Incorporating risk factors in transport project economic evaluations

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Abstract

Project economic viability is a key consideration in funding transport infrastructure. The decision making to date has often been relying on the point estimate of the Benefit Cost Ratio (BCR), or some other economic criterion, which is underpinned by a number and range of input variables and assumptions. These input variables usually have a degree of variance which could lead to biased BCR estimates and thus represents a risk to the project economic viability. This paper introduces a probabilistic approach to quantify and incorporate risk factors into the BCR estimate. Building on the existing literature, this research focuses on the identification key risk factors in transport project economic appraisals and the approach to determining the probability distributions of risk factors using a case study.

1. Introduction

Risk assessment is a key task in planning and development of transport infrastructure projects. During the project development process, risk assessment is required to identify project risks and to inform the development of risk mitigation strategies.

A possible drawback of the current industry approach is that the risk assessment is primarily undertaken to reduce the impact of project risks after the project option has been defined, with a lack of risk identification and assessment during the options assessment stage.

Identifying and quantifying project risks earlier in the project development process could assist the project proponents to identify the preferred option which has the lowest, or acceptable associated risks. This can be undertaken by incorporating the project risks into the economic evaluation as an evidence base to inform options assessment.

The common industry practice of economic evaluations is to calculate a point estimate of benefit cost ratio (BCR) using a cost benefit analysis (CBA) methodology. As is widely known, the estimated BCR is underpinned by a range of input data, economic parameters and assumptions. Inevitably, many of the input variables, such as expansion or annualisation factors, are subject to a level of variance, which may lead to over or under-estimation of the BCR.

The current approach to assessing the impact of risk factors on economic evaluation is to undertake sensitivity tests on key input variables. The limitation of sensitivity tests is that they do not show the likelihood of risk occurrence (i.e. variance in the risk factor), and hence the decision making still relies largely on the point estimate of BCR.

The above drawback of the current economic evaluation approach can be overcome by undertaking a probabilistic cost benefit analysis, which estimates a probability distribution for risk factors and the BCR and using a Monte Carlo simulation. The probabilistic BCR can provide more information on the project's economic viability to assist with decision making.

2. Literature review

The literature review begins with the definitions of risks. Patrick et al. (2004) suggested that risks arise where a statistical assessment of probability is possible, whereas uncertainty refers to a situation where it is not possible to measure the probability of occurrence of an event. In practice, while the above definition is recognised by Infrastructure Australia, the Infrastructure Australia Assessment Framework (2018) used the terms risk and uncertainty synonymously for simplicity.

This paper adopts Infrastructure Australia's approach to treating risk and uncertainty interchangeably. The definition of risk in relation to other statistical terms are defined and represented in Figure 1, which indicates that:
- Bias - the difference between the true and estimated means;
- Variance - difference between the mean and a value of the variable for the distribution;
- Risk - represented by the cumulative probability that the variable has a value falls below a particular value "*V*".

Figure 1: Definitions of statistical terms
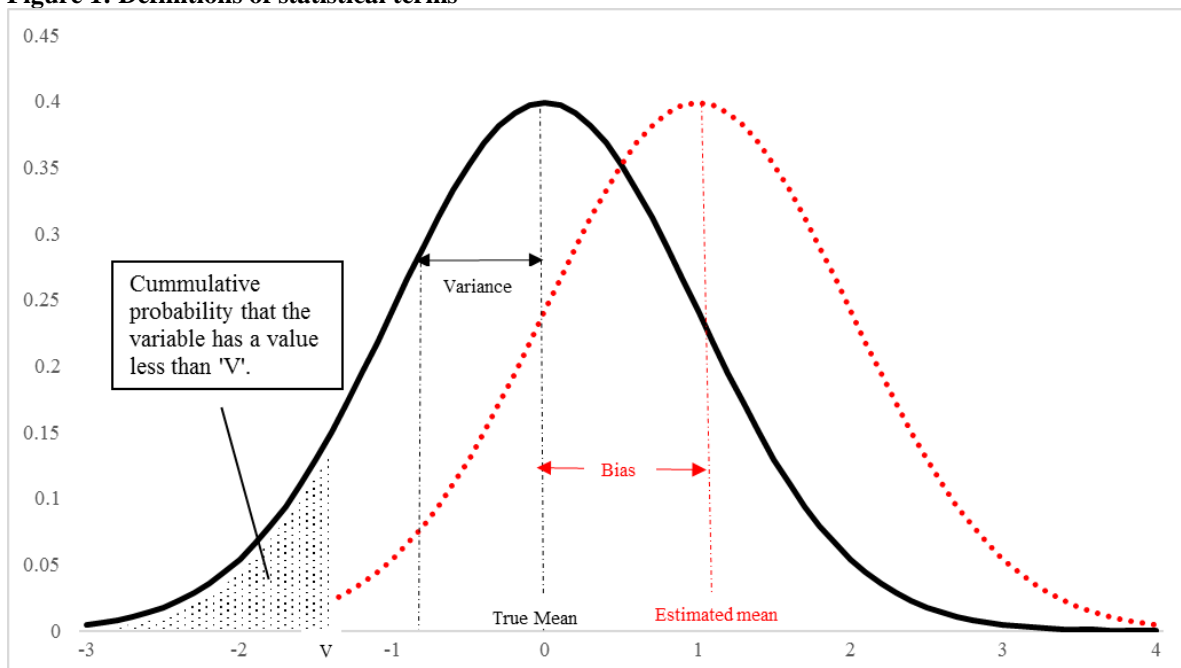
Source: developed by GTA

The impact of risk factors on economic evaluation is well-recognised in the field of transport economics. In Australia, most transport economic evaluation guidelines have highlighted the importance of addressing risk factors with recommended approaches as summarised in Table 1.

Table 1: Risk assessment approaches recommended by industry guidelines

Guidelines	Risk assessment approaches
Australian Transport Assessment and Planning Guidelines (2016)	• Simple sensitivity analysis as a basic tool • Simple risk weighting for large initiatives • Probabilistic analysis may be warranted for complex risk assessment
Infrastructure Australia Assessment Framework (2018)	• Sensitivity tests on project-specific risks • Estimate the BCR of the worst case scenario
Transport for NSW Guidelines (2017)	• Sensitivity tests on key assumptions • Monte Carlo simulation when there is significant uncertainty that can impact on results
NSW Treasury Guidelines (2017)	• Sensitivity tests on key assumptions • Scenario planning • Simple risk weighting • Monte Carlo simulation for high-risk projects • Real option analysis
New Zealand Economic Evaluation Manual (2016)	• Sensitivity tests on key assumptions • Simple risk weighting • Monte Carlo simulation for high-risk projects
Victoria Department of Treasury and Finance Guidelines (2013)	• Real options analysis • Sensitivity and scenario analysis • Monte Carlo simulation when risk is a major issue
Building Queensland Guidelines (2016)	• Single variable testing • Scenario analysis • Break even Analysis • Monte Carlo analysis

Of all the guidelines reviewed, risks in economic evaluation are widely acknowledged by all jurisdictions. Most guidelines recommend undertaking sensitivity tests on key input assumptions as a basic tool, supported by more a detailed probabilistic risk analysis for complex and high-risk projects. However, where the probabilistic risk analysis approach is mentioned, there is a lack of a step by step technical guidance with the exception of the Transport for NSW guidelines.

The methodology of probabilistic cost benefit analysis has been well-developed in the literature. Patrick et al. (2004) applied a Monte Carlo simulation to assess the impact of traffic growth rate, traffic composition rate and construction cost on the estimated BCR for a highway upgrade project. They concluded that the incorporation of risk analysis is an essential development to achieving more efficient allocations of resources.

Prakash and Mitchell (2015) tested the impact of assigning probabilistic distribution of the estimated costs and benefits on the project BCR, using Australian High Speed Rail as a case study. The analysis provided further information, such as the confidence level of BCR, to facilitate decision making.

Previous research was mostly undertaken to demonstrate the applicability of Monte Carlo simulations to project evaluations. Building on the existing literature, this research focuses on the following two aspects of probabilistic cost benefit analysis:

- **Selection of key input variables** – previous studies undertook Monte Carlo simulations by assigning probability distributions of the estimated costs and benefits, with limited insight into what risk factors might have a material impact on the estimated BCR in the context of transport projects. This paper develops a framework that outlines typical risk factors in transport economic appraisals to assist practitioners with risk identification (Section 3).

- **Determination of probabilistic distributions** – one of the key steps in probabilistic cost benefit analysis is to determine the likely distribution of the risk factors. There is a lack of discussion in the literature with regard to the approach to the determination of probability distributions. This paper provides some guidance on how the approach can be enhanced by using supporting data (Section 3).

3. Methodology

The steps to undertake a probabilistic cost benefit analysis are described as follows.

Step 1. Identify key risk factors of cost benefit analysis

A cost benefit analysis is underpinned by various data inputs, parameters, analysis procedures and assumptions. Some of the input data or assumptions are subject to a level of variance and hence may lead to over or under-estimation of project economic viability. Table 2 presents common risk factors in economic evaluation of transport projects.

Table 2 Risk factors in cost benefit analysis of transport projects

Transport modelling	Cost estimates	Economic parameters	Project specific assumptions
• traffic volume • vehicle hours travelled • vehicle distance travelled • traffic composition	• capital cost • operating cost • cost escalation rate • contingency allowance	• discount rate • value of travel time • value of statistical life • real growth of value of time	• expansion / annualisation factors • benefit ramp-up factor • benefit interpolation and extrapolation • other project specific assumptions

Transport modelling and cost inputs are usually provided by technical specialists and their associated risk factors could be addressed prior to undertaking economic evaluation. For example, the current industry practice requires probabilistic cost estimates which take into account risk contingency. According to a recent study undertaken by Bureau of Infrastructure, Transport and Regional Economics (2018), the use of probabilistic cost estimates for funding request has resulted in a decrease in cost overruns.

Economic parameters, such as discount rate and value of travel time, are typically incorporated into cost benefit analysis using default values as recommended in relevant guidelines. These parameters are typically treated as fixed variables in economic evaluations unless there is a speculation that the parameter values might substantially deviate from the

default values for a particular case. Therefore, the economic parameters are not the focus of this paper.

The key risk factors that require project analysts' attention relate to project specific assumptions determined based on professional judgement due to lack of supporting data. For example, expansion and annualisation factors applied to extrapolate peak hour benefits (estimated from transport modelling input) to annual figures may vary with the location and the type of infrastructure initiatives. These factors can impact the estimated project benefits significantly in some cases as the estimated transport benefits such as travel time savings are almost proportional to the annualisation factor assumed.

Step 2. Determine the probability distributions of key risk factors

In order to quantify the probability of risk occurrence, it is necessary to determine a probability distribution of the risk factors. This task usually requires a certain level of professional judgements and sometimes causes criticism due to a lack of evidence base. However, it is possible to identify a plausible range of the values based on other supporting information, such as historical data, benchmarking analysis and experts' judgement. The supporting information would also inform the determination of probability distributions of the risk factors for Monte Carlo sampling.

The most commonly-used probability distribution function for describing variance in the risk factors is the normal distribution. However, some observed data analysis about risk factors suggests that sometimes other probability distributions could describe the risks better. In fact, it is not unusual that risk factors have skewed or trunked tail probability distribution. Under this circumstance, the normal distribution would not be the most appropriate distribution and other distributions such as the Triangular, the Lognormal, the Erlang or the Generalized Extreme value distributions could better describe the risk factors. Some commercial risk analysis software, such as @Risk, offer a Distribution Fitting function to assist analysts with determining an appropriate distribution.

Step 3. Account for correlation between risk factors

The correlation is a measure on how two factors are related to each other. The correlation can be represented by the Pearson's product moment coefficient. For the probabilistic cost benefit analysis, it is important to take into account how the different risk factors are correlated if identified. If the correlation was not accounted for in sampling, some iterations of the simulation would contain unrealistic sampled values and lead to biased estimates of the BCR.

Step 4. Generate probability distributions of economic indicators using Monte Carlo simulation

The proposed quantitative risk analysis relies on Monte Carlo simulation approach. This is an iterative approach where, for each iteration, the average risk factor values are substituted with random values extracted from the defined risk probability distributions. Using this approach, the model outcomes are calculated for each iteration. At the end of the simulation, all the iteration outcomes are used to develop an envelope which describes the model results as a probabilistic process. Where possible, the Monte Carlo approach considers more than 1000 simulation iterations for considering all the possible input risk factor combinations deriving from the probability distributions and correlations assumptions. The number of Monte Carlo simulations required depends on the number of risk factors, correlation between risks and the nature of the probability distribution.

4. Case study

This section presents a case study of a probabilistic cost benefit analysis. The case study adopts an existing cost benefit analysis model developed for assessing the economic benefits of a road upgrade project in an Australian capital city. Due to commercial confidentiality, details of the project have been redacted from this paper.

The project involved road re-alignment and bus priority upgrades to improve traffic flow and road safety. The quantified project benefits include travel time savings, improved journey time reliability, reduced vehicle operating cost and reduced accident cost.

The economic evaluation was underpinned by traffic modelling outputs for 3 hour AM peak period and 3 hour PM peak period of the road corridor. The core economic evaluation results are presented in Table 3.

Table 3 Economic evaluation results of the case study ($m, discounted present values)

Cost/benefit item	Project option
Travel time saving	$12
Bus reliability benefit	$24
Vehicle operating cost saving	$1
Crash cost saving	$2
Total benefit	**$40**
Total cost	**$28**
NPV	**$12**
BCR	**1.4**

Source: confidential

4.1 Identify key risk factors

As described in Section 3, the first step of undertaking a probabilistic cost benefit analysis is to identify risk factors. For the proposed road project, the following risk factors were identified as the factors likely to have a material impact on the estimated BCR:

1. **Annualisation factor** – given that the traffic modelling was undertaken for peak hours only, an annualisation factor was required to extrapolate the project benefits from the modelled peak hours to annual benefits. While the annual traffic counts in the study area were available, the traffic volume does not necessarily represent the number of beneficiaries. For example, it is possible that travel time and reliability benefits are minimal during off-peak period when the traffic condition is significantly better than peak hours. Therefore, the project benefits outside modelled hours remain uncertain and hence represent a risk to the project's economic viability.

2. **Capital costs** – as the economic evaluation was undertaken for a strategic business case, risk-adjusted cost estimates were not available and strategic cost estimates were provided with lower bound, mean and upper bound values.

3. **Crash reduction rates** – there has been a significant number of incidents on the proposed road corridor in the past. However, it is unclear to which extent the

proposed road upgrades will reduce the number of incidents. The expected crash reduction rate is key to the calculation of the crash cost saving benefit, but also is uncertain.

4.2 Determine the probability distributions of key risk factors

For the above risk factors identified, there is no strong evidence suggesting the presence of correlation. Therefore, the next step is to determine the probability distributions of the risk factors identified above. While this task usually requires a certain level of professional judgement, the assumptions on the statistical distributions can be enhanced by supporting data.

With the annualisation factor, the project is expected to benefit road users during weekday peak hours based on the traffic modelling outputs. Therefore, the lower bound of the annualisation factor was determined as the number of weekdays (excluding public holidays) in a year, at 252 days.

When including weekend days, the annualisation factor would increase to 356. However, the peak period during weekends is expected to be shorter than the peak period on the weekdays, and hence the annualisation factor could range between 252 and 356.

Another consideration of the annualisation factor relates to off-peak travel. According to the observed traffic counts, the all-day traffic volume on the study corridor is about 2.1 times higher than the modelled peak hours. However, the transport benefit of this project primarily arises from reduced congestion, which implies that vehicles and buses travelling in an uncongested condition are expected to receive minimal benefits. As a result, the upper bound of the annualisation factor is set as 765 (i.e. the product of 356 and 2.1).

The above data and a statistical distribution 'fit' procedure indicated that the probability distribution of the annualisation factor could have a Lognormal form, as shown in Figure 2. The distribution is skewed to the lower bound between 252 and 356 with a mean value of 328. It is assumed that there is less than 50% of probability that the annualisation factor will exceed 328.

Figure 2 Probability distribution of annualisation factor
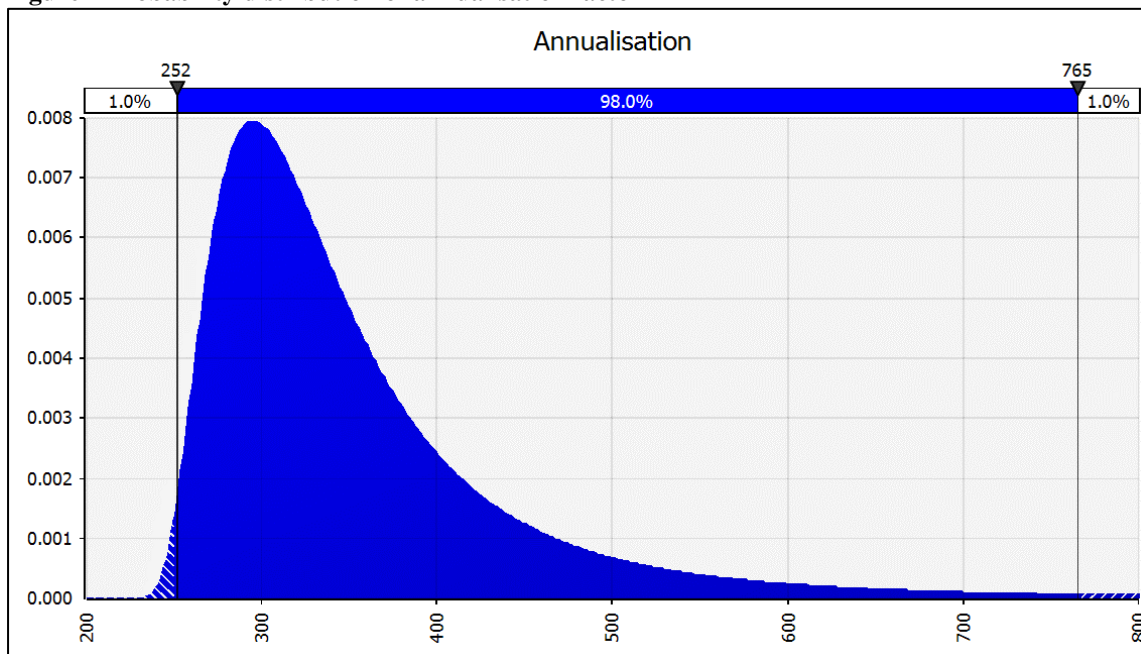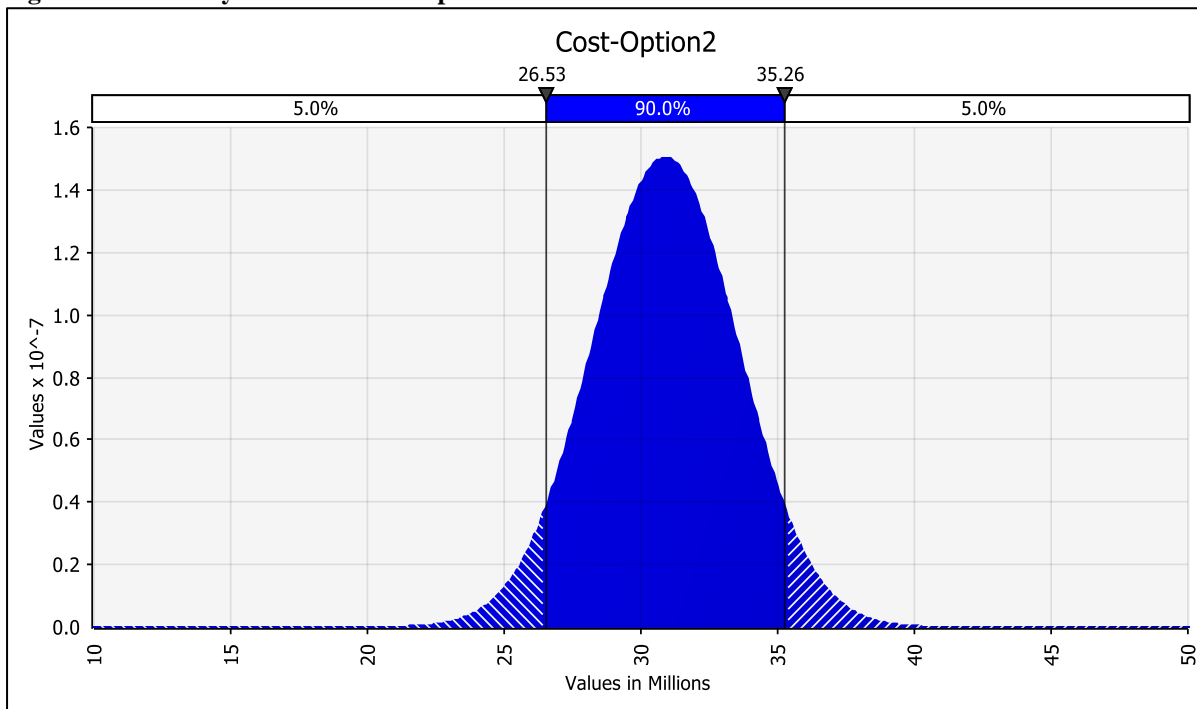
Source: GTA analysis

The probability distribution of capital cost would ideally be developed by professional quantify surveyors by examining the potential risks that may impact the cost estimates. For this analysis, this information was not available and hence the distribution was determined based on the lower bound ($24 million), central ($31 million) and upper bound ($37 million) estimates provided by the quantity surveyor.

A normal distribution is assumed as shown in Figure 3. The distribution was determined by assigning the lower bound and upper bound cost estimates as P1 and P99 values, assuming that there is a one per cent of probability that the actual cost is less than the lower bound, with a 99 per cent of probability being less than the higher bound estimate. The normal distribution assumes a mean of $31 million and a standard deviation of $2.6 million.

**Figure 3 Probability distribution of capital cost**

Source: GTA analysis

Crash reduction rates can be determined by several methods. One approach is to apply the average crash rate per million vehicle distance travelled. This approach was considered inapplicable as the project will not change the travel distance. Instead, the road re-alignment is expected to reduce the traffic weaving behaviour and hence is expected to reduce the number of incidents.

The expected crash reduction rates are available in Austroads Guidelines (2010), ranging approximately between 5% and 45% depending on the type of road upgrades. This analysis assumes a normal distribution for the expected crash reduction rate with a mean value of 25% and a standard deviation of 7.5% based on a coefficient of variation estimated around 0.3. As shown in Figure 4, the distribution of the crash reduction rate is wider than the distribution of the cost estimate, reflecting a larger variance expected in the assumed crash reduction rate.

**Figure 4 Probability distribution of crash reduction rate**
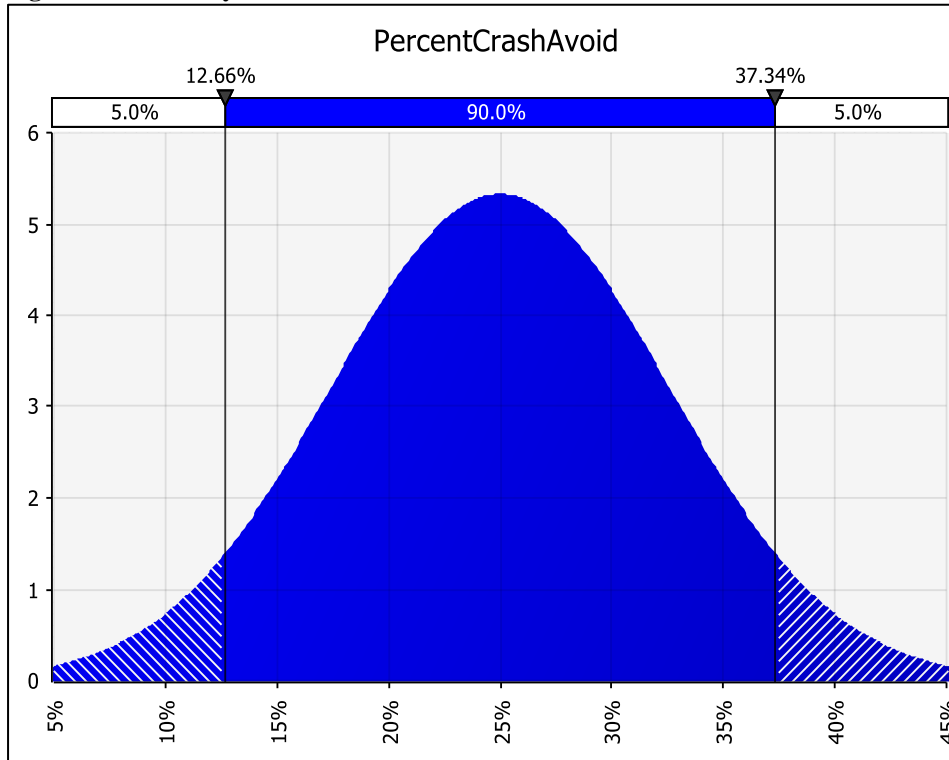
Source: GTA analysis

4.3 Probabilistic cost benefit analysis results

The impact of risk factors is quantified and incorporated into the BCR estimate as presented by probability density functions as shown in Figure 5 and Figure 6. As opposed to a single point of BCR estimate, the probabilistic cost benefit analysis provides a statistical distribution of the BCR based on the likelihood of variances in the above risk factors. The following information can be extracted from the findings:

- The BCR is expected to be between 1.13 and 2.38 with a probability of 90% being within this range (Figure 5);
- The probability of the BCR less than the pointe BCR estimate of 1.4 is 40.6% (Figure 6), which demonstrates the variability of the BCR due to risk factors;
- The probability of the BCR being less than 1.0 is minimal in this case, which suggests the there is a very high likelihood that the project will generate net economic benefits, after taking into account the variances in the identified risk factors.

Figure 5 Probability density function of BCR distribution – expected 90% values
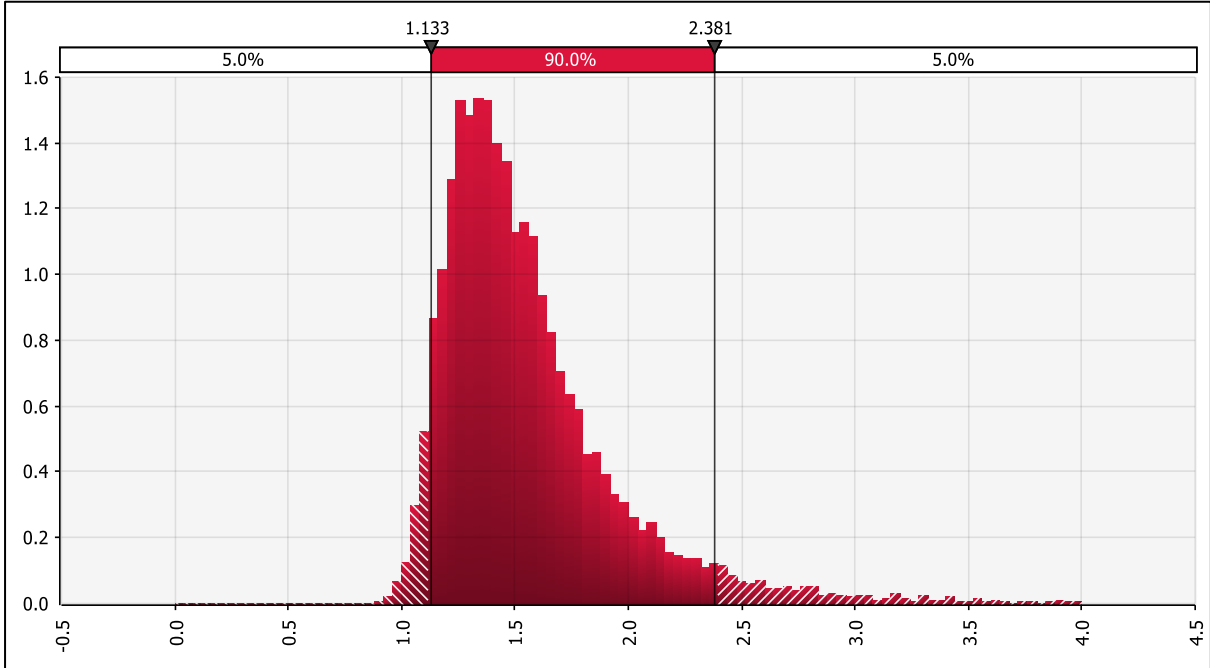
Source: GTA analysis

**Figure 6 Cumulative probabilistic distribution of BCR**
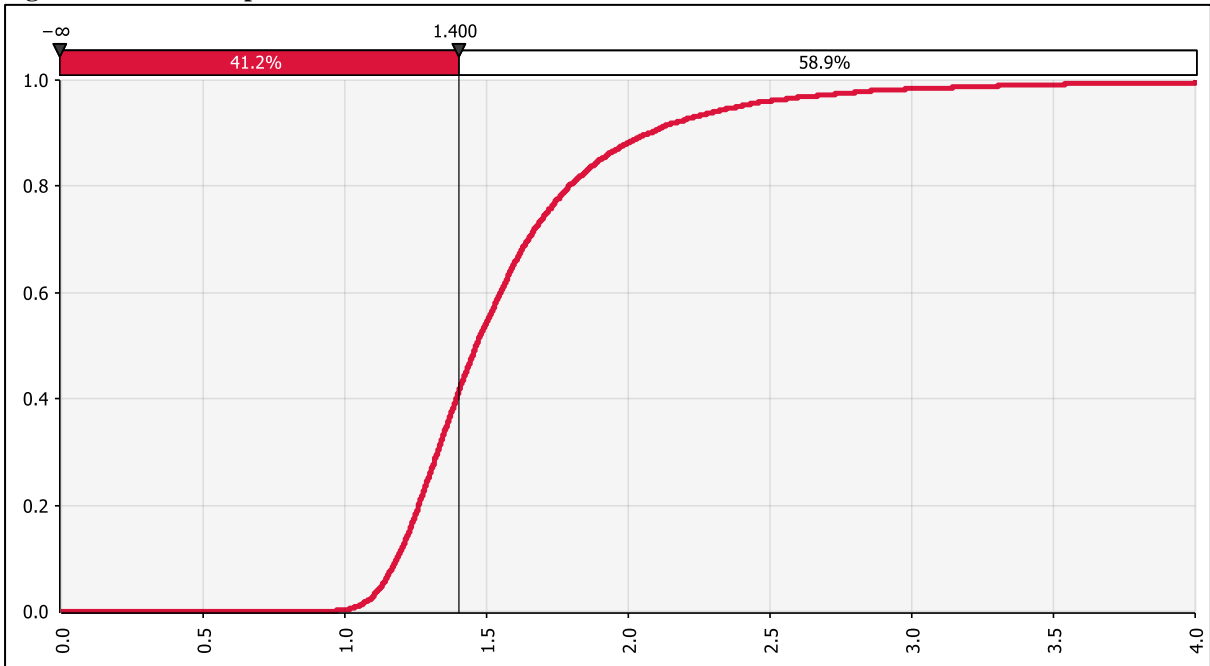
Source: GTA analysis

Figure 7 shows the impact of risk factors on the estimated BCR. It can be clearly seen that the annualisation factor is expected to affect the BCR most substantially, resulting in a BCR ranging between 1.19 and 2.59 with 50 per cent of probability being less or greater than 1.58. The baseline BCR of 1.58 is slightly higher than the point BCR estimate of 1.4 due to potential upside risks (e.g. the distribution of annualisation factor being tilted to the upper

bound). Compared to annualisation factor, the capital cost estimate and crash reduction rate are expected to have less impact on the BCR.

Figure 7 Impact of risk factors on BCR
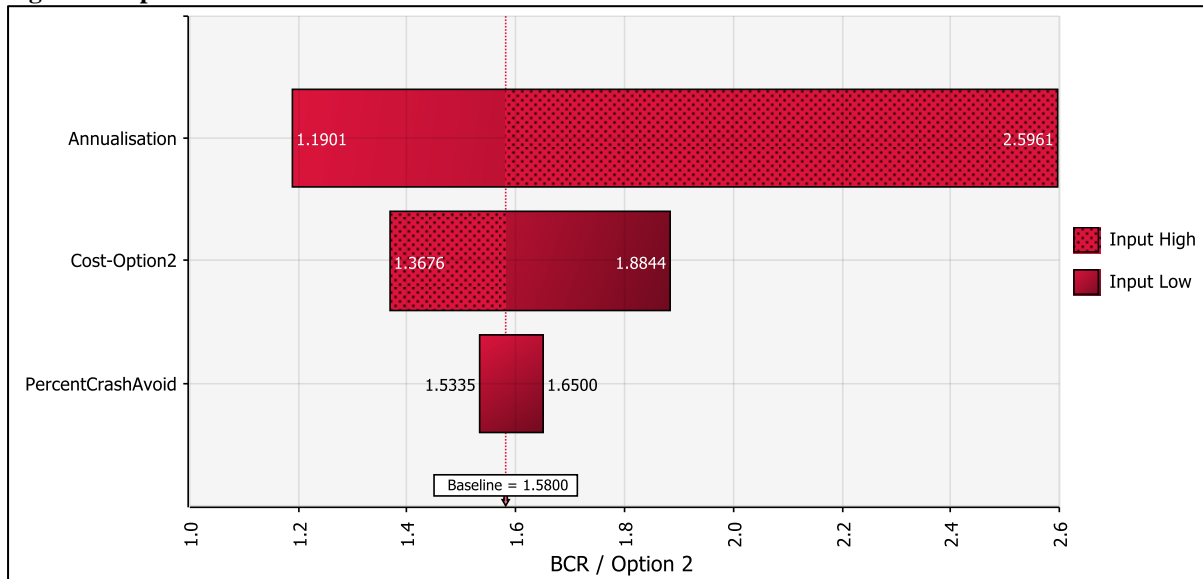
Source: GTA analysis

5. Conclusions

The probabilistic cost benefit analysis is an effective tool to investigate the impact of risks on the BCR estimate. It provides more detailed information about project economic viability that was unavailable in a standard economic evaluation using the current industry practice.

This study builds on existing knowledge of the probabilistic risk analysis and extends it by undertaking a further investigation into the common risk factors in transport project appraisals and the approach to determining the probability distributions. In particular, the case study identified that the impact of annualisation factors on project BCR can be significant. While there are default annualisation factors recommended in appraisal guidelines, there needs to be a more thorough consideration when adopting those default values with regards to annualisation or expansion factors.

Undertaking probabilistic cost benefit analysis sometimes is perceived as a complex task which requires additional resource and cost. However, the case study of this paper suggests that a simple Monte Carlo analysis on key risk factors can be implemented efficiently. The Monte Carlo analysis could also incorporate different scenarios such as considerations of the impact of interdependent projects and land use scenarios. Such detailed risk assessments may be warranted for high-value and high-risk projects.

Incorporating risk analysis into economic evaluations can improve the robustness of analysis by capturing the variances of input variables that were determined by analysts. It can also enhance decision makers' confidence in the BCR estimate which has been a key consideration in transport project funding. The risk analysis presented in this paper can be effectively extended to transport modelling to account for risk factors embedded in the underlying modelling assumptions.

Acknowledgements

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