Monte Carlo Simulation for Project Risk Prioritisation

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Abstract. Qualitative project risk assessment is standard practice in project management and involves prioritising risks using a probability and impact matrix. Due to the shortcomings of using this tool for risk prioritisation (poor resolution, errors, suboptimal resource allocation or ambiguous inputs and outputs, among others), we propose a quantitative prioritisation of project risks in this article, analysing the impact of each risk on the project's duration and cost objectives.

Keywords: Probability-Impact Matrix · Quantitative Risk Analysis · Risk Management · Quantitative Risk Analysis · Monte Carlo Simulation · MCSimulRisk

1 Introduction

The risk matrix is a commonly used tool to assess, visualise and analyse risks (Goerlandt and Reniers, 2016). It consists of a two-dimensional graphical representation of the probability ("likelihood" or "frequency") of an outcome occurring and the impact ("severity" or "consequences") that the outcome would have if it were to occur (Duijm, 2015). Each of the two dimensions of the matrix is further divided into different levels of probability, usually located on the ordinate axis of the matrix, and different levels of impact, located on the abscissa axis. The result of each cell, formed by interconnecting a given probability level with the corresponding impact level, is associated with a risk level (urgency, priority, or management action).

The risk matrix (or probability-impact matrix) has been widely implemented as a decision-support tool in both the public and private sectors in areas such as well-integrity risk, drilling hazard management, climatic change responses, or health and safety (Cox, Babayev and Huber, 2005; Li, Bao and Wu, 2018). Using these matrices to set priorities and guide resource allocation has been established as a recommendation within various international standards and industry guidelines (Goerlandt and Reniers, 2016).

The risk matrix is widely used, among other reasons, because it is easy to construct and simple to apply compared to other risk assessment methodologies (Levine, 2012). Also, they provide a clear framework for the systematic review of risks, practically justify

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risk ranking and prioritisation, and keep stakeholders informed visually and attractively, among other reasons (Ball and Watt, 2013).

Despite this, recent studies have shown that the risk matrix has some shortcomings and limitations, which make authors question its functionality and accuracy (Cox, Babayev and Huber, 2005; Cox, 2008; Thomas, Bratvold and Bickel, 2014; Duijm, 2015; Li, Bao and Wu, 2018). Some of the criticisms made by Cox (2008) concern how risk matrices are constructed and risk factors are assessed (correlation between risk factors, different expert opinions for estimating factors or, for example, aggregation of individual risk matrices). On the other hand, Levine (2012) states that it is unusual to consider uncertainty when estimating probability and impact when using risk matrices. Risk matrices do not include information on the possible correlation between probability and consequence, and, finally, many risk matrices assign the same qualitative rating to very different quantitative risks.

Taking these limitations into account, in this article, we propose a quantitative method based on Monte Carlo simulation for prioritising the risks of a project, avoiding the use of the probability-impact matrix. To carry out the simulation, we will have the probability and impact data of the risks identified in the project and use MCSimulRisk (Acebes et al., 2023) as a simulation tool. We will be able to quantitatively determine the impact of each risk on the cost objective and total duration of the project. The magnitude of the resulting impact will allow us to determine a quantitative prioritisation of the risks identified in the project.

From this point, the article will review the use of risk matrices in project management. We will then present our quantitative analysis proposal for prioritising risks, ending with the conclusions drawn from our research.

2 Current Practices in Risk Management

The probability-impact matrix is not only standard in sectors as varied as an industry, health and safety, or chemicals (among others) (Li, Bao and Wu, 2018) but also appears as a primary tool in risk analysis within project management (Qazi and Dikmen, 2021).

Thus, we can find how the PMBoK Guide (Project Management Institute, 2021) proposes the probability-impact matrix as a fundamental tool for qualitative risk analysis. It uses a 5x5 matrix, with five levels of probability (Very Low, Low, Medium, High and Very High) and five levels of impact. The risk is graded in three levels (Low, Medium, High), assigning a numerical value to each cell of the matrix to allow discriminating the importance of each cell with the same level of risk. In addition, the PMBoK standard proposes a symmetrical matrix for risks identified as threats and another for risks identified as opportunities.

The PM2 Methodology (European Commission, 2018) proposes a Risk Management Plan within its artefacts. This plan includes a Risk Likelihood/Impact matrix as a tool to be used for risk management. According to the proposed matrix, the risk level will be calculated as the product of likelihood and impact, resulting in three possible risk levels.

Furthermore, ISO 31010:2019 (International Organization for Standardization, 2019) includes in appendix B 10.3 the concept of the consequence/likelihood matrix (or heat map). The strengths and weaknesses of using such matrices and recommendations are described.

Finally, it is worth mentioning the structured project management method proposed by PRINCE2 (Axelos, 2017), which, like the PMBoK guide, proposes an impact probability matrix with five different levels for each variable, and three levels of risk, labelling the cells with numerical values that facilitate the prioritisation of each cell of the matrix.

In our review of the most common standards and methodologies in project management, we have observed that it is common practice to use the probability-impact matrix to prioritise the risks identified in the project, despite the deficiencies previously identified by various authors (Cox, 2008; Duijm, 2015).

3 Quantitative Risk Prioritisation

This article aims to provide a list of prioritised risks according to each risk's impact on the overall project schedule and cost objectives. With the proposed method, we refrain from using the probability-impact matrix, which, as we have seen, has serious shortcomings. Using the suggested methodology, we intend to give cohesion to the risk management process by connecting the identification of risks and estimating the probability and impact of the identified risks with the quantitative risk analysis.

Our developed method will provide quantitative values of the impact of each risk on the total duration and cost of the project. This proposal is developed schematically in Fig. 1. Starting from the information on the project activities (duration, cost and relation of precedence of the activities), we managed to build our project model. In the next step, we identify the project risks, estimating the probability and impact of these risks. This data is then fed into our project model, and Monte Carlo simulation is applied. As a result of the simulation, we obtain the distribution functions of the total duration and cost of the project, having incorporated the identified risks into the model.

Next, we quantitatively determine each project risk's impact on the cost and duration objectives. To do this, we sequentially reduce each risk's probability and impact values to zero. After running a new simulation in this situation, we obtain the project duration and cost statistics without considering the corresponding risk. This allows us to prioritise each risk according to its impact on the project duration and, independently, the total cost.

After applying the proposed method and using the 'MCSimulRisk' application, we obtain the total duration (Dur_R) and cost (Cost_R) values of the project, discounting the impact of each corresponding risk (see Fig. 1). For each identified risk, we calculate the difference between the total project duration considering all project risks and the duration, discounting the impact of the corresponding risk (Dur_Ri). The value obtained for each risk (Dif_Dur_Ri) will be the effective impact on the total project duration of that risk. In the same way, we do for the project's total cost, obtaining the total impact of each risk on the project cost (Dif_Cost_Ri).

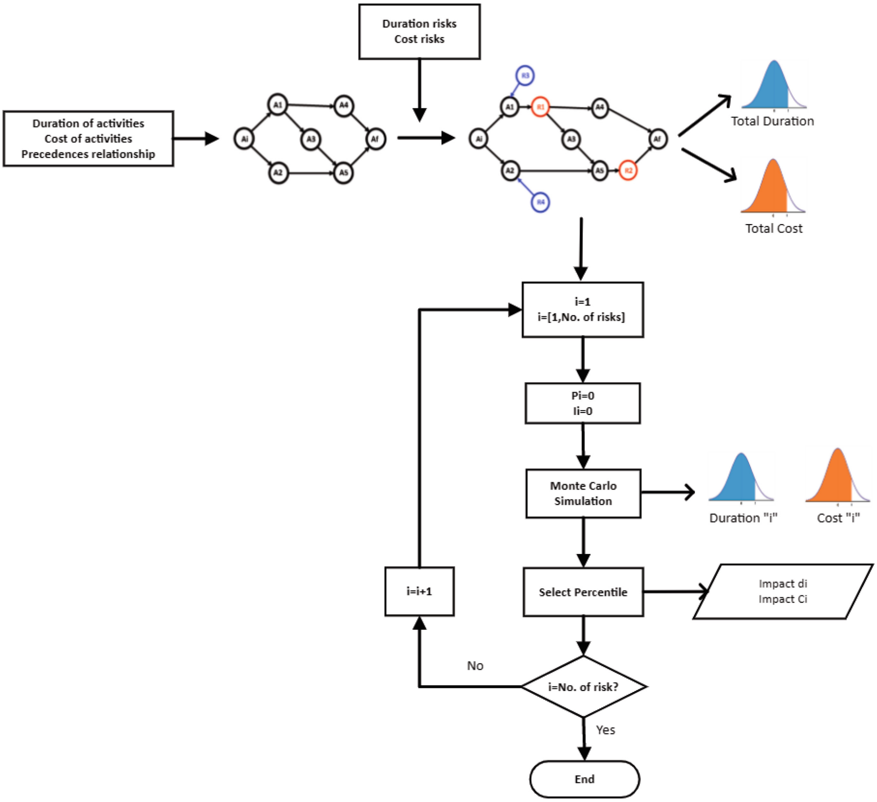

Fig. 1. Process flow diagram

In Table 1, we have incorporated the prioritisation of the risks identified in a project used as a model, in which five risks have been identified (three of them impact the duration of the activities and two of them on the project's costs).

The first ranking corresponds to the priority obtained using the traditional probability-impact matrix, with each risk's probability, impact and risk level assessments. The second ranking corresponds to the order of impact on the duration of each identified risk. The specific risks that impact cost (R4 and R5) do not impact duration.

Table 1. Risk prioritisation: P x I matrix & quantitative risk prioritisation

	Probability-Impact Matrix				Simulation results: Duration (weeks)			Simulation results: Cost (€)		
Risk	P	I	P x I	Ranking PxI	Dur_R	Dif_Dur_R	Ranking_Dur	Cost_R	Dif_Cost_R	Ranking_Cost
R1	A	B	0,07	5	15,837	0,481	2	40038,05	801,14	4
R2	M	A	0,2	1	14,842	1,476	1	38959,62	1879,57	2
R3	MB	MA	0,08	4	16,056	0,262	3	40199,75	639,44	5
R4	B	A	0,12	3	16,318	0,000	4	37856,57	2982,62	1
R5	A	M	0,14	2	16,318	0,000	4	39291,41	1547,78	3

The last classification corresponds to the impact of each risk on the project's cost. In this case, the risks previously identified as impacting project duration also impact the total project cost. We can quantitatively verify how risk "R2", which is initially identified as having an impact on the duration, has a more significant impact on the cost of the project than risk "R5" (a risk that has a direct impact on the cost of the project).

4 Conclusions

In this work, we have used Monte Carlo simulation to conduct a quantitative analysis of the impact of each risk identified in the project on the cost and duration objectives.

On the one hand, we have avoided using the probability-impact matrix, as the results it offers are only partially valid, according to the literature. On the other hand, we have managed to connect the qualitative risk analysis, after estimating the probability and impact of the project's risks, with the quantitative analysis, by quantitatively prioritising the identified risks. In current risk management processes, there is a disconnect between qualitative risk analysis and quantitative risk analysis (the information used in the former is not used in the latter). In addition, we have managed to quantify the impact of each risk on the cost and duration objectives. We observed existing risks that significantly impact the project's cost, even though they were initially identified for their possible impact on the project duration.

As a result of applying the proposed method, we obtain a list of prioritised risks according to their impact on the duration objective and another list, different from the previous one, with the prioritised risks on the impact on the project's cost. The order is different; thus, we can discriminate on which risk to act according to which is the most crucial objective in our project and the impact each risk has on the project.

The results affirm that the qualitative analysis of the risk using the probability-impact matrix needs to be revised to carry out a precise prioritisation of the risks identified. This method will allow us to precisely determine the risk on which we must act, depending on the objective we intend to control, to adequately manage the resources necessary for its control.

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