COST CONTINGENCY ESTIMATION: A NEW METHOD FOR QUANTITATIVE RISK ANALYSIS APPLIED TO A REAL CONSTRUCTION PROJECT

David Curto, David Poza, Félix Villafáñez, Fernando Acebes*

GIR INSISOC-Department of Business Organization and CIM, School of Industrial Engineering, University of Valladolid, Valladolid, 47011, Spain.

*Corresponding author: fernando.acebes@uva.es

DOI: https://doi.org/10.6036/10815 | Received: 05/jan/2023 • Reviewing: 11/jan/2023 • Acepted: 03/may/2023

To cite this article: CURTO, David; POZA, David; VILLAFÁÑEZ, Félix; ACEBES, Fernando. COST CONTINGENCY ESTIMATION: A NEW METHOD FOR QUANTITATIVE RISK ANALYSIS APPLIED TO A REALCONSTRUCTION PROJECT. DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

ABSTRACT:

The main objective of this work is to propose a method based on Monte Carlo simulation (MCS) to estimate the allocation of project cost contingency reserves in the planning phase, incorporating the different types of uncertainty described in the literature, associating them to each of the risks identified in the project. The method was applied to validate our proposal on an actual construction project carried out by the University of Valladolid (Spain).

Applying the proposed method has allowed us to obtain a more accurate estimate of cost contingencies than the method traditionally used by the company, which consisted of reserving a fixed and arbitrary percentage of the total project execution budget.

Keywords: Monte Carlo Simulation; Quantitative Risk Analysis; Cost Contingency; Risk Management; MCSimulRisk

RESUMEN:

El objetivo principal de este trabajo es proponer un método basado en la simulación de Monte Carlo (MCS) para estimar la asignación de reservas de contingencias de coste del proyecto en la fase de planificación, incorporando los diferentes tipos de incertidumbre descritos en la literatura, asociándolos a cada uno de los riesgos identificados en el proyecto. El método ha sido aplicado en un proyecto real de construcción ejecutado por la Universidad de Valladolid (España).

La aplicación del método propuesto nos ha permitido obtener una estimación de contingencias de coste más precisa que la obtenida por el método tradicionalmente empleado por la compañía, el cual consistía en reservar un porcentaje fijo y arbitrario del presupuesto total de ejecución del proyecto.

Palabras clave: Simulación de Monte Carlo; Análisis Cuantitativo de Riesgos; Contingencia de Coste; Gestión del Riesgo; MCSimulRisk

FUNDING

This research has been partially financed by the Regional Government of Castilla and Leon (Spain) with Grant (VA180P20).

1.- INTRODUCTION

All projects have risks since the goal is to produce a superior result. Furthermore, the projects are being developed in a complex, uncertain environment, implying a need for understanding the environment and future (1). This lack of stability in the natural environment is to blame for the altered starting conditions used to develop the projects. Over time, the Risk Management procedure has evolved to examine the elements that affect project planning and its consequences. It is an organised method for discussing how risks might affect projects and setting up backup plans to ensure the creation and accomplishment of intended objectives.

Therefore, there is a need to control the unplanned cost of projects and monitor its evolution during the execution phase. Currently, although there are organisations that apply advanced quantitative simulation techniques for risk management, a significant proportion of organisations do not use them, so the accuracy to correctly estimate real cost contingencies is very low. As a result, projects often end up with an actual cost that is much higher than the planned cost.

Additionally, several authors have researched contingency assignments as a valuable tool for addressing the effects of uncertainty on Projects (2–4).

This study's primary objective is to offer a method based on Monte Carlo Simulation (MCS) to calculate the cost allocation of contingencies. At the same time, considering the various types of uncertainty identified in the literature during project planning. All project risks identified will be included in the analysis, regardless uncertainty that causes them.

This study compares the effectiveness of the proposed method to the conventional method for estimating cost variances, which establishes reserving a specific percentage of the project's total cost, being used with some frequency 10%. Doing this will prevent the arbitrary allocation of cost escalations for project management.

The intent is to examine the ramifications of incorrectly estimating project cost escalations. Beginning with a review of the state of the art of risk management and how it is applied within project management, quantitative risk assessment is included as a helpful method that enables us to carry out the project per the prepared plan.

In this planning, potential risks or surprises will be assessed to consider and include them in the previous analysis. We will be able to estimate the project's cost variances by analysing the scenarios that are most likely to occur through the Monte Carlo simulation.

This model has been used in a simple project, congruent with the building of the Aulario IndUVa for the University of Valladolid (Spain), in cooperation with the university's school of architecture and the business Constructora San José S.A. The results obtained from the simulation allowed us to compare the contingency allocation that should have been set aside if an integrated risk analysis had been carried out, as opposed to the allocation traditionally used by the construction company, which consists of setting aside a percentage of the total planned project budget, set at 10% of the total budget.

The article takes on the following structure from this point on. The next chapter will review the literature on risk management and the concepts of risk and uncertainty, and different quantitative methods used in Risk Management. Later, in Chapter 3, the suggested method for analysing the study case will be presented. The study case is introduced in Chapter 4. Finally, in Chapter 5, the simulation results will be examined, and Chapter 6 will offer the conclusions.

2.- LITERATURE REVIEW

2.1.- RISK MANAGEMENT

Risk management consists of several processes. Thus, the 6th edition of the PMBOK (5) sets out seven processes for risk management: management planning, identification, qualitative and quantitative analysis, response planning, response implementation, and risk monitoring and control. These processes can be grouped into three phases of risk management: identification, evaluation, and risk response (6). The identification process aligns with the method for identifying and recording project-related uncertainties and risks. The evaluation entails examining the hazards identified by researching their features, likelihood of occurrence, and effect. Finally, finding a solution to risk is focused on researching the risk management actions to take and their implementation and evaluation.

Analysis qualitative and quantitative analysis are the two main types of analysis used during risk evaluation (7), for which there are several indicators (8). The first step is assessing the risks' importance and relevance to the project (9). The quantitative evaluation examines numerically how the project's goals have changed due to risks (2,10).

Given the wide range of methods and risk management tools available for calculating project cost variations (11), including both quantitative and qualitative techniques (12), the proposed method concentrates on the study of Monte Carlo Simulation (MCS) as an ideal/suitable quantitative technique for allocating project cost variations (13).

To do this, Following the methods recommended by the American Association of Cost Engineering (AACE), we used information from a simple building project (10). We identified all potential project-related risks' goals (aleatoric, stochastic, and epistemological), incorporating them into the Monte Carlo Simulation and determining the project's cost contingencies.

2.2.- RISK AND UNCERTAINTY

According to the Project Management Institute (5), a "risk" is any "event or uncertain condition that, if it occurs, has an impact on one or more project objectives, either positively or negatively". In contrast, Hillson (14) defines risk as "an uncertainty that, if it materialises, may have an impact on one or more objectives." The risk is seen by the author as a subset of all uncertainties and is only associated with uncertainties that may influence the project's goals. This perspective views risk as "the important uncertainty." As a result, the project's environment's uncertainty creates risk (14), leading to the existence of several risk sources (8).

Beyond the various definitions of uncertainty, there is a need to distinguish between two different forms of uncertainty. Various research (15,16) supports the need to distinguish between two different types of uncertainty: aleatoric uncertainty (this almost usually finds its way into every activity, such as the range of duration) and epistemological uncertainty (caused by ambiguity or imperfect knowledge).

Expanding on this concept of uncertainty, Hillson (14) argues that two additional types of uncertainty should be added to the previous classification: uncertainty regarding the future (known as "risk of the event", specified as "possible future events"), and uncertainty regarding the nature of reality ("unknown unknowns" or "black swans," the knowledge of what is impossible to know, which is not acknowledged).

2.3.- SIMULATION IN QUANTITATIVE RISK ANALYSIS

An accurate way to manage risks is to perform quantitative analyses using simulation techniques. Panova & Hilletofth (17) conclude that simulation models are optimal for risk assessment and management.

Some authors choose to use several quantitative methods in the same study. In the case of Lei & MacKenzie (18) a Markov Chain Model, MCS and Dynamic Fault Trees Analysis are used. While Lee et al. (19) use Monte Carlo Simulation (MCS) and Petri Nets. Costantino & Pellegrino (20) opt for MCS and sensitivity analysis to compare whether diversification is a significantly better strategy than not doing so in multiple uncertainty environments.

Likewise, Mangla et al. (21) perform a risk assessment capturing the random uncertainty of a project, focusing on deviations and delays. Even so, he considers CSM a valid method for incorporating uncertainty. Tokdemir et al. (22) also measure the delay in a project using CSM, which allows them to estimate deviations and develop response strategies such as contingency plans. However, they do not consider stochastic risks that may occur at some point in the project.

Qazi et al. (23) conclude that their CSM could be improved by including positive risks - opportunities. They also point to the need for research on critical risks and the search for models to capture individual risks. Once the risks are obtained, the authors propose incorporating a risk matrix into the simulation capable of quantifying the risks. Monte Carlo simulation not only provides a more complete structure than other quantitative methods in terms of probabilistic aspects but also excels in incorporating uncertainties when the probability of occurrence is present (24). Only a few authors have proposed quantitative models to support decision making in the presence of risk and uncertainty, being limited to resource allocation and considering the views of the client and the project provider (20).

In this article, we will use Monte Carlo simulation to perform a quantitative risk analysis to statistically determine the range of cost contingencies that should be considered in a project based on the risk aversion of the promoter, incorporating all types of uncertainty.

3.- PROPOSED METHOD

This method can be resolved in three steps: (i) identification of project risks, (ii) inclusion of the uncertainty identified by a Monte Carlo simulation, and (iii) results in analysis for cost sensitivity assignment.

All uncertainties that may influence the financial goals of one or more activities must be listed in the first phase's risk register. Following a review of the literature, we divided the uncertainties into three groups.: stochastic, aleatoric, and epistemological. We must respect the existence of additional types of uncertainty (ontological) whose sole remedy is setting aside a contingency margin for these unknown risks.

We use the project sequencing and risk register data in the second phase to perform a Monte Carlo simulation. This risk register data includes the probability of each risk materialising and its potential influence on the cost of the activity. For this purpose, we use a MATLAB® application developed specifically for our method, which allows any uncertainty to be introduced into the model following stochastic programming. The application is called "MCSimulRisk" (25), registered in the Central Registry of Intellectual Property under number 765-704822. Figure 1 shows a flowchart of the MCSimulRisk application.

Because of the simulation, we have the statistics and graphics corresponding to the project's total cost available. We are currently in the third stage of the method, which involves analysing these results and choosing how the project's cost contingencies will be allocated. The project director must consider the organisation's level of risk aversion to making this decision. Greater risk aversion will result in a higher percentage of the cost function to choose from when fixing contingencies.

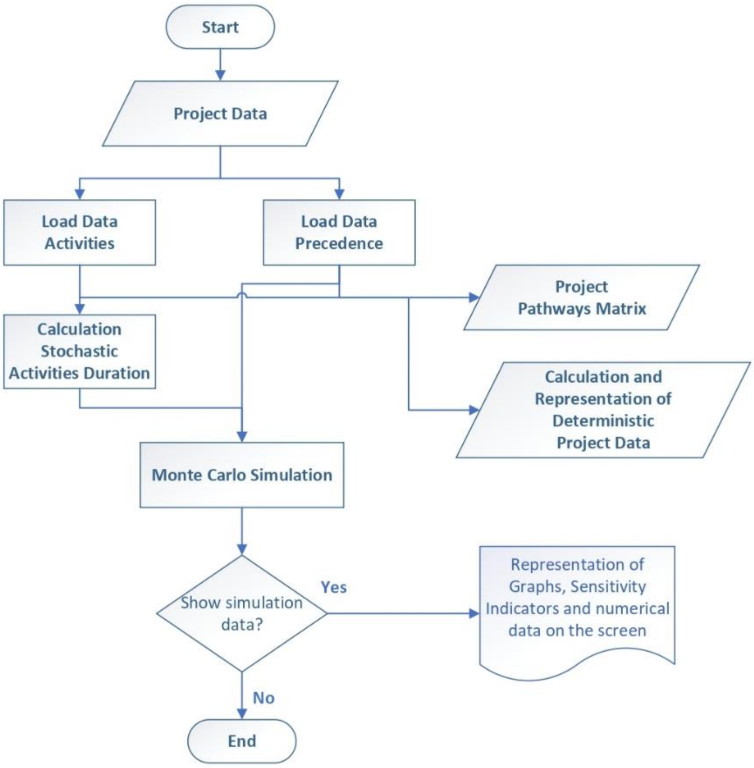

Fig. 1: Flowchart of the MCSimulRisk application developed in MATLAB®

4.- CASE STUDY

At the University of Valladolid in Spain, the Industrial Engineering School's classrooms are at the Aulario IndUVa. During the construction of the building, the construction company in charge of the execution of the project established the margins traditionally used for contingencies, set at 10% of the project's total cost.

The project comprises 59 activities and 14 work packages (Table 1). We aimed to lessen complexity and maintain the confidentiality of information provided by the construction company and university. We will not include anything about project activities.

The project works were scheduled to begin on December 2, 2016, and was expected to be completed on June 1, 2018, corresponding to 546 natural days. The overall planned project duration, or unit of measure for this project, is 383 working days.

The project management team consisted of, on the one hand, the project manager of the construction company, in charge of the work; and on the other hand, the technical architect of the University of Valladolid, in charge of the tender and promoter of the project, as well as the Recognised Research Group of the University of Valladolid GIR-INSISOC. The team established the different levels for modelling the probability of this project, as indicated in Table 2. The probability distribution functions (PDF) associated with the probability will be uniform, where the minimum value of the interval will be the minimum value of the uniform distribution function, and the maximum value of the interval will correspond to the maximum value of the uniform PDF.

Using the interview technique and expert judgement, information was obtained regarding the risks (threats or opportunities) detailed in Table 3, with "A" being the threats, "O" the opportunities, "IDp" an identifier for the work packages and "IDr" an indicator for the identified risks. The eight-person expert group includes the management team, the construction manager and middle management of the construction company and the team of the University of Valladolid responsible for the tender.

To carry out this work, the Lognormal distribution function was used to incorporate the random uncertainty in the duration of the activities, on the understanding that the random uncertainty in the cost of the activities comes from the variability of the duration of these, as proposed by Colin and Vanhoucke (26) and Traynor and Mahmoodian (3). After analysing a database of 101 construction projects, Ballesteros-Pérez et al. (27) propose using the lognormal distribution function to incorporate uncertainty in construction project activities.

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

Events with stochastic uncertainty are known, and a specific value for the probability can be asserted with some certainty. In this case, the probability of occurrence is treated with the Bernoulli distribution function or dichotomous distribution (2).

To model epistemic uncertainty, we first define the probability and impact intervals required for this particular project (4) since, for this type of risk, we do not know precisely what its impact will be or how likely it will be (28). In Table 2, we propose to set five levels: Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH) for probability and cost impact.

The interval limits are pre-defined. This way, experts can determine which activities are at a particular risk level. Thus, the characteristics of the distribution functions can be defined according to the experts' opinions for both probability and impact.

The minimum and maximum values for each interval correspond to the values the corresponding PDF will take when the simulation is conducted. From these values, the risks associated with epistemic uncertainty are modelled as a uniform function in the resulting interval.

ID	Work package	Duration	Variable Cost	Fixed Cost	Total Cost
1	Land conditioning	50	52.976,76 €	48.821,90 €	101.798,66 €
2	Foundations	25	10.463,36 €	53.764,17 €	64.227,53 €
3	Structure	112	138.017,78 €	849.450,16 €	987.467,94 €
4	Facades and partitions	152	73.301,94 €	782.100,02 €	855.401,96 €
5	Carpentry, glass and sun protection	111	10.211,80 €	194.070,02 €	204.281,82 €
6	Aid	80	30.872,00 €	1.020,00 €	31.892,00 €
7	Facilities	328	59.344,20 €	1.010.772,68 €	1.070.116,88 €
8	Isolates	5	12.832,99 €	91.087,44 €	103.920,43 €
9	Cover	30	14.193,38 €	68.984,83 €	83.178,21 €
10	Coatings and cladding	165	48.665,85 €	120,00 €	353.069,95 €
11	Sanitary appliances, signs and equipment	25	204,84 €	9.005,40 €	9.210,24 €
12	Urbanization	85	3.932,67 €	13.895,00 €	17.827,67 €
13	Waste management	369	1.900,00 €	25.783,27 €	27.683,27 €
14	Healt and safety	383	4.894,28 €	20.917,81 €	25.812,09 €
	Cost of project execution	383	*461.811,84 €*	*3.474.076,81€*	*3.935.888,65 €*

Table 1. Duration and cost of the Aulario IndUVa construction project

The Table summary with all the probability-related information is shown in Table 4. Similarly, the cost impact information included in the Monte Carlo simulation is indicated in Table 5.

The “Type” column in Table 4 indicates the type of uncertainty, “N.P.” refers to the level of probability, “PDF” refers to the probabilistic distribution function used in probability, and the “Min”, “M.P.,” and “Max” columns refer to the minimum, most likely, and maximum values that can be used for the distribution function, respectively.

While the column “Tipo” in Table 5 also indicates the type of uncertainty, the columns “NRc” and “PDFc” relate to the level of cost impact and probability distribution functions, respectively, and the columns “Min,” “M.P.,” and “Max” have the same meanings as in Table 4 respectively.

In contrast, the following abbreviations have been used to refer to the types of uncertainty and the distribution functions that have been used: aleatoric (Alea), epistemic (Epis), stochastic (Estoc), deterministic (Det), triangular (Triang), uniform (Unif), and Bernoulli (Bern).

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

Level	Probability	Impact on Cost
Very Low (MB)	0% – 5%	0 – 3k €
Low (B)	5% – 12%	3k – 10k €
Medium (M)	12% – 20%	10k – 25k €
High (A)	20% – 35%	25k – 60k €
Very High (MA)	35% – 100%	> 60k €

Table 2. Levels of probability and impact for the analysed project

IDr	Risk	Observations	Type	Idp	Work package affected
1	Availability of labor	Subcontractors may have other staffing needs and their involvement in the project may be affected. Depending on your needs in other projects, it can be a threat or an opportunity.	T/O	3 4 5 8	Structure Facades and partitions Carpentry, glass and P. Solar Isolates
2	Availability of materials and equipment	There may be delays in certain strategic supplies to secure the project, such as restrictions on the import of goods or blocking international trade.	T	5 7 10 11	Carpentry, glass and P. Solar Facilities Coatings and cladding Sanitary appliances, S&E
3	Legalization of facilities	Local authorities may be slow to legalize facilities due to red tape	T	10	Coatings and cladding
4	Archaeological remains	The discovery of archaeological remains can paralyze the work until it is determined whether or not they have historical-cultural relevance	T	1 2	Land conditioning Foundations
5	Water in water table	The existence of pockets of water in the water table of the soil would paralyze the work until they were eliminated and allowed to continue with the foundations	T	1 2	Land conditioning Foundations
6	Inclement weather	The great frosts, snowfalls and floods would paralyze the project in its early stages of the foundation, preventing the machinery and operators from working. However, in the event of a milder than normal winter, the work can be carried out more quickly. Due to the region's own climate and the start date of the project, at the beginning of winter weather, planning could be reduced	T/O	2	Foundations
7	Rock in the subsoil	The appearance of rock in the subsoil would stop the work until it is eliminated	T	1 2	Land conditioning Foundations
8	Accident	The occurrence of an accident at work would immediately paralyze the work for an indefinite time, until the reasons for this are clarified and the additional safety measures necessary to restart the activity are established.	T		Complete Project
9	Lack of documentation	The lack of the mandatory and necessary documentation to carry out any construction would prevent the normal development of the work, until the situation is regularised. Among this documentation would be the registrations of self-employed and salaried workers in Social Security, or special work permits	T	5 11 14	Carpentry, glass and P. Solar Sanitary appliances, S&E Health and safety
10	Finding asbestos unexpectedly	The unexpected and undocumented appearance in the asbestos or asbestos plans forces to stop the work until it is correctly extracted and eliminated due to the high danger to public health presented by these materials.	T	1	Land conditioning
11	Commodity price change	The price of raw materials is subject to constant variations in the international market, which, on certain occasions, forces to review the prices agreed with subcontractors, generating a cost overrun.	T		Complete Project

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

12	Changes in regulations	Changes in the legal system can generate an opportunity, in the sense that an urgency is generated to comply with current legislation and avoid having to adapt to the new changes proposed, thus shortening the project's execution period.	O	14	Health and safety
13	Foundation measurement problems	Measurements of the building foundations may not correspond to reality due to variations in the conditions or environment of the project, which may lead to a delay in the execution of the project.	T	2	Foundations

Type: T-Threat; O-Opportunity; T/O-Threat or Opportunity

Table 3. Risks Identified in the Project

ID	Risk	Type	Probability (%) NP	PDF	Min	MP	Max
1	Availability of labor	Alea	-	Triang	85	95	100
2	Availability of materials and equipment	Alea	-	Triang	85	95	100
3	Legalization of facilities	Epis	MA	Unif	35	-	100
4	Archaeological remains	Epis	B	Unif	5	-	20
5	Water in water table	Epis	M	Unif	12	-	20
6	Inclement weather	Alea	-	Triang	85	95	100
7	Rock in the subsoil	Epis	B	Unif	5	-	12
8	Accident	Epis	MB	Unif	0	-	5
9	Lack of documentation	Estoc	-	Bern	-	25	-
10	Finding asbestos unexpectedly	Epis	MB	Unif	0	-	5
11	Commodity price change	Alea	-	Triang	85	95	100
12	Changes in regulations	Epis	MB	Unif	0	-	5
13	Foundation measurement problems	Estoc	-	Bern	-	20	-

Table 4. Probability of the Risks of the Aulario IndUVa Classroom Building Project

ID	Riesgo	Type	Cost Impact (k€) NRc	PDF	Min	MP	Max
1	Availability of labor						
2	Availability of materials and equipment						
3	Legalization of facilities	Epis	B	Unif	0		3
4	Archaeological remains	Alea		Unif	50		100
5	Water in water table	Epis	M	Unif	10		25
6	Inclement weather						
7	Rock in the subsoil	Epis	A	Unif	25		60
8	Accident	Epis	A	Unif	25		60
9	Lack of documentation	Alea		Unif	5		10
10	Finding asbestos unexpectedly	Epis	MA	Unif	60		80

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

11	Commodity price change	Alea	Triang	62	77.5	93
12	Changes in regulations					
13	Foundation measurement problems	Alea	Unif	30		60

Table 5. Impact on Cost of the Risks of the Aulario IndUVa Construction Project

Based on the above data, a series of risks have been identified that impact in different ways on the project objectives. On the one hand, there are risks that only, if they occur, impact the cost objective, such as risk ID 11 in Table 5. On the other hand, other risks are identified that directly impact the duration of some project activity, such as risk ID 4 in the same table. If risk ID 4 occurs, there will be a delay. Conversely, if an opportunity occurs, there would be an advance in the activity affected by that risk, such as risk ID 12. As the variable cost of the activities is directly associated with the duration of the activities, a change in duration inevitably leads to a change in the cost of that activity. Therefore, the risks identified as likely to impact duration will also have an indirect impact on the cost of the project.

5.- RESULTS

Most building projects are focused on a small, risk-averse business sector, and the P80 percentile was selected to estimate the cost-varying factors for this project. The statistics and graphs obtained from the simulation are shown in Tables 6, 7 and 8 and Figure 2. The impact of the risks can be seen in these figures.

Consequently, we have decided that, for this project, and considering the risks listed in Table 9, we should allocate a total of 210213€ as a contingency margin for the project's cost. This amount reserved accounts for 5.3% of the project's overall budgeted expenditures.

Variable	Cost (€)
Planned value	3935888
Average value simulation (integration of all risks)	4.0932e+06
Variance simulation (integration of all risks)	8.9607e+09

Table 6. Main cost statistics. Integration of all identified risks in the Monte Carlo Simulation

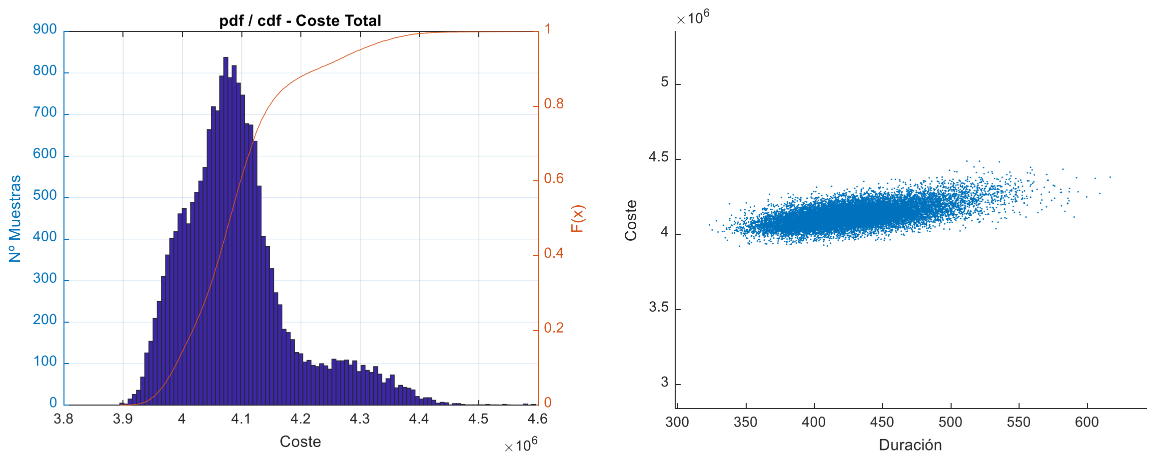

Fig. 2. PDF and cumulative distribution for Cost (left) and Point Cloud for duration and cost (right). Integrating risk into the simulation.

It is crucial to remember that the project's promoter assigned 10% of the budget to the construction project or a total of 393589 euros. We demonstrate how the amount obtained through simulation is less than the amount withheld. However, more importantly, the value obtained through simulation is closer to reality since it considers all identified risks that might impact the project during execution.

Publicaciones DYNA SL -- c) Mazarredo nº69 - 2º -- 48009-BILBAO (SPAIN)
Tel +34 944 237 566 – www.revistadyna.com - email: dyna@revistadyna.com

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

The final contingency value determined by simulation will always be supported by a thorough analysis of all risks that may affect the project. The result is independent of whether the standard estimate of 10% of the budget is higher or lower than the result obtained.

Percentile	Cost (€)
10.0	3986083.959
20.0	4017208.883
30.0	4042922.237
40.0	4062953.267
50.0	4080502.649
60.0	4098090.042
70.0	4118122.440
80.0	4146100.994
90.0	4228488.399
100.0	4596002.433

Table 7. Cost percentiles. Integration of risks in simulation

Variable	Coste (€)
Planned value	3935888
P80	4146101
Contingency Margin	210213
% Over planned value	5.3%

Table 8. Cost Contingencies

Finally, it is discovered that more is needed to calculate cost variances by considering random activity uncertainty. It is essential to incorporate all identified risks into the project, assess each, and appropriately model them before introducing all of this information into the simulation. Only then will we be able to determine the best contingency margin given the organisation's risk tolerance.

6. CONCLUSION

This research presents a novel method for allocating cost escalations within projects. Furthermore, the project's cost and schedule risks are thoroughly analysed to achieve this. We must remember that activity duration variations led to activity costs and, consequently, to the project's cost.

This method has been tested in a simple project, congruent with the building of the Aulario IndUVa for the University of Valladolid (Spain), in cooperation with the university's school of architecture and the business Constructora San José S.A. Thanks to the simulation's results, we could compare the allocation of necessary contingencies if an integrated risk analysis had been conducted with the conventional allocation, which is compatible with allocating 10% of the entire budgeted expenditure.

The main conclusion that can be drawn is that it has been possible to correctly estimate the cost contingencies using the Monte Carlo simulation method. This quantitative Risk Management technique has made it possible to incorporate all the types of uncertainty identified into the simulation, unlike the other methods studied in the literature review, which only aleatoric model uncertainty or focus on resource allocation problems. From the analysis of the results obtained, it can be seen that the effect of risks can significantly modify the planning of a project. Therefore, taking into account the specific type of uncertainty caused by each risk, it is possible to obtain an estimate of contingencies, including all the identified risks. The difference between the planned values for the cost makes applying the Risk Management process necessary. Therefore, this method could also calculate the contingencies concerning the risk.

Compared with the traditional method of allocating 10% of the total project budget as cost contingencies, this method is more accurate in quantifying the contingency reserve. This is because the reserves are adjusted to the reality and the particular context of each

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

project. In this sense, there could be two situations that could modify the planning. On the one hand, if the simulation offers us scenarios with much lower contingencies than the one provided by the traditional percentage method, we can dedicate the difference to other, more profitable investment items. On the other hand, if the simulation offers us scenarios where higher costs will be incurred than those estimated by the percentage method, we will have to reserve an enormous amount of economic resources not to compromise the project's viability economically. In both cases, the chances of success increase for the project and, in this case, for the construction company since it would have more precise information on the reality of the work.

We could foresee worst-case scenarios that were worse than planned, allowing us to take appropriate action and increase the likelihood that the project would succeed. The methodology we provide in this work helps estimate project cost allocation.

REFERENCES

[1] Lam TYM, Siwingwa N. Risk management and contingency sum of construction projects. J Financ Manag Prop Constr. 2017;22(3):237–51.
[2] Kwon H, Kang CW. Improving Project Budget Estimation Accuracy and Precision by Analyzing Reserves for Both Identified and Unidentified Risks. Proj Manag J. 2019;50(1):86–100.
[3] Traynor BA, Mahmoodian M. Time and cost contingency management using Monte Carlo simulation. Aust J Civ Eng [Internet]. 2019;17(1):11–8. Available from: https://doi.org/10.1080/14488353.2019.1606499
[4] Acebes F, Pajares J, Galán JM, López-Paredes A. A new approach for project control under uncertainty. Going back to the basics. Int J Proj Manag. 2014 Apr;32(3):423–34.
[5] Project Management Institute. A Guide to the Project Management Body of Knowledge (PMBOK® Guide). 6th ed. Pennsylvania - USA: Project Management Institute; 2017.
[6] Zhang Y, Fan ZP. An optimization method for selecting project risk response strategies. Int J Proj Manag [Internet]. 2014;32(3):412–22. Available from: http://dx.doi.org/10.1016/j.ijproman.2013.06.006
[7] Acebes F, Poza D, González-Varona JM, Pajares J, López-Paredes A. On the project risk baseline: Integrating aleatory uncertainty into project scheduling. Comput Ind Eng. 2021 Oct 1;160:107537.
[8] Hong J, Shen GQ, Peng Y, Feng Y, Mao C. Uncertainty analysis for measuring greenhouse gas emissions in the building construction phase: A case study in China. J Clean Prod [Internet]. 2016;129:183–95. Available from: http://dx.doi.org/10.1016/j.jclepro.2016.04.085
[9] Moreno-Cabezali BM, Fernandez-Crehuet JM. Application of a fuzzy-logic based model for risk assessment in additive manufacturing R&D projects. Comput Ind Eng. 2020;145(May).
[10] AACE International A for the A of CE. Integrated cost and schedule risk analysis using Monte Carlo simulation of a CPM model. AACE International Recommended Practice No. 57R-09. 2011.
[11] Curto D, de Antón J, Poza D, Acebes F. Uncertainty Management: A Review of Tools and Techniques. In: 14th International Conference on Industrial Engineering and Industrial Management (ICIEIM) & XXIV Congreso de Ingeniería de Organización (CIO2020). Madrid (Spain); 2020.
[12] Baccarini D. Estimating project cost contingency-Beyond the 10% syndrome. In: AIPM05. 2005.
[13] Liu J, Jin F, Xie Q, Skitmore M. Improving risk assessment in financial feasibility of international engineering projects: A risk driver perspective. Int J Proj Manag. 2017 Feb 1;35(2):204–11.
[14] Hillson D. How to manage the risks you didn't know you were taking. PMI® Glob Congr. 2014;1–8.
[15] Elms DG. Structural safety–Issues and progress. Prog Struct Eng Mater. 2004;6(2):116–26.
[16] Frank M V. Treatment of uncertainties in space nuclear risk assessment with examples from Cassini mission applications. Reliab Eng Syst Saf. 1999 Dec 1;66(3):203–21.
[17] Panova Y, Hilletofth P. Managing supply chain risks and delays in construction project. Ind Manag Data Syst. 2018;118(7):1413–31.
[18] Lei X, MacKenzie CA. Assessing risk in different types of supply chains with a dynamic fault tree. Comput Ind Eng [Internet]. 2019;137(September):106061. Available from: https://doi.org/10.1016/j.cie.2019.106061.
[19] Lee CKM, Lv Y, Hong Z. Risk modelling and assessment for distributed manufacturing system. Int J Prod Res. 2013;51(9):2652–66.
[20] Costantino N, Pellegrino R. Choosing between single and multiple sourcing based on supplier default risk: A real options approach. J Purch Supply Manag [Internet]. 2010;16(1):27–40. Available from: http://dx.doi.org/10.1016/j.pursup.2009.08.001
[21] Mangla SK, Kumar P, Barua MK. Monte Carlo simulation based approach to manage risks in operational networks in green supply chain. Procedia Eng [Internet]. 2014;97:2186–94. Available from: http://dx.doi.org/10.1016/j.proeng.2014.12.462
[22] Tokdemir OB, Erol H, Dikmen I. Delay Risk Assessment of Repetitive Construction Projects Using Line-of-Balance Scheduling and Monte Carlo Simulation. J Constr Eng Manag. 2019;145(2):1–12.
[23] Qazi A, Simsekler MCE, Formaneck S. Supply chain risk network value at risk assessment using Bayesian belief networks and Monte Carlo simulation. Ann Oper Res [Internet]. 2022; Available from: https://doi.org/10.1007/s10479-022-04598-3
[24] Olson DL, Wu D. Risk management models for supply chain: A scenario analysis of outsourcing to China. Supply Chain Manag. 2011;16(6):401–8.
[25] Acebes F, de Antón J, Villafáñez F, Poza D. A Matlab-Based Educational Tool for Quantitative Risk Analysis. In: García Márquez FP, Segovia Ramirez I, Bernalte Sánchez PJ, Muñoz del Río A, editors. Lecture Notes on Data Engineering and Communications Technologies. IoT and Data Science in Engineering Management. CIO 2022.; 2022.
[26] Colin J, Vanhoucke M. Empirical Perspective on Activity Durations for Project-Management Simulation Studies. J Constr Eng Manag. 2016;142(1):04015047.
[27] Ballesteros-Pérez P, Cerezo-Narváez A, Otero-Mateo M, Pastor-Fernández A, Vanhoucke M. Performance comparison of activity sensitivity metrics in schedule risk analysis. Autom Constr. 2019 Oct 1;106:102906.
[28] Acebes F, Pajares J, González-Varona JM, López-Paredes A. Project risk management from the bottom-up: Activity Risk Index. Cent Eur J Oper Res. 2021 Dec 1;29(4):1375–96.

ACKNOWLEDGEMENTS

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815

The authors wish to sincerely thank the Department of Architecture of the University of Valladolid and the company Constructora San José S.A. for providing the necessary information to prepare this document.

ISSN: 0012-7361 eISSN: 1989-1490 / . DYNA. vol. 99, n.1, DOI: https://doi.org/10.6036/10815