

Australasian Transport Research Forum 2015 Proceedings
30 September - 2 October 2015, Sydney, Australia
Publication website: <http://www.atrf.info/papers/index.aspx>

Probabilistic Benefit Cost Ratio – A Case Study

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The opinions expressed in this article are the authors' own and do not reflect the view of their employers.

Abstract

In this paper, a Monte Carlo approach to arriving at a probabilistic distribution of Benefit Cost Ratio (BCR) is presented and discussed. BCR is the ratio of the benefits of a project relative to costs and is generally seen as an indicator of the overall value for money of a project. A BCR calculation generally forms an integral part of a project proposal and used by governments to assist them in making investment decisions on projects.

Project costs are increasingly being prepared by using a Monte Carlo approach whereby cost items and attendant risks are represented as probability distributions and then multiple simulations are computed to generate a probability distribution of the total cost of the project. However, the BCR is usually presented as a single number instead of a distribution, often because project benefits are still calculated as a single number.

In this paper, probabilistic estimation (Monte Carlo) method is presented and then probabilistic distributions of total costs and total benefits are used to generate a probabilistic distribution of the BCR using the Monte Carlo approach. Finally the application and implications of the BCR probabilistic distribution are discussed via a case study.

1. Introduction

In businesses and government, major investment decisions have to be made based on predicted future, inherently uncertain outcomes. Understanding and evaluating the level of the uncertainty involved can help businesses and governments make more informed, and potentially better, decisions.

Probabilistic methods or quantitative risk analysis approaches are now widely utilised to quantify the uncertainties of the predicted outcomes and produce a distribution of probable outcomes (Galloway et al. 2012, Baccharini 2005) as opposed to a single value produced by deterministic approaches.

In the project world, probabilistic methods, utilising approaches like Monte Carlo simulation, are becoming increasingly popular to produce project-related estimates, especially cost estimates, because it improves the qualitative understanding of the estimates by explicitly addressing the potential risks of the item(s) being estimated. *“Quantifying risk and uncertainty is a cost estimating best practice addressed in many guides and References”* (GAO 2009, p. 154).

The benefit cost ratio (BCR), being ratio of the benefits of a project relative to costs, is one of the most common measures used by businesses and government decision makers to determine the overall value to society of a project proposal. However, it appears, anecdotally at least, that project BCRs are typically based on predominantly deterministic approaches. Take, for instance, the deterministic BCR values provided in the high dollar value and highly publicised projects such as the Australian High Speed Rail (HSR) project and Canberra light

rail (Capital Metro Agency 2014). The reasons for this could be that the requirements for a project proposal to Governments do not require a probabilistic approach and/or the project proponents do not realise the benefits of using a probabilistic BCR. There are been several publications encouraging deriving a probabilistic BCR (Austroads 2012, Boardman et al. 2014).

In this paper, probabilistic estimation and the Monte Carlo approach is discussed and then a probabilistic distribution of total cost and total benefits is used to generate a probabilistic distribution of the BCR. Finally the applications and implications of the BCR probabilistic distribution are discussed and a case study applying the probabilistic BCR approach to the HSR project presented.

2. Probabilistic Benefit Cost Ratio (BCR)

2.1 Probabilistic estimation method

Probabilistic estimation methods, or quantitative risk analysis, involves using Monte Carlo simulation (dominant method used) to generate a probability distribution for estimated costs and, less commonly, benefits and therefore generating a number of possible scenarios. This is achieved by accounting for every possible value that a cost item could take and combining them with every possible value of all other cost items. Also taken into consideration is the probability (or likelihood) of occurrence of each cost item.

Generation of a probability distribution for estimated project costs generally involves the following sequential process:

Step 1: Estimate the project base cost

Estimating the project base cost is usually the common starting point for any project evaluation. Estimation of the base cost for major transport infrastructure projects will typically require expert civil engineering and quantity surveying services, and possibly geotechnical investigations, to identify the likely scope of construction works, the quantity of each project component and the unit rate cost for each project cost component. Depending on the nature of the project, construction works may include environmental remediation works, public utility adjustments and temporary traffic management elements. The base cost should also include not only the direct construction costs, but also indirect costs, contractor margins and client costs. Note that the project base cost does not include any contingency.

In practice, cost estimates (including base cost) are often undertaken several times, as a project progresses from scoping, through development and on to delivery, and the accuracy of the cost estimate should improve as the project nears delivery (and completion).

Step 2: Determine the associated cost drivers and risks

All possible risks to a project should be identified and quantified to be able to adequately capture the uncertainty associated with the project. Risks are generally categorised as either inherent or contingent risks.

Inherent risks relate to items that will definitely contribute to the overall cost (i.e. items specifically identified within the various components of the project base cost estimate). In other words, the likelihood of occurrence of this risk is 100%. Inherent risk can be applied to the quantities and rates of the cost items either separately or applied to the combined element cost. Inherent risk is applied to cost items in direct costs, indirect costs, margin and client costs.

Contingent risks, on the other hand, relate to items that may or may not contribute to the overall cost. In other words, the likelihood of occurrence is less than 100%. Some examples of contingent risks are risks related to weather impact, industrial disputes and disruptions, etc.

Step 3: Assign appropriate probability distributions to all risk items

The next step is to assign appropriate probability distributions to each of the inherent and contingent risk items, and to also assign probabilities to the occurrence of each contingent risk item. The probability distribution chosen for each cost item should account for all possible outcomes and are typically determined using lowest, most likely and highest possible values. These ranges around the cost items are usually established by the project team including owners, contractors and other experts as appropriate. Ideally, everyone with significant knowledge and experience involved with the project and its risks should be involved. Approximating the ranges carefully is important because use of inappropriate or unrealistic ranges can produce unreliable results.

The assigned probability distribution represents the shape of the risk item and the tails of the distribution reflect the best and worst case scenario. Note that while using software packages such as @RISK, it is also important to choose appropriate probability distributions so as to assign appropriate levels of spread and skew. The choice of distribution function is beyond the scope of this paper. Note that there is an extensive literature available on the type of distribution functions to use in project risk evaluation, and under what circumstances, including Vose (2009).

Step 4: Account for correlation between cost elements

Correlation between cost items should be given important consideration. When modelling associated cost drivers and risks (i.e. inherent and contingent risks), it is important to consider the impact of inter-relationships (correlation) between risk items to generate accurate and sensible output. Failure to suitably account for correlation between project risks can result in artificially tight project cost distributions, and an incorrect assessment of true project risk.

Step 5: Generate a probability distribution using Monte Carlo simulation methods

The most common technique for combining the individual elements and their distributions is by using Monte Carlo simulation. Monte Carlo simulation is a computerised mathematical technique that facilitates accounting for risks in quantitative analysis and decision making. A number of easy-to-use proprietary tools exist for implementing Monte Carlo simulations to incorporate risk in project evaluation—the most widely used ones are: @RISK and Oracle's Crystal Ball. In the case study simulations presented in Section 3 (below) @RISK was used.

During a Monte Carlo simulation, values are sampled at random from the input probability distributions of the inherent and contingent risks, and the results combined to obtain an outcome for each iteration. This process is repeated hundreds or thousands of times, and the result is a probability distribution of possible outcomes. This resultant probability distribution of possible outcomes tells you not only what could happen, but also the likelihood of it happening.

2.2 Probabilistic BCR – An example

This section presents a simple example of a probabilistic BCR using some simple assumed values for the cost and benefits of a hypothetical transport project. The method applies the steps outlined in Section 2.1, above, by generating probability distributions for each major cost and the benefit item, and then undertaking Monte Carlo simulation to combine these items. Table 1 shows the sample values for the most likely and lowest and highest possible benefits, by project benefit components. Table 2 shows the sample values for the most likely, and lowest and highest possible costs, for operating and capital cost components. Note that the choice of benefit and cost items in the example are for demonstration purposes only, and

are not an indication of the suggested cost and benefits items to be used in project evaluation.

Note that the project BCR is calculated using the most likely value of benefits and costs, which for the values presented in Tables 1 and 2 implies a project BCR of 1.1, i.e. $BCR = \frac{880}{820} \sim 1.1$

To generate a probability distribution for the BCR, using the steps outlined in Section 2.1, assuming that steps 1 and 2 are done for the Project Benefits and Project Costs items. Step 3 is to assign distributions to these items and for this exercise, a PERT type distribution is used (refer to Figure 1).

Step 4 involves accounting for correlation between and within project cost and benefit components, but we assume for this simple case that there is no correlation involved. Monte Carlo simulation (step 5) is used to combine these distributions appropriately, i.e. the total of benefits is divided by the total of costs. For each iteration of the Monte Carlo simulation, a random number is generated for each cost/benefit item according to its distribution and the BCR calculated. That is, for each iteration, the selected random numbers for the benefits are totalled and divided by the sum of the random numbers for cost to calculate a BCR value. All the BCR values thus obtained from every iteration are then used to generate the BCR probability distribution as shown in Figure 2.

Table 1: Hypothetical probabilistic benefits schedule

Project benefit components	Present value benefits (\$m)		
	Lowest possible	Most likely	Highest possible
Transport benefits:			
Time Savings	150	200	250
Public transport operating savings	110	150	170
Other transport benefits	100	130	180
Land Use benefits	300	400	500
Total		880	

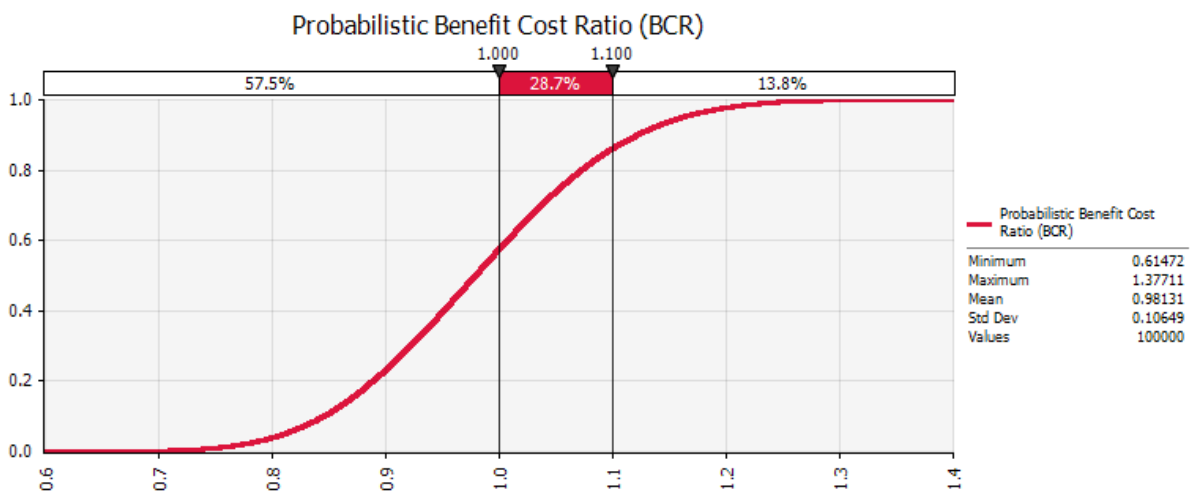
Table 2: Hypothetical probabilistic project cost schedule

Project cost components	Present value cost (\$m)		
	Lowest Likely	Most Likely	Highest Likely
Capex	600	620	1000
Opex	100	200	450
Total		820	

Figure 1: Input distributions



Figure 2: BCR probability distribution



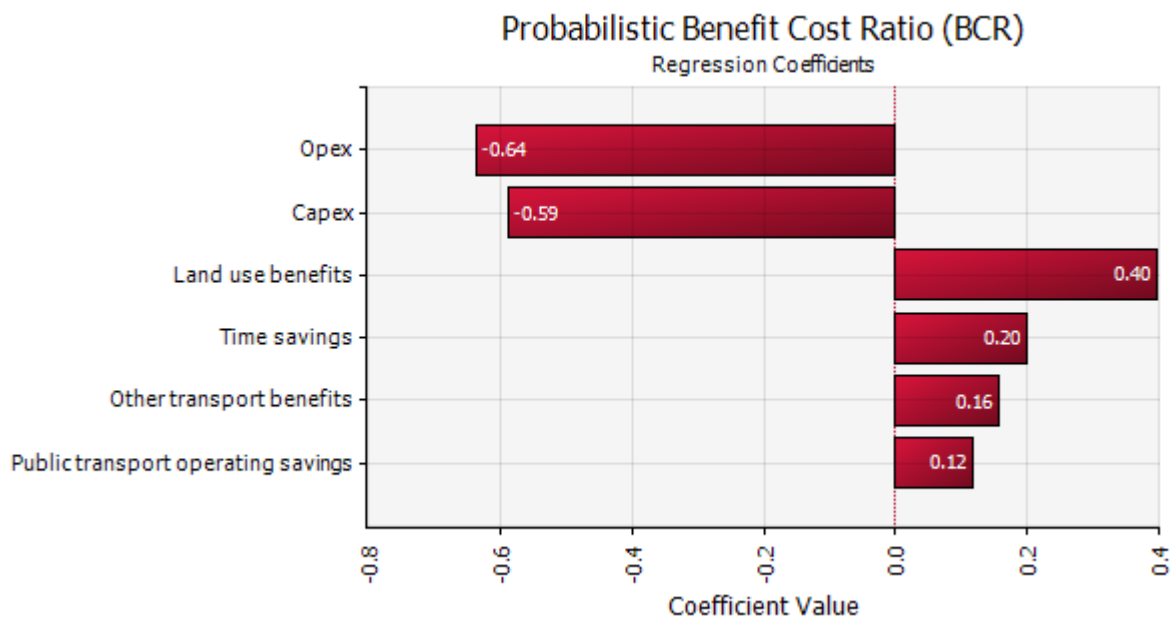
From the generated probability distribution of the BCR (as shown in Figure 2), the following additional details can be extracted:

- the possible values of the BCR: this provides the range of all possible BCR values. Figure 2 implies all BCR values are between 0.6 and 1.4. (Taking a more probabilistic approach, approximately 99 per cent of BCR values are likely to lie between 0.66 and 1.30.)
- the worst case scenario of the BCR figure: a corollary of the BCR range, Figure 2 provides the minimum BCR value (0.6), i.e. if total costs are at their maximum likely level and all the benefits at their lowest likely level.
- the confidence level of any chosen single point BCR: for instance, the BCR value of 1.1 is obtained if the most likely values of benefits and costs are used. But Figure 2 implies that the likelihood of the $BCR \leq 1.1$ is 86.2%. That is, it is more likely for the BCR value to be less than 1.1 as opposed to it being greater than 1.1.
- the likelihood of this project achieving a break-even point in the BCR: the likelihood of the project achieving a breakeven BCR (i.e. 1.0) may also be of interest to decision makers since it provides an estimate of the chances the total project benefits equals

total project costs. In the example, the probability of achieving a breakeven point or less is 57.5% which indicates that it is more likely for the BCR value to be less than 1.0 as opposed to it being greater than 1.0.

Together with the probability distribution of the BCR, a regression analysis can be done to obtain a tornado graph showing the relative impact each of the inputs has on the BCR results. The regression analysis results for this example, as shown in Figure 3, indicate that for a one standard deviation change in Opex, the BCR can be expected to change by slightly more than 0.64. This provides the reader to identify the item(s) that the BCR is most highly dependent on and make decisions accordingly.

Figure 3: Regression Analysis of the BCR



While hypothetical simulations can illustrate the potential utility of applying probabilistic methods to BCR results, it is more interesting to test them on 'real' project evaluations. The following section illustrated probabilistic methods applied to a recent project evaluation.

3. Case Study – Australian HSR Project

3.1 Introduction

A recent high profile, and high cost, transport infrastructure project, High Speed Rail (HSR) has been chosen for the purposes of the case study.

In 2012, the Australian Government commissioned a strategic study on the implementation of a HSR network on the east coast of Australia. The study proceeded in two stages, resulting in two reports:

- *High Speed Rail Study Phase 1 (DIT 2011); and*
- *High Speed Rail Study Phase 2 (DIT 2013).*

These reports provide analysis on the feasibility of HSR and advice on the next steps. For the purposes of this case study, we focus on the results reported in the Phase 2 study—*High Speed Rail Study Phase 2* (the report)—which built on the results of the Phase 1 study, and undertook a more detailed analysis of likely future HSR market demand and a more detailed assessment of the project costs.

3.2 Context

The economic evaluation results presented in the *High Speed Rail Study Phase 2* report are reproduced in Figure 4, below. The economic benefit cost ratio (EBCR) is the ratio of the present value of net economic benefits to the present value of the economic investment costs. This table is part of the executive summary and executive summaries usually contain a summary of all important findings and recommendations in a report such that it can be used to make important decisions.

Figure 4: High speed rail study Phase 2 – Summary economic evaluation results

Table ES-12 Summary economic indicators for the HSR program (present value discounted to 2028, \$2012, \$billion)

	4% discount rate	7% discount rate
Total costs	79.3	58.9
Total benefits	180.6	63.8
EIRR	7.6%	7.6%
ENPV	101.3	4.9
EBCR	2.3	1.1

Source: Reproduced from *Department of Infrastructure and Transport* (2013, p. 31).

The report estimated that the HSR project had a net present value (NPV) of \$101.3 billion, and an EBCR of 2.3, at a 4 per cent discount rate, but an NPV of \$4.9 billion, and an EBCR of 1.1, at a 7 per cent discount rate. The results reported in Figure 4, however, give only part of the information that an EBCR is supposed to relay. The results would be more useful to decision makers if it also included:

- the probability distribution of the EBCR values;
- the confidence level of this EBCR figure;
- the worst case scenario of the EBCR figure;
- the likelihood of this project achieving a break-even point in the EBCR; and
- the items (cost or benefit items) that would be most influential to the EBCR figure.

The HSR report included a probabilistic distribution of total project costs and a separate probabilistic distribution for future patronage, upon which the majority of the project benefits relate. We use these reported probabilistic results to estimate a probabilistic EBCR.

3.3 Estimating the probabilistic BCR

In estimating a probabilistic BCR for HSR there are two approaches that could be taken. Approach 1 uses the probabilistic cost distribution reported in the HSR Phase 2 report and combines it with the point estimate of total benefits. Approach 2 involves combining the probabilistic cost estimates with probabilistic benefit estimates, and requires some additional simulations to derive probabilistic benefits. Approach 2 is preferable, as it includes probabilistic estimates for both benefits and costs, however, Approach 1 is more likely to be most readily and easily applicable to project evaluations, since most project evaluations will include probabilistic cost estimates, but may not estimate probabilistic benefit ranges.

Approach 1 estimates

This approach involves using all possible values of the total cost using the estimated probabilistic cost distribution (*Department of Infrastructure and Transport 2013*, pp. 18 & 348-349), as shown in Figures 5 & 6, and combining it with the total benefits point estimate. Note that the EBCR of 2.3 provided in the report, as described in the previous section, uses a point estimate of total cost with a point estimate of total benefits.

The EBCR calculated in the report includes rolling stock costs, asset renewal costs as well as project development and construction costs.

Figure 5: High speed rail study Phase 2 – Risk-adjusted results

Table 7-21 HSR program risk-adjusted results (\$2012, \$billion)

Item	Risk adjustment %	Expected value	P10	P50	P90
Development costs	7%	10.4	9.5	10.4	11.1
Construction costs	13%*	103.6	92.5	103.5	115.9
Total construction costs		114.0	102.0	113.9	127.0
Rolling stock	5%	10.0	8.8	10.0	11.2
Revenue	4%	277.8	298.6	277.2	258.7
Operating costs	10%	189.4	180.1	189.2	198.9
Asset renewals	4%	16.1	14.9	15.9	18.0
FNPV**	-	-47.0	-35.2	-46.6	-58.5
FIRR	-	0.8%	1.7%	0.8%	0.0%

* The risk adjustment percentage excludes an allowance for contractors' standard risk that has been included in the indicative costs (2.3 per cent for non-tunnel civil infrastructure and 4.0 per cent for tunnel infrastructure).

** Four per cent discount rate.

Source: Reproduced from Department of Infrastructure and Transport (2013, p. 348).

Figure 6: High speed rail study Phase 2 – Risk-adjusted results

Figure 7-18 Total construction costs (including development costs) (\$2012, \$billion)

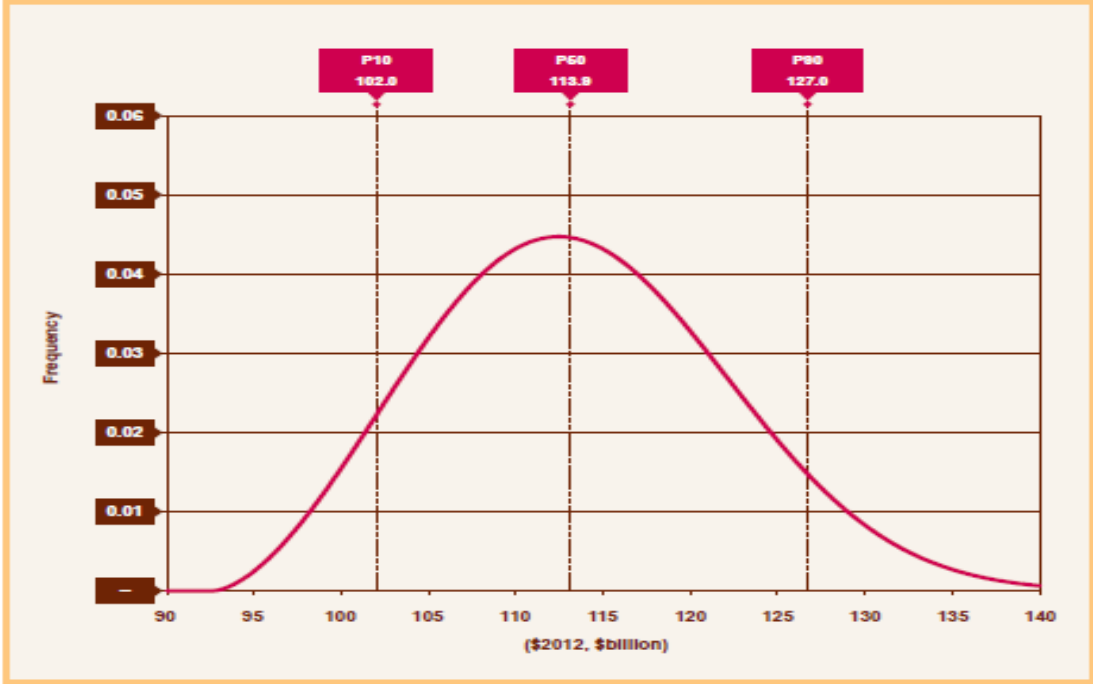


Figure 7-18 illustrates that:

- In 50 per cent (P50) of simulations, total construction costs are expected to be less than \$113.9 billion (\$2012).
- In 90 per cent (P90) of simulations, total construction costs are expected to be less than \$127.0 billion (\$2012).

The expected value of construction costs (which is the risk-adjusted value presented throughout this chapter) is \$114.0 billion (\$2012).

Source: Reproduced from Department of Infrastructure and Transport (2013, p. 349).

The obtained probability distribution of total costs is then used to generate the probability distribution of the EBCR using the total benefit point estimate as \$180.6 Billion. Both these figures are in 2012 dollar present value terms, with 4% discount rate. The probability distribution of total cost in 2012 dollars (4% discount rate) is shown in Figure 7 and the probability distribution of the obtained EBCR is shown in Figure 8.

Figure 7: Total cost probability distribution

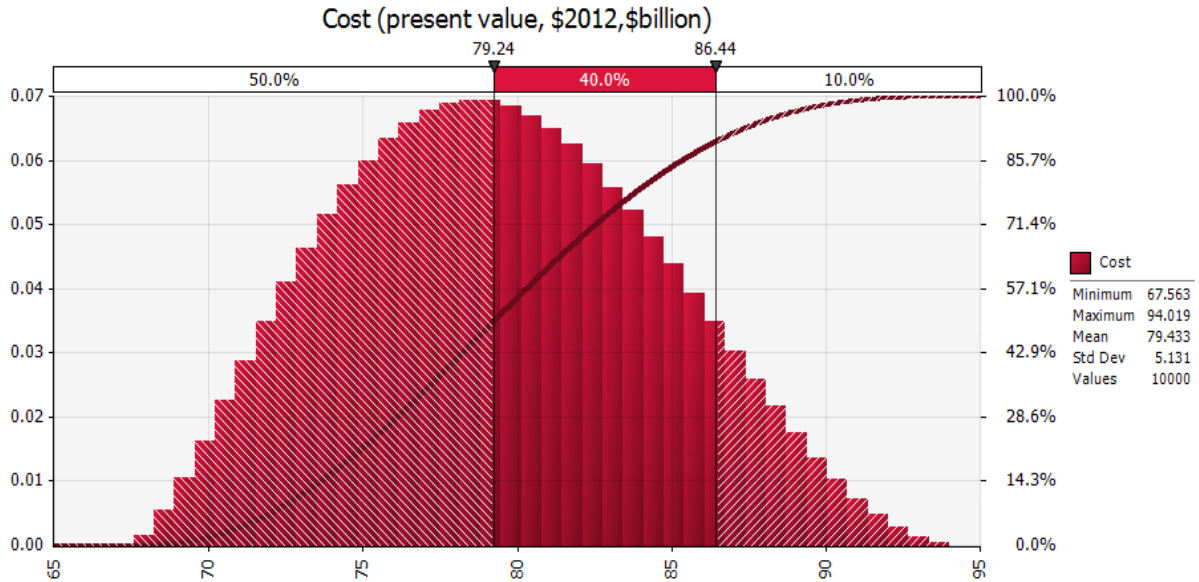
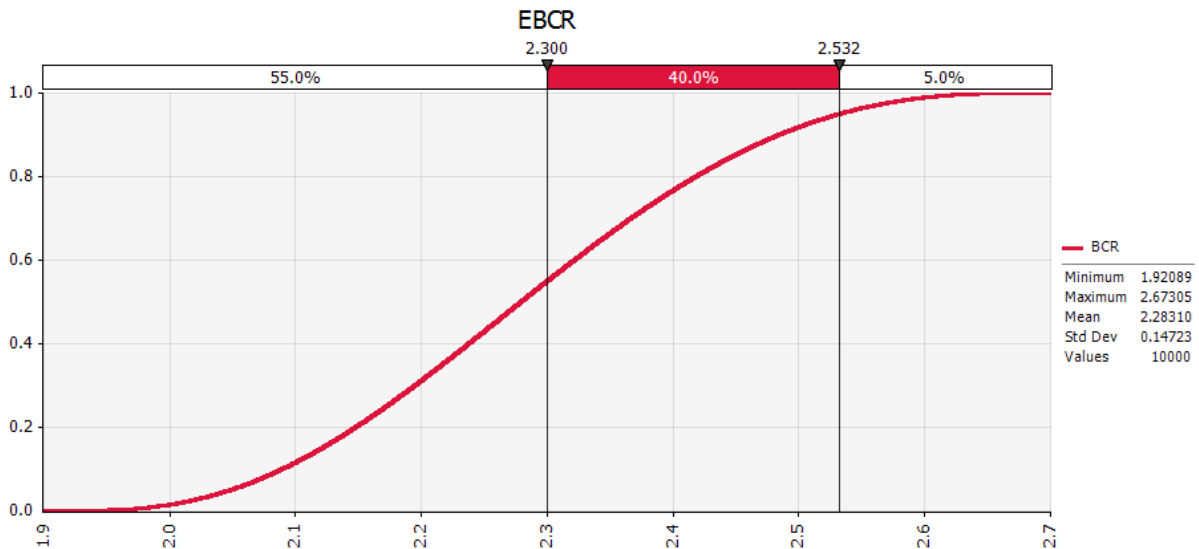


Figure 8: The cumulative probability distribution of the EBCR (S-curve) using 4% discount rate



The following information can be extracted from the depicted EBCR probabilistic distribution shown in Figure 8:

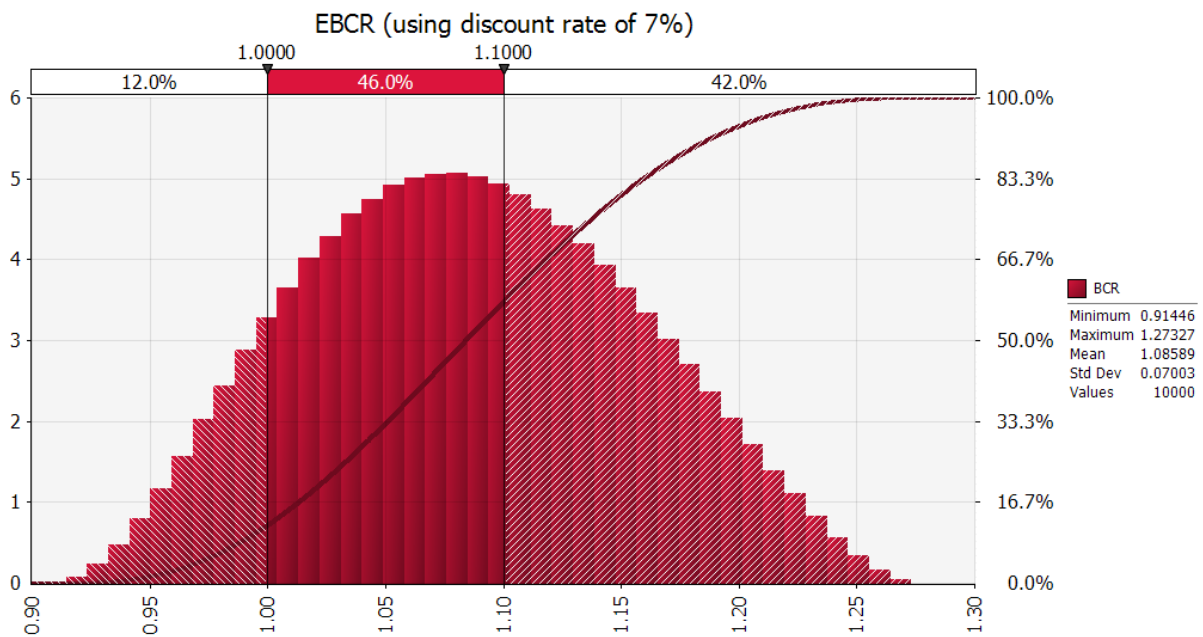
- The probability of having an EBCR of less than or equal to the quoted value of 2.3 in the report is 55%. In other words, the chances of the EBCR value being less than 2.3 is more than the chances of this value being exceeded.
- The EBCR figure could be as low as approximately 1.9 if all risks are realised.

- The EBCR figure will most likely be always greater than 1 – the breakeven point.

Similarly, the following additional information can be extracted from the depicted EBCR probabilistic distribution curve shown in Figure 9 which uses a discount rate of 7%:

- The probability of having an EBCR of less than or equal to the quoted value of 1.1 in the report is 58%. In other words, the chances of the EBCR value being less than 1.1 is greater than the chances of this value being exceeded.
- The EBCR figure could be as low as approximately 0.9 if all risks are realised.
- The likelihood of the EBCR figure being less than the breakeven point of 1 is 12%.

Figure 9: The cumulative probability distribution of the EBCR (S-curve) using 7% discount rate.



Approach 2 estimates

Considering the level of the data available in the report, a better approach, in comparison with approach 1 above, would be to use the probability distribution of total costs and combine it with the probability distributions of the items that make up the total benefits. In other words, the Monte Carlo simulation is performed taking the probability distribution of total costs and the probability distributions of user benefits, operator benefits, externalities and residual values.

Figure 10, below, reproduces the scenario analysis results from the HSR Phase 2 study, which includes high and low case estimates of project benefits. We use the scenario values for total benefits to derive a probabilistic distribution for project benefits, which we subsequently combine with the cost distribution to estimate the probabilistic EBCR.

Figure 11 shows the resulting probability density and cumulative distributions for the BCR, using the 4% discount rate results. The results imply:

- The probability of the EBCR being less than or equal to the reference case BCR (2.3) is 44.3%.
- The EBCR figure could be as low as approximately 1.5 if all risks are realised and the benefits are low.

- The EBCR is very unlikely to be below 1 – the breakeven point.

Figure 10: High speed rail study Phase 2 – Scenario analysis results

Table 24: Impact of alternative growth assumptions on the economic results (PV, \$2012, \$billion)

Measure	4% discount rate			7% discount rate		
	Reference Case	Low Case	High Case	Reference Case	Low Case	High Case
Total costs	79.3	78.4	80.7	58.9	58.5	59.5
User benefits	140.7	95.0	217.7	54.0	37.6	80.8
Operator benefits	13.7	9.8	19.4	5.8	4.1	7.8
Externalities	1.2	0.6	1.9	-0.1	-0.2	0.2
Residual value	25.0	14.6	44.7	4.3	2.5	7.8
Total benefits	180.6	120.1	283.7	63.8	43.9	96.6
EIRR	7.6%	5.9%	9.4%	7.6%	5.9%	9.4%
ENPV	101.3	41.8	203.0	4.9	-14.6	37.1
EBCR	2.3	1.5	3.5	1.1	0.8	1.6

Source: Reproduced from *Department of Infrastructure and Transport (2013, p. 387)*.

Figure 11: The probability density and cumulative probability distribution of the EBCR (S-curve) using 4% discount rate

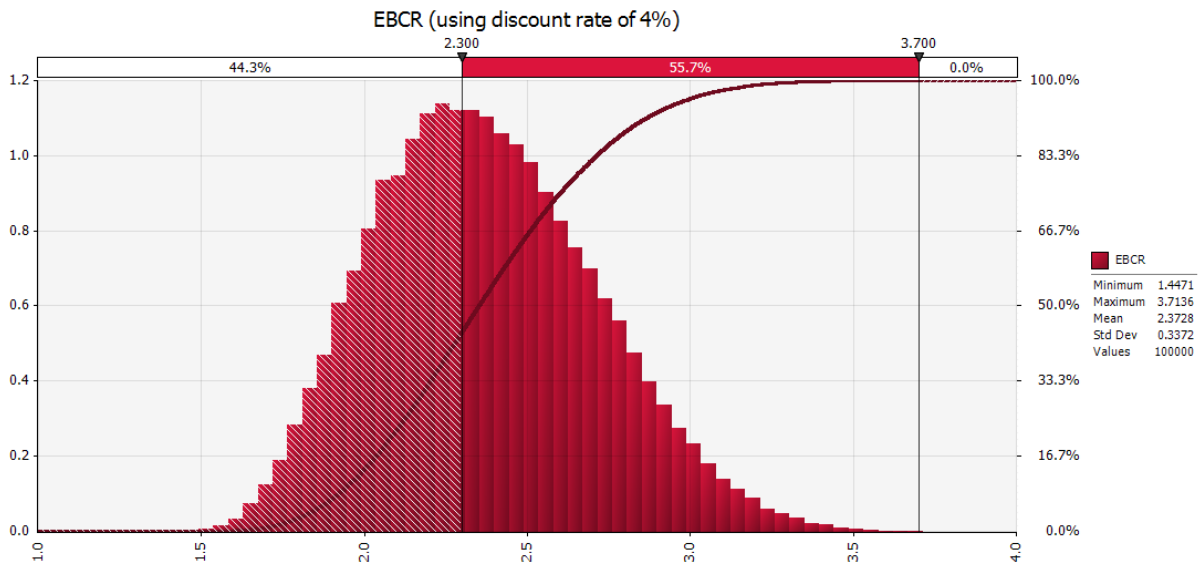
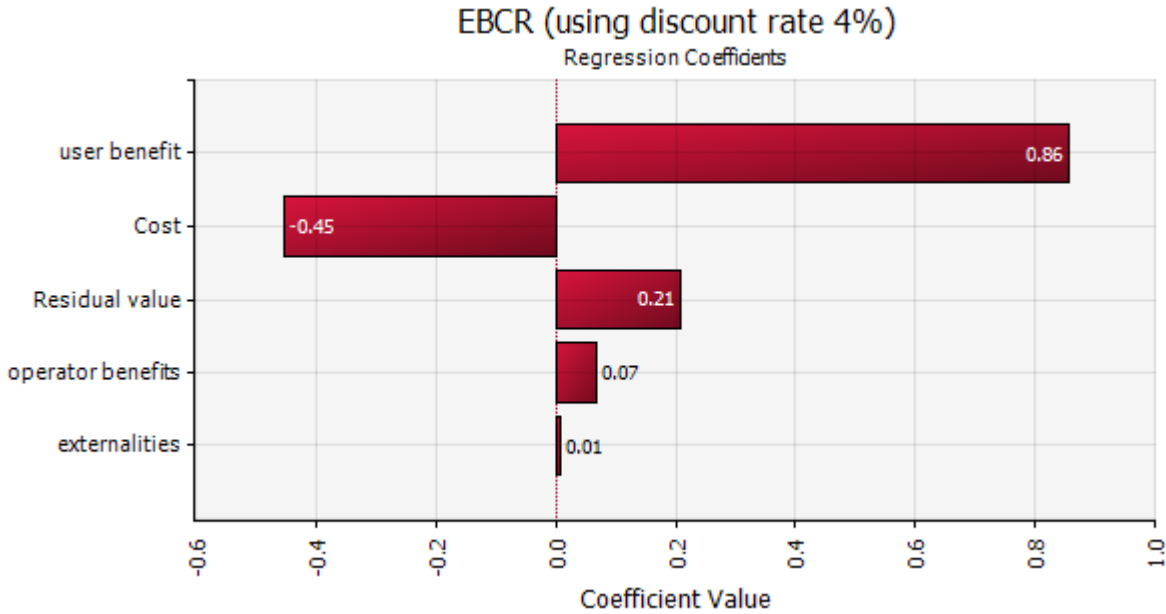


Figure 12 shows regression analysis results for the probabilistic BCR shown in Figure 11. The results imply that the EBCR is highly dependent on user benefits. Therefore before making concrete decisions based on the EBCR, one should look closely at the user benefit data and determine the reliance one should put on the user benefit data/results.

Figure 12: Regression Analysis of the EBCR (S-curve) using 4% discount rate.

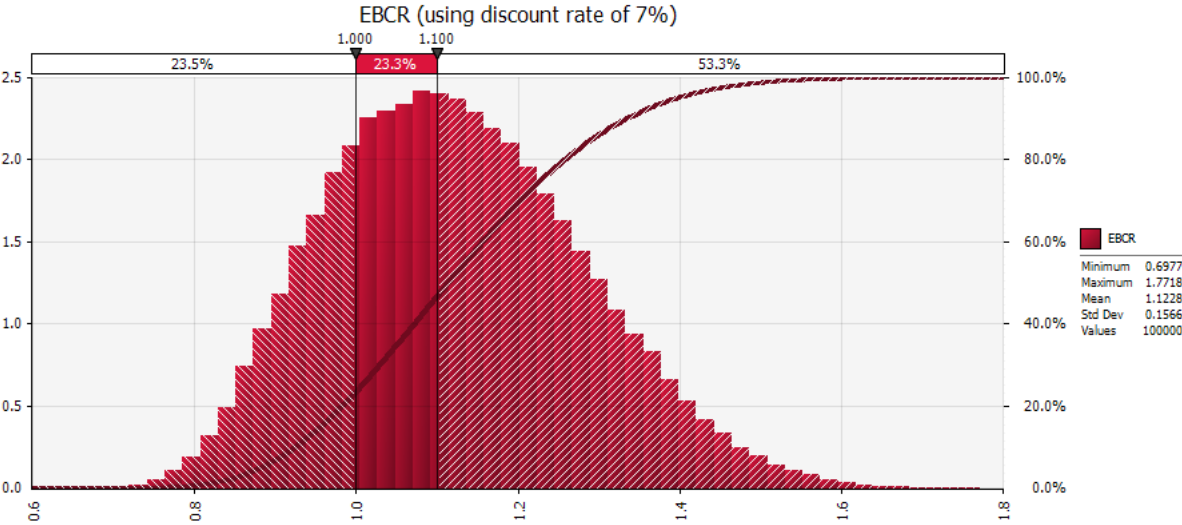


Finally, Figure 13 shows the probability density and cumulative distribution function for the BCR using the 7% discount rate project evaluation results. The probabilistic results imply:

- The probability of the EBCR being less than or equal to the quoted value of 1.1 in the report is 47%.
- The EBCR figure could be as low as approximately 0.7 if all risks are realised.
- The likelihood of the EBCR figure being less than the breakeven point of 1 is 23.5%.

So, despite the HSR project BCR estimated to be just above 1 using a 7% discount rate, the probabilistic analysis suggests that likelihood of the project having a BCR > 1.0 is above 75%.

Figure 13: The probability density and cumulative probability distribution of the EBCR (S-curve) using 7% discount rate



4. Conclusions

The *National Guidelines for Transport System Management in Australia* (TIC 2006), notes that detailed appraisal of project proposals usually involves detailed benefit–cost analysis (BCA), complemented by detailed financial assessments, and often specific impact analyses (e.g. environmental, regional, employment, equity). The outputs of BCA have traditionally been expressed as ‘single-number’ estimates of the total net present value (or benefit cost ratio) of a project. Sensitivity analysis of the BCA results to variations in key assumptions, such as discount rates, patronage levels, etc. may also be presented to provide decision makers with more evidence on the possible range of economic outcomes of a project. However, sensitivity analyses generally only changes one variable at a time, while holding all others unchanged, whereas Monte Carlo analysis considers variations across all variables simultaneously, thus providing a more realistic picture of how risks could affect project outcomes.

With project costings for major infrastructure projects increasingly incorporating explicit quantification of inherent and contingent project risks, and the ready availability of software tools to translate those risks into an overall project risk, it is possible to provide decision makers with not only the most likely project BCR, but also the estimated distribution of the BCR outcomes. If the uncertainty inherent in the project benefits has also been estimated, then it is possible to go further and incorporate the range of uncertainty inherent in both cost and benefits to provide a more ‘comprehensive’ statement about the distribution of a project potential BCR.

This paper has used results from the recent Australian Government HSR study Phase 2 Report (DIT 2013) to illustrate the potential outputs and the benefits of generating a probabilistic distribution of BCR. That study found that a HSR system between Melbourne–Sydney–Brisbane, on the east coast of Australia, would have a BCR of 2.3, using a 4% discount rate, and 1.1, under a 7% discount rate. Utilising the separate probabilistic cost and benefit information contained in the report, we derive combined probability distributions for the BCR for the different discount rate results presented in the report. The derived BCR probability distributions results do provide some additional perspectives on the ‘headline’ BCR results. Most usefully, they provide an estimate of the likelihood that the BCR exceeds one, i.e. that benefits exceed costs and the minimum BCR. The case study results suggest that the HSR rail project BCR exceeds one across all eventualities for the 4% discount rate case, and even under the 7 per cent discount rate case, the study results suggest the likelihood that the HSR BCR exceeds one is more than 75 per cent. Similarly the confidence level of any chosen BCR value can be extracted from the probabilistic distribution of BCR. This additional information, if provided, would enable decision makers to make more informed, and potentially better, decisions.

Of course, the accuracy of the imputed BCR distribution is critically dependent on the robustness and accuracy of the risk assessment and risk evaluation processes used in the cost estimation process, e.g. correlation between risks has been properly assessed and treated in the process and the accuracy of uncertainty in demand forecasts.

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