Module 1— Benefit-Cost Analysis of Dam Construction Projects

Module 2 — Monte Carlo Simulation

ALY6050: Introduction to Enterprise Analytics

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INTRODUCTION

Risk analysis is an increasing part of every decision we make where aircraft maintenance planning & reliability are concerned. As aircraft maintenance engineers, we are constantly faced with uncertainty, ambiguity, and variability. These days, operators and maintainers have access to information, yet we can't accurately predict the future in terms of system or component reliability. Monte Carlo simulation (also known as the Monte Carlo Method) lets you see all the possible outcomes of maintenance planning decisions and assess the impact of risk, thus allowing for better decision making under uncertainty.

Monte Carlo simulation is a computerized mathematical technique that allows engineers to account for risk in quantitative analysis and decision making. The 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. Monte Carlo simulation furnishes the reliability engineer with a range of possible outcomes and the probabilities they will occur for any choice of action. It shows:

- Extreme possibilities—the outcomes of going for broke
- The most conservative decision
- Possible consequences for middle-of-the-road decisions.

We conducted a Cost Benefit Analysis (CBA) for a dam building project in this project. This is the process of analysing and comparing the expected benefits and costs of two distinct dam construction projects. Monte Carlo simulations, which are commonly used to illustrate the likelihood of alternative outcomes in a process, are utilized to do this. It's employed in situations when it's tough to predict values owing to random factors interfering with the process. It's a technique for determining how risk and uncertainty impact forecasting models in the long run.

Though dam building has many favourable effects on global warming, hydroelectric power generation, climatic changes, and other factors, it has recently had numerous severe effects on the environment and human lives. As a result, the cost and advantages of two distinct projects are compared, and the one with the best cost-benefit ratio is chosen for execution. The stages of CBA are as follows:

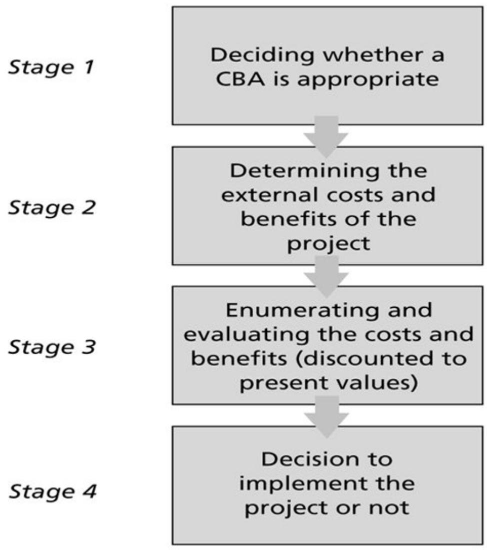


Fig : CBA Stages

- **Part 1**:

(i) Perform a simulation of 10,000 benefit-cost ratios for Dam #1 project and 10,000 such
simulations for Dam #2 project. Note that the two simulations should be independent of each other. Let these two ratios be denoted by $\alpha 1$ and $\alpha 2$ for the dams 1 and 2 projects respectively.

Table 1: Dam #1

Dam #1: Benefits & Costs

	Estimate		
Benefit	***Minimum***	***Mode***	***Maximum***
Improved navigation **B1**	1	2.1	2.9
Hydroelectric power **B2**	7.9	11.5	15
Fish and wildlife **B3**	1.5	1.5	2.3
Recreation **B4**	6.3	9.9	14.9
Flood control **B5**	1.6	2.6	3.7
Commercial development **B6**	0	1.5	2.5
Cost	***Minimum***	***Mode***	***Maximum***
Annualized capital cost **C1**	13.3	13.9	18.8
Operations & Maintenance **C2**	3.6	5	7.5

Table 2: Dam#2

Dam # 2: Benefits & Costs			
	Estimate		
Benefit	*Minimum*	*Mode*	*Maximum*
Improved navigation **B1**	2.3	3.1	4.7
Hydroelectric power **B2**	8.6	11.8	13.9
Fish and wildlife **B3**	2.2	2.9	2.9
Recreation **B4**	5.5	8.5	14.8
Flood control **B5**	0	3.2	3.2
Commercial development **B6**	0	1.1	1.7
Cost	*Minimum*	*Mode*	*Maximum*
Annualized capital cost **C1**	12.7	15.7	20.3
Operations & Maintenance **C2**	3.5	5.5	8

Because we have three parameters in this example, namely the lower end, mode, and higher end, we get a triangle distribution. We estimated K, M, and N values using the a, b, and c values. The theoretical M and theoretical VAR are determined in the tables below.

Theoretical VAR and M values for DAM#1 and DAM#2

DAM#1:

Benefits	
Theoretical Mean: E(X) = = (a+b+c)/3	**Theoretical Variance**
2.000	**0.152**
11.467	**2.101**
1.767	**0.036**
10.367	**3.109**
2.633	**0.184**
1.333	**0.264**
Costs	
Theoretical E(X)	**Variance**
15.333	**1.517**
5.367	**0.651**

DAM#2:

Benefits	
Theoretical Mean: E(X) = = (a+b+c)/3	Theoretical Variance
3.367	0.249
11.433	1.187
2.667	0.027
9.600	3.755
2.133	0.569
0.933	0.124
Costs	
Theoretical E(X)	Theoretical Variance
16.233	2.442
5.667	0.847

The variance is a prediction of how much a certain random variable will deviate from the mean of the data. The theoretical mean value is the average of a, b, and c values from the supplied data, and the variance is an estimate of how much any given random variable will fluctuate around the data's mean. Following that, the RAND() function is used to create random numbers, and the benefited values are calculated using the formula below.

Triangular random number generation:

if r <= K, x = a + sqrt(rM)
if r > K, x = b - sqrt((1-r) N)

For costs we will be repeating this process and complete process is This process is repeated for costs and the entire process is done for both Dam 1 and Dam 2. From the observed random values, the tuned for Dam #1 & Dam #2. For each dam, we will be examining cost and benefit ratio is separately.

The excel shows the benefit cost ratio for both DAM#1 and DAM#2.

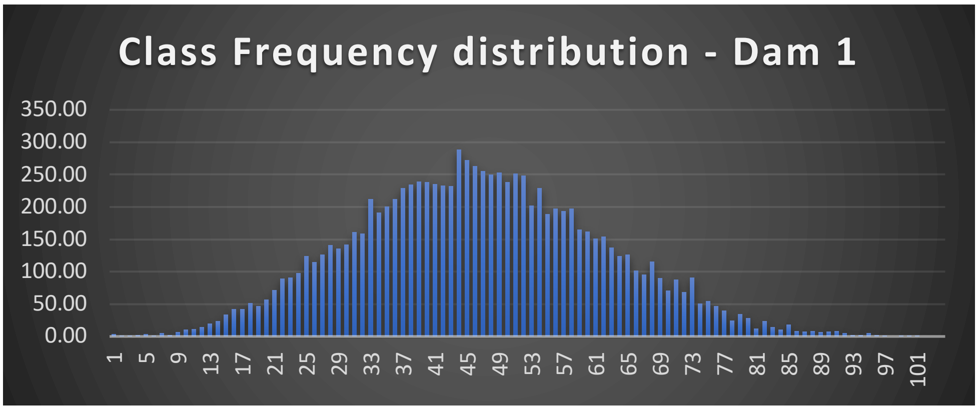
Descriptive Statistics for DAM#1 and DAM#2

Components	Dam 1	Dam 2
Minimum	0.96	0.91
Maximum	2.04	2.06
Number of data	10000.00	10000.00
No. of Bins	100.00	100.00
Class Width	0.01	0.01

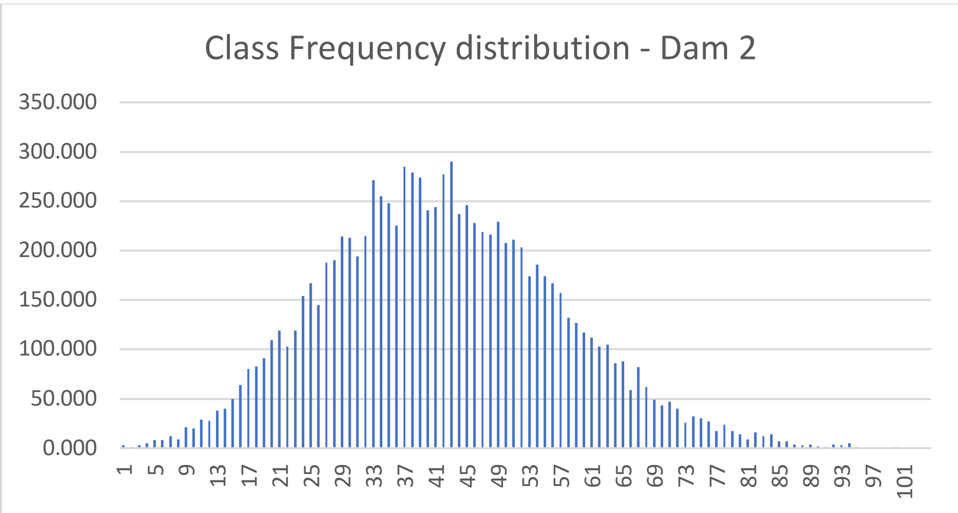
From above table, we can see that the minimum, maximum CBR ratio for dam #1 is **0.96** & **2.04** whereas the minimum, maximum CBR for dam #2 is **0.91** & **2.06**. The total number of data and the number of bins is equal for both the dams. The class width is **0.01**.

(ii) Construct both a tabular and a graphical frequency distribution for $\alpha1$ and $\alpha2$ separately (a tabular and a graphical distribution for $\alpha1$, and a tabular and a graphical distribution for $\alpha2$- a total of 4 distributions). In your report, include only the graphical distributions and comment on the shape of each distribution.

Triangular distribution values such as class R, class L, and (mode) are determined from the acquired values, and then we examine the class frequencies. The frequency distribution is represented by the graphs below.



Class Frequency distribution - Dam #1



Class Frequency distribution - Dam #2

The graphs indicate both the dams are normally distributed in terms of frequencies.

(iii) For each of the two dam projects, perform the necessary calculations in order to complete the following table. Excel users should create the table in Excel with all cells being occupied by the appropriate formulas, and R users should display the table as a "data frame". Remember to create two such tables – one table for Dam #1 and another table for Dam #2. Include both tables in your report.

Dam 1	Observed	Theoretical
Mean of the Total Benefits	29.558	29.567
SD of the Total Benefits	2.455	2.418
Mean of the Total Cost	20.703	20.700
SD of the Total Cost	1.468	1.472
Mean of the Benefit-cost Ratio	1.435	X
SD of the Benefit-cost Ratio	0.156	X

Dam 2	Observed	Theoretical
Mean of the Total Benefits	30.150	30.133
SD of the Total Benefits	2.423	2.431
Mean of the Total Cost	21.905	21.900
SD of the Total Cost	1.810	1.814
Mean of the Benefit-cost Ratio	1.386	X
SD of the Benefit-cost Ratio	0.160	X

Above table shows the theoretical and observed values for both DAM#1 and DAM#2.

Observed Mean of Total benefits for DAM#1 is less when compared to DAM#2. Observed mean of total cost is less for DAM#1 when compared to DAM#2. Mean of benefit-cost ratio for DAM#2 is more when compared to DAM#2.

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- **Part 2:**

Use your observation in Question (ii) of Part 1 to select a theoretical probability distribution that, in your judgement, is a good fit for the distribution of $\alpha 1$. Next, use the Chi-squared Goodness-of-fit test to verify whether your selected distribution was a good fit for the distribution of $\alpha 1$. Describe the rational for your choice of the probability distribution and a description of the outcomes of your Chi-squared test in your report. In particular, indicate the values of the Chi-squared test statistic and the P-value of your test in your report, and interpret those values.

SOLUTION:

The Ho and Ha are formulated to determine the goodness of fit test.

Ho: There is no significant difference between class frequency and expected frequency

Ha: There is a significant difference between class frequency and expected frequency

Alpha value is considered to be 0.05 which is 95% confidence interval.

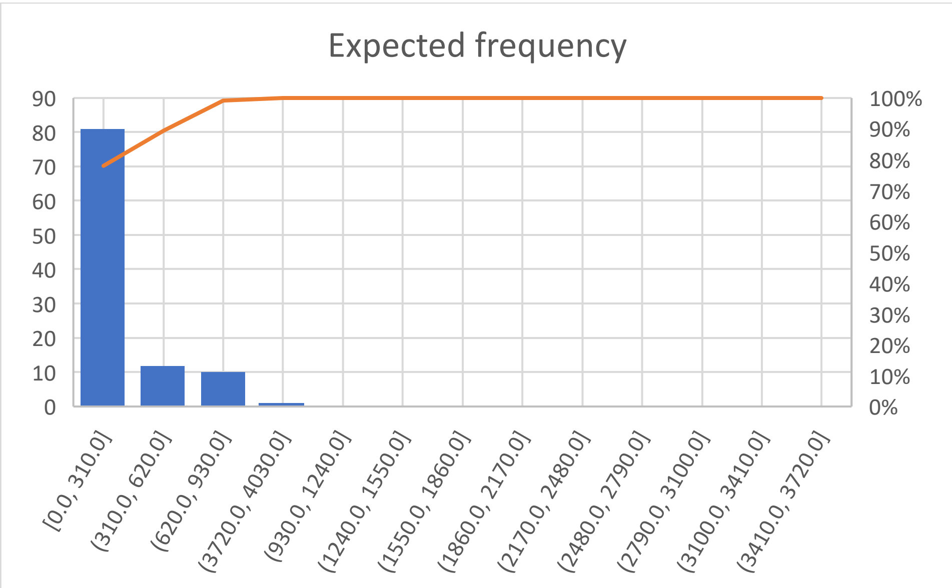
Chi-squared Test Statistic:	**16623.9**
Chi-squared P-value:	**0.000**

Chi-Square goodness of fit test to determine the model

From above table, we see that the chi square test value is equal to 16623.0 and P value is found to be 0.

Inference:

We see that p value is < alpha value (0.05) for a 95 percent confidence level. Hence, we have enough evidence to REJECT the Ho and embrace the Ha. As result, our distribution is an excellent match, with a 95% confidence interval.



Expected Frequency distribution - Dam 1

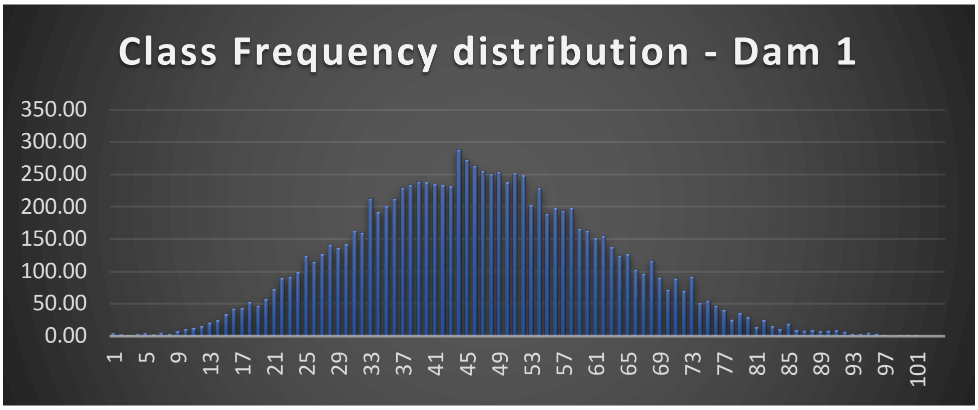


Figure 1: Class Frequency distribution - Dam 1

The choice to reject the Ho is correct based on the previous graphs, as there is a discrepancy between the class & the predicted frequency. However, we can consider this discrepancy. As a result, the triangular distribution does not match this model well.

- **Part 3**:

  (i) Use the results of your simulations and perform the necessary calculations in order to complete the table below. Excel users should create the table in Excel with all cells being occupied by the appropriate formulas, and R users should display the table as a "data frame". Include the completed table in your report.

We are calculating the following numbers in order to make the essential advice to management for the best choice on picking the right dam building project that will result in a favorable cost-benefit ratio. The calculation table below might assist you in making the best selection for the management.

Final comparing between dam1(α1), dam2(α2)

Components	α_1	α_2
Minimum	0.875	0.941
Maximum	2.014	2.105
Mean	1.434	1.385
Median	1.430	1.374
Variance	0.023930769	0.025920942
Standard Deviation	0.154695731	0.160999821
SKEWNESS	0.185769951	0.328971506
$P(\alpha_i > 2)$	0.0002	0.0008
$P(\alpha_i > 1.75)$	0.0114	0.0098
$P(\alpha_i > 1.5)$	0.327	0.233
$P(\alpha_i > 1.25)$	0.9409	0.8815
$P(\alpha_i > 1)$	0.9998	0.9979
$P(\alpha_1 > \alpha_2)$	**0.594**	

Inference:

When comparing dam 1 with dam 2, we can observe that the bulk of the values where alpha is larger than 1, 1.25, 1.5, and 1.75 are more numerous in dam 1. The skewness also reveals that dam1 is less skewed than dam 2, indicating that the distribution is less skewed. Finally, when counting the number of higher cost-benefit ratios from the 10,000 observed values, dam 1 has a larger number of high benefits than dam 2, which is comparably smaller.

CONCLUSION

We discovered that Dam #1 is the better investment idea when compared to Dam #2 based on the graphs, chi square test, and p value comparison. The mean, variance, and standard deviation of the dams are nearly comparable. In the instance of Dam#2, the mean value and standard deviation value have a lot of discrepancies. We can observe that the bulk of the cost benefit ratio figures in Dam#1 are greater, indicating that the project has substantial benefits. The predicted frequency and As a result, based on the cost benefit analysis, we conclude that the project Dam#1 is more suited for building than the project Dam#2 since the costs are lower and the benefits are higher in Dam#1.

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Glasserman, P. 2003. Monte carlo methods in financial engineering. N.Y., USA: Springer.

APPENDIX

The excel file used for the calculation is given below. These files are attached in Canvas.

ALY6050_MOD2Project_ VidyanandaS.xlsx