MCSimulRisk: an Educational Tool for Quantitative Risk Analysis

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Abstract. MCSimulRisk (Monte Carlo Simulation for Risk Analysis) is an application developed in MATLAB for Monte Carlo Simulation and quantitative risk analysis. In the Master's Degree in Project Management at the University of Valladolid, "Risk Management" is taught. Quantitative risk analysis is an essential part of teaching this subject. In the last few courses, students have used commercial applications that allow Monte Carlo Simulation in this subject. To correct the problems detected while students did laboratory exercises, we decided to develop this educational tool with the following main objectives: (1) allow students to efficiently carry out Monte Carlo Simulation for any project network, regardless of its complexity; (2) easily integrate different types of uncertainty (aleatoric, stochastic and epistemic) that can impact project objectives into the model. In addition to the above, this tool should help research tasks by extending research lines not yet addressed in the literature to integrate distinct types of uncertainty.

Introduction

The Risk Management course, which runs throughout the first semester of the Master's Degree in Project Management at the University of Valladolid, provides specifically theoretical knowledge on quantitative risk analysis. Practical exercises where students solve, interpret and discuss the results reinforce theoretical knowledge. Specific commercial software applications exist for Monte Carlo simulation, such as Crystal Ball (Oracle) or @Risk (Palisade).

These applications run as extensions of a well-known spreadsheet application. However, the experience in this subject has made us see that students spend too much time configuring the project proposed as a problem, a time that turns out to be unproductive, taking away time dedicated to the observation and commentary on the results obtained.

This paper aims to present a tool implemented in Matlab®, specifically designed to facilitate the project configuration with which the Monte Carlo simulation is to be performed. The teachers who teach this subject have developed the application. The results obtained from the tool provide the data that students need to solve the exercises. These results are provided attractively and visually, including the possibility of exporting the simulation data as external files for processing in auxiliary applications. This tool eliminates unproductive time for students, allowing them to dedicate it to solving the problem and finding an explanation for the results.

The rest of the paper is organised as follows. The following section introduces the context where Monte Carlo simulation is used to perform quantitative risk analysis. Next, we describe the educational tool developed, including the explanation of the results it offers. The results of students' use of this new tool are presented below. Finally, we present the conclusions of our work.

1 Risk Management

Project risk management identifies, analyses, and proactively responds to potential project risks. Project Risk Management objectives aim to increase the probability and impact of positive events and to decrease the likelihood and impact of adverse events for the project. We understand project risk as any uncertainty that, if it occurs, may affect project objectives (Project Management Institute, 2021).

The vast majority of standards and methodologies dealing with risk management (European Commission, 2018; Project Management Institute, 2021, and others) include a specific process for risk assessment.

The risk assessment process can be divided into two parts. The first consists of performing a qualitative analysis to prioritise individual project risks. The second consists of performing a quantitative analysis to quantify the combined effect of the individual project risks and other sources of uncertainty on the overall project objectives. In this context, Monte Carlo Simulation is a widespread quantitative technique that allows analysis of this uncertainty's impact (Rezaie et al., 2007).

Monte Carlo Simulation is a method that focuses on solving problems of a mathematical nature with a statistical model to generate possible scenarios resulting from an initial set of data. This method tries to simulate a real scenario and its different possibilities, allowing us to predict the behaviour of the variables according to the estimations made.

Monte Carlo simulation is beginning to be used more widely in the areas of cost and schedule management for the calculation of project cost contingencies or time margins to determine how likely it is that the project budget will be met or what the project duration will be with a given percentage probability (T. Williams, 2003).

Nowadays, all the above can be easily solved with standard project management software, such as Microsoft Project or Primavera, and complementary Monte Carlo simulation applications, such as @Risk or Crystal Ball. Another standard option is to use spreadsheets, such as MS Excel.

The education tool presented in this paper focuses on quantitative risk analysis and uses Monte Carlo simulation for data processing. The application will be developed using Matlab as the programming language.

2 MCSimulRisk

MCSimulRisk (Monte Carlo Simulation for Risk analysis) is an application developed in the Matlab® environment for Monte Carlo Simulation. The application, developed as a set of Matlab functions, offers various graphical and numerical results related to quantitative risk analysis. It allows the user to obtain graphical and tabular data of the problem to be solved, interacting through menus with different options (Figure 1).

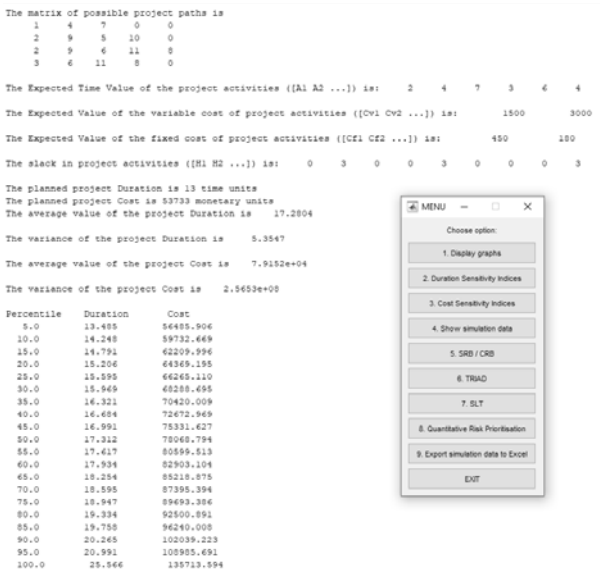

Figure 1: MCSimulRisk working environment.

Figure 2 shows the application flowchart, which includes the sequence of steps we have followed in its programming and the utilities this application offers users.

The student must have information about the project he/she wishes to complete before executing the application. For this purpose, it is necessary to encode in a supplementary Excel table the information relating to project activities, characterised by the duration and cost (fixed cost and variable cost) of the activities; project risks, which can come from aleatoric, stochastic or epistemic uncertainties; the relationship of precedence of activities; and the number of simulations to be carried out.

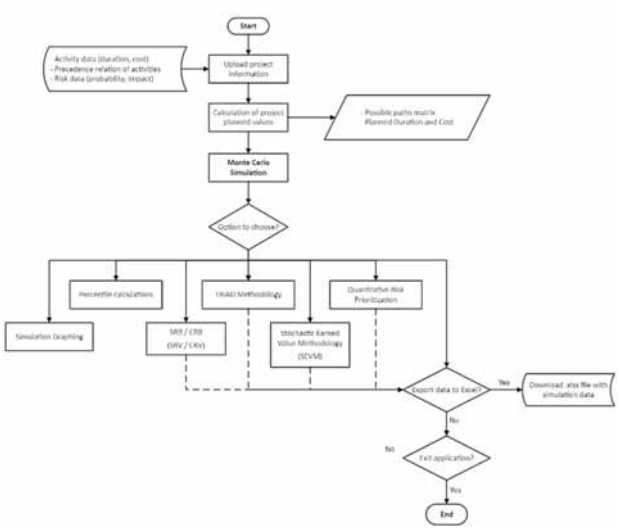

Figure 2: Flowchart describing the simulation process followed by MCSimulRisk.

Once the application loads the project information, it runs the Monte Carlo simulation. It offers a drop-down menu with a wide range of options that can be selected depending on the exercise the student is doing in class. Therefore, we can obtain the probability distribution and cumulative probability curves corresponding to the project's total duration and cost (Figure 3).

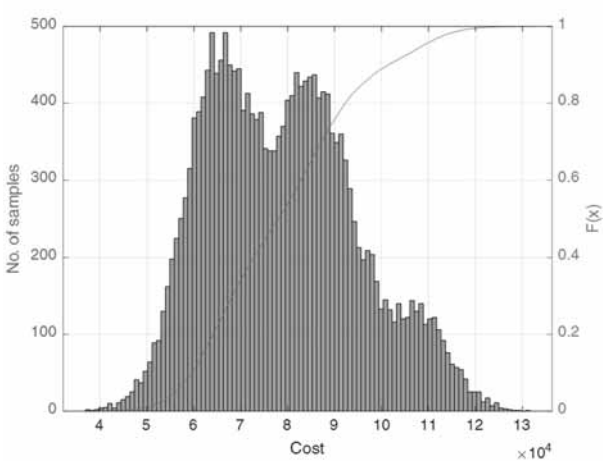

Figure 3: Probability distribution curves and cumulative probability for the total project cost.

In addition to graphical data, MCSimulRisk offers numerical data that the user can download locally if he/she intends to process the data further.

MCSimulRisk incorporates different utilities that allow the monitoring and control of projects considering the uncertainty of the activities (ScoI/CcoI (Pajares & López-Paredes, 2011), Triad methodology (Acebes et al., 2014) and SEVM (Acebes et al., 2015)).

It also offers information on the prioritisation of the importance of project activities (Criticality Index (Martin, 1965) (Figure 4), Cruciality Index (T. M. Williams, 1992), or Management Oriented Index (Madadi & Iranmanesh, 2012)).

For each of the chosen options, MCSimulRisk offers the possibility to display graphical and numerical results and, in addition, to export the results to a '.xlsx' file for further statistical treatment if the student wishes. Finally, MCSimulRisk allows students to quickly obtain graphical and numerical simulation results to solve the tasks assigned in their laboratory classes. In addition, this tool can be used by researchers who need to extend their studies on the contribution of the diverse types of uncertainty to the project's total risk.

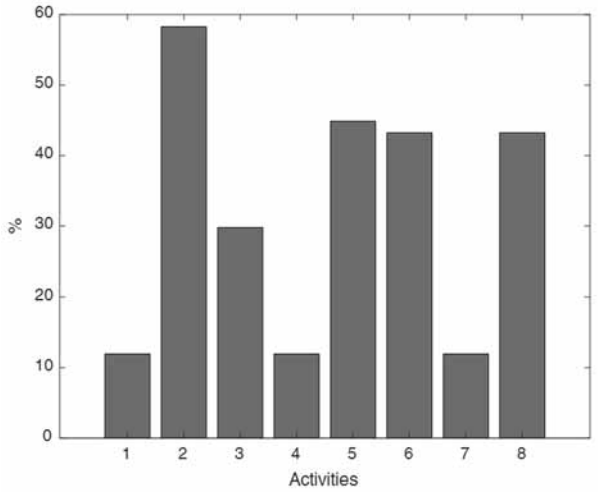

Figure 4: Graphical representation of the Criticality Index.

3 Teaching Using the Application

During the present course, it was decided to introduce the MCSimulRisk application in test mode to check its effectiveness and usefulness as a teaching tool for students in Risk Management classes. After the students had completed their exercises using the commercial tool (@Risk), they were asked to repeat the same exercises using, in this case, MCSimulRisk.

The students used the same problem statements, describing the project activities and the identified risks. They have incorporated this information into the MCSimulRisk application and have directly obtained the desired results.

Before the end of the course, we conducted a questionnaire for the students. The questionnaire aims to collect the students' impressions while solving the exercises using the new tool introduced in class (MCSimulRisk). The aim is for the students to compare the effort made and the teaching usefulness of this tool compared to the commercial one.

Eight questions were asked; seven were closed questions, with a score between 1 and 5 points, "1" is a highly negative score, and "5" is an incredibly positive score for the question asked. The last question corresponds to an open question where the student can comment on suggestions, improvements or negative aspects not included in the previous questions. We have configured the questionnaire based on existing literature (Yin et al., 2021).

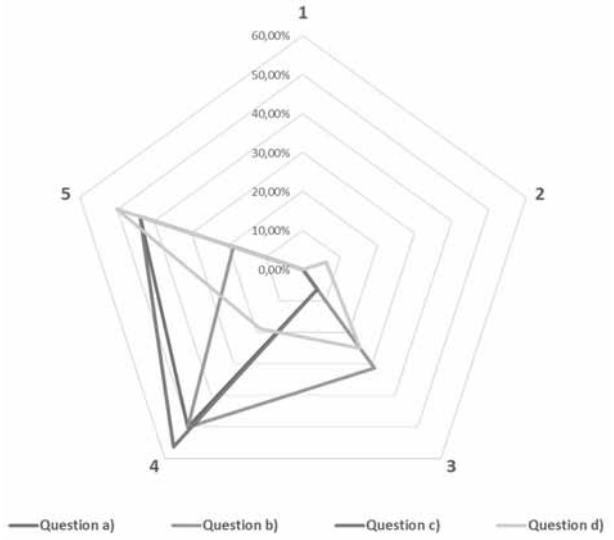

Figure 5: Feedback received from students. A vertex in a polygon represents the percentage of students who gave a particular rating to the tool according to the specific questions.

Figure 5 includes some of the questions given to the students. The percentage score given to each question by the students surveyed is also included.

If we look in detail at the questionnaire and the answers given by the students, they consider the application to be easy to use and helpful in teaching the subject, and they recommend it for use by other students.

As teachers of the subject who have observed the students using the application, we can affirm that the time they have invested in conducting the practice has been much less using MCSimulRisk than the time invested with other applications. The students entered the problem data into the application, and the application provided the results. Subsequently, the students spent their time evaluating the results obtained, reasoning whether they were appropriate or not, proposing solutions to the problem posed, and eliminating the time spent on other occasions modelling the project in MS Excel.

4 Conclusions

Although there are commercial tools specifically designed to perform Monte Carlo simulation for project quantitative risk analysis, our experience has shown that their use requires students to devote much time to the project setup, reducing the available time for interpretation and discussion of the simulation results.

The application 'MCSimulRisk' bridges this gap. It fulfils a dual purpose. On the one hand, it is a tool that allows the configuration of any project type with complex structures, even with many activities, without taking up excessive configuration time for students (definition of activities, sequencing, definition of risks, and others). In this way, students can use this time to reason about the configuration parameters of the problem project and the results obtained according to the programmed parameters.

On the other hand, 'MCSimulRisk' allows the integration of any uncertainty beyond aleatory uncertainty, which is the only type of uncertainty considered by commercial software.

Therefore, this tool allows for a comprehensive quantitative risk analysis that integrates not only aleatory uncertainties but also stochastic and epistemic uncertainties (Curto et al., 2022; Hillson, 2009).

The results offered by the application are very varied, as we can determine the duration and cost contingency margins (depending on the chosen percentile), prioritise activities according to different sensitivity indexes, or monitor and control the project by incorporating uncertainty in the project activities, among other applications.

The software application has been used during the present course as a test version; however, we intend to incorporate it in the following academic years as an educational tool for solving the risk management exercises proposed in the course.

As future lines of research, we plan to expand the application's functionalities, focused on quantitative risk assessment. The medium-term objective is also to change the programming environment and develop the same application as the Python language.

Under this new programming environment, the possibilities for developing and disseminating the software application would be greater than in the Matlab environment.

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