INFRASTRUCTURE AND
TRANSPORT MINISTERS

Australian Transport Assessment
and Planning Guidelines

T7 Risk and uncertainty assessment

October 2020

atap

Table of Contents

List of Figures and Tables

Risk and uncertainty assessment

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.

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

Tables 1 to 3 below (Austroads 2012) illustrate risk assessment using a qualitative category approach. Tables 1 and 2 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				
		Catastrophic	Major	Moderate	Minor	Insignificant
Level of likelihood	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   Categorised measures of risk (combining likelihood and consequence/impact) - example, 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
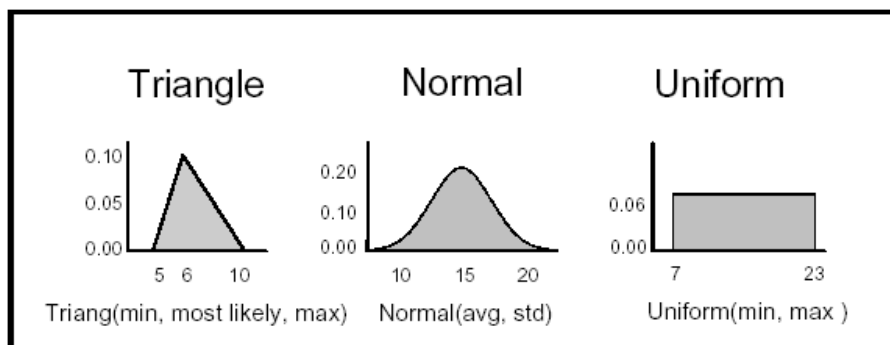
Source: Austroads (2012, citing FHWA 1998)

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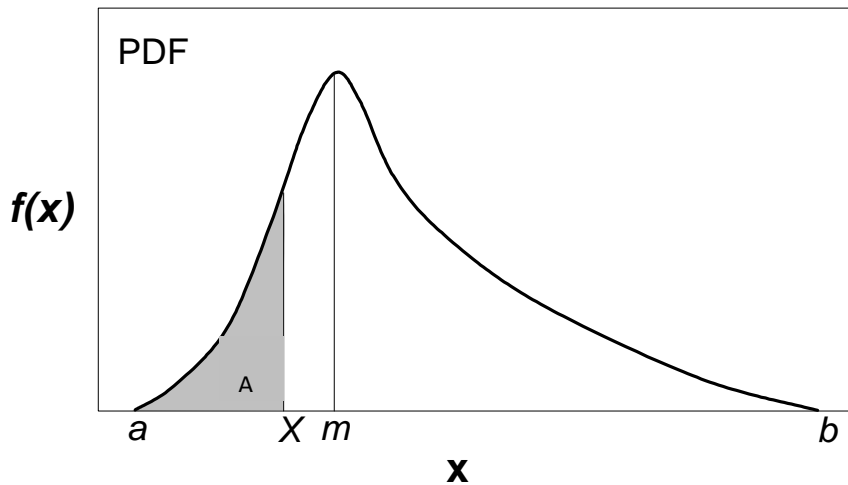
Source: Austroads (2012, citing Hardaker et al 1997)

- **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
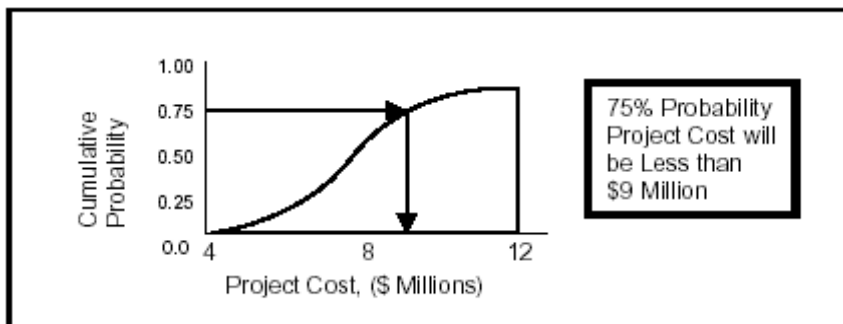
Source: Austroads (2012, citing FHWA 1998)

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

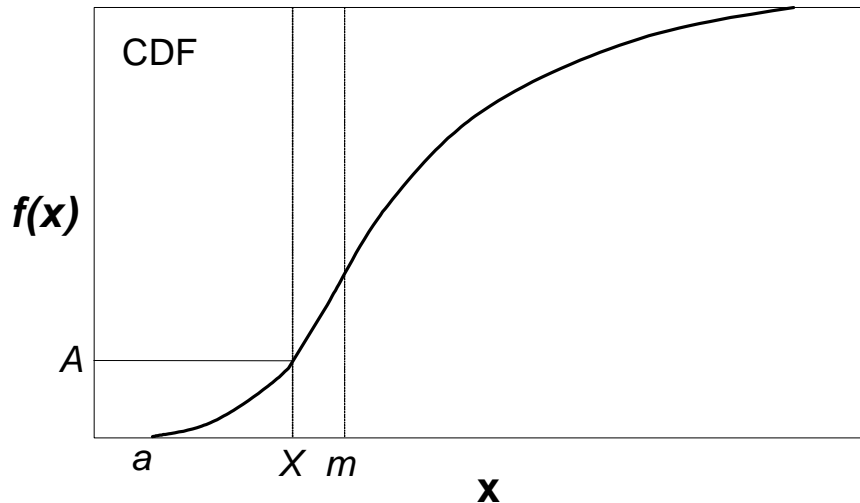In situations where a particular distribution function is unknown, a triangular distribution may be selected for simplicity. The triangular distribution function has the advantage that it can be fully specified using only three distinctive values of a distribution (the minimum value, the maximum value 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
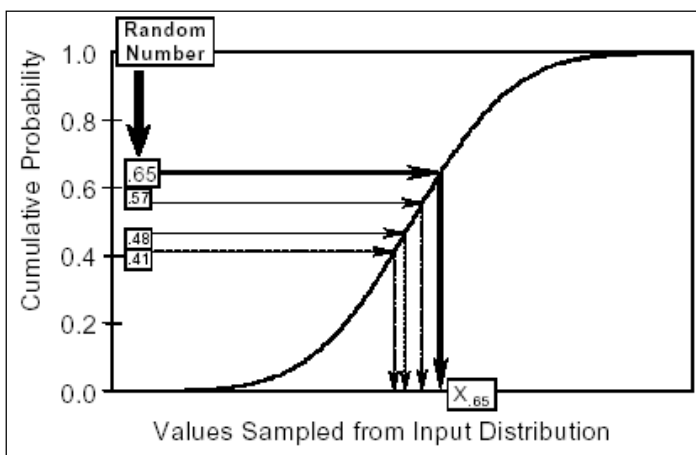
Source: Austroads (2012, citing FHWA 1998*)*

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
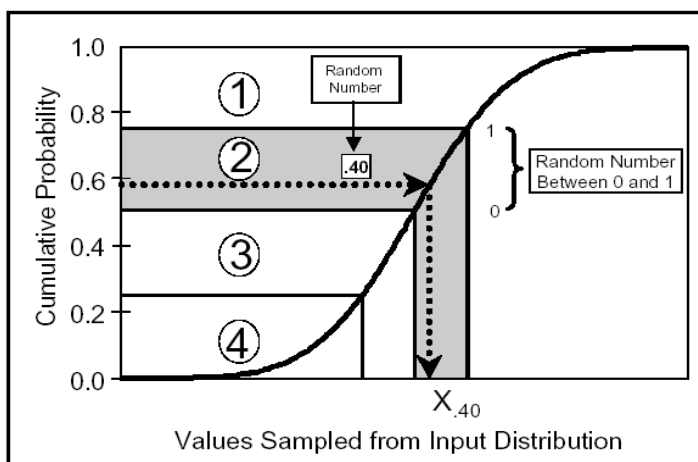
Source: Austroads (2012, citing FHWA 1998)

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:

- Decision variables: In a CBA, probability distributions would be produced for net present values (NPV) and benefit–cost ratios (BCR).

- Component variables: 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

Benefit Cost Ratio, BCR
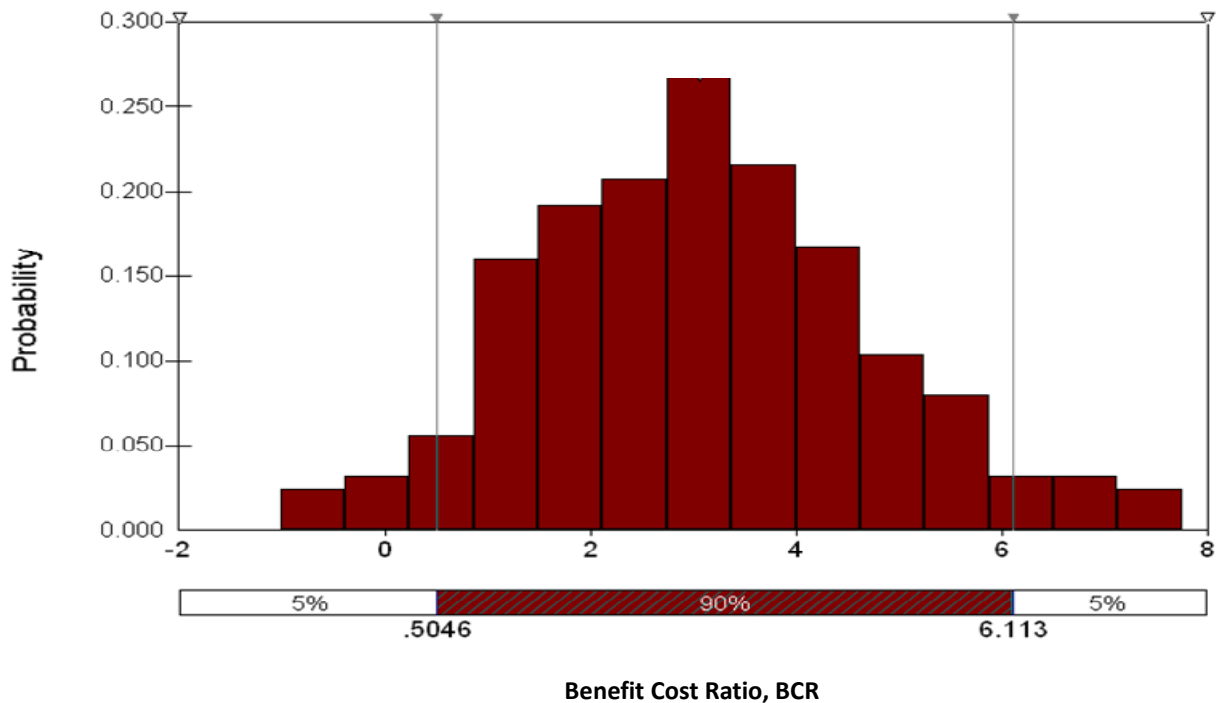
Source: Austroads 2012

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
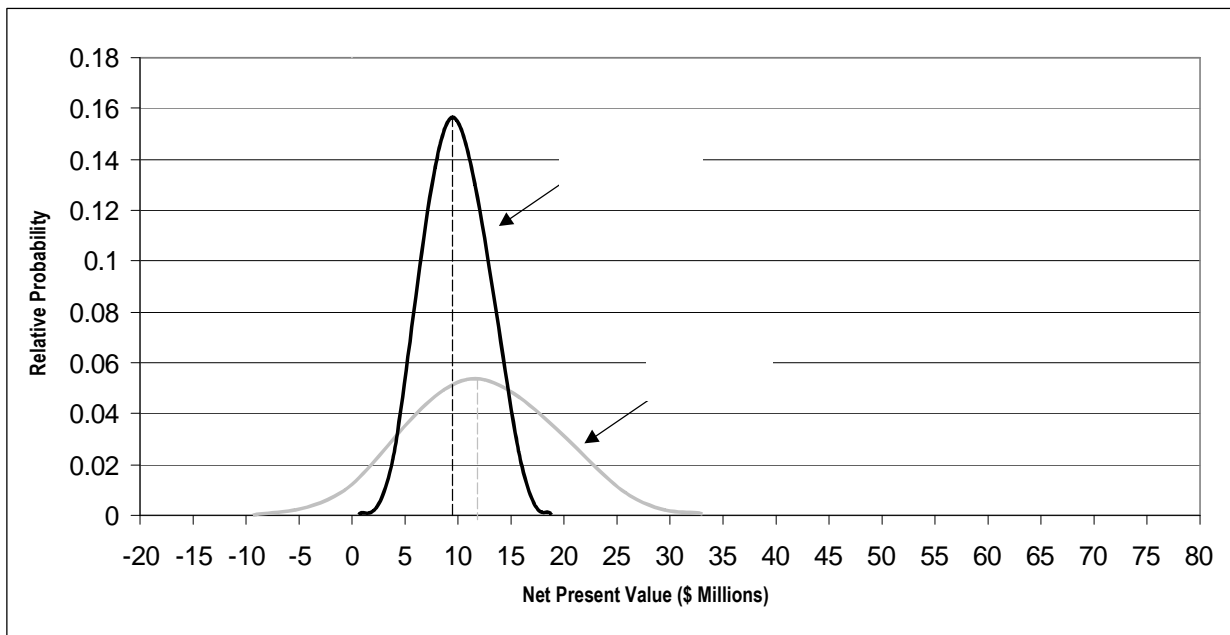
7. Scenario analysis

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.

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

NPV	Probability	Probability x NPV	Expected NPV
With an extra $50 spent to reduce the probability of failure			
$150	0.95	$142.5	
−$350	0.05	−$17.5	
			$125

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 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.

References

ATC 2006, National guidelines for transport system management, Australian Transport Council, Commonwealth of Australia

ATAP 2015, F0.1 Policy choices and system planning, Australian Transport Assessment and Planning Guidelines

Austroads 2002, Economic evaluation of road investment proposals: Risk analysis, AP-R203/02, Austroads, Sydney, NSW

Austroads 2012, Guide to Project Evaluation, Part 2: Project evaluation methodology, AGPE02-12, Austroads, Sydney, NSW

Belli, P, Anderson, J, Barnum, H, Dixon J & Tan, J 2001, Economic analysis of investment operations: analytical tools and practical applications, World Bank Institute, Washington DC, USA

FHWA 1998, Life-cycle cost analysis in pavement design: in search of better investment decisions, interim technical bulletin FHWA-SA-98-079 Federal Highway Administration, Washington DC, USA

FHWA 2003, Economic analysis primer, Office of Asset Management, Federal Highway Administration, Washington DC, USA

Hardaker, JB, Huirne, RBM & Anderson, JR 1997, Coping with risk in agriculture, CAB International, Wallingford, UK

IA 2018, Infrastructure Australia assessment framework, Infrastructure Australia, March