

Alternative approach to estimating crash costs for cost-benefit analysis using Monte Carlo simulation

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Abstract

Cost-benefit analysis (CBA) is used as a tool to inform investment decisions in both the government and private sectors. An essential part of any CBA for road infrastructure projects is the calculation of crash cost savings. Currently, crash cost savings are typically addressed via deterministic methods, as the product of projected future traffic volumes and the expected accident rate of the road after project completion. Road traffic crashes, especially fatality and casualty crashes, typically occur only infrequently, and at unpredictable intervals, this doesn't naturally accord with the deterministic model.

This paper demonstrates how probabilistic methods can be applied to better account for crash cost savings in CBAs. The benefits of this approach are demonstrated via an example.

1. Introduction

A Cost-benefit analysis (CBA) is usually conducted to inform decisions makers of the net economic benefits of a project ahead of its construction. It provides information about whether the project benefits outweigh costs, and if so, by how much. It is important to note that the cost and benefits being compared are forecast values and hence involve uncertainties, which should be addressed as effectively as possible so as to ensure that the comparison is valid. The uncertainties inherent in a project will mean that there will be separate distributions of possible cost and benefits outcomes, which are not adequately captured in a single number.

Probabilistic methods, or quantitative risk analysis approaches, are now widely utilised to quantify the uncertainties of the predicted outcomes and produce a probability distribution across all possible outcomes (Galloway et al. 2012, Baccarini 2005) as opposed to a single value produced by deterministic approaches. Probabilistic methods, utilising approaches like Monte Carlo simulation, are becoming increasingly popular to produce project-related estimates, because they improve the overall 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).

In Australia, project proposals for road projects submitted for funding applications/requests are required to submit, amongst other things, a probabilistic cost estimate along with a benefit cost ratio (BCR) (Infrastructure 2014). Currently there is no requirement for the estimated benefits or overall benefit-cost ratio (BCR) to be probabilistic. The Department of Infrastructure, Regional Development and Cities requires a probabilistic cost estimate for all projects exceeding \$25 million in out-turn costs.

Similar to cost estimates, the estimated benefits of projects will also be more informative if based on probabilistic methods. This paper builds on Prakash & Mitchell (2015), which considered derivation of probabilistic BCRs, by demonstrating how probabilistic methods could be applied to better estimating the crash cost savings element of expected projects' benefits. The crash cost element was chosen because the probability of road crashes is highly probabilistic and more readily lends itself to the application of probabilistic methods. The motivation for this paper also comes from a recent ex-post economic evaluation report of National Road Investment projects (BITRE 2018), recommending that "*Reporting of probability distributions of BCR and NPV should be encouraged*" due to large uncertainties accompanying the deterministic estimates of BCR and NPV.

2. Probabilistic estimation methods

Probabilistic estimation methods, or quantitative risk analysis, usually involves using Monte Carlo simulation (the predominant method used) to generate a probability distribution for all possible outcomes or scenarios. This is achieved by accounting for every possible value that an item, involved in the estimate, and the probability of occurrence of that value, and combining across all other items.

Boardman et al. (1996) outlines the general stages involved in performing CBA (see Figure 1).

Figure 1: CBA stages

1	• Specify the set of alternative projects
2	• Decide the benefits and costs to be included
3	• List all costs and benefits including items over the life of project
4	• Monetize the costs and benefits
5	• Apply discount rates to obtain present values
6	• Compute the preferred benefit over cost, [BCR, NPV etc], for each option
7	• Assess risks and uncertainty (sensitivity analysis)

Source: Adapted from Boardman et al. (1996).

If a probabilistic approach is adopted, the steps shown in Figure 1, would be modified from stage 6 onwards to account for the range of possible outcomes, as shown in Figure 2. In particular, note that the original "*stage 7— sensitivity analysis*"—may not be necessary by the application of probability distributions to all likely possible outcomes.

Figure 2: Probabilistic CBA stages

1	• Specify the set of alternative projects
2	• Decide the benefits and costs to be included
3	• List all costs and benefits including items over the life of project
4	• Monetize all identified items (costs and benefits)
5	• Apply discount rates to obtain present values
6	• Assign appropriate probability distributions to all items
7	• Account for correlations between items, if any
8	• Generate a probability distribution for the required item (NPV, BCR etc) using Monte Carlo simulation

The step of assessing sensitivities risks is not required since a Monte Carlo simulation produces sensitivity analysis by default. During a Monte Carlo simulation, values are sampled at random from the input probability distributions of the inherent and contingent items, and the results combined to obtain an outcome for each iteration. For the purposes of this paper, inherent items are referred to items that will definitely contribute to the overall estimate. In other words, the likelihood of occurrence of this item is 100%. I define contingent items, on the other hand, as items that may or may not contribute to the overall estimate. In other words, the likelihood of occurrence is less than 100%.

This process is repeated hundreds or thousands of times. This resultant probability distribution of possible outcomes produces not only the range of possible outcomes, but also the likelihood of those outcomes.

The details on the changes made to Figure 1 as shown in Figure 2 are explained below:

Assigning appropriate probability distributions to all items (step 6)

This step is to assign appropriate probability distributions to each of the inherent and contingent items, and to also assign probabilities to the occurrence of each contingent item.

The probability distribution chosen for each cost or benefit item should account for all possible project outcomes and are typically determined using lowest, most likely and highest possible values. Carefully approximating the range of possible outcomes is critical because use of inappropriate or unrealistic ranges can lead to 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. The choice of distribution function is beyond the scope of this paper however there is an extensive literature available on the type of distribution functions to use, and circumstances under which to apply them, in project risk evaluation (see, for example, Vose 2009).

Accounting for correlation between cost elements (step 7)

Correlation between items needs to be given consideration. When modelling, it is important to consider the impact of inter-relationships (correlation) between items to generate accurate and sensible outputs. Failure to suitably account for correlation can result in artificially tight project cost/benefit distributions, and an incorrect assessment of the true estimate.

Generating a probability distribution using Monte Carlo simulation methods (step 8)

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 this paper, @RISK was used for all simulations.

3. Crash Cost Savings in a BCA

For a road-related project, the estimated savings due to expected reductions in crashes is extremely important potential benefit, and has great societal impacts due to the loss of life and serious injury of those involved in serious crashes. Estimated reductions in the cost of road crashes are classified as part of the safety benefits of a road project.

Calculating the crash cost savings involves the following steps (TIC 2018a):

- Estimating the expected number of crashes by crash type for each year under the base case and the project case
- Multiply the crash numbers for each type by their respective unit costs

The expected number of crashes during a period of time is typically obtained by multiplying expected crash rates by forecast traffic volumes. The relevant crash rate for estimating future crash numbers in the base and project options is a number of crashes per year to unit of traffic (vehicles, trains, cyclists and pedestrians) or traffic-kilometre. Road crash rates are typically expressed per 100 million vehicle kilometres travelled (VKT). Crashes may be considered at different severity levels such as fatal, serious injury, minor injury or property damage only. The levels are dependent on the data availability.

For a specified period,

$$crash\ cost, cc^i = N^i * \mu^i \quad (1)$$

where:

N^i is the estimated crash number for crash type i severity level of accident; and

μ^i is the unit crash cost of severity type i .

To derive the crash cost savings (benefit) for a project case, either: i) project case crash costs are subtracted from base case crash costs; or ii) the base crash cost is multiplied by the crash cost reduction factor for the identified project option (TIC 2018a).

For a specified period, crash cost savings for severity type, i for option, j of a project is

$$crash\ cost\ savings, cc_j^i = N^i * \alpha_j^i * \mu_j^i \quad (2)$$

where:

N^i is the estimated crash number for the base case for crash type i severity level of accident;

α_j^i is the crash cost reduction factor with project option j implemented; and

μ_j^i is the unit crash cost of severity type i with project option j implemented.

4. Probabilistic Crash Cost Savings in a BCA

To better account for the uncertainties involved in calculating crash cost savings, I apply the relevant steps as shown in Figure 2, primarily to consider the variables as probability distributions instead of a single number. Hence, Equation 2 is transformed as below:

$$prob. dist(crash cost savings, cc_j) = prob. dist(N^i) * prob. dist(\alpha_j^i) * prob. dist(\mu_j^i) \quad (3)$$

Notice that all the three quantities, estimated crash number, crash cost reduction factor and unit crash cost, in Equation 2 are represented as separate probability distributions, because all these three quantities have uncertainties associated with them.

The next step would be to consider any correlations between these items and perform a Monte Carlo simulation to obtain a probability distribution for crash cost savings.

The following section illustrates this method to a worked example provided in (TIC 2018b) and compares the generated results. For the purposes of this paper, I focus on the crash cost calculation and leave the other items as deterministic.

5. Worked example

This example has been adapted from (TIC 2018b) on *Pedestrian/cycle signalized crossing or overpass*.

5.1. Problem description

The scenario presented is that currently pedestrians and cyclists are crossing a major sub-arterial road. The crossing is not presently signalised but there is pedestrian refuge in the roadway median. The annual average daily traffic (AADT) is 5,000 vehicles growing at 2% per annum. On average, 150 walkers and 100 cyclists use the crossing each day, making an average of two crossings per day per person. Active travel trips are growing at 2% pa.

The problem statement: facilitate safer pedestrians and cyclists crossing.

5.2. Options

There are two options (Options 1 and 2) being investigated with the base case being ‘Do Nothing’.

Option 1: Provide signals at the crossing to allow active travellers to cross safely; and

Option 2: Provide a pedestrian and cycle overpass.

5.3. Inputs and assumptions

The inputs required for an analysis are as listed in Table 1.

Table 1: Inputs

Base year and price year:	2015
Construction period years:	2016
Real discount rate	7%
Appraisal period:	construction period plus 30 years of operation

Ref	Item	Base Case	Option 1	Option 2
A	Construction costs		\$250,000	\$4,250,000
B	Asset (economic) life		30-year life	40-year life
C	Residual value			\$1,062,500 ¹
D	Maintenance costs		\$4,000 per year	\$25,000 per year
E	Number of crossing trip/day – walkers	300	300	300
F	Number of crossing trip/day – cyclists	200	200	200
G	Active transport trips ² as % of total trips	60%	60%	60%
H	Annual average daily traffic (AADT) (2015)	5000	5000	5000
	% private car	80%	80%	80%
	% business car	15%	15%	15%
	% commercial	5%	5%	5%
I	Average delay – walkers/cyclists (secs)	0	45	45
J	Average delay – all vehicles (secs) (F)	0	3	0
K	Days per year	365	365	365
L	Average crash cost –fatal (2013 values)	\$7,573,412	\$7,573,412	\$7,573,412
M	Average crash cost –serious injuries (2013 values)	\$526,606	\$526,606	\$526,606
N	Crash cost reduction factor relative to median refuge	0	61%	77%
O	Fatal crashes per year	0.1	0.039	0.023
P	Serious injury crashes	0.1	0.039	0.023
Q	Weighted average value of travel time - vehicles	\$31.34 per hr	\$31.34 per hr	\$31.34 per hr
R	Average value of travel time – active travellers	\$14.99 per hr	\$14.99 per hr	\$14.99 per hr
S	CPI June 2013	102.8	102.8	102.8
T	CPI June 2015	107.5	107.5	107.5
U	Growth rate	2%	2%	2%

¹ Shown as a benefit in the final year of appraisal. Based on: straight line depreciation method, 10 years of 40-year life remaining at end of appraisal period (40 – 30).

² Active trips implies walking and cycling with a purpose and not for recreational purposes.

For more details and other assumptions, please refer to TIC (2018b)

The benefits and costs for the BCR calculation can be classified as follows:

Benefits:

- Travel time savings (disbenefit)
- Crash cost savings
- Residual value

Costs:

- Construction costs
- Maintenance costs

See below for the values of these items derived via different approaches.

5.4. Deterministic Approach

The calculations were performed as follows (TIC 2018b).

Note:

- All dollar values are multiplied by CPI June 2015 / CPI June 2013 to inflate the 2013 unit cost parameter values to the price year of 2015;
- Upper case letters in the formulas refer to the reference labels (Ref) appearing in Table 1;
- Benefits for 2018 and onwards are calculated by applying the growth rate (2% each year from 2017 onwards—i.e. multiply by $(1 + \frac{Growth\ rate}{100})$).
- All values have been discounted rate at a 7% discount rate.

Crash cost savings for base year (this is the combined cost of fatal and serious injury crashes saved due to the initiative):

$$crash\ cost\ savings, cc_j = \sum_{i=1}^2 N^i * \alpha_j^i * \mu_j^i = (O*L+P*M)*N \quad (4)$$

where:

N^i is the estimated crash number for the base case for crash type i severity level of accident;

α_j^i is the crash cost reduction factor with project option j implemented;

μ_j^i is the unit crash cost of severity type i with project option j implemented;

$i = \begin{cases} 1, & \text{severity level: Fatal} \\ 2, & \text{severity level: serious injury} \end{cases}$ and;

$j = \begin{cases} 1, & \text{Option 1} \\ 2, & \text{Option 2} \end{cases}$

Time travel benefit (disbenefit):

$$\text{Time travel benefit} = (E + F) * G * R * I * \left(\frac{K}{3600}\right) * \left(1 + \frac{U}{100}\right)^2$$

Residual value:

$$\text{Residual value} = C$$

Table 2: Total cost, discounted, \$,000

	Option 1	Option 2
Total cost (capital and maintenance)	280	4262

Table 3 shows the calculations for these quantities using the deterministic approach as suggested in (TIC 2018b).

Table 3: Deterministic calculations (\$,000)

Year	Option 1			Option 2				
	Crash reduction	Travel time savings-active travellers	Travel time savings - cars, trucks	Total benefits	Crash reduction	Travel time savings-active travellers	Travel time savings - cars, trucks	Total benefits
2017	520	-22	-52	446	655	-22	0	632
2018	530	-23	-53	455	668	-23	0	645
2019	541	-23	-54	464	681	-23	0	658
2020	552	-24	-55	473	695	-24	0	671
2021	563	-24	-56	483	709	-24	0	685
2022	574	-25	-57	492	723	-25	0	698
2023	586	-25	-58	502	737	-25	0	712
2024	597	-26	-60	512	752	-26	0	726
2025	609	-26	-61	522	767	-26	0	741
2026	622	-27	-62	533	782	-27	0	756
2027	634	-27	-63	544	798	-27	0	771
2028	647	-28	-64	554	814	-28	0	786
2029	660	-28	-66	566	830	-28	0	802
2030	673	-29	-67	577	847	-29	0	818
2031	686	-29	-68	588	864	-29	0	834
2032	700	-30	-70	600	881	-30	0	851
2033	714	-31	-71	612	899	-31	0	868
2034	728	-31	-73	624	917	-31	0	886
2035	743	-32	-74	637	935	-32	0	903
2036	758	-33	-76	650	954	-33	0	921
2037	773	-33	-77	663	973	-33	0	940
2038	788	-34	-79	676	992	-34	0	959
2039	804	-35	-80	689	1012	-35	0	978
2040	820	-35	-82	703	1032	-35	0	997
2041	837	-36	-83	717	1053	-36	0	1017
2042	853	-37	-85	732	1074	-37	0	1038
2043	870	-37	-87	746	1096	-37	0	1058
2044	888	-38	-89	761	1118	-38	0	1079
2045	905	-39	-90	776	1140	-39	0	1101
2046	924	-40	-92	792	1163	-40	0	1123

The total values of benefits as shown in Table 3 after applying discount rates is provided in Table 4.

Table 4: Total benefits, discounted, \$,000

	Option 1	Option 2
Total crash reduction discounted at 7%	7408	9326
Total travel time savings – active travellers	-318	-318
Total travel time savings – cars, trucks	-739	0
Residual value	0	130
Total	6351	9138

Using the values of the total cost (Table 2) and the total benefits (Table 3) for the two options, the BCR¹ values (rounded to one decimal place) are then 22.7 (Option 1) and 2.1 (Option 2):

$$\text{Option 1: } BCR = \frac{\text{Total Benefits}}{\text{Total Costs}} = \frac{6351}{280} = 22.7$$

$$\text{Option 2: } BCR = \frac{\text{Total Benefits}}{\text{Total Costs}} = \frac{9138}{4262} = 2.1$$

Table 5: BCA calculations

	Option 1	Option 2
BCR= $\frac{\text{Total Benefits}}{\text{Total Costs}}$	22.68	2.14
NPV= Total Benefits - Total Costs	6.07	4.88

5.5. Probabilistic Approach

As detailed in Section 4, to account for uncertainties, all variables should be treated as probability distributions instead of a single number. In this following example, all variables have an associated probability distribution.

Benefits:

- Travel time savings: there is uncertainty in the value of travel time savings due to uncertainty in the underlying items such as dollar value of travel time and number of crossings, etc;
- Crash cost savings: There is uncertainty in the expected number of crashes and expected crash severity; and
- Residual value: Uncertainty in the estimated residual dollar value.

Costs:

- Construction costs: Uncertainty in estimated costs; and
- Maintenance costs: Uncertainty in estimated maintenance costs

Basically, when relying on estimates, it cannot be said that there is no uncertainty, including the uncertainty in the acceptance of the solutions brought about by the projects. For instance, for option 2 of the project being considered in the paper, there could be a tendency for pedestrians and cyclists to not use the overhead pass built. This would then mean that the crash cost reduction factor would not be as predicted, i.e., accidents still occurring at the previous rate. Uncertainty is inherent in all estimates and the estimating processes hence it is highly misleading to represent an estimate as a single number. Ideally, all the items for the costs and benefits calculation should be replaced with appropriate distributions and modelled.

The probability distribution utilized depends on the characteristics of the quantity to be represented. For instance, benefit due to travel time savings is dependent upon “*number of*

¹ This BCR corresponds to BCR1 in Australian and Infrastructure Council (2018b).

crossings per day by walkers/cyclists” and the “*average value of time savings*”. The possible values of the former variable can only be whole numbers, ie {0,1,2,3, ... }, therefore the use of a discrete distribution is appropriate where the latter variable, includes values (dollar amounts) upto two decimal places where a continuous distribution is required. Continuous distributions, unlike discrete ones, can take any value over a continuous range of values. For more details, see Baccarini (2018).

For the purposes of this paper, I focus only on the crash costs calculation and then only on uncertainty in the estimated number of crashes, simply assuming that average crash costs are “*certain*”, and model the benefits by treating the estimated number of crashes as a distribution.

Hence, after these assumptions, Equation 3 transforms to:

$$prob. dist(crash cost savings, cc_j^i) = prob. dist(N^i) * \alpha_j^i * \mu_j^i$$

where:

N^i is the estimated crash number for the base case for crash type i severity level of accident;

α_j^i is the crash cost reduction factor with project option j implemented; and

μ_j^i is the unit crash cost of severity type i with project option j implemented.

From the information provided, N^i , for both severity types (fatal and serious injuries) was taken as 0.1. In other words, the probability for a crash for both severity types is 0.1. This value has been used in the calculations as shown in Section 5.4. Notice that the deterministic approach, as per Equation 4, the crash reduction benefit for 2017, for option 1, is calculated as below:

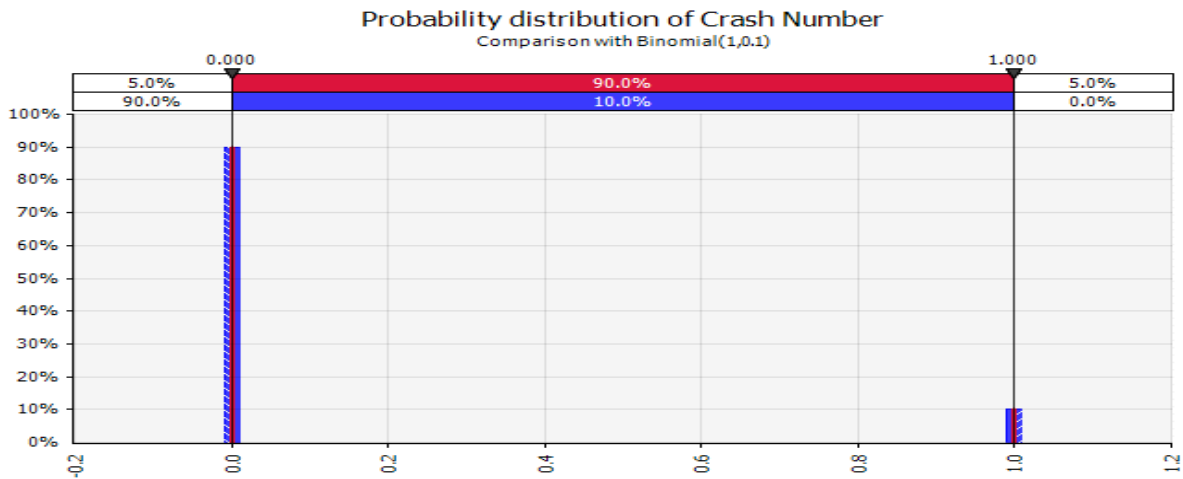
$$\begin{aligned} crash\ cost\ savings, cc_1 &= \sum_{i=1}^2 N^i * \alpha_j^i * \mu_j^i \\ &= (0.1 * 7,573,412 * 0.61) + (0.1 * 526,606 * 0.61) \cong 494,101 \end{aligned}$$

After multiplication by CPI adjustment factor $\left(\frac{CPI\ June\ 2015}{CPI\ June\ 2013}\right)$, the crash cost savings for 2017 is \$0.52 million as also provided in Table 3. Note that this figure is an approximated average and is not representing the possible reality. For a possible crash in 2017, for both severity types (fatal and serious injury), the crash cost savings would be \$5.2 million and not one tenth of it.

To overcome this approximation, I model N^i by using the $prob. dist(N^i)$ as a binomial distribution (Baccarini 2018). A binomial distribution has only two values with each having an associated probability. In this case, the two values would be either “0” or “1”. I assign “0” for the crash not happening and “1” for a crash happening with the associated probabilities as 0.9 and 0.1 respectively. It is important to point out that, for any given year, the reality is that either the cost is going to be zero or the cost is going to be the cost of crash if it happens. This is how the crash number is modelled and the Monte Carlo simulation done.

This function is provided in @Risk software as “RiskBernoulli” and Figure 3 depicts $prob. dist(N^i)$.

Figure 3: Probability distribution function of estimated crash number per year, N^i .



5.5.1 Monte Carlo results

Monte Carlo simulation then involves taking repeated random draws from the distribution, for each year and for each severity case— either a “0” (no crash) or “1” (crash) and multiplied by the respective cost to obtain the crash cost for that year. For instance, for a random iteration for option 1, if the crash number for a fatal crash is drawn as “1”, then this is multiplied to the crash cost of \$7,573,412 and the reduction factor of option 1, 0.61 to obtain the crash cost savings of approximately \$4.6 million (before any CPI or discount rate adjustment); on the other hand, if the crash number for a fatal crash is drawn as “0” then the crash cost savings is \$0 as expected.

The results of the Monte Carlo simulation are presented in Table 6 and Figures 4-11.

Table 6: Summary of Monte Carlo simulations results

	Option 1			Option 2		
	P(>= breakeven*)	P50**	P90	P(>= breakeven)	P50	P90
BCR	95.5%	21.1	42.5	82.4%	2	3.8
NPV	95.5%	5.6	11.6	82.4%	4.3	11.9

* refers to the breakeven points of 1 for BCRs and 0 for NPVs.

** P50 value is the value with a 50 per cent likelihood that it will not be exceeded

For instance, refer to Figures 4 & 5 which depict the distribution of the total crash reduction savings. The deterministic total for this item as provided in Table 4 was \$7,408,000 and \$9,326,000 for options 1 and 2 respectively. The additional information that Figures 4 and 5 provide is that the probability of achieving these totals or less is 54%. Since this is related to benefits, the other way to look at this would be to state that the probability of achieving a crash cost saving of *at least* \$7,408,000 for option 1 and \$9,326,000 for option 2 is 46% for both. Which therefore indicates that there is a bigger chance of the total crash cost savings *being less* than the identified totals for both the options.

Figure 4: Total crash reduction, discounted for Option 1

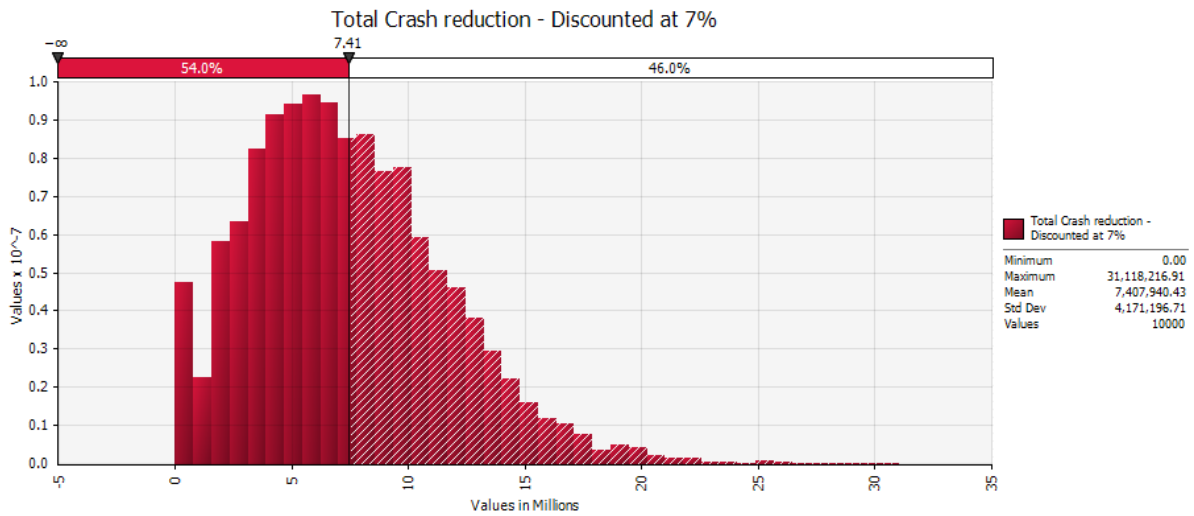
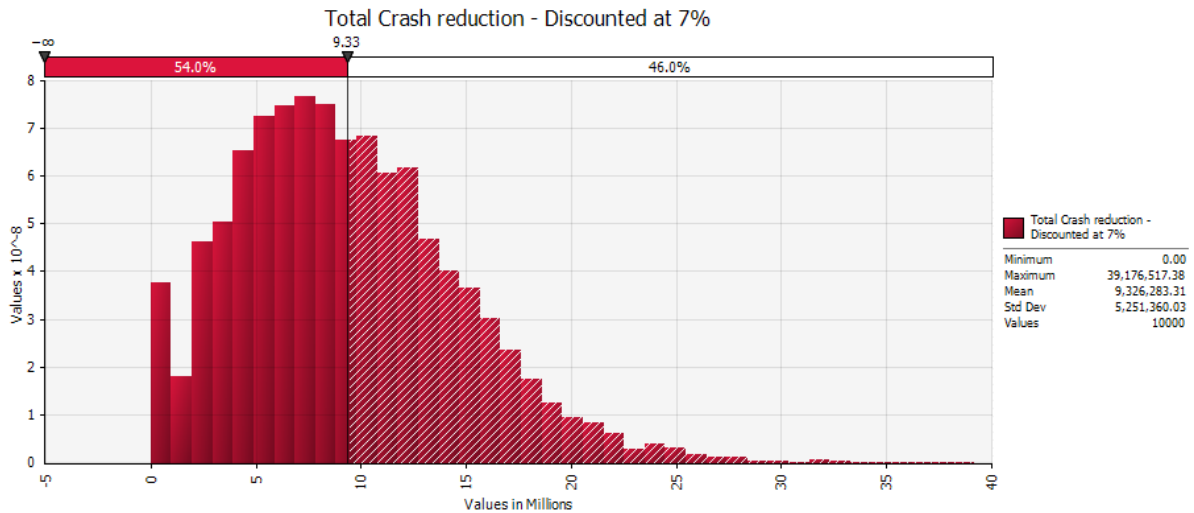
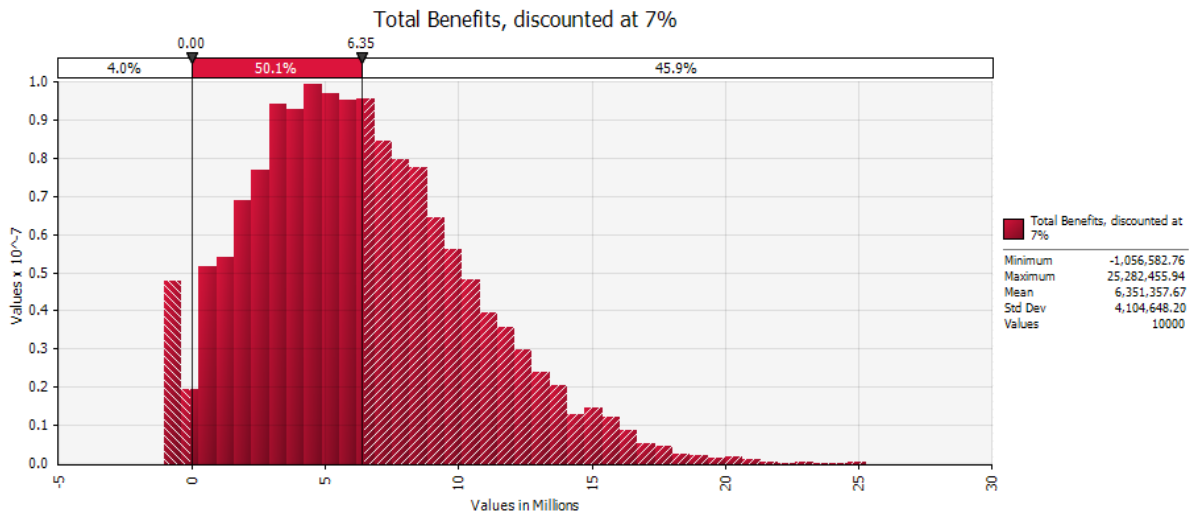


Figure 5: Total crash reduction, discounted for Option 2



The effects of the consideration of probability for a crash as a probability distribution also flows onto the total benefits. The extra details that can be extracted from the probability distributions of the total benefits (Figures 6 and 7) are that the probability of achieving a *negative benefit* are 4.0% and 0.5% respectively for options 1 and 2. Also that the probabilities of getting at least the deterministic figures of total benefits (Table 4) of \$6,351,000 for option 1 and \$9,138,000 for option 2 are approximately 46% for both. Similar to the conclusion drawn for the total crash savings, the results indicate there is a bigger chance of the total benefits *being less* than the identified totals for both the options.

Figure 6: Total benefits, discounted for Option 1



Similar observations can be made from the BCR distributions (Figures 8 and 9). The probability of a negative BCR due to negative benefits for option 1 is 4% while it is 0.5% for option 2. The probabilities of getting the deterministic values of BCR (Table 5) of at least 22.68 for option 1 and 2.14 for option 2 are about 46% for both and therefore there is a bigger chance of the BCR values *being less* than the identified values for both the options. In relation to the breakeven point of BCR being 1, Option 1 has a 95.5% of achieving at least a 1 as compared to Option 2’s 82.4%.

The Net Present Value (NPV) distributions are shown in Figures 10 and 11.

The probability for getting a negative NPV due to negative benefits for option 1 is 4.5% while it is 17.6% for option 2. The probabilities of getting the deterministic values of NPV (Table 5) of at least \$6.07 million for option 1 and \$4.88million for option 2 are about 46% for both and therefore there is a bigger chance of the NPV values *being less* than the identified values for both the options.

Preferred Option

The distributions of BCRs and NPVs (Figures 8-11) can be used to inform the decision making process when choosing between Option 1 and Option 2, if decision is to be made on these indicators and not for political reasons. In this case, Option 1 has a greater BCR and NPV values for a chosen point of comparison, for instance a chosen “P” value. For instance, a P50 value is the value with a 50 per cent likelihood that it will not be exceeded. Usually for a deterministic BCR, the “expected value” or mean is utilized for the computations. Having these distributions provides one with more information to facilitate the decision making process. For instance, also available is the probability of an Option breaking even. In the example presented Option 2 has a 17.6% chance of not achieving a BCR of 1 as compared to 4.5% chance for Option 1. Similarly Option 2 has a greater chance (17.6%) of achieving a NPV of less than 0 as compared to 4.5% for Option 1.

Hence Option 1 would be the project to pursue because it has greater BCR and NPV values for a chosen “P” value and it also shows a greater chance of achieving a greater than or equal to the breakeven point.

Figure 7: Total benefits, discounted for Option 2

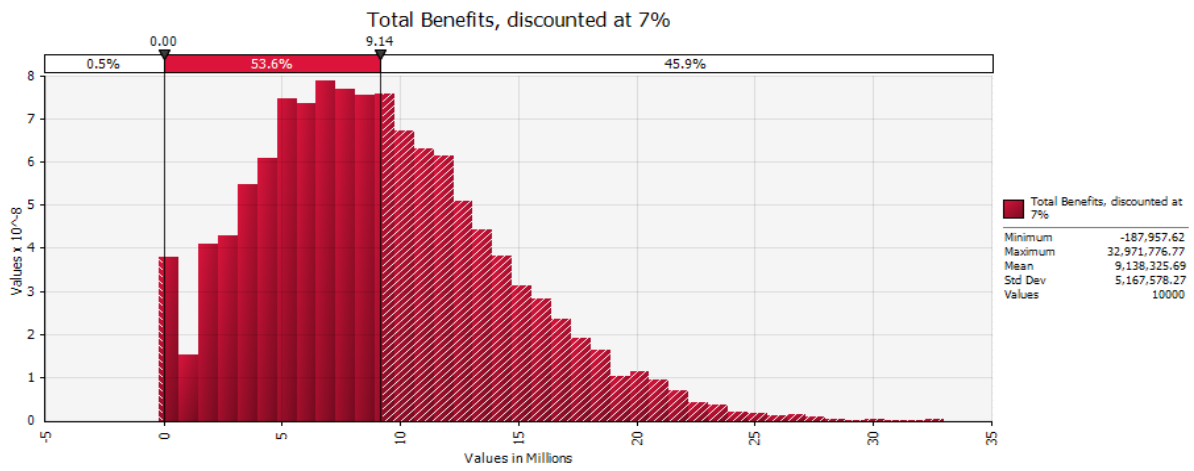


Figure 8: BCR for Option 1

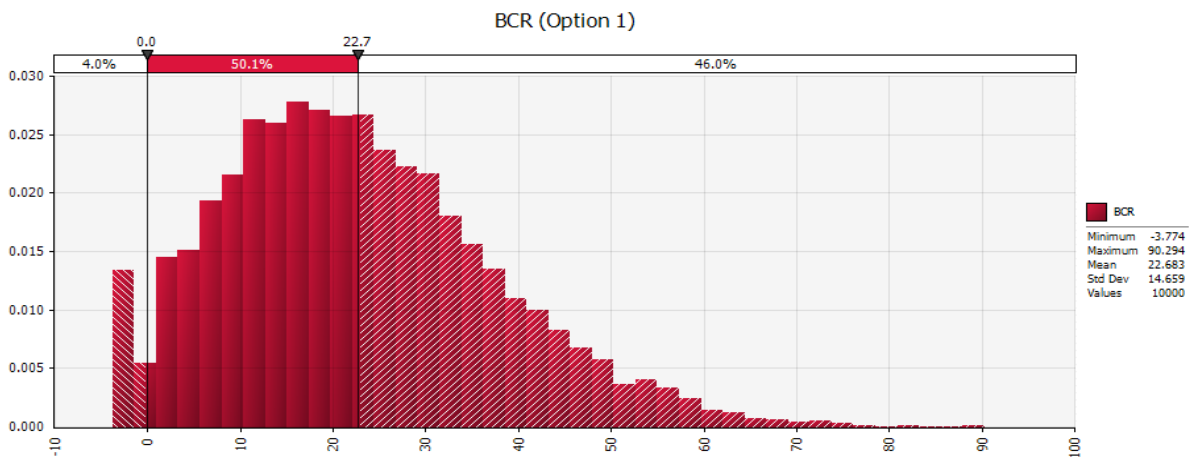


Figure 9: BCR for Option 2

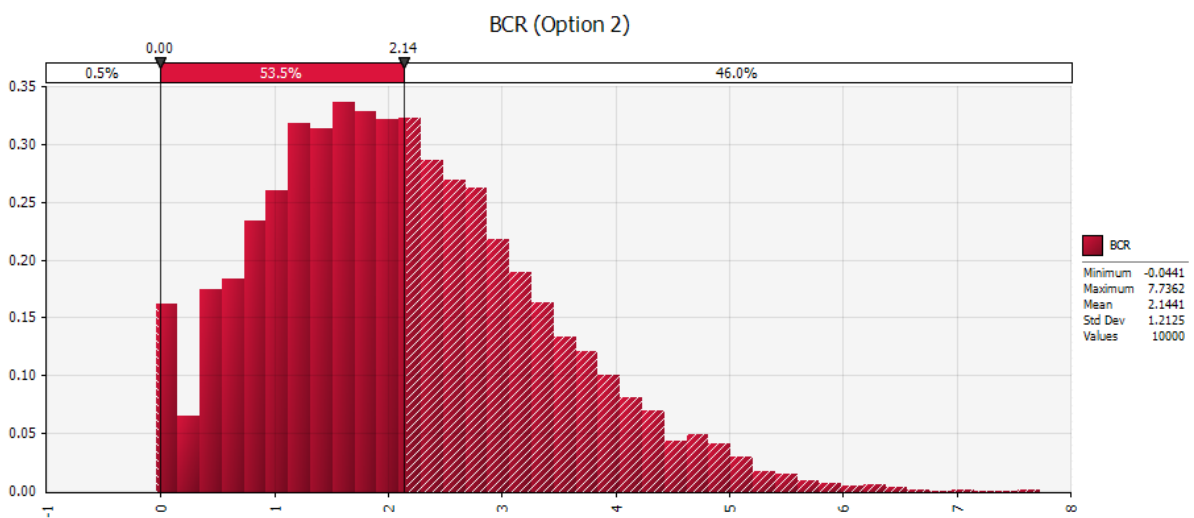


Figure 10: NPV for Option 1

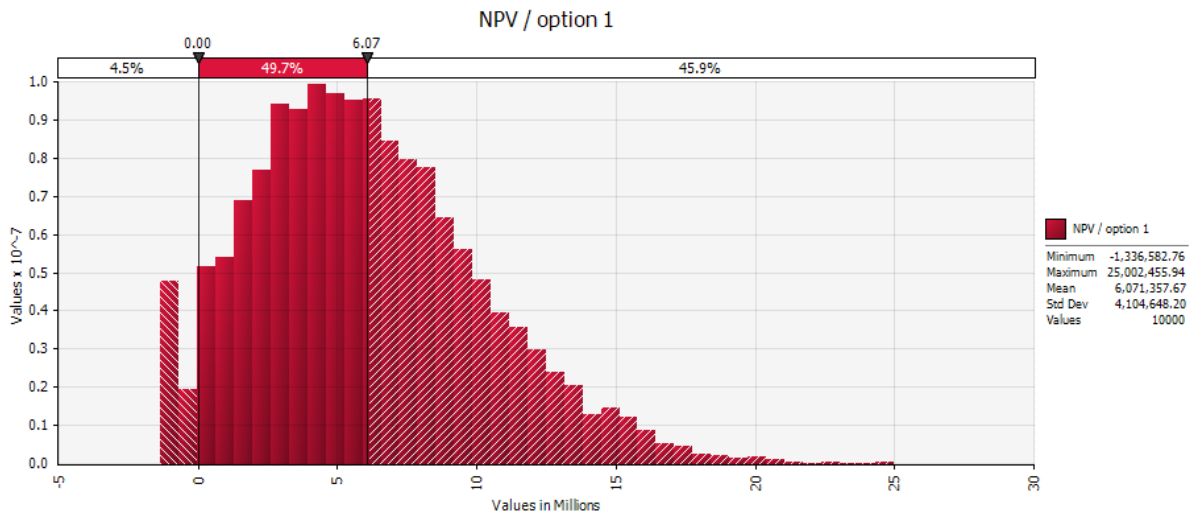
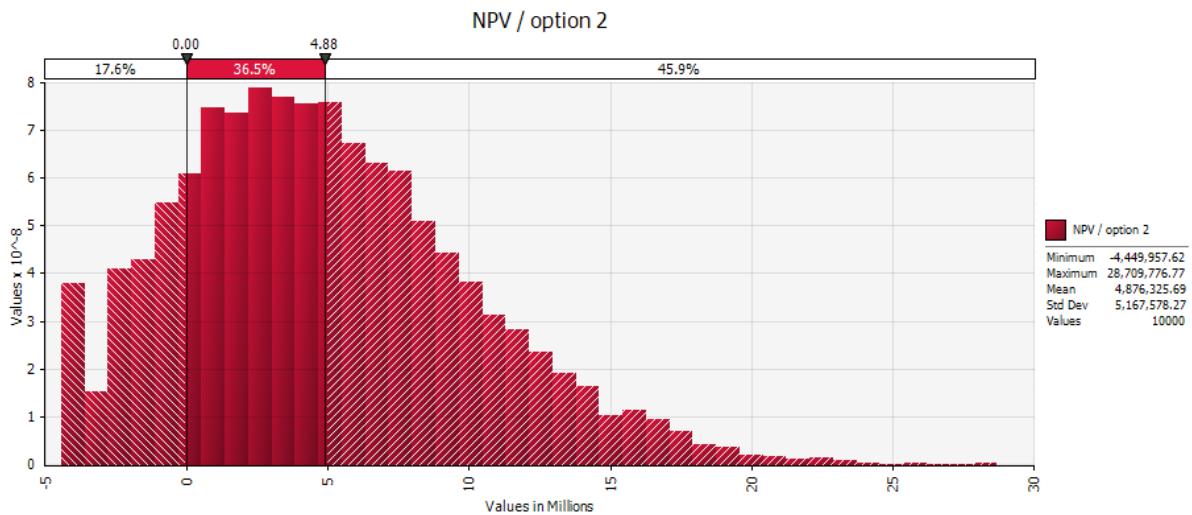


Figure 11: NPV for Option 2



6. Conclusions

In this paper, I have presented a probabilistic approach to calculating the crash cost benefits, as part of performing a CBA, in a road project. The infrequent and uncertain nature of road crashes lend themselves to probabilistic methods. As shown via a demonstrated example, a probabilistic approach provides more information, as compared to a deterministic approach, to assist decision makers to choose between projects. The additional information provides decision makers with an idea as to the nature of the risks involved in projects, including extreme outcomes, which can be very useful when comparing projects. This paper presented the results by replacing the deterministic crash cost savings with its probabilistic equivalent. This analysis would be better if all items were substituted by their respective distributions and hence provided deeper analysis which possibly renders separate the sensitivity analysis unnecessary because the probability distribution generated by the Monte Carlo simulations contain the sensitivity analysis and more.

7. Acknowledgements

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