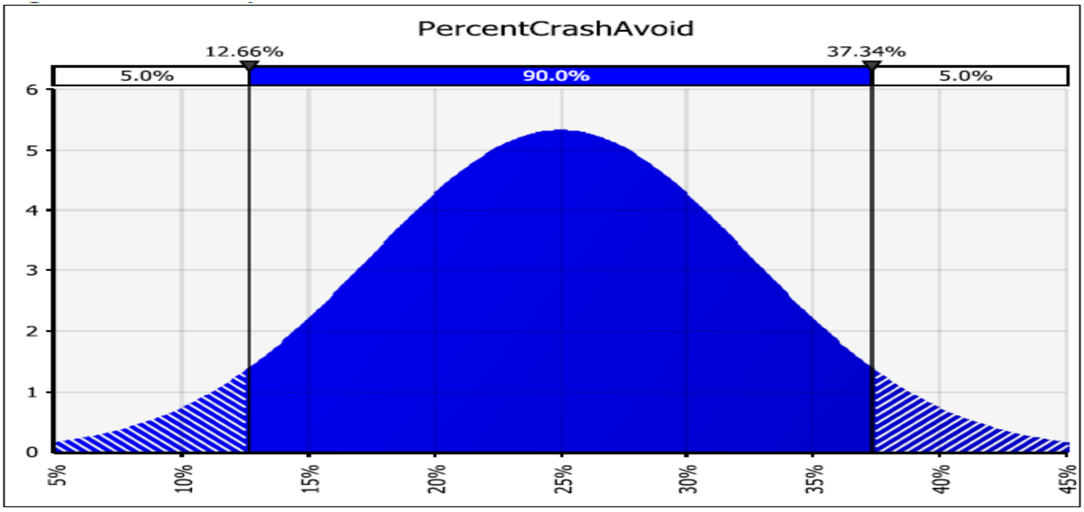
Source: Tsai et al (2018)

Figure 17 Input probability distribution — capital cost



Source: Tsai et al (2018)

Figure 18 Input probability distribution — crash reduction rate



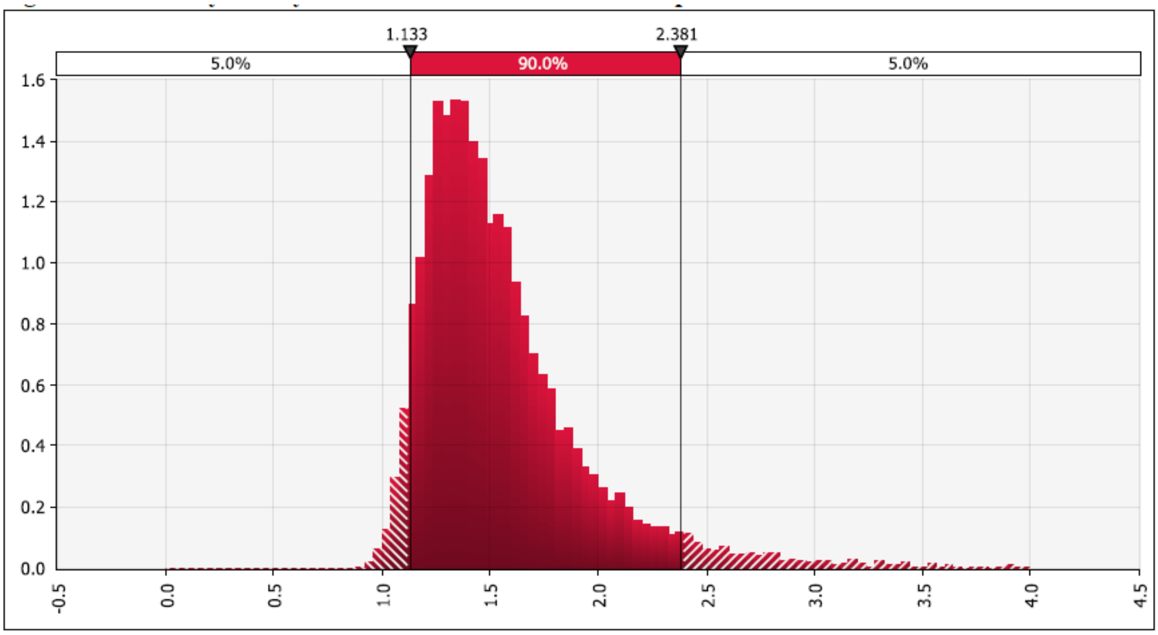
Source: Tsai et al (2018)

The study found there was no strong evidence suggesting the presence of correlation.

The simulation produced the BCR probability density function in Figure 19 and cumulative distribution in Figure 20:

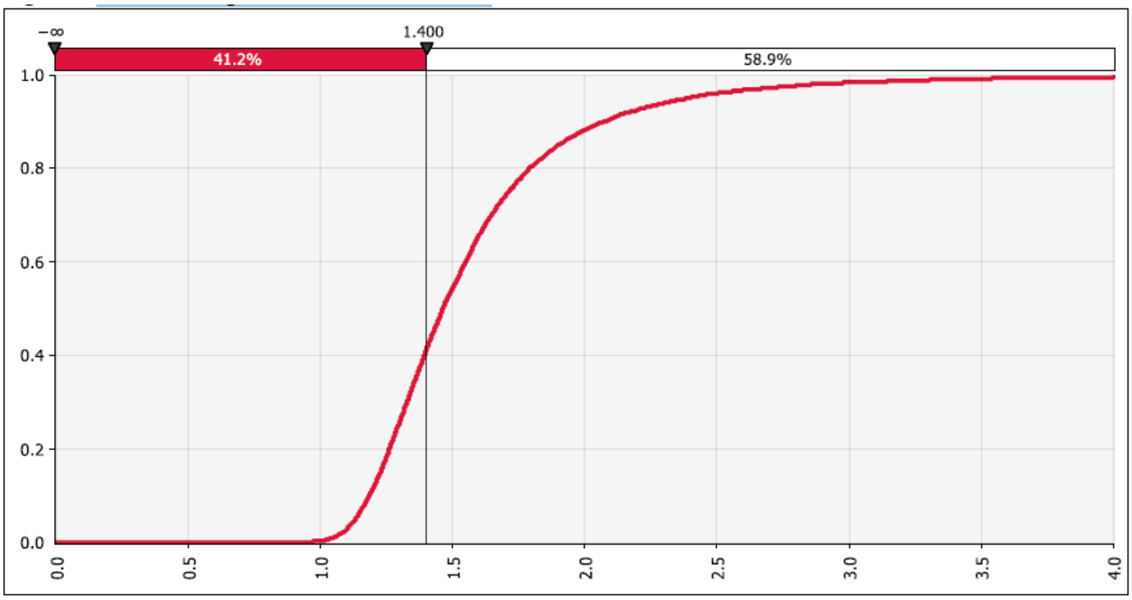
- The BCR was expected to be between 1.13 and 2.38 with a probability of 90% being within this range (Figure 19)
- The probability of the BCR less than the point BCR estimate of 1.4 was 41% (Figure 20)
- The probability of the BCR being less than 1.0 is minimal in this case, which suggests there is a very high likelihood that the project will generate net economic benefits, after taking account of variances in the identified risk factors.

Figure 19 Probability density function of BCR distribution



Source: Tsai et al (2018)

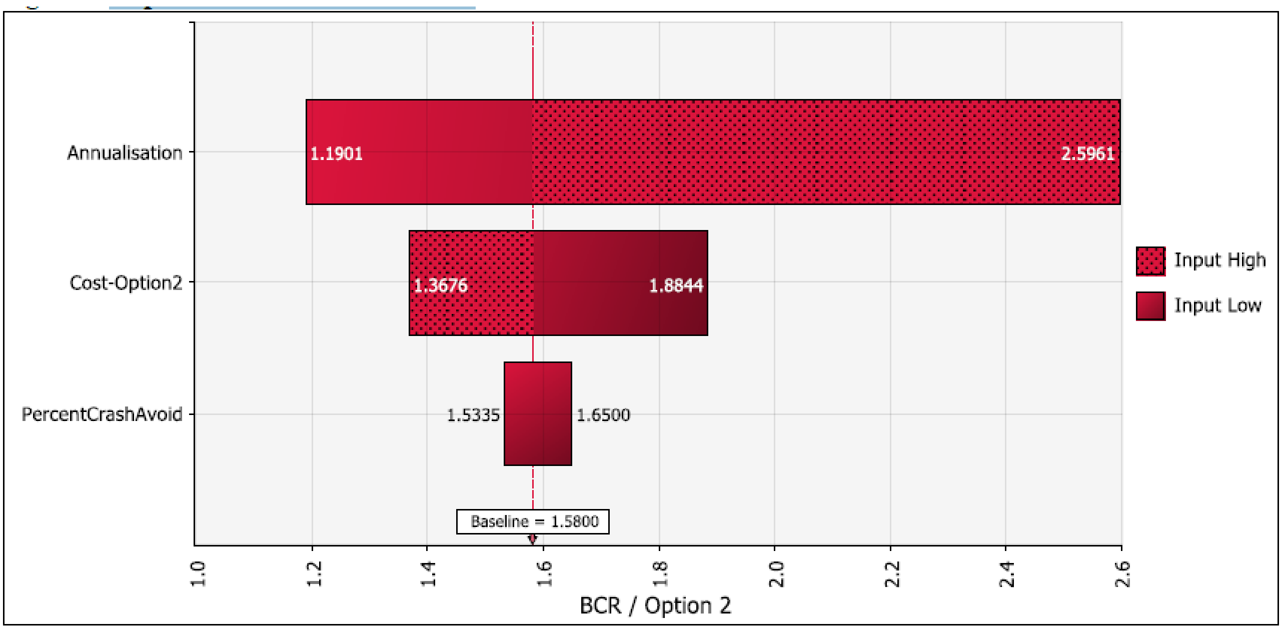
Figure 20 Cumulative probabilistic distribution of BCR



Source: Tsai et al (2018)

Tsai et al also assessed the impact of each risk factor on the overall results, as shown in Figure 21. This shows that the annualisation factor affects the BCR results most substantially. Note that that the three low estimates in Figure 21 for variation of individual factors are higher than the single low estimate in Figure 19 reflecting the combination of factors.

Figure 21 Impact of risk factors on BCR



Source: Tsai et al (2018)

A.5 Case study 3: Vehicle purchase feebate scheme

The New Zealand Ministry of Transport (2018) have used probabilistic CBA in its assessment of the vehicle purchase feebate scheme applied to the importation of light vehicles. The aim of the scheme is to contribute towards reductions in greenhouse gas emissions in road transport. The scheme involves payment of a fee by purchasers of emissions-intensive vehicles, with the fees then used to reward buyers of vehicles with zero or low carbon emissions.

Figure 22 shows the wide range of input variables for which a probability distribution was assigned in the assessment.

A Monte Carlo simulation was undertaken, the results of which are shown in Figure 23. The results of the simulation indicate that:

- The scheme is economically viable, with nearly the entire BCR distribution being > 1, and the NPV distribution being > 0
- The 90% confidence interval is 1.44 < BCR 4.22. That is, there is a 90% probability that the BCR will be between 1.44 and 4.22
- Similarly, there is a 90% probability that NPV will be between $111 million and $821 million.

A.6 Recommendations

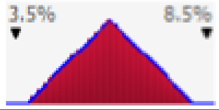
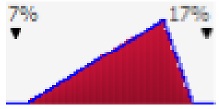
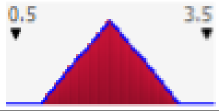
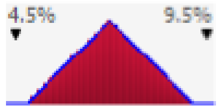
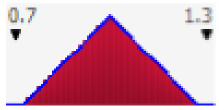
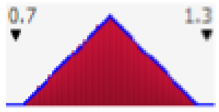
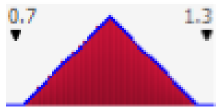
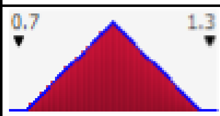
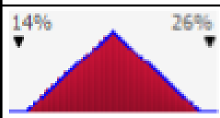
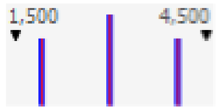
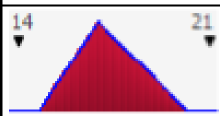
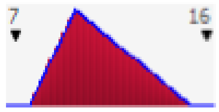
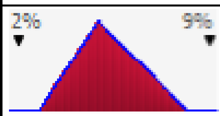
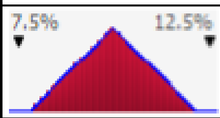
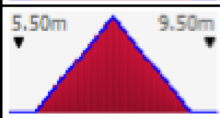
This appendix has provided an overview of the application of Monte Carlo simulation software to undertaking probabilistic cost-benefit analysis. It has summarised the key steps involved, illustrated with a worked example and summarised two case studies from the literature.

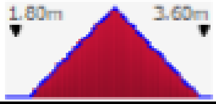
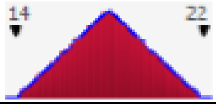
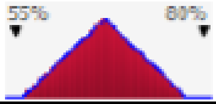
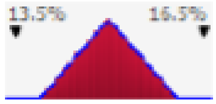
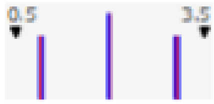
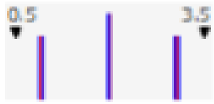
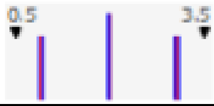
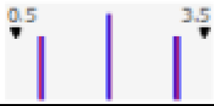
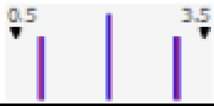
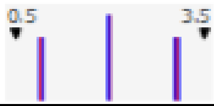
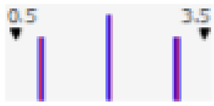
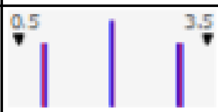
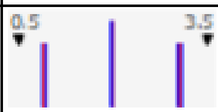
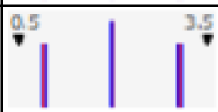
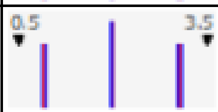
In practice, there appears to be limited detailed published material supporting the application of the methodology, especially on how to determine and assess correlation between input variables. Accordingly, caution is urged in the use of the methodology. It would be beneficial if:

- More research is undertaken on the shape of benefit probability distributions
- The methodology were applied on some large infrastructure projects where funds are available to fully apply the technique
- Applications are shared in the practice community to facilitate learning.

At this stage, full use of the method is likely to be most justified on the largest project proposals where funds are available for a detailed assessment, including consultation with risk assessment specialists with practical application experience. For other projects, the method could be used at the strategic assessment and rapid appraisal stages to provide an indicative guide to probability-based CBA results.

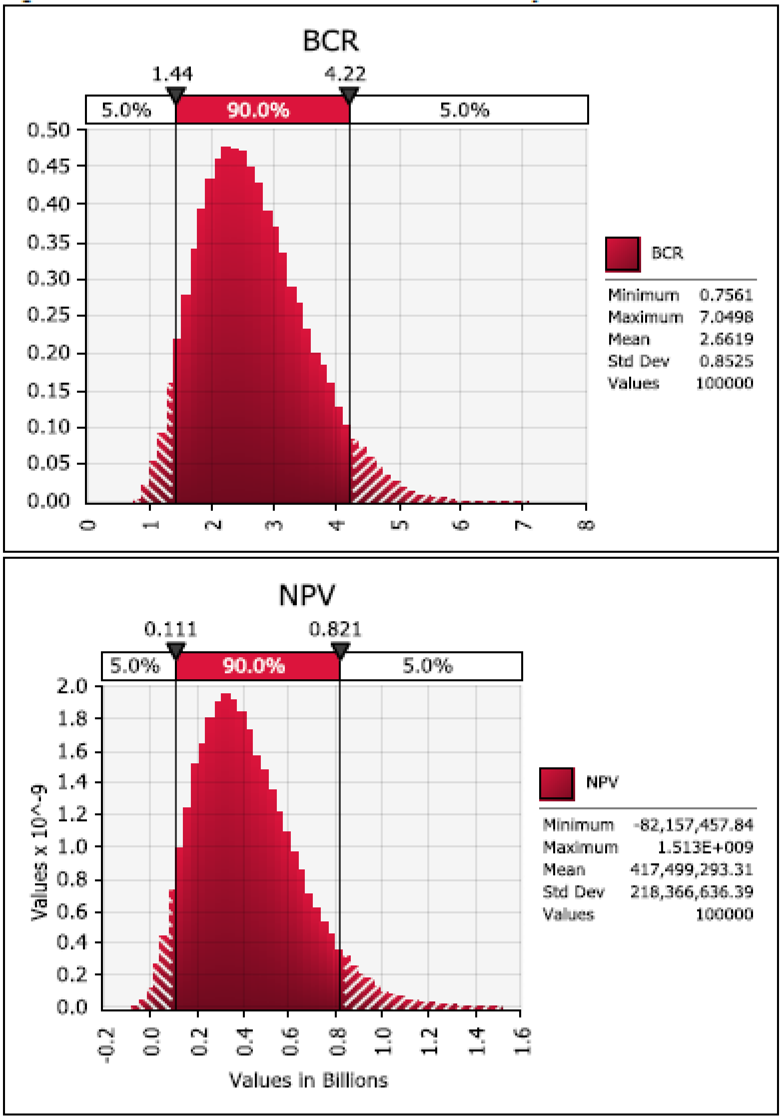
Figure 22 Input probability distributions

Name	Graph	Min	Mean	Max	5%	95%
Discount rate (policy)		4%	6%	8%	5%	7%
Discount rate (financial)		8.0%	12.9%	16.0%	9.6%	15.3%
Internalisation Fuel Cost		1.00155	2	2.99762	1.316209	2.683764
Annual % change in own-price elasticity of Evs		5%	7%	9%	6%	8%
Own-price elasticity of new vehicles		0.7503557	1	1.249219	0.8290557	1.170936
Cross-price elasticity of new vehicles		0.7507959	1	1.24974	0.8290527	1.17094
Own-price elasticity of used vehicles		0.7509511	1	1.248903	0.8290553	1.170941
Cross-price elasticity of used vehicles		0.7501878	1	1.249328	0.8290513	1.170939
Depreciation rate of used vehicles		15%	20%	25%	17%	23%
Import cost of used vehicles		$2,000	$3,000	$4,000	$2,000	$4,000
Average lifetime of new vehicles		15.01	17.33	19.99	15.71	19.13
Average lifetime of used vehicles		8.01	11.00	14.99	8.84	13.68
Substitution effect		3%	5%	8%	4%	7%
Rebound Effect		8%	10%	12%	9%	11%
Implementation cost (CAPEX)		$6,002,058	$7,500,000	$8,995,521	$6,474,316	$8,525,642

Name	Graph	Min	Mean	Max	5%	95%
Implementation cost (OPEX)		$2,002,009	$2,750,000	$3,497,369	$2,237,157	$3,262,823
ETS		14.40391	18	21.58871	15.5384	20.46157
ETS %		57%	67%	77%	60%	74%
GST		14%	15%	16%	14%	16%
Annual reduction in VKT		3%	4%	5%	3%	5%
Fuel Price		1	2	3	1	3
Carbon Price		1	2	3	1	3
Electricity Price		1	2	3	1	3
Annual change in the average purchase price of used vehicles		1	2	3	1	3
Annual change in the average purchase price of new vehicles		1	2	3	1	3
Average purchase price of used vehicles in base year		1	2	3	1	3
Average purchase price of new vehicles in base year		1	2	3	1	3
Average VKT driven by an ICE vehicle		1	2	3	1	3
Growth rate in used vehicle imports		1	2	3	1	3
Growth rate in new vehicle imports		1	2	3	1	3
Average VKT driven by an electric/hybrid vehicle		1	2	3	1	3

Source: New Zealand Ministry of Transport (2018)

Figure 23 **Probability distribution results for BCR and NPV**



Source: New Zealand Ministry of Transport (2018)

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