Using A Free Excel Add-in And Monte Carlo Simulations To Perform Project Risk Analysis

Conference Paper · November 2022

1 author:

Schalk Grobbelaar
University of Pretoria

Using A Free Excel Add-in And Monte Carlo Simulations To Perform Project Risk Analysis

Schalk Grobbelaar
Department of Engineering and Technology Management, Univeristy of Pretoria
Enterprise Building, 140 Lunnon Rd, Hillcrest, Pretoria, 0083
+27 82 8858985
schalk.grobbelaar@up.ac.za

Abstract. Project Risk Analysis is used to manage the uncertainty associated with projects. Various tools can be used for this purpose. The Monte Carlo Technique is a random sampling technique that can be used to analyse project costs and schedules. It is a relatively simple method; however, its implementation has been limited due to low levels of training and the limited availability of free models. This paper illustrates how an Excel-based Monte Carlo Simulation could be built using a free Excel Add-in. Real Statistics Using Excel was used to develop models for the simulation of Project Costs and Project Schedule Risk. The paper illustrates the process followed, providing one Project Cost example and one Project Schedule example. The goodness-of-fit for the models is also evaluated. Finally, the limitations of the models are discussed, and future directions are recommended.

Introduction

Portfolios, programs and projects are complex systems that are inherently risky (Project Management Institute 2019) and effective risk management is critical for proactive systems management (Sage 1995). The aim of systems modelling is to enable decision makers to evaluate decision situations and consider uncertainty related to the decision (Sage 1995). Stochastic simulations are frequently used to model complex systems since they may be able to provide answers to problems that cannot be solved deterministically and may be simpler to understand and manipulate (Bonate 2001) (Harrison 2009). Modelling the overall project cost and schedule enables one to indirectly experiment, analyse and evaluate the risk associated with various system characteristics (Blanchard and Fabrycky 2006). The Monte Carlo simulation is a technique that enables one to develop a holistic model to evaluate a project's overall cost or schedule risk (Pritchard 2001). It is a stochastic (probabilistic) model that uses random sampling for inputs and deterministically calculates outputs to develop a probability distribution (Schuyler 2001).

In many cases, commercial software, for example, GoldSim (GoldSim Technology Group 2022), @Risk (Palisade 2022), ModelRisk (Vose Software 2022), and XLSTAT (Addinsoft 2022) is used for this purpose. Using an Open Source tool to perform Monte Carlo simulations in Project Risk Management (PRM) courses could improve contextualised learning, student-centred application, and student motivation and promote testing of a broader range of data (Alasbali and Benatallah 2016). In addition, using widely available and relatively simple tools like Microsoft Excel may enhance students' understanding of the concepts and improve learning (Chaamwe and Shumba, 2016). For these reasons, a Monte Carlo simulation tool for PRM courses was developed using Real Statistics Using Excel (Zaiontz 2022). The objective was to provide students with an Open Source tool that would enable them to test the application of Monte Carlo in PRM. The use of the model is illustrated through a couple of examples. The first example compares two ways of calculating the cost contingency of a project. The first method uses a simple rule of thumb (percentage of the expected cost), and the second method is based on a confidence level. The second example compares project schedule estimation using Monte Carlo with the Program Evaluation Review Technique (PERT).

Literature Survey

Project Uncertainty

From a project client's perspective, the primary objective of the project management process is to ensure that the project is completed within the agreed budget, schedule and expected quality (Barnes 1988). However, many projects fail to meet expectations due to poor execution, poor identification of activities, poor integration (Matta and Ashkenas 2003) or high levels of uncertainty (Pohl and Mihaljek 1992). Project risks include compliance, hazard, control and opportunity risks (Hopkin and Thompson 2022) and are defined as the positive or negative impact of uncertainty on objectives (Project Management Institute 2019). Project Risk Management (PRM) aims to improve control over the project (Van Well-Stam et al. 2003) and typically includes risk identification, analysis and evaluation (ISO 2018). The risk analysis step involves assessing the probability and consequence of a risk (Steyn et al. 2018). Ward and Chapman (2003) argue that there should be more focus on the origin of uncertainty and determining its relevance before attempting to manage it. In the context of projects, Perminova et al. (2008) describe uncertainty as "*an event or a situation, which was not expected to happen, regardless of whether it could have been possible to consider it in advance.*" The uncertainty can range from variations, foreseen uncertainty, and unforeseen uncertainty to chaos (Meyer, Loch, and Pich 2002). Significant uncertainty is typical even up to the start of the execution phase (Howell, Laufer, and Ballard 1993). Usually, many of the sources of uncertainty can be identified and compared to similar projects (McLain 2009). An effective uncertainty management culture includes understanding, active application and a holistic view of uncertainty (Terje Karlsen 2011). Uncertainty brings with it opportunities that can be exploited (Kolltveit, Karlsen, and Grønhaug 2005). Probabilistic techniques may assist with managing uncertainty, but their complexity and availability may hamper utilisation (Dawson and Dawson 1998).

The Monte Carlo Method and Project Risk Forecasting

Metropolis and Ulam (1949) were the first to present the Monte Carlo Method, and Hertz (1964) argued that its applications could be beneficial in business decision-making since it provides the decision makers with expected results based on weighted probabilities and an indication of variability. Thus, it doesn't just give the mean but also the worst and best case possibilities, indicating the likelihood of its occurrence and thus providing decision-makers with a better understanding of the potential outcomes (Loizou and French 2012). However, the input distributions and correlation between inputs may influence the model (Nawrocki 2001) (Wall 1997) (Peleskei et al. 2015), and if the interdependencies of variables are not considered, it may lead to input values that are impossible to achieve (Rezaie et al. 2007).

In Project Management, the Monte Carlo simulations can assist project managers with quantifying and justifying appropriate contingencies assuming limited corrective management actions and reasonably accurate input estimation (Kwak and Ingall 2009). A conventional Monte Carlo simulation doesn't account for management interaction during the course of a project (Williams 2004). However, the Monte Carlo method is relatively simple to use (Zhao and Liu 2008) (Clarke and Low 1993) and a valuable tool for evaluating project uncertainty and contingencies (Clark 2001). Its application may, for example, reduce the capital cost required for a programme of capital projects (Joubert and Pretorius 2017b) or enable one to develop a ranked risk checklist (Joubert and Pretorius 2017a). Still, the application of quantitative risk assessment tools is low (Hugo, Pretorius, and Benade 2018), and the development of easy-to-use tools (Avlijas 2018) and wider training (McCabe 2003) are required to increase confidence (Bouayed 2016) and acceptance by more practitioners

Microsoft Excel can be used for Monte Carlo simulations, and add-ins can be used for the functions typically not available in the standard versions of Excel (Tysiak and Sereseanu 2009). Add-ins that enable one to use the triangular distribution are particularly useful since the triangular distribution is intuitively simple to use in practical applications (Tysiak and Sereseanu 2009).

Methodology

This research aimed to develop a simple Excel-based Monte Carlo simulation tool for students in Project Risk Management courses. In addition, the aim was to enable students to experiment with the tool on their own and subsequently, it would be ideal to use a free add-in for Excel. Excel has a number of statistical functions built in to enable the development of a Monte Carlo simulation tool, but unfortunately, other functions are also required. For example, due to its simplicity, the triangular distribution (Steyn et al. 2018) would be ideal to use for the input variable estimation, but Excel doesn't include it. For these reasons, Real Statistics Using Excel (Zaiontz 2022) was used to develop the model. Conceptually the model combines the triangular distribution probabilities of the individual cost items to develop a combined Total Cost Distribution, typically in the form of a Weibull distribution (see Figure 1).

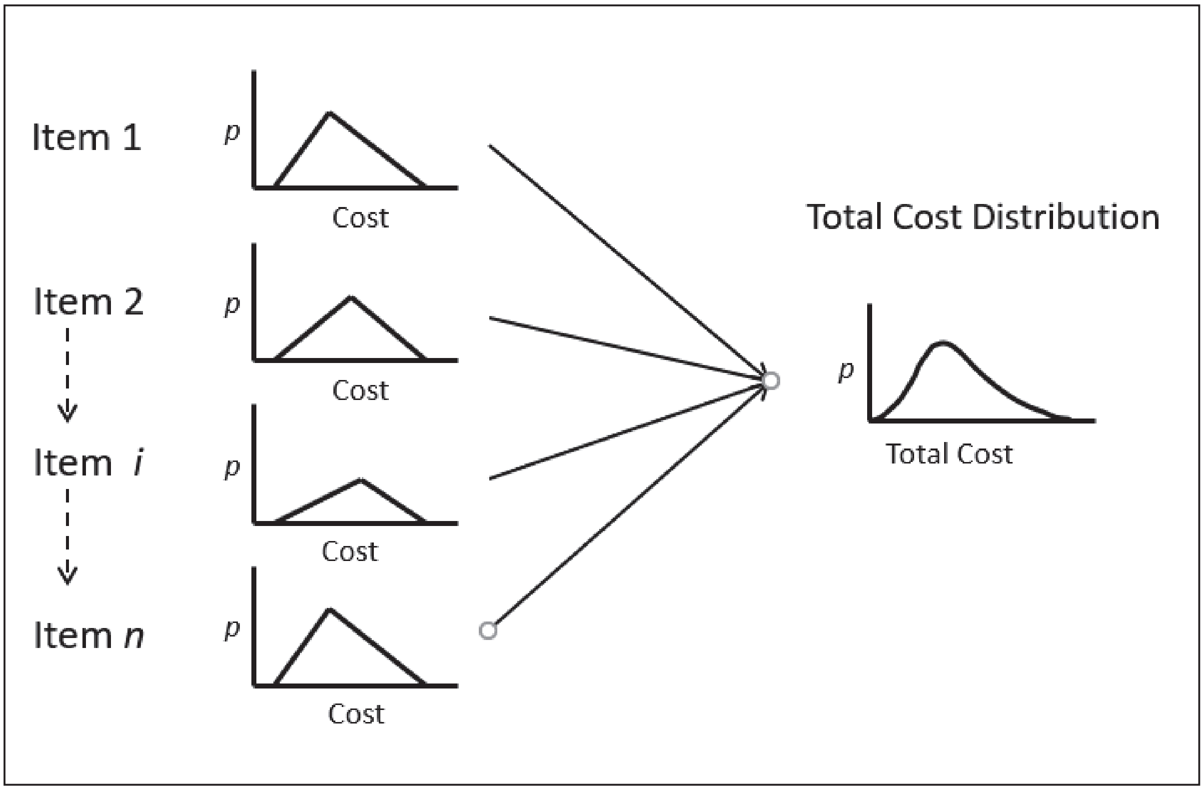

Figure 1: Conceptual process of the model

The application is illustrated through two examples:

1. Cost Risk Model
2. Schedule Risk Model

The process for each of the models is indicated below.

Cost Risk Model

The Cost Risk Model was developed by following these steps:

1. Provide twenty cost items and estimate the Lower bound, Most likely, and Upper bound cost for each item.
2. Run a thousand simulations starting with generating random variables between 0 and 1. The RAND() function was used.
3. Calculate the inverse of the random variable for each cost item using a triangular distribution represented by f(x). This process effectively determines the expected cost for a given probability on a cumulative distribution function (see Figure 2) represented as F(x). The TRIANG_INV(x;a;b;c) function was used.
4. Add all the expected costs per simulation together to calculate the Total Expected Cost. The SUM(a;b;…n) function was used.
5. Sort the Total Expected Cost for each simulation from small to large using the QSORT() function.
6. Calculate the shape and scale variables for the Weibull distribution using the regression method as explained at: https://www.real-statistics.com/distribution-fitting/fitting-weibull-regression/. The solver method can also be used. However, since this model uses random variables to run the model, which is updated every time something is changed in Excel, the shape and scale variables calculated would no longer be an accurate representation of the distribution after any changes. For this reason, the regression method was preferred.
7. Use the data to plot histograms and use the WEIBULL_INV(x;b;a) function to calculate the expected cost given a probability using the cumulative distribution function.

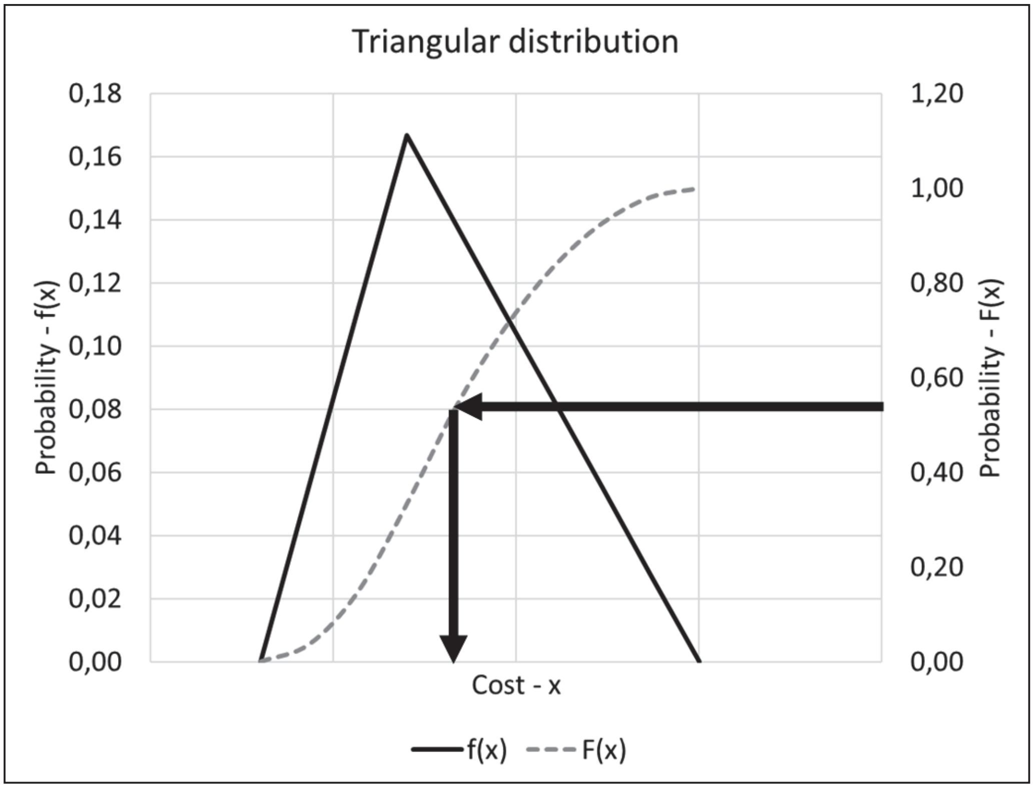

Figure 2: Determining the expected cost based on a given probability

Schedule Risk Model

The process for determining the Total Project Schedule for a project is very similar to the procedure for determining the Total Project Cost. Still, the Total Project Schedule must be calculated using the Critical Path Method (Steyn et al. 2018). The first step in this process entails drawing a network diagram for the project (see Figure 3). Once the network diagram has been constructed, the Lower bound, Most likely, and Upper bound estimations for each activity can be inserted into the model. This is then used to calculate the project's Critical Path (the series of activities with the longest expected duration). This Critical Path is then used as the Total Project Schedule. Once this has been established, for each of the thousand simulations, the shape and scale variables can be estimated for the Weibull distribution using the same method as the Cost Risk Model

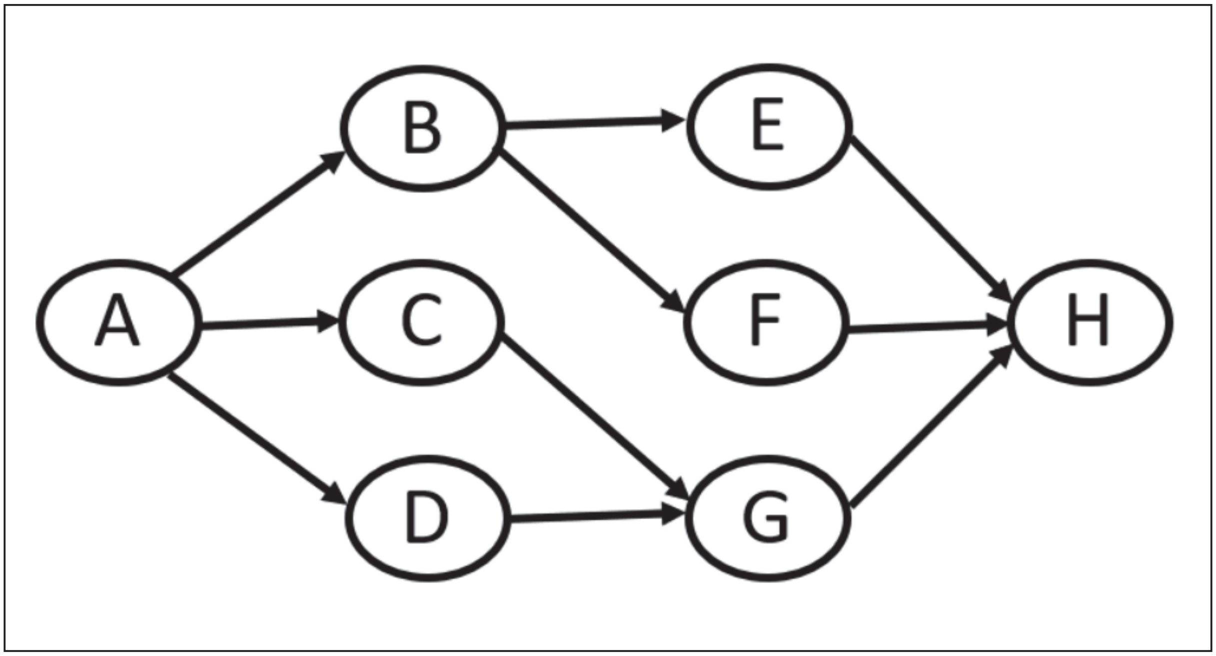

Figure 3: Project network diagram

Results

Cost Risk Model

The Cost Risk Model used generated hypothetical data using a randomisation method. The input data is illustrated in Table I.

Table I: Cost Risk Model Input Data

	Estimated Cost		
Cost Item	Lower bound	Most likely	Upper bound
1	R 10 000	R 11 600	R 16 400
2	R 11 500	R 13 915	R 17 250
3	R 16 700	R 24 883	R 28 056
4	R 28 500	R 38 190	R 43 320
5	R 33 300	R 41 625	R 48 951
6	R 26 700	R 30 438	R 39 249
7	R 13 500	R 17 820	R 20 385

	Estimated Cost		
Cost Item	Lower bound	Most likely	Upper bound
8	R 20 200	R 26 260	R 29 290
9	R 17 400	R 20 184	R 26 796
10	R 13 800	R 17 526	R 20 424
11	R 25 800	R 33 282	R 45 924
12	R 14 500	R 17 980	R 20 445
13	R 16 200	R 22 842	R 27 864
14	R 36 500	R 52 925	R 60 590
15	R 24 500	R 30 135	R 40 915
16	R 17 600	R 21 120	R 24 816
17	R 9 000	R 13 320	R 16 380
18	R 21 500	R 25 155	R 27 950
19	R 33 200	R 49 136	R 60 424
20	R 18 700	R 24 497	R 28 798
Total	R 409 100	R 532 833	R 644 227

Using the Monte Carlo Method, a graph (Figure 4) was generated that illustrates the sampling histogram (frequency plot) and the Weibull probability distribution (continuous plot) developed for the dataset. The graph also indicates the cumulative distribution plots for the sampling data and the Weibull distribution. Finally, the Budget value (R569 479) was calculated assuming an 80% confidence level.

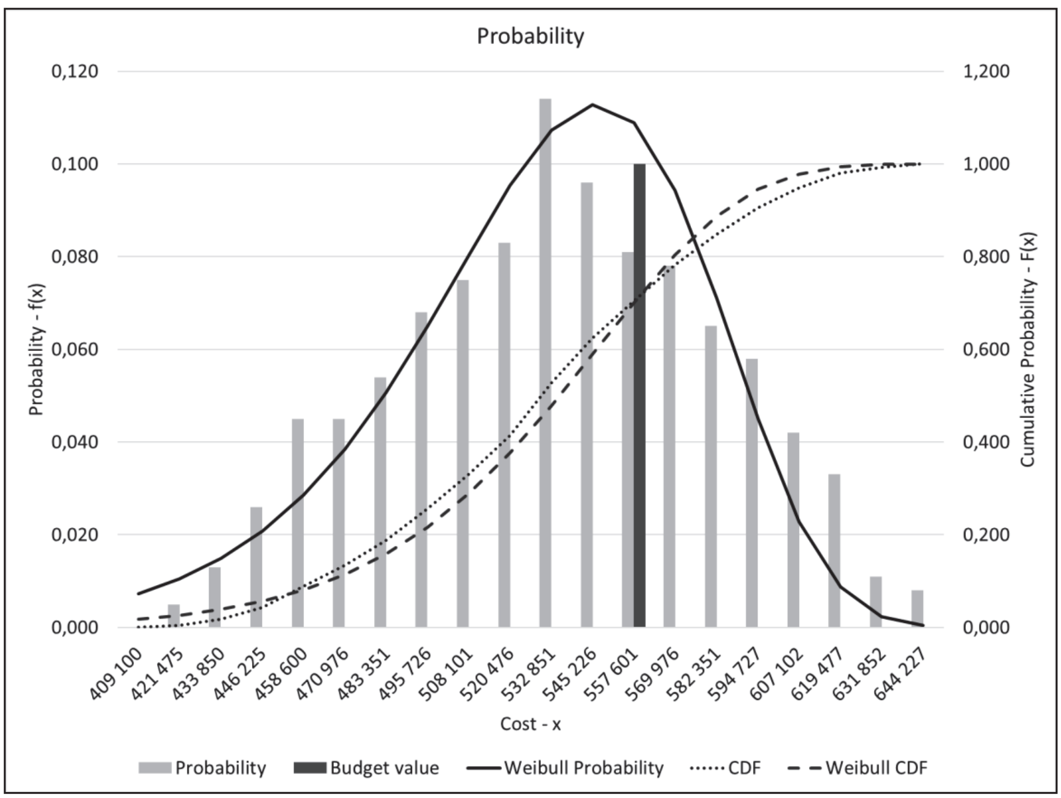

Figure 4: Weibull Distribution for Project Cost Model

The Weibull shape parameter (13,6) and scale parameter (549 891) was determined using the regression method. The standard deviation was R48 082. The sum of the most likely costs was R532 833. If a 20% (R106 567) contingency had been added, the total budget would have been R639 400. For this example, the Pearson correlation between the sampling data and the Weibull distribution was 0,95 with a p-value of 1,47464E-10. The R^2 was 0,9; thus, the Weibull distribution can be assumed to be a reliable fit for the sampling data.

Schedule Risk Model

For the Schedule Risk Model, hypothetical data was generated using a randomisation method. The input data is illustrated in Table II.

Table II: Schedule Risk Input Data

	Estimated Time		
Activity	Lower bound	Most likely	Upper bound
A	4	6	8
B	4	5	9
C	4	6	10
D	3	5	11
E	7	9	13
F	6	10	14
G	7	9	12
H	5	7	10
Expected Duration	20	28	41

Using the Monte Carlo Method, a graph (Figure 4) was generated that illustrates the sampling histogram (frequency plot) and the Weibull probability distribution (continuous plot) developed for the dataset. The graph also indicates the cumulative distribution plots for the sampling data and the Weibull distribution. Finally, the Budget value (32,8) was calculated assuming an 80% confidence level. The expected duration using PERT is 28,67.

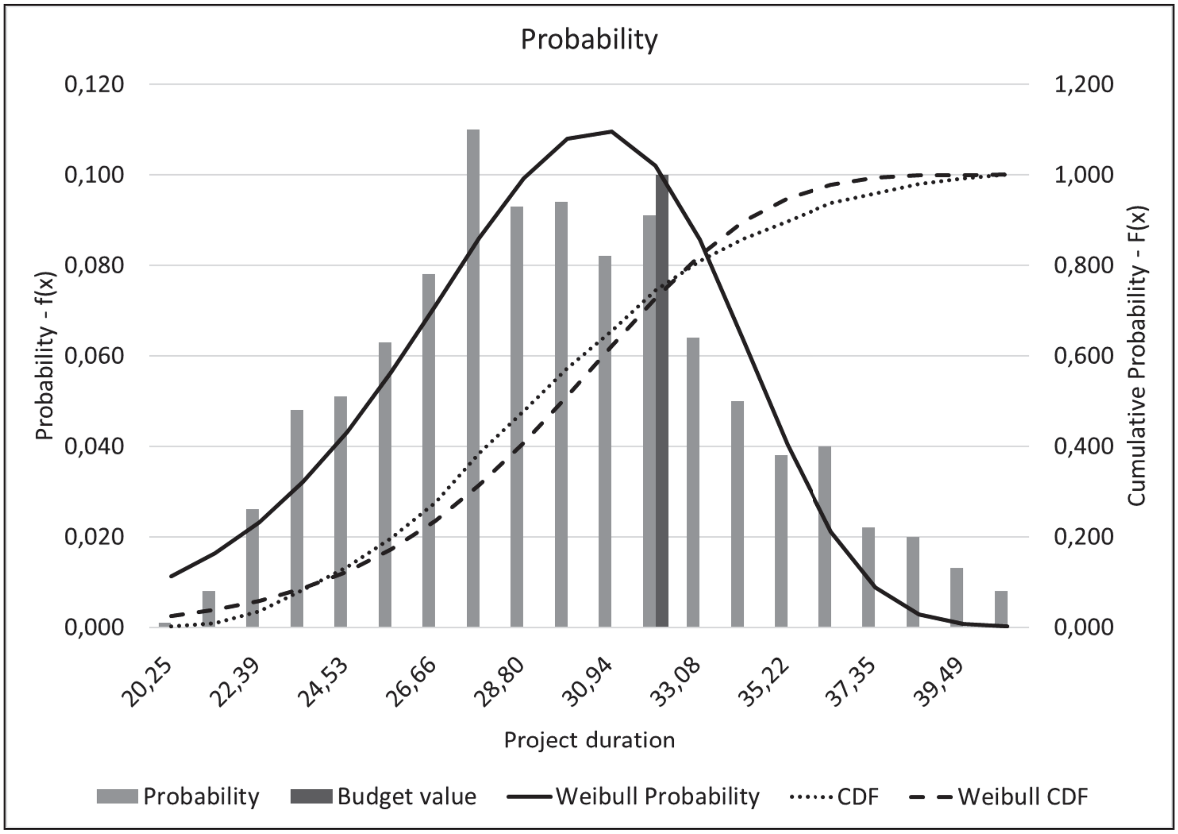

Figure 5: Weibull Distribution for Project Schedule Model

The Weibull shape parameter (8,62) and scale parameter (31,05) was determined using the regression method. The standard deviation was 4. The sum of the most likely duration was 28. If a 20% (5,6) contingency had been added, the total budget would have been 33,6. For this example, the Pearson correlation between the sampling data and the Weibull distribution was 0,93 with a p-value of 2,27953E-09. The R^2 was 0,87; thus, the Weibull distribution can be assumed to be a reliable fit for the sampling data.

Discussion

The two examples illustrate how the Monte Carlo method can be used to perform project risk analysis regarding cost and schedule. The Weibull functions provided a good fit for the hypothetical examples. In addition, the models can be used to calculate budget confidence levels and standard deviations.

For the Cost Risk example, the most likely cost was calculated at R532 833. Adding a 20% contingency would provide a budget of R639 400. This is almost at a 100% confidence level. At an 80% confidence level, the project budget would be R569 479. Thus, depending on the risk threshold of the project manager, there could be a significant capital commitment saving if the Monte Carlo technique was used to determine the project budget for this hypothetical example.

For the Schedule Risk example, the expected duration of 28,67 was calculated using PERT. However, this only provides a confidence level of approximately 40%. This would most likely be below the acceptable threshold for most project managers and thus illustrates the benefit of using Monte Carlo above PERT. Incidentally, the 20% contingency method would have provided a budget close to the 80% confidence level. However, using a 20% contingency doesn't enable a project manager to define an acceptable risk threshold.

In isolation, assessing the uncertainty associated with a specific project is challenging. However, suppose this simulation is performed for several projects. In that case, the standard deviations of various projects can be compared to determine which projects have a high level of uncertainty. Once projects with a high level of uncertainty have been identified, the cause for this can be investigated and actioned if appropriate. The simulations illustrate how systems thinking can assist in improving decision-making related to project risk management.

Conclusions

Projects will always have a level of uncertainty associated with it. The Monte Carlo Method can be used to evaluate the Cost or Schedule risk. It is a relatively simple tool to use, but its implementation has been limited. The development of open source tools and training on their application could possibly increase their adoption by practitioners. This paper illustrated how Real Statistics Using Excel could be used to develop a Monte Carlo model in Excel. The models used triangular distributions as inputs and provided Weibull probability distributions as outputs. The models could be used to calculate a project budget estimate given an expected level of confidence. The models can also be used to determine the confidence level of a budget estimated using another method.

Recommendations

The models developed for this paper did not consider any correlation between variables. For future models, it is recommended that the models also include a correlation between variables.

The reliability of these models should be compared to the results of commercially available models. This could improve confidence in these open source models.

The model inputs could only use a triangular distribution, and the output could only be based on the Weibull distribution. Future work could increase the number of functions being used.

The practical application of Monte Carlo simulations is limited. However, using open source models in risk management modules can test its application potential.

The schedule risk model is only applicable for the illustrated sequence of activities; subsequently, it is not possible to simulate different sequences or expand the model with relative ease. Future work may include a model where the sequence of events can be changed and where the number of activities that could be added is increased.

The models only used hypothetical input data. Future work may use these models in actual projects to evaluate their usefulness.

References

Addinsoft. 2022. “Monte Carlo Simulations.” https://www.xlstat.com/en/solutions/features/simulation.

Alasbali, Nada, and Boualem Benatallah. 2016. “Open Source as an Innovative Approach in Computer Science Education A Systematic Review of Advantages and Challenges.” *Proceedings of the 2015 IEEE 3rd International Conference on MOOCs, Innovation and Technology in Education, MITE 2015*. IEEE, 278–83. doi:10.1109/MITE.2015.7375330.

Avlijas, Goran. 2018. “Examining the Value of Monte Carlo Simulation for Project Time Management.” *Management:Journal of Sustainable Business and Management Solutions in Emerging Economies* 24 (1): 11. doi:10.7595/management.fon.2018.0004.

Barnes, Martin. 1988. “Construction Project Management.” *International Journal of Project Management* 6 (2): 69–79. doi:10.1016/0263-7863(88)90028-2.

Blanchard, Benjamin S., and Wolter J. Fabrycky. 2006. *Systems Engineering and Analysis*. 4th ed. New Jersey, US: Pearson Prentice Hall.

Bonate, P. L. 2001. “A Brief Introduction to Monte Carlo Simulation.” *Clinical Pharmacokinetics* 40 (1): 15–22. doi:10.2165/00003088-200140010-00002.

Bouayed, Zakia. 2016. “Using Monte Carlo Simulation to Mitigate the Risk of Project Cost Overruns.” *International Journal of Safety and Security Engineering* 6 (2): 293–300. doi:10.2495/SAFE-V6-N2-293-300.

Chaamwe, Nchimunya, and Langstone Shumba. 2016. “ICT Integrated Learning: Using Spreadsheets as Tools for e-Learning, A Case of Statistics in Microsoft Excel.” *International Journal of Information and Education Technology* 6 (6): 435–40. doi:10.7763/ijiet.2016.v6.728.

Clark, Dale E. 2001. “Monte Carlo Analysis: Ten Years of Experience.” *Cost Engineering* 43 (6): 40–45.

Clarke, Roland, and Allan Low. 1993. “Risk Analysis in Project Planning: A Simple Spreadsheet Application Using Monte-Carlo Techniques.” *Project Appraisal* 8 (3): 141–46. doi:10.1080/02688867.1993.9726903.

Dawson, R. J., and C. W. Dawson. 1998. “Practical Proposals for Managing Uncertainty and Risk in Project Planning.” *International Journal of Project Management* 16 (5): 299–310. doi:10.1016/S0263-7863(97)00059-8.

GoldSim Technology Group. 2022. “GoldSim.” https://www.goldsim.com/#:~:text=GoldSim is the premier Monte,inherent in all complex systems.

Harrison, Robert L. 2009. “Introduction to Monte Carlo Simulation.” *AIP Conference Proceedings* 1204: 17–21. doi:10.1063/1.3295638.

Hertz, David B. 1964. “Risk Analysis in Capital Investments.” *Harvard Business Review* 42 (1): 95–106.

Hopkin, P., and C. Thompson. 2022. *Fundamentals of Risk Management - Understanding, Evaluating and Implementing Effective Enterprise Risk Management*. Edited by The Institute of Risk Management. 6th ed. London, United Kingdom: Kogan Page Limited.

Howell, Gregory, Alexander Laufer, and Glenn Ballard. 1993. “Uncertainty and Project Objectives.” *Project Appraisal* 8 (1): 37–43. doi:10.1080/02688867.1993.9726884.

Hugo, F. D., L. Pretorius, and S. J. Benade. 2018. “Some Aspects of the Use and Usefulness of Quantitative Risk Analysis Tools in Project Management.” *South African Journal of Industrial Engineering* 29 (4): 116–28. doi:10.7166/29-4-1821.

ISO. 2018. *ISO 31000: Risk Management - Guidelines*. 2nd ed. Geneva, Switzerland.

Joubert, F.J., and Leon Pretorius. 2017a. “Using Monte Carlo Simulation to Create a Ranked Check List of Risks in a Portfolio of Railway Construction Projects.” *South African Journal of Industrial Engineering* 28 (2): 133–48. doi:10.7166/28-2-1604.

———. 2017b. “Using Risk Simulation to Reduce the Capital Cost Requirement for a Programme of Capital Projects.” *Business, Management and Education* 15 (1): 1–13. doi:10.3846/bme.2017.355.

Kolltveit, Bjørn Johs, Jan Terje Karlsen, and Kjell Grønhaug. 2005. “Exploiting Opportunities in

Uncertainty during the Early Project Phase." *IEEE Engineering Management Review* 33 (1): 26–35. doi:10.1109/EMR.2005.25174.

Kwak, Young Hoon, and Lisa Ingall. 2009. "Exploring Monte Carlo Simulation Applications for Project Management." *IEEE Engineering Management Review* 37 (2): 83–83. doi:10.1109/emr.2009.5235458.

Loizou, Pavlos, and Nick French. 2012. "Risk and Uncertainty in Development: A Critical Evaluation of Using the Monte Carlo Simulation Method as a Decision Tool in Real Estate Development Projects." *Journal of Property Investment and Finance* 30 (2): 198–210. doi:10.1108/14635781211206922.

Matta, Nadim F, and Ronald N Ashkenas. 2003. "Why Good Projects Fail Anyway." *Harvard Business Review* 81 (9): 109–16.

McCabe, Brenda. 2003. "Proceedings o f the 2003 Winter Simulation Conference S. Chick,." *Knowledge Creation Diffusion Utilization*, no. 1993: 1541–47.

McLain, David. 2009. "Quantifying Project Characteristics Related to Uncertainty." *Project Management Journal* 40 (4): 60–73. doi:10.1002/pmj.

Metropolis, Nicholas, and S Ulam. 1949. "The Monte Carlo Method." *Journal of the American Statistical Association* 44 (247): 335. doi:10.2307/2280232.

Meyer, Arnoud D E, Christoph H. Loch, and Michael T. Pich. 2002. "Managing Project Uncertainty : From Variation to Chaos." *MIT Sloan Management Review* 43 (2): 60–67. https://ink.library.smu.edu.sg/lkcsb_research/5450/.

Nawrocki, David. 2001. "The Problems with Monte Carlo Simulation." *Journal of Financial Planning* 14 (11).

Palisade. 2022. "@Risk." https://www.palisade.com/risk/.

Peleskei, CLAUDIUS A, VASILE Dorca, RADU A Munteanu, and RADU Munteanu. 2015. "Risk Consideration and Cost Estimation in Construction Projects Using Monte Carlo Simulation." *Management (18544223)* 10 (2): 163–76. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=110130673&site=eds-live.

Perminova, Olga, Magnus Gustafsson, and Kim Wikström. 2008. "Defining Uncertainty in Projects - a New Perspective." *International Journal of Project Management* 26 (1): 73–79. doi:10.1016/j.ijproman.2007.08.005.

Pohl, Gerhard, and Dubravko Mihaljek. 1992. "Project Evaluation and Uncertainty in Practice: A Statistical Analysis of Rate-of-Return Divergences of 1,015 World Bank Projects." *World Bank Economic Review* 6 (2): 255–77. doi:10.1093/wber/6.2.255.

Pritchard, Carl L. 2001. *Risk Management: Concepts and Guidance*. 2nd ed. ESI International.

Project Management Institute. 2019. *The Standard for Risk Management in Portfolios, Programs, and Projects*. 1st ed. Newtown Square: Project Management Institute. https://www.pmi.org/pmbok-guide-standards/foundational/risk-management.

Rezaie, K., M. S. Amalnik, A. Gereie, B. Ostadi, and M. Shakhseniaee. 2007. "Using Extended Monte Carlo Simulation Method for the Improvement of Risk Management: Consideration of Relationships between Uncertainties." *Applied Mathematics and Computation* 190 (2): 1492–1501. doi:10.1016/j.amc.2007.02.038.

Sage, Andrew P. 1995. “Risk Management Systems Engineering.” *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics* 2: 1033–38. doi:10.1109/icsmc.1995.537905.

Schuyler, John. 2001. *Risk and Decision Analysis in Projects*. 2nd ed. Project Management Institute.

Steyn, Herman, Michael Carruthers, Adriëtte Dekker, Yvonne Du Plessis, Deon Kruger, Birgit Kuschke, Ad Sparrius, Stefan Van Eck, and J. K. Visser. 2018. *Project Management - A Multi-Disciplinary Approach*. 4th ed. Pretoria, South Africa: Funda Project Management (Pty) Ltd.

Terje Karlsen, Jan. 2011. “Supportive Culture for Efficient Project Uncertainty Management.” *International Journal of Managing Projects in Business* 4 (2): 240–56. doi:10.1108/17538371111120225.

Tysiak, Wolfgang, and Alexander Sereseanu. 2009. “Monte Carlo Simulation in Risk Management in Projects Using Excel.” *Proceedings of the 5th IEEE International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS’2009*, no. August: 581–85. doi:10.1109/IDAACS.2009.5342913.

Vose Software. 2022. “Monte Carlo Simulation a Simple Guide.” https://www.vosesoftware.com/Monte-Carlo-simulation.php.

Wall, David M. 1997. “Distributions and Correlations in Monte Carlo Simulation.” *Construction Management and Economics* 15 (3): 241–58. doi:10.1080/014461997372980.

Ward, Stephen, and Chris Chapman. 2003. “Transforming Project Risk Management into Project Uncertainty Management.” *International Journal of Project Management* 21 (2): 97–105. doi:10.1016/S0263-7863(01)00080-1.

Well-Stam, D. Van, F. Lindenaar, S. Van Kinderen, and B. Van den Bunt. 2003. *Project Risk Management - An Essential Tool for Managing and Controlling Projects*. 1st ed. London, United Kingdom: Kogan Page Limited.

Williams, Terry. 2004. “Why Monte Carlo Simulations of Project Networks Can Mislead.” *Project Management Journal* 35 (3): 53–61. doi:10.1177/875697280403500307.

Zaiontz, Charles. 2022. “Real Statistics Using Excel.” https://www.real-statistics.com/.

Zhao, Wanhua, and Ruiyu Liu. 2008. “Study on Engineering Project Investment Risk Measure Based on Monte Carlo Method.” *Proceedings of the International Conference on Information ManagementProceedings of the International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2008* 3. IEEE: 407–11. doi:10.1109/ICIII.2008.312.

Biography

Schalk Grobbelaar received his PhD from the Graduate School of Technology Management (GSTM) at the University of Pretoria in 2019. He is currently a senior lecturer at the GSTM. Before joining the GSTM, he was the Group Engineer at York Timbers (Pty) Ltd. During his time at York Timbers, he was responsible for Engineering Management and Project Management. He is lecturing Technology and Innovation Management and Risk Management to postgraduate students. His research interests include Innovation Strategies, Risk Management and the application of Artificial Intelligence.