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Monte Carlo for selecting risk response strategies

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Abstract

A risk is any factor that may potentially interfere with the successful completion of a project. It is an event that has not yet happened or may not happen in the future. Project risk may adversely affect the cost, schedule or the quality of a project. The practice of addressing the identified risks so that the likelihood of the risk occurrence and its impact is reduced is commonly known as risk response strategy. In practice, not all risk response strategies can be implemented and hence the selection of a subset of risk response strategies to address potential risks is an important aspect in project risk management. If the subset of risk response strategies to be implemented is not chosen well, it may have critical implications for the project.

In this paper, a Monte Carlo approach is applied for the risk response strategy selection problem. Monte Carlo simulation is used in many aspects of a project including deriving project costs, schedules and benefit cost analysis. The Monte Carlo model developed in this paper integrates project scope, schedule and quality, together with the costs and benefits of implementing each risk response strategy. The results of the Monte Carlo simulations can be used by project managers to facilitate the decision making process while choosing the preferred and practical combinations of risk response strategies for implementation. A benefit-cost ratio approach is also suggested which the project managers can utilise to facilitate their decisions on the combinations of risk strategies to implement after the Monte Carlo simulations results are in hand. The proposed approach is then applied to simple project data to illustrate the simplicity, versatility and practicality of the approach and compared to existing methods.

1. Introduction

A risk is any factor that may potentially interfere with the successful completion of a project by adversely affecting the cost, schedule or the quality of a project. Hence project risk management is an integral part of project management and is becoming increasingly a subject of focus and research. Project risk management involves three practices: Risk assessment, Risk response strategy preparation; and Risk management plan development (Hill 2009)

Risk assessment practice includes three activities namely risk identification, risk analysis and risk prioritization. Risk identification is, as the name implies, the process of identifying risks to a project and documenting them. Risk analysis involves examining the identified risks to assess the probability of occurrence and impact of each. If the probability of occurrence of a risk event is 100%, that is, its occurrence is certain, it should be treated separately and distinguished from those risks whose likelihood of occurrence is less than 100% (Hill 2009). Risk prioritization is a step in risk assessment practice, whereby the identified risks are ranked according to their relative importance or significance. The significance is determined by the likelihood of a risk's occurrence combined with its impact to the project, if it eventuates.

Risk response strategy preparation practice involves addressing the identified risk so that the likelihood of a risk's occurrence and its impact is reduced. The response strategies are provided for all risks and particularly for highly prioritised risks with high likelihood and critical impact. The strategies are referred to as preventative response strategies if they are selected or activated in advance of the occurrence of a risk, and reactive response strategies if the strategies are enforced or activated after a risk occurs. Risk response strategy preparation activity also involves the assessment of risk response strategies. This assessment entails evaluating the impact of risk response strategies on the cost, schedule, and quality of the project. It should also assess whether if a certain risk response strategy is implemented; it will not only lower the probability and impact of a risk or risks but will not result in creating any additional significant risk. The results of this assessment are taken into consideration when deciding on selecting a risk response strategy from among two or more response strategies, that is, to select a subset of response strategies to implement from an extended list of strategies.

This paper addresses the problem of selecting a subset of response strategies to implement, from a list of strategies, using a Monte Carlo simulation approach. A Monte Carlo model is developed while integrating project scope, schedule and quality together with costs and benefits of implementing risk response strategies. Monte Carlo simulation is used for many applications in Project Management including cost estimation, schedule estimations, risk assessments, benefit cost analysis, see for example (Prakash and Mitchell 2015, Raychaudhuri 2008). The reason for its wide usage is its applicability and also for the simplicity in which one can construct models as compared to certain optimisation models, which would require expert knowledge.

This paper commences with a literature review related to selecting project risk response strategies. Then the Monte Carlo method is introduced in general and a model is presented for the project risk responses strategies selection problem. Later the proposed method is applied to simple project data and the simulation method and results discussed and concluded.

2. Literature Review

Selection of risk response strategies have been focussed on from different perspectives (Hatefi and Seyedhoseini 2012, Zhang 2016). The different perspectives have been classified as zonal-based approach, trade-off approach, the work breakdown structure (WBS) approach and the optimisation-model approach. A comprehensive literature review for this topic is provided in (Zhang and Fan 2014).

In the zonal approach, two selected criteria with respect to risks are plotted on a two dimensional graph. Multiple zones are formed on the graph according to different values of the two criteria and these zones are then used to select appropriate strategies. However, this approach has a limitation that only two criteria can be considered and decisions made thereon (Datta and Mukherjee 2001, Hatefi et al. 2007, Miller et al. 2001).

In the trade-off approach, trade-offs are made to obtain candidate risk response strategies. These trade-offs are made between criteria associated with risk associated with factors of a project, such as cost, quality etc. Various methods are used to select the strategies among the candidate strategies such as efficient frontier rule ((Kujawski 2002, Pipattanapiwong and Watanabe 2000), pareto optimal approach (Haimes and Engineering 2005) and the decision makers preference (Klein, 1993). The restrictions in these approaches are that either only two factors are considered or trade-offs are qualitative analysis based.

The WBS approach involves risk management and project management processes. The risk response strategies are associated to the WBS of a project. This approach enables risks to be identified and strategies formulated directly associated with applicable activity (Chapman 1979) or selection is made using the index of deviation expected from scope (Seyedhoseini et al., 2009). The drawback is that the set of selected strategies may not be the optimal one.

The research in this paper can be classed in the category of optimisation-model approach and the related work on this approach is as follows.

Ben-David and Raz (2001) presented a model that integrates work elements, risk events and mitigation actions with their effects. The model then uses optimisation techniques to generate the most cost-effective combinations of risk strategies. This model was then extended, using model constraints, to include the interactions among risk strategies (Ben-David 2002). Later, (Kayis et al. 2007) in their paper developed a new risk mitigation methodology for new product and process design in concurrent engineering projects. After ranking the identified risks, five computational algorithms are used to find feasible solutions to mitigate the identified risks. The algorithms used were Least-cost-first, Highest-risk-first, Minimum cost-risk-ratio-first, Random search and genetic algorithm. Then the best strategy is recommended based on the budget and the strategic constraints. Fan et al. (2008) use optimization analysis to derive a minimum-cost risk handling strategy for a particular risk event. Their study involved constructing a conceptual framework to define the relationship between risk response strategies and relevant characteristics of the project and then developing a model to describe the relationship between relevant project characteristics. Fang et al. (2013) develop a mathematical model including budget requirements, risk response strategies effects and costs into the objective function. Nik et al. (2011)propose an optimization model, now incorporating time and quality as well. Their model incorporated the project work breakdown structure, risk events, risk responses and their effects into a framework and minimize the total expected loss arising from quality, cost, time and the cost of risk response strategies. Further work that include time and quality are by (Zhang and Fan 2014). They develop an optimization model integrating project cost, schedule and quality. By solving the model, the most desirable strategies may be found. In the absence of a most desirable solution being obtained, a loop is provided which makes trade-offs project cost, schedule and quality to arrive at a satisfactory solution of the selection risk response strategies to implement. This work was then extended in (Zhang 2016) to include the interdependence of risks. They constructed an optimization model to solve the selection of the risk response strategies problem while considering the expected loss and the risk interdependence.

Since Monte Carlo is applied and readily used by project managers due to its simplicity and versatility in many aspects of projects and their management, it is necessary to apply this simulation technique to solve selection of the risk response strategies problem and analyze and compare the results. This approach can also be used when traditional heuristics methods fail to find the solution of selecting the optimal response strategies to implement for a project.

3. Monte Carlo Simulation

In the project world, probabilistic methods, including 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).

Monte Carlo simulation is a computerized mathematical technique that approximates solutions to quantitative problems through statistical sampling. This technique is used by professionals in fields such as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation, and the environment. This method is useful for obtaining numerical solutions to problems which are too complicated to solve analytically. Monte Carlo simulations can be done using add-ins, such as Crystal Ball from Oracle® and @RISK from Palisade, to commonly used spreadsheets software like Microsoft® Excel. Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities of the possible outcomes. The technique was first used by scientists working on the atom bomb (Kochanski 2005).

Monte Carlo simulation involves building models of possible results by substituting all the input values having inherent uncertainties, with probability distributions. It then calculates results repeatedly, each time using a different set of random values from the probability distributions. The results of Monte Carlo simulation are not single values but distributions of possible outcome values (Vose 2008).

Generally, the following steps are involved in performing a Monte Carlo simulation:

- Step 1: Create one (or more) parametric Model(s), $y = f(x_1 x_2, \ldots\ldots, x_m)$
- Step 2: Represent the inputs $(x_1 x_2, \ldots\ldots, x_{m)}$ using probability distributions
- Step 3: Generate a set of random inputs $(x_{k1} x_{k2}, \ldots\ldots, x_{km)}$ from the distributions for each iteration $k,\ k = 1\ to\ t$
- Step 4: Evaluate the model using the random inputs, $y_k = f(x_{k1} x_{k2}, \ldots\ldots, x_{km})$ for each iteration, k
- Step 5: Analyse the results of $y_k = f(x_{k1} x_{k2}, \ldots\ldots, x_{km})$, obtained for all the iterations, $k = 1\ to\ t$.

4. Model Formulation

The risk response strategy selection problem involves choosing a combination of risk response strategies from an extended list, taking into consideration, at the very least, the effects of implementing these combinations of strategies, such as to the costs, benefits, schedule and quality of the project.

To demonstrate Monte Carlo approach applied to the risk response strategy selection problem:

Suppose there are m total risk response strategies $(A_1, A_2, \ldots, A_m)$, from which a subset or combination has to be chosen that can be implemented for the project. The selection is represented by $(x_1, x_2, \ldots, x_m)$ where $x_i = 1$, if A_i is selected and 0 otherwise.

The cost for implementing strategy A_i is denoted by c_i.

Let the set of risk events that can occur be denoted by $(R_1, R_2, \ldots, R_n)$ and let $(W_1, W_2, \ldots, W_l)$ be the set of work activity or event.

Let T_j^k and Q_j^k be the total estimated number of days delayed and reduced quality respectively of work activity W_k, once risk event, j, occurs.

Let d_i, t_i and q_i be the dollar benefit, number of days in advance and improved quality respectively after implementing risk response strategy A_i.

Hence, for each Monte Carlo iteration, the parametric equations to be evaluated are:

- Total Cost, $C_i = \sum_{i=1}^{m} x_i * c_i$;
- Total benefit in dollars,$DB_i = \sum_{i=1}^{m} x_i * d_i$;
- Total benefit in time, $TB_i = \sum_{j=1}^{n} T_j^k - \sum_{i=1}^{m} (x_i * t_i)$ for each work activity, W_k, $k = 1, 2, \dots l$; and
- Total benefit in quality, $QB_i = \sum_{j=1}^{n} Q_j^k - \sum_{i=1}^{m} (x_i * q_i)$ for each work activity, W_k, $k = 1, 2, \dots l$

Once the results of all iterations are in hand, then analysis can be undertaken to choose the most practical and applicable combination of risk response strategies $(A_1, A_2, .., A_m)$to implement. The analysis has to take into consideration factors such as available budget to implement the strategies and other constraints, though these can be incorporated into the Monte Carlo simulation as well. For instance, the correlation of strategies, such as the occurrence of one requires the other strategy to be implemented, can be incorporated using a correlation matrix during the Monte Carlo simulation.

The analysis of the Monte Carlo simulation results can include expert opinion, the availability and/or the practicality of implementing the response strategies. In this paper, a benefit-cost ratio (BCR) approach is also suggested and utilised to demonstrate its usage and applicability in deciding on the risk response strategies to implement.

5. Applied Model

In this section, we present an example adopted from Zhang and Fan (2014) to demonstrate the use for Monte Carlo simulation approach for risk response strategy selection.

The task is to select a subset from risk response strategies $(A_1, A_2, .., A_{20})$ whereby:

1. The costs of implementing each risk response strategies and their respective dollar benefits are as provided in Table 1;
2. The estimated number of days delayed and the reduced quality once risk events occur are as provided in Table 2;
3. The estimated number of days in advance and the improved quality after implementing each risk response strategy are as provided in Table 3;
4. The number of days delayed for each activity should be no more than 10 days, except for W_3 for which no delay is acceptable, i.e. delay of 0 days
5. Strategy A_7 requires A_{17} to be selected as well;
6. Only one of $A_{14}$and A_{15} can be selected. The same applies to A_{18} and A_{19}.
7. The budget for implementing the risk response strategies is no more $300,000.

Risk response strategy	Estimated Cost (c_i)	Estimated Benefits (d_i)
A_1	156900	326600
A_2	65350	135400
A_3	7845	22800
A_4	1569	2830
A_5	785	7350
A_6	313	6120
A_7	120	7700
A_8	470	9800
A_9	627	1320
A_{10}	12600	10510
A_{11}	7800	11400

A_{12}	450	2010
A_{13}	4800	28640
A_{14}	78450	13750
A_{15}	21500	31450
A_{16}	350	2040
A_{17}	120	2620
A_{18}	785	2120
A_{19}	7060	6530
A_{20}	3920	22180

Table 1: The costs and dollar benefits of implementing each risk response strategy

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}
W_1	4/7%	2/3%	0	0	0	0	0	0	0	0
W_2	3/5%	0	0	0	0	0	0	0	0	0
W_3	3/5%	0	0	0	0	0	0	0	0	0
W_4	0	0	0	14/15%	11/10%	0	0	9/10%	0	0
W_5	0	0	0	0	7/8%	17/18%	0	14/11%	0	0
W_6	0	0	4/11%	0	0	0	0	0	2/9%	0
W_7	0	0	0	0	0	0	0	0	0	3/20%
W_8	8/5%	0	0	0	0	0	7/5%	0	0	0

Table 2: The estimated number of days delayed and the reduced quality once risk events occur (T_j^k/Q_j^k, for each $\mathbf{R_j}$, w.r.t. each work event)

	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8
A_1	3/3%	3/3%	3/3%					5/3%
A_2								6/4%
A_3	4/4%	4/4%	4/4%					5/3%
A_4	2/1.5%							
A_5						1.5/5%		
A_6						1.5/5%		
A_7				4/7%				
A_8				4/6%				
A_9				2/3%	2/3%			
A_{10}				3/6%	3/6%			
A_{11}				3/5%	3/5%			
A_{12}					13/15%			
A_{13}				10/7%	10/7%			
A_{14}				9/6%	9/6%			
A_{15}				9/5%	9/5%			
A_{16}						2/3%		
A_{17}						2/3%		
A_{18}						1/4%		
A_{19}						1/4%		

A_{20}							3/18%	

Table 3: The estimated number of days in advance and the improved quality after implementing each risk response strategy ($\boldsymbol{t_i/q_i}$, for each $\boldsymbol{A_i}$, w.r.t. each work event).

Each Monte Carlo iteration randomly selects a set of risk strategies to implement and evaluates:

- Total Cost, $C_i = \sum_{i=1}^{20} x_i * c_i$ and
- Total benefit in dollars, $DB_i = \sum_{i=1}^{20} x_i * d_i$
- Total benefit in time, $TB_i = \sum_{j=1}^{10} T_j^k - \sum_{i=1}^{20}(x_i * t_i)$ for each work activity, W_k, $k = 1, 2, \dots l$
- Total benefit in quality, $QB_i = \sum_{j=1}^{10} Q_j^k - \sum_{i=1}^{20}(x_i * q_i)$ for each work activity, W_k, $k = 1, 2, \dots l$

The graphical results of a simulation, including costs, benefits, with 100000 iterations are as below:

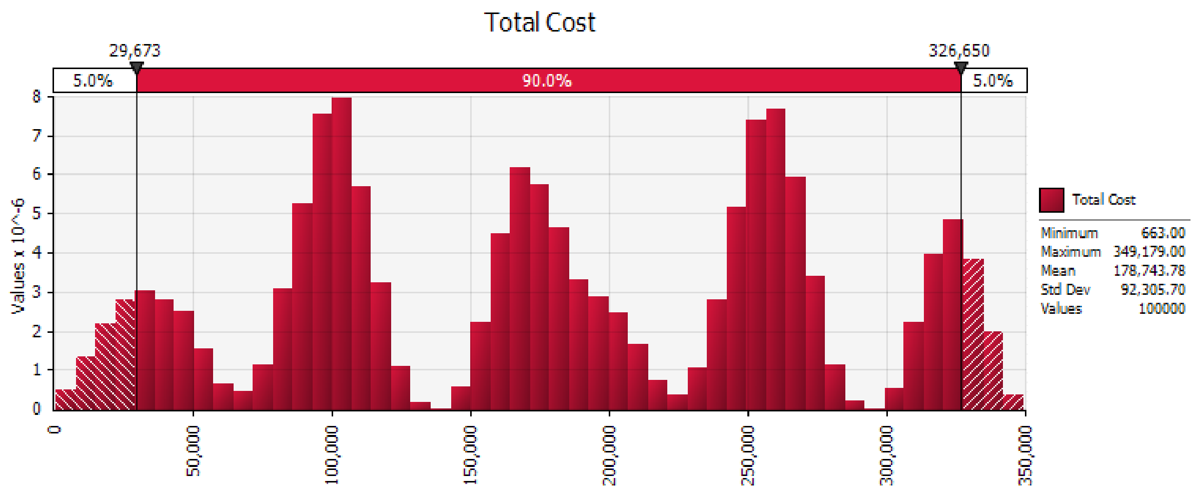

Figure 1: Distribution of the cost of implementation of selected strategies.

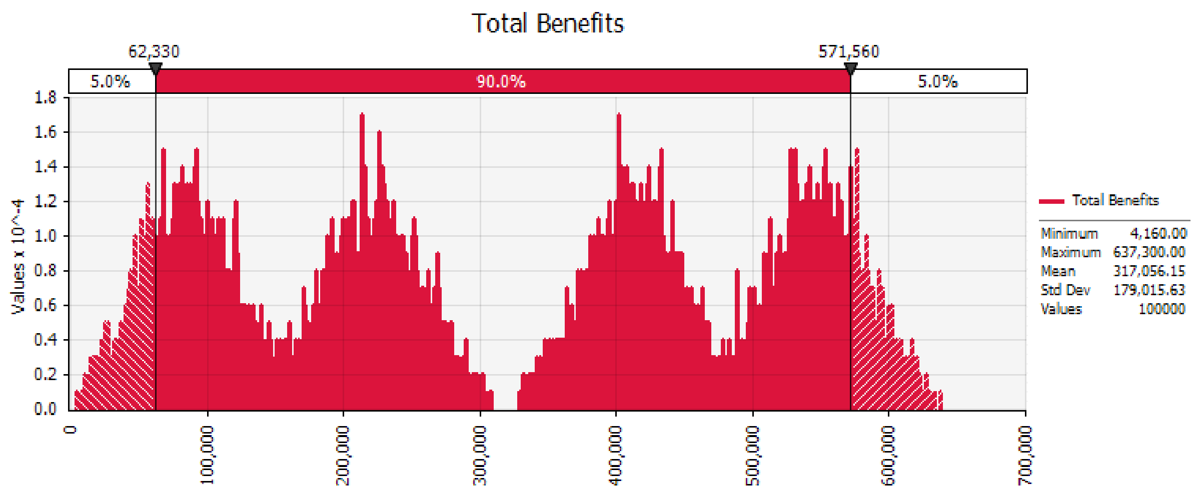

Figure 2: Distribution of the dollar benefits of implementation of selected strategies.

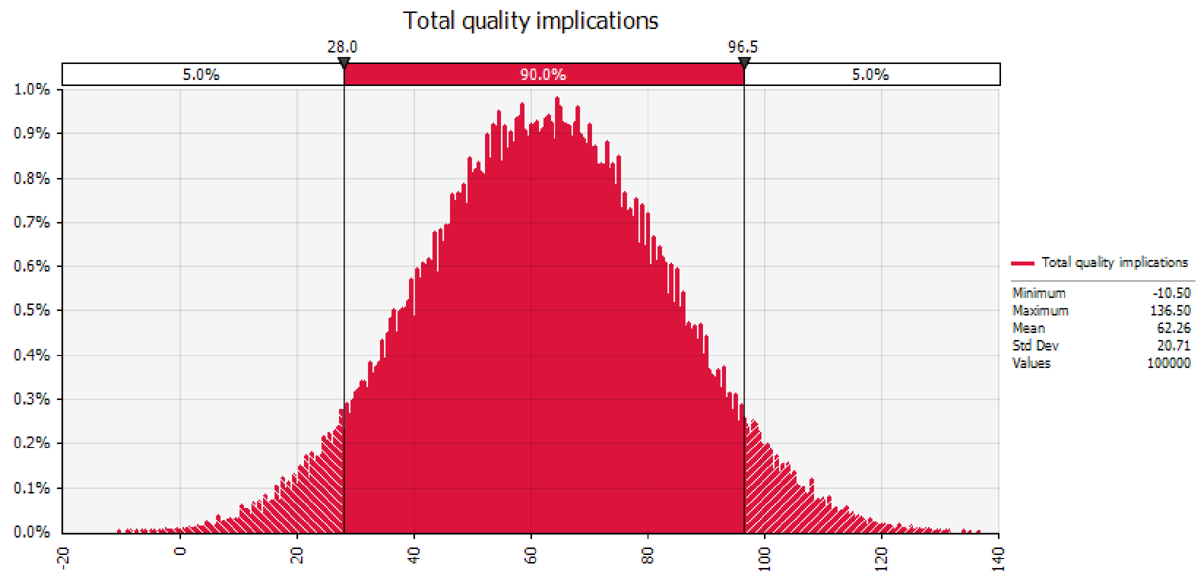

Figure 3: Distribution of the effects on quality upon implementation of selected strategies.

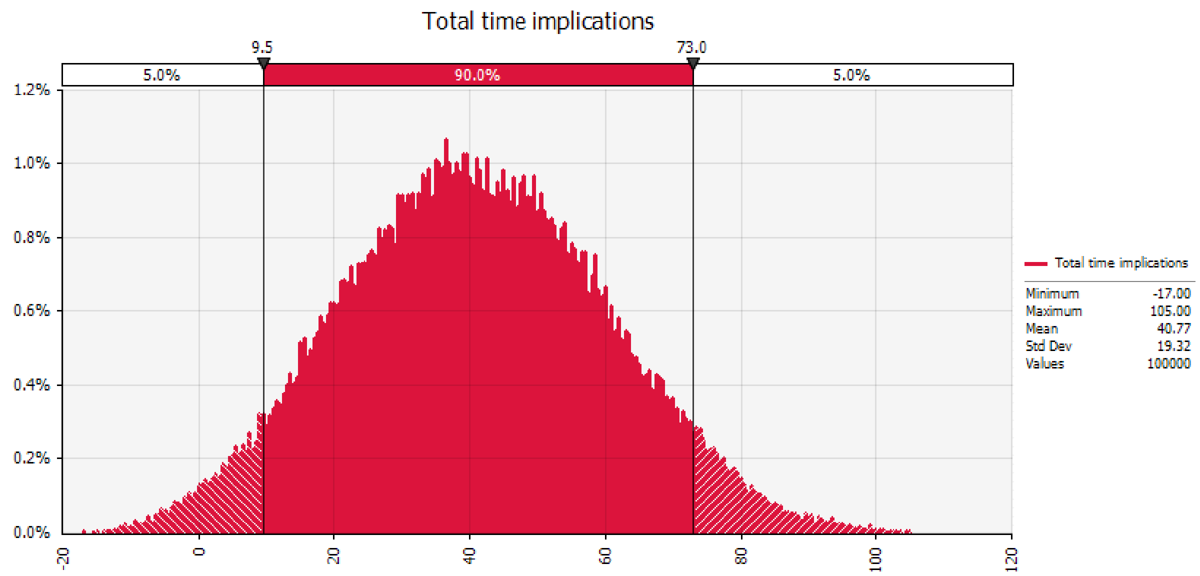

Figure 4: Distribution of the effects on time upon implementation of selected strategies.

6. Analysis of Results

To facilitate the decision making process of selecting the risk response strategies after being provided with the costs, dollar benefits and the implication on time and quality, a measure of the benefit-cost ratio (BCR) was applied. This measure would provide an indication as to the benefits reaped compared to costs. The distribution of BCR is shown in Figure 5.

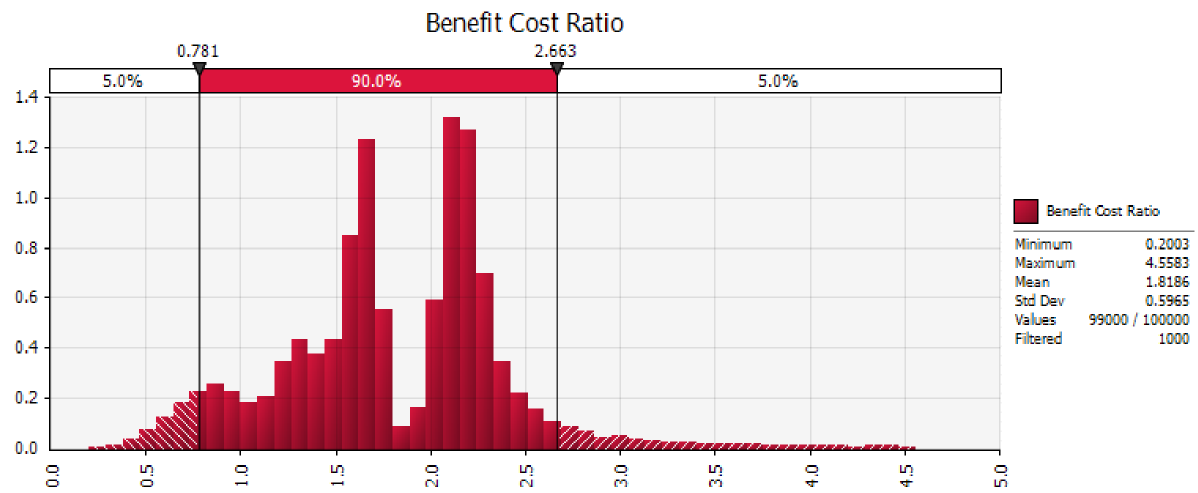

Figure 5: Distribution of the benefit-cost ratios (BCR) from the simulated costs and benefits.

After obtaining the results of the Monte Carlo simulation, the results were screened to ensure that the results satisfied all the required conditions and then the BCR values were used to obtain a set of results. A selection of risk response strategies using BCR are presented in table 4.The values of $\mathrm{A_i}$ being one (1) means that $\mathrm{A_i}$is selected and not selected otherwise (value being 0). Relating to each set of chosen subset of risk response strategies, the cost and benefit figures are displayed with their responding BCR value.

	Selection 1	Selection 2	Selection 3	Selection 4	Selection 5	Selection 6	Selection 7	Selection 8	Selection 9
Cost ($)	255863	257432	258059	257709	255705	264290	263505	265232	265859
Benefit ($)	584030	586860	588180	586140	578000	596750	594630	598260	599580
BCR	2.2825	2.2796	2.2792	2.2744	2.2604	2.2579	2.2566	2.2556	2.2552
A_1	1	1	1	1	1	1	1	1	1
A_2	1	1	1	1	1	1	1	1	1
A_3	0	0	0	0	0	0	0	0	0
A_4	0	1	1	1	0	0	0	1	1
A_5	1	1	1	1	0	1	1	1	1
A_6	1	1	1	1	1	1	1	1	1
A_7	1	1	1	1	1	1	1	1	1
A_8	1	1	1	1	1	1	1	1	1
A_9	0	0	1	1	1	1	1	0	1
A_{10}	0	0	0	0	0	0	0	0	0
A_{11}	0	0	0	0	0	1	1	1	1
A_{12}	1	1	1	1	1	1	1	1	1
A_{13}	1	1	1	1	1	1	1	1	1
A_{14}	0	0	0	0	0	0	0	0	0
A_{15}	1	1	1	1	1	1	1	1	1
A_{16}	1	1	1	0	1	1	1	1	1
A_{17}	1	1	1	1	1	1	1	1	1

A_{18}	1	1	1	1	1	1	0	1	1
A_{19}	1	0	1	1	0	0	0	0	1
A_{20}	1	1	1	1	1	1	1	1	1

Table 4: A Selection of risk responses strategies using BCR

Note that table 4 also contains the combination of risk response strategies which Zhang and Fan (2014) identified as one with low budget ($258,059) and maximum effect ($588,180). This is selection number 3 (highlighted) in table 4 with a BCR value of 2.2792 (4 d.p.). However, as shown, there are other combinations, at least two, that have a better BCR value. Selection 1 can be considered to be a better "value for money" for the generated benefit which leads to its BCR being greater than the other combinations shown in the table. The cost of selection 1 is $255863 and the benefit is $584030 with a BCR value of 2.2825. Selection 2 also has a relatively better BCR value. Hence selections 1 and 2 are two combinations that can be considered to deliver better value for money if BCR is taken as a measure.

Thus, having Monte Carlo results at hand enables project managers to compare and contrast. For instance, in this example it would be easier to see if selection 1 or 2 is really better and desirable, as indicated by BCR values, as opposed to selection 3 and also if selection 3 is better in terms of derived benefit value or would it be better (if affordable) to invest a little more and choose selection 9 which has a comparatively better dollar benefits and can be obtained by including A_{11}as well. The cost and the benefits are readily provided by the simulation results together with the other effects of the choice of the particular selections thus facilitating the decision making process.

Additionally, the results depicted in table 4 also show that all of the selections favour implementing $(A_1, A_2, A_6, A_7, A_8, A_{12}, A_{13}, A_{15}, A_{17}, A_{18}, A_{20})$ and are not in favour of implementing (A_3, A_{10}, A_{14}). Therefore, it leaves the decision makers only strategies $(A_4, A_5, A_9, A_{11}, A_{16}, A_{19})$ to decide upon. The list can be further reduced if a rule of the majority is considered. The selections also suggest that the majority of the results favour implementing (A_5, A_{16}). The entire list of 20 strategies is now reduced to considering just 4 strategies, $(A_4, A_9, A_{11}, A_{19})$ in detail while implementing all the others.

7. **Conclusion**

Using simple project data, a Monte Carlo approach to solve the response strategy selection problem was demonstrated. The obtained results were analysed to show the benefits of using the Monte Carlo approach and how it may assist stakeholders to make more informed decisions. A benefit-cost ratio approach was also proposed and demonstrated which can be utilised to narrow down the combinations of risk strategies for consideration. The results confirm the practicality and benefits of using the Monte Carlo approach to solving the response strategy selection problem.

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