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Paper title: **Risk analysis in the evaluation of transport proposals**

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Abstract

Recent ARRB research from which this paper is drawn provides a framework for risk analysis in project evaluation. Project evaluation is frequently based on the assumption that input data values are known with certainty. In practice, however, many project variables have the potential to produce a range of different project outcomes to those estimated using a deterministic approach.

There are uncertainties in all stages of the project development cycle including uncertainty in the costs involved in planning, designing, constructing and operating transport infrastructure. These uncertainties represent project risks that have the potential of influencing the outcomes of projects. The project evaluation process should consider project uncertainty via the use of risk analysis techniques. This paper arises from research undertaken by ARRB Transport Research in developing the Austroads *Guide to Project Evaluation*, and provides an overview of risk analysis for the transport practitioner and its role in the project evaluation process.

A discussion of the definitions of risk and types of risks that arise within the project development process is provided, including an example illustrating key steps of the risk analysis method. A *Risk Explorer*™ tool that provides a learning environment to help the user identify, assess and analyse risks related to project evaluation is also introduced.

Introduction

Risk identification and analysis are critical elements of project risk management and project evaluation. Several uncertainty causing factors are often at work when projects are evaluated. It is important to identify a small set of key factors that most influence the risk distribution for a project. Recent ARRB research from which this paper is drawn provides a framework for risk analysis in project evaluation.

This research also suggests a series of guidelines to provide a starting point for practitioners with limited experience in risk analysis. To assist with this, the guidelines are supplemented with a software exploration tool (*Risk Explorer*™) used for identifying, assessing and analysing risks related to uncertain factors impacting on project benefits and costs.

There are uncertainties in all stages of the project development cycle including uncertainty in the costs involved in planning, designing, constructing and operating transport infrastructure. These uncertainties represent project risks that may result in outcomes different from those intended. Therefore, the project evaluation process would benefit from considering project uncertainty through the use of risk analysis techniques.

This paper looks at the benefits of using risk analysis within project evaluation, including a discussion of risk definitions and types of risks. There are many viewpoints of risk and each of them may emphasise alternative thinking and action. This paper examines selected viewpoints and proposes a simplifying (practical) unification that gets to the essence of risk. This essence is concerned with the need to develop a 'precautionary mode of thought and action'.

Risk management is a key aspect of the transport infrastructure investment process. It is important, therefore, that the transport practitioner be aware of the links between selected transport solutions, risk management and the precautionary principle. The essence of risk management is based on the view that there is an *association* but, also at the same time, a *distinction* between concepts such as 'risk' and 'uncertainty'. These fine line of the relationship between the two concepts can be resolved through,

- a focus on practical outcomes (which necessarily means consideration of potential consequences); and
- the nature of the hazard (which includes characteristics such as the level of uncertainty, ignorance and indeterminacy).

Risk in project evaluation

Evaluation is frequently based on the assumption that input data are deterministic, that is, their values are known with certainty. In practice, however, many project variables have the potential to produce a range of project benefits and costs which are different from those estimated using a deterministic approach. Rather than being treated as deterministic, these variables can be considered as probabilistic (or stochastic) variables using probability distributions rather than single ('crisp') values. In doing so, additional information is generated that can be used to improve decision making related to the understanding of the implications and prioritisation of project investments.

Cripwell (1992) notes that, by quantifying the risks of the key inputs to a forecast, risk assessment allows explicit recognition of those factors which are only implied in traditional estimates. Risk assessment also enhances the decision process by enabling decision makers to make use of the full extent of their knowledge and experience. It also enables the use of knowledge and experience of others who may have an interest in the decision process. For example, Lewis (1995) wrote that risk analysis can encompass virtually any reasoned view, albeit with different degrees of probability. By encompassing all perceivable outcomes, risk analysis can assist in avoiding disputes about who is right and who is wrong, or a presumption of a 'best' or the 'most accurate' forecast.

Overall, risk analysis provides many benefits including improved project evaluation. In addition, it can assist in avoiding misunderstandings and misinterpretations of available information provided to decision makers and the public (Austroads, 2002).

On the definitions of risk

As noted above there are many viewpoints on risk. This section examines selected viewpoints so the reader is aware of the depth and breadth of the context within which risk concepts arise.

As a starting point the paper looks at the definitions of 'risk' and 'uncertainty'. These are terms that are used frequently, often interchangeably, and have been well discussed in economics for decades without any real consensus on their differences. To some there is an important difference in their meaning – to others, it does not matter and terms are used more fluidly.

It is proposed in this paper that despite different definitions of concepts (in particular the meaning of uncertainty), that the basic understanding of the purpose of risk analysis is the same. The purpose here is not to attempt, once and for all, to find a definition of risk and uncertainty that suits everyone, but rather to find a simplifying workable meaning (or essence) for the purpose of evaluating risk in project evaluation.

Through an exploration of a range of definitions of risk and uncertainty, it was found that viewpoints on the issue can be split into several categories, as follows:

Viewpoint 1: This viewpoint regards risk and uncertainty as distinct concepts. This distinction runs through economic literature from the early work of Frank Knight (1921), who argued that 'risk' was concerned with definable variables, while 'uncertainty' relates to some value that is undefinable in a statistical or probabilistic sense.

The same viewpoint is also found in the work of many others. The distinction is also used in the business of insurance, to define between what is insurable and what is not. The reasoning for this point of view is as follows:

- A 'riskless' or 'certain' variable is one that has the same value in every state of nature. There is perfect information; all relevant information is known.
- 'Risk' arises where it is possible to make a statistical assessment of probability. Information is only partial; some of the relevant information is stochastic.
- 'Uncertainty' is a situation where it is not possible to attach a probability to the likelihood of an occurrence of an event, that is, variables have *unknowable* probabilities. In the words of Keynes (1937), this means "there is no scientific basis on which to form any

calculable probability whatsoever". Information is incomplete; some of the relevant information is missing.

Viewpoint 2: This viewpoint regards distinguishing between risk and uncertainty as not useful, particularly for the purpose of 'real world' economics. In contrast to Knight's view, many economists argue that risk and uncertainty are one and the same thing. This alternative position is based on a view that uncertainty is a problem of 'knowledge' of the relevant probabilities, not of their existence (Fonseca and Ussher, 2004). This means that if a practitioner knows that a particular variable exists, it can be assigned some kind of probability distribution, which is a subjective expression of a belief that may or may not be consistent with different perceptions of reality in the world.

It is also argued that risk as described by Knight (where mathematical probabilities are 'known') is the exception, and is only found in controlled scenarios or repeatable experiments, such as gambling. This second viewpoint suggests that defining risk in this way doesn't offer much to economic decision making in the 'real world' where situations are unique and alternatives are not fully understood.

In any case, the analysis of projects under uncertainty requires the specification, implicit or otherwise, of probability distributions for the variables of interest (Quiggin in BTRE 2004). Raftery (1994) explains that uncertainty simply represents a 'greater unknown' than a quantified risk attached to the same event. Probabilities for uncertain variables may be developed in one of two general ways. First, they can be built up from observations of the relative frequency of the various events that characterise those variables. Alternatively, they may represent the informed judgement of those undertaking the analysis (Quiggin in BTRE 2004).

Viewpoint 3: This viewpoint holds that risk is uncertainty arising from the combination of the likelihood of an event and the consequence of an event. This view extends viewpoint 2 above by noting that defining 'uncertain' as something that is indescribable is not helpful, given that the objective distributions defined by Knight as risk are rarely 'known' in real world economics.

Hardaker *et al* (1997) describe uncertainty as a state of imperfect knowledge, in comparison to perfect knowledge being a state of certainty. Risk is a state of uncertainty where you *have some reason to be interested in the outcome* (because there is a potential for a loss or gain). The following definitions of risk are examples of this approach:

- "The chance of something happening that will impact on objectives, measured in terms of consequence and likelihood" (Standards Australia/Standards New Zealand, 1999).
- "(Risk) is a situation where there is potential for realisation of unwanted consequences of an event" (Rowe 1977).
- "The likelihood of events, the nature of consequences, or both, are uncertain" (Malherbe et al, 1981).

More recently, Wynne (1996) has examined risk from four different perspectives that can be characterized by the key words – risk, uncertainty, ignorance and indeterminacy. These can be explained by considering a situation that can be described by a set of parameters that are stochastic in nature (i.e. can be described by some probability distribution function). The four perspectives discussed by Wynne can be understood as follows. First, Wynne describes 'risk' as a situation where we know the parameters and the 'odds' (or distribution functions).

Second, Wynne describes 'uncertainty' as a situation where we know only the parameters but the probability functions are unknown. Third, Wynne describes 'ignorance' as a situation where we do not know what the parameters are. Fourth, Wynne describes 'indeterminacy' as a situation where everything is open ended.

There are other viewpoints that can inform our understanding of risk. There is insufficient space in this paper to examine them in detail so they will simply be noted so that the reader is aware of the breadth and depth of perspectives that may need to be considered. In simple terms, risk can be understood from a number of perspectives. Three examples follow. First, a perspective based on psychology would examine the cognitive structures of risk and would be interested in the individual perceptions of what constitutes a hazard. In some cases these hazards may not be real (from a particular psychological viewpoint) but could be conceived as 'wildcards'. Second, a collective perspective of risk may be informed by cultural theory and the political structure of risk. Such a perspective may focus on political negotiation, governance and institutional responses. Third, a systems perspective may focus on how problems are structured (for example from a disciplinary or inter-disciplinary perspective) and explore how policy making process arise within such domains. Each of these different viewpoints may elect to define risk in different ways.

Towards a common understanding

The different viewpoints above demonstrate alternative ways of making sense of risk. However, there is a common strand of understanding where risk is understood in terms of uncertainty, consequences and likelihood of an event. The previous discussion has shown that making a hard distinction between risk and uncertainty does not provide additional insight to the practical aspects of economic decision making (for example, relating to transport investments). It does, however, deflect attention away from the real purpose of evaluating risk: identifying and examining the consequence and likelihood of the occurrence of events. All viewpoints result in describing a possible outcome/occurrence/event/consequence by its likelihood/probability/chance of happening, no matter how the concepts are framed.

Figure 1 below illustrates in a schematic way, these different viewpoints and the essence of risk as proposed in this paper.

Types of risk

The assessment of risk can be *subjective* or *objective*. The range of probabilities for an outcome may be determined empirically by using observations, statistical data, or previous experience. This is similar to a situation of flipping a coin, where you are uncertain what the result will be, but based on statistical knowledge, you know the probability of a head facing up is 0.5. If, however, there is a lack of quantifiable information to work with, the situation is more uncertain. Deciding on the probability of different outcomes becomes subjective, and the decision maker has to rely on an informed opinion instead of data, to form the range of probabilities.

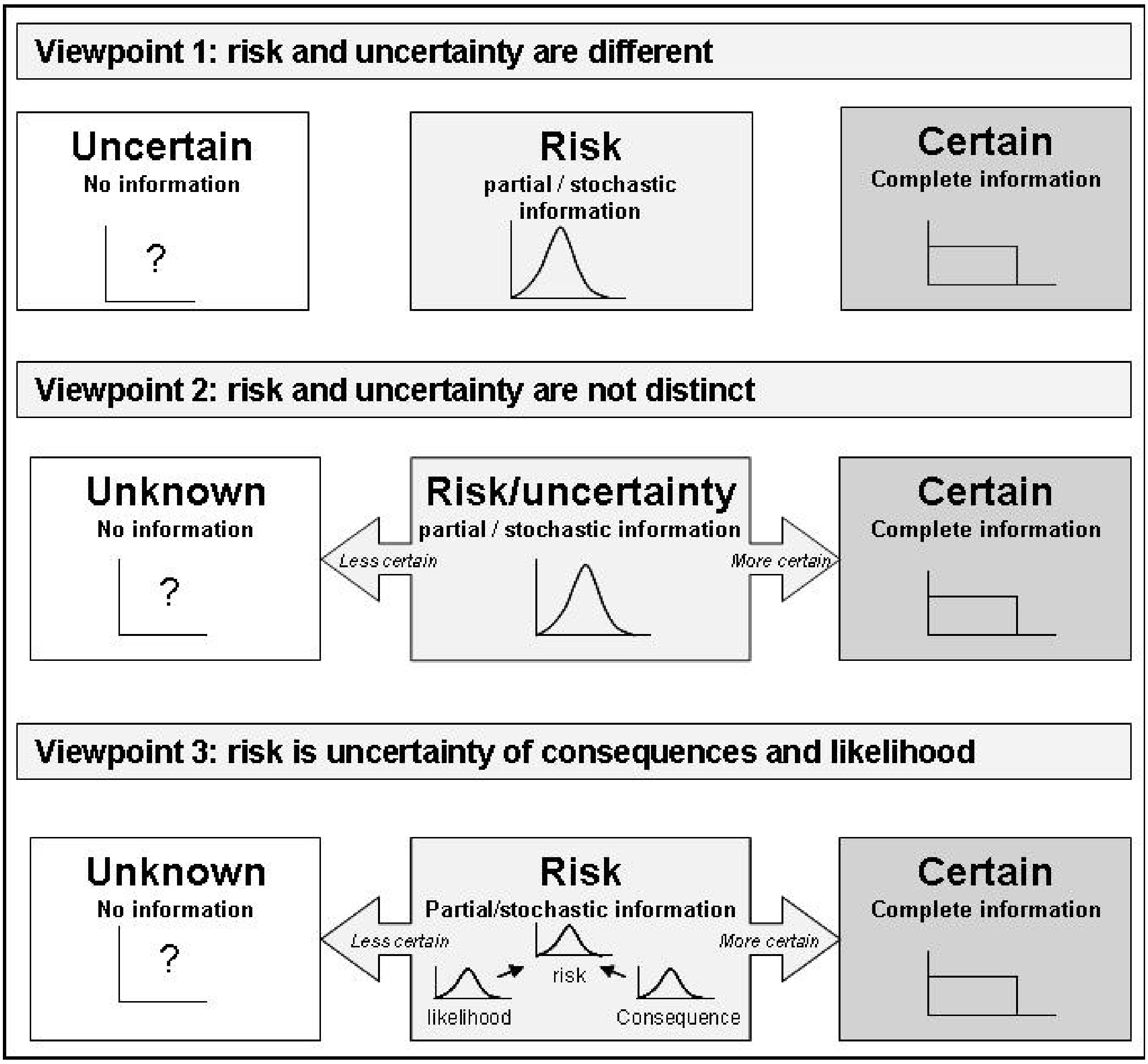

Figure 1 Diagrammatic representation of various thinking on risk and uncertainty

Different terms are used in the literature to describe various types of risk. BTRE (2004) refers to two main types of risk called *pure risk* and *downside risk*. Pure risk is described as the variability of a random variable about a mean value, commonly split into *systematic* and *idiosyncratic* categories of risk. Idiosyncratic risk is explained as random variation of an uncertain variable, which is likely to be small and can be *ignored* for practical purposes. Systematic risk is risk arising from project benefits being correlated with each other or with movements in the economy as a whole. However, it has been found that there is little to be gained from detailed consideration of systematic risk in project evaluation, as the adjustment estimated is likely to be small (BTRE, 2004). However, it may be good practice for the practitioner to consider systematic risk and understand it as part of the evaluation process before it is dismissed from the analysis[1]. The second type of risk (downside risk), normally results from over-optimistic forecasts, meaning that the probability of a below-forecast outcome is greater than for an above-forecast outcome. Efforts should be mostly concentrated

[1] The Risk Explorer Tutorial developed for Part 2 of the Guide has been designed to assist the practitioner in considering all types of risk related to project evaluation.

on identifying and assessing the complete range of possibilities to *eliminate* downside risk related to project evaluation decisions.

Risk analysis in project evaluation

The aim of the work reported in this paper on risk analysis is to make the practitioner aware of the tendency to produce over-optimistic forecasts for projects. Practitioners should investigate and examine all input variables that may contribute to project risk to gain a better understanding of possible outcomes and their probabilities of occurrence. The inclusion of risk in evaluation leads to better forecasting of project outcomes, better understanding of the risks involved with projects, and a stronger base of information for project selection.

Risk analysis in project evaluation is part of a project's wider risk management process. Risk management is an iterative process, as shown in Figure 2. The key steps in a risk management process are:

1. *Risk identification:* Identification is the process of identifying variables causing uncertainty, both internal and external to a project. Relatively 'standard' lists of factors or variables can be identified as the key sources of uncertainty in the evaluation of projects. For example, the main sources of uncertainty for transport project evaluation come from:
   - Traffic (demand) forecasting and network uncertainties that affect the outcome *benefits* of a project. User effects are closely linked to changes in traffic levels and composition, vehicle operating costs (VOC), travel time savings (TT), accident costs and other 'external' costs such as environmental and congestion costs. Variables related to estimating, forecasting and assigning network traffic are important determinants, as well as sources of uncertainty, in estimating user effects.
   - Construction cost uncertainties that affect the *cost* of a project. The cost of a project can be underestimated if risks are not identified and managed, and unfavourable outcomes eventuate. Environmental and planning, land and property, earthworks, engineering costs and services issues all present elements of risk to project evaluation.

   Lack of information about a site or underestimating the resource requirements of a project (such as time) can severely impact on project costs. Investigating projects thoroughly reduces the probability of cost blowouts. However, a balance needs to be struck between the costs of investigations and the benefits resulting from such investigations.

   It is necessary to consider uncertainty in all phases of project development and management. For example, at the planning phase, issues relating to environmental factors (such as ground conditions for example) may influence the design process.

2. *Risk analysis:* Analysis involves the quantification and analysis of risk-bearing uncertain factors. It provides the information necessary to determine the *likelihood* and *consequences* (loss or additional benefit) that could result from the identified risks. Spreadsheet-based applications for analysing risk are practical. Simulation techniques (such as Monte Carlo analysis) are a popular approach in analysing overall project risk comprehensively.

3. *Risk evaluation:* Evaluation involves comparing the level of risk found during analysis with set criteria to judge the economic viability of the project. Other risk criteria may also be used depending on the particular decision context, for example, relating to project

sustainability considerations. Risk evaluation aims to determine whether a project should proceed (or perhaps which option should proceed), whether risk treatment is required, and ranking risks for treatment. This gives the decision maker information to enable them to adopt a considered response in advance of a deviation from the expected value of an uncertain factor occurring.

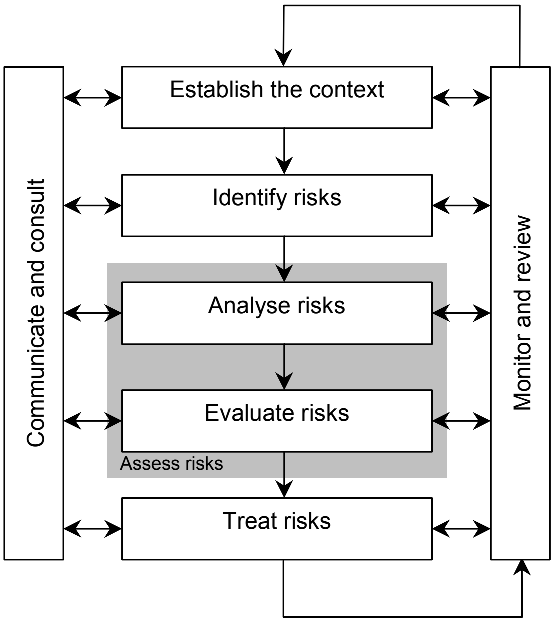

Figure 2 Risk management process

The output of risk analysis

The output from a quantitative risk analysis is a probability distribution that describes the range of possible outcomes along with a probability weighting of occurrence. Figure 3 is an example of a histogram showing the possible range of BCR values that could occur and the estimated probability of each value occurring. This histogram shows that the BCR is most likely to be around 1.5. However, there is a possibility, albeit less likely, that the BCR could be as high as 2 or as low as 1.2. For some projects, this level of risk may be acceptable. This information should be then used to understand which variable most effects the BCR and look at what can be done to prevent the BCR dropping to an unacceptable value.

Risk analysis assists in the choice between alternative projects by producing valuable information on the probability of success and failure. Decision makers must still decide which project option to pursue (and this will be influenced by their risk aversion in addition to other decision criteria).

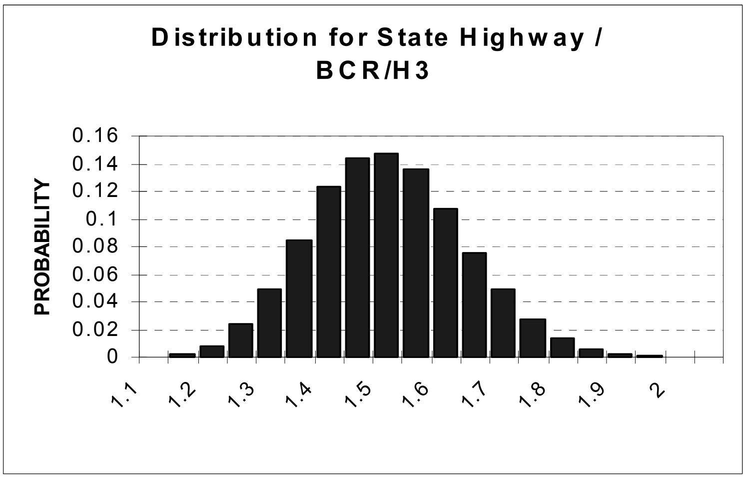

Figure 3 Example of output from risk analysis

Development of a risk analysis tool

This section of the paper describes the development of a risk explorer software tool. To perform risk analysis we require the use of analytical techniques and tools which may include user-designed spreadsheet calculations, or more advanced software functions. The tutorial tool (*Risk Explorer*) illustrates both approaches using an illustrative Excel based model and the use of third-party software from Palisade called *@Risk*. In doing so, additional information is generated that can be used to improve decision making related to the prioritisation of project investments.

The *Risk Explorer* tool provides a learning environment to help the user identify, assess and analyse risks related to project design and construction. *@Risk* is then used to generate probability distributions for uncertain variables in project evaluation. The *Risk Explorer* is intended as a tutorial and exploration tool only – it is not a generic risk evaluation tool. The tool is intended only to illustrate different approaches so that the practitioner can implement their own risk evaluation system using a simulation and analysis software package such as *@Risk*.

The *Risk Explorer* tool provides the following functionality:

- Identification of variables of interest. The user is prompted by a list of common variables effecting transport project benefits and costs. Additional variables can also be identified by the user to incorporate risks that may be particular to that project.

- Qualitative analysis and ranking of variables as low, medium or high in the judged effect that a variable could have on the benefits or costs of a project. The tool provides descriptions of low, medium and high ratings to assist the user to assign an applicable rating.

- Quantification of the nature of the uncertainty through distribution functions. Variables ranked as having a high risk can be described through distribution functions (triangular, normal, binomial, gamma, poisson, discrete or uniform). The user inputs to the *Risk Explorer* a distribution that describes the spread of possible values for that variable, and the associated probability of those values occurring. The other variables, selected as low or medium, are still valuable as they provide a record of the systematic analysis undertaken and choices made by the analyst.

- Simulation using the Palisade *@Risk* software package. The distributions are recorded in the *Risk Explorer* in the format of an equation used in *@Risk.* The user, by way of a spreadsheet internal to the *Risk Explorer*, can then use those equations to formulate their own calculations to be simulated using *@Risk*. *@Risk* generates probability distributions for selected output variables used in project evaluation.

An Example illustrating key steps of the risk analysis method

This example demonstrates how risk analysis (and the *Risk Explorer* tool) can be used to help make decisions about significant risks which are likely to influence the economic outcome of a project. It also illustrates the extent to which risk analysis can provide additional information for each project, and assists in prioritisation of project investments.

The example is about the duplication of a 1.5 km of state highway by a state road authority. This project is the second of four projects that is to be compared by decision makers for inclusion in an investment program. In this context, risk analysis is seen as providing decision makers with additional information allowing them to compare and make trade-offs between projects which will aid in the choice of which of the ‘marginal’ projects to fund.

The results of an economic evaluation of the four projects are set out in Table 1. This table summarises the evaluation result (i.e. project benefit-cost ratio), which is normally presented to policy makers to guide their project investment allocations.

Table 1 Economic evaluation (BCR) of four projects

Project	BCR
Project 1	4.17
Project 2	4.56
Project 3	0.85
Project 4	1.54

The *Risk Explorer* tool is used to assist in the identification of ‘risky’ variables. The cost and benefit variables, shown in the left column of Table 2, are selected from representative lists in the *Risk Explorer* as having relevance for this project.

A level of risk is then assigned to each of the variables that have been selected. This process allows the user to consider the level of ‘riskiness’ of the factor/variable under consideration. By considering the descriptions of risk as ‘high’, ‘medium’ or ‘low’, the user selects a risk level rating for each uncertain factor. A brief comment on the reasoning behind the variable selection and the assigning of risk levels is shown in Table 3.

The next step in the process is to consider the effects of the ‘high’ risk factors more closely. Three factors (as shown in column one in Table 2) are examined more closely and quantified to provide the data required to perform the risk analysis. For this example, each variable is defined as a triangular distribution within the *Risk Explorer* software. Minimum, most likely and maximum values for each variable are defined as shown in Table 2. A spreadsheet within *Risk Explorer* is then used to set up equations for simulation using the *@Risk* software package.

Table 2 Quantification (data generation) of 'high' risk variables

Variable	Value	Project A
Traffic growth (% per year)	Minimum	2
	Most likely	2.5
	Maximum	3
Traffic composition (%CV)	Minimum	6
	Most likely	8
	Maximum	10
Construction Costs($000)	Minimum	3,045
	Most likely	3,500
	Maximum	4,025

Table 3 Selected variables and risk ratings obtained

Variable	Reasoning	Analysis (summary)	Rating
Age of data source	The project team have noted that some of the data used to set up the project base case is now several years old.	After further consideration it was decided that the age of the data source was acceptable and posed little risk to project benefits.	**Low risk**
Other future projects	A possible future project is another arterial road within the same corridor that could erode the benefits of this project.	Proposed nearby arterial road may not proceed. Further modelling tests indicated that if it proceeds, the traffic flows on the project road will have only a small effect on this road.	**Medium risk**
Traffic growth	Based on a number of factors, the accuracy of the traffic growth projections can be considered a significant uncertainty.	For this area, it is worth factoring in some uncertainty in traffic growth rates.	**High risk**
Traffic composition	Assumptions made about traffic composition make this an uncertain variable worth considering further.	Linked to traffic growth, it is also worth factoring in the effects of an uncertain traffic composition for the project.	**High risk**
Identification of environmental risks	There are concerns for the ecological effects of the project on two rare plant species in the general area.	The two rare plant species were found in a thorough investigation of the area. All environmental issues in the area are well defined and understood.	**Medium risk**
Physical location (remoteness, access to site)	Similar projects in the area have experienced some difficulty with the location.	Learnings from previous projects in the area have allowed these issues to be dealt with, leaving only a low risk of these factors greatly varying project cost.	**Low risk**
Project construction costs	Due to political factors, the timelines set for this project will impact on project construction costs.	The construction cost may be a high risk due to the speed of construction required, which places additional pressure on project costs.	**High risk**

The results obtained are illustrated in Figure 4, which indicates that for Project 2, while the average (deterministic) BCR is evaluated at around 4.5, risk analysis estimates that there is a possibility for it to vary from as low as 1.7 to as high as 7.3.

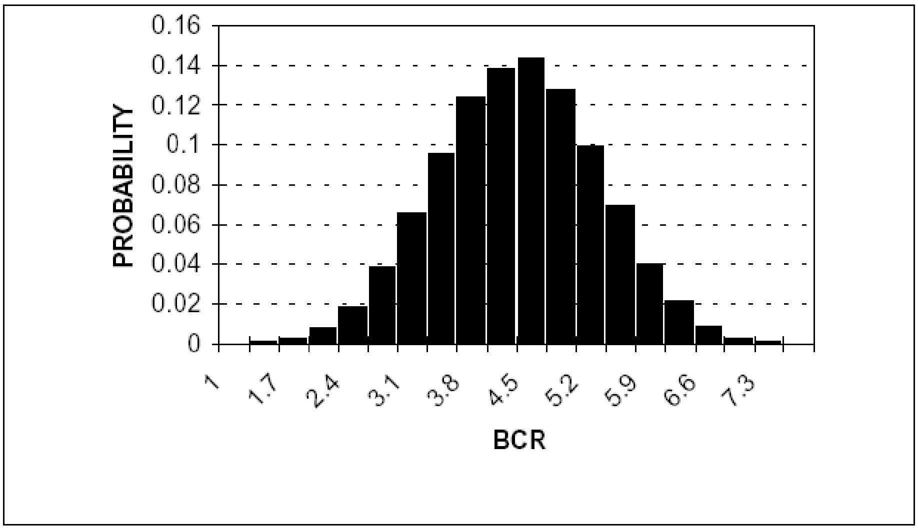

Figure 4 Distribution of BCR output for Project 2

If the above process is repeated for the three other projects being considered, a number of conclusions can be drawn about the relative position of the four projects in the investment program.

Figure 5 shows that comparisons can be drawn between projects in terms of the trade-off between average BCRs and associated levels of risk (or uncertainty). For example, Project 4 while it does not have the highest mean BCR, has the lowest level of uncertainty or risk associated with that value. This can be interpreted as indicating that it is highly unlikely that the ‘true’ BCR for this project will vary much from the mean. However, Projects 1 and 2 display greater levels of uncertainty associated with their BCRs. For example, there is some probability that the BCR for Project 2 could be as low as 2 or as high as 8. For Project 3, risk analysis indicates only a small probability that this project could be justified on the basis of its BCR.

In summary, it can be said that risk analysis has provided a richer data set, than that generated by conventional evaluation methods, on which to base decisions relating to project selection for funding,.

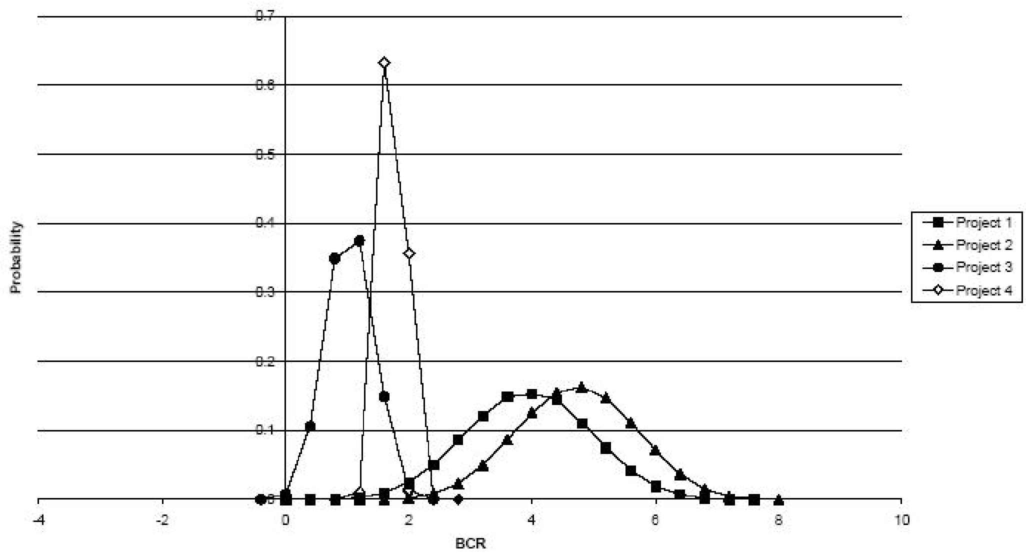

Figure 5 Comparison of the BCR of four projects

Conclusion

This paper has covered key viewpoints relating to definitions and understanding of risk. The previous discussion has shown that making a hard distinction between risk and uncertainty does not provide additional insight to the practical aspects of economic decision making (for example, relating to transport investments). It does, however, deflect attention away from the real purpose of evaluating risk: identifying and examining the consequence and likelihood of the occurrence of events. This paper proposes a simplifying (and practical) unification of viewpoints that cuts to the essence of risk - the need to develop a 'precautionary mode of thought and action'.

To assist with the development of this mode of thought and action, the paper presents an overview of a six step risk management process and details the development of the *Risk Explorer* software environment that is intended to assist the transport practitioner in dealing with decisions that are characterised by complexity, diversity of opinion, high decision stakes, and high uncertainty and risk.

The example demonstrates how risk analysis and the *Risk Explorer* tool can be used to help make decisions about the risks of highest importance to the economic outcome of a project. This example also demonstrates the extent to which risk analysis provides additional information for each project, and assists in inter-project comparisons and possible selection for funding complications.

The incorporation of risk analysis, and the incorporation of this mode of thought and action into decision making processes, is an essential development to achieving more efficient allocations of scarce resources in an environment of increasingly constrained budgets.

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