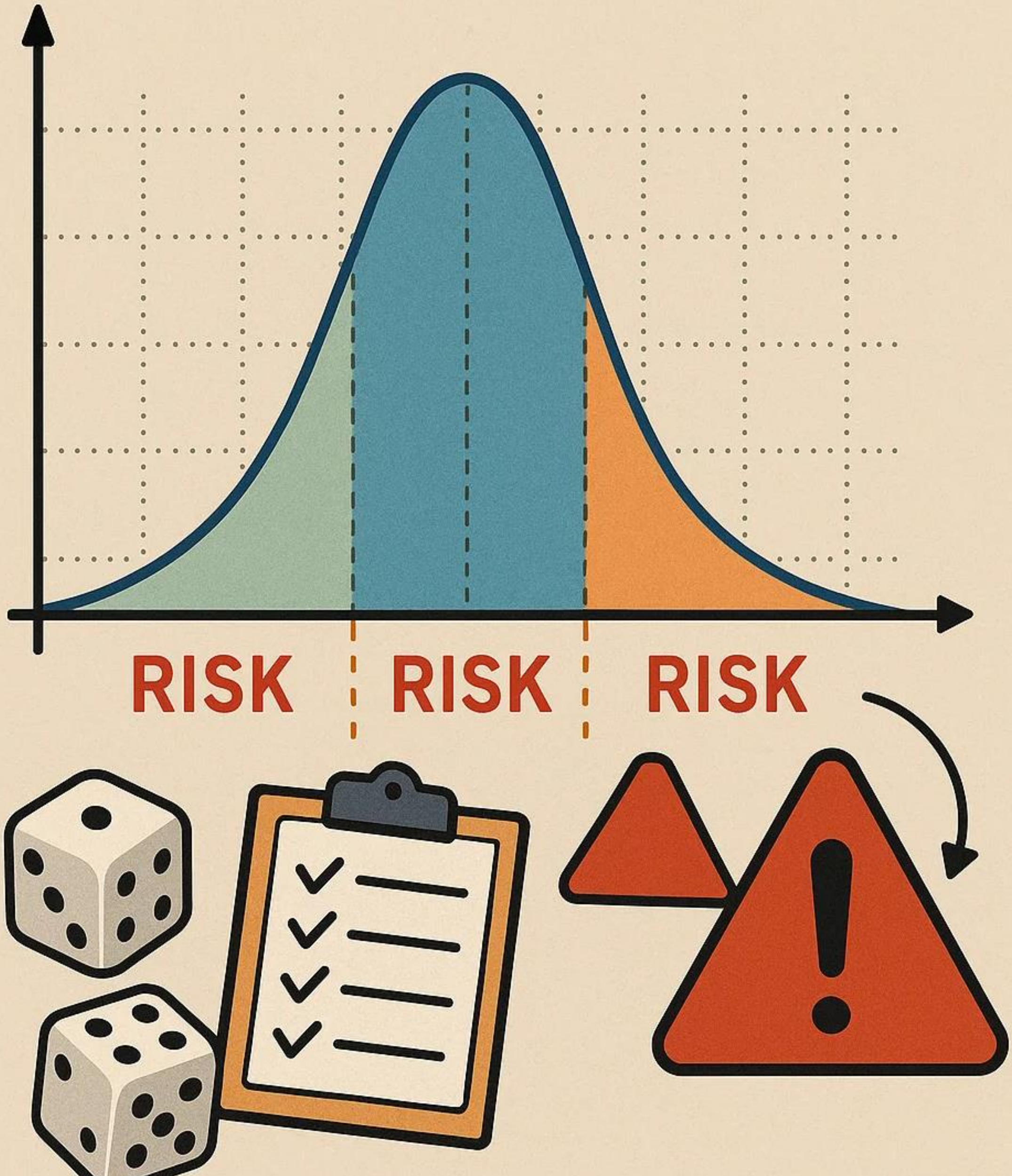
Quantitative Risk Analysis with MCSimulRisk



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INSISOC
SOCIAL SYSTEMS ENGINEERING CENTRE

MCSimulRisk

User Guide

(Monte Carlo Simulation for Risk Analysis)

V 1.0

February 2025

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Contents

Welcome

Welcome to the user manual for MCSimulRisk®, an advanced educational and research tool for quantitative risk analysis in projects using Monte Carlo simulation. This software, developed in the Matlab® environment, is specifically designed to provide students and professionals with a profound understanding of project risk management. MCSimulRisk® not only performs risk simulations, but also offers a detailed and comprehensible analysis of various types of uncertainty, such as random, stochastic and epistemic.

The educational tool MCSimulRisk® is a comprehensive solution for teaching and quantitative risk analysis in project management. Developed within the Matlab® framework, it is tailored for conducting Monte Carlo simulations, a widely used methodology for quantifying project uncertainties. MCSimulRisk® enables students and professionals to simulate diverse project scenarios of varying complexities by allowing for a detailed and precise analysis of the risks that may affect key project factors, such as duration and cost.

One of MCSimulRisk®'s main advantages is its capability to handle numerous types of uncertainties in risk analysis, including random risks (linked with unpredictable events), stochastic risks (dependent on random variables) and epistemic uncertainties (stemming from lack of knowledge). This flexibility is crucial for creating analysis models that closely resemble real-world scenarios that projects face in uncertain environments. By incorporating these different uncertainties, MCSimulRisk® not only enhances the teaching of advanced risk management concepts, but also paves the way for profounder and more precise academic research into how various uncertainties influence decision making and contingency planning in projects.

From a didactic perspective, MCSimulRisk® represents a significant advancement compared to typical commercial tools, such as @Risk, Crystal Ball or ModelRisk, which generally require advanced Excel® programming skills. Unlike these tools, MCSimulRisk® eliminates the need to manually code complex project models, and allows students to focus on analysing and interpreting results to, thereby, optimise lab times. Students can spend more time understanding issues and justifying their decisions instead of wasting time programming models. Moreover, this tool significantly reduces the costs of purchasing commercial software licences, which represents a considerable economic advantage for educational institutions and students.

MCSimulRisk® goes beyond its educational value and finds applications in research and professional practice. In the research field, this software opens up new opportunities to explore the impact of risks on projects by enabling researchers to experiment with project control methodologies in uncertain environments. By incorporating sensitivity metrics, such as the Criticality Index and the Cruciality Index, the tool helps to identify which activities are the most likely ones to affect overall project duration by providing a solid foundation for prioritising mitigation efforts and making informed decisions.

Of the additional features that MCSimulRisk® offers, you can find project monitoring and control options. These are implemented through advanced methodologies like the Cost Control Index (CCoI) and the Schedule Control Index (SCoI), which allow users to analyse and monitor project progress based on potential risks and changes. The tool also includes specific indicators like the Activity Risk Index (ARI), which facilitates prioritising activities according to their contribution to project risks. These advanced features provide a deeper understanding of project risks and variables, and promote the adoption of modern risk management practices tailored to the current complexities of projects in industry.

Another notable aspect of MCSimulRisk® is its easy use. Although developed in Matlab®, users do not need prior programming knowledge to operate the tool. Its intuitive design allows students and professionals to focus on analysis rather than on technical aspects of programming, which makes integrating it into academic and training programs easier. Thanks to its user-friendly interface and control and analysis menu options, users can quickly access probability distribution graphs, planned value curves, and other visual representations that enrich the analysis. This accessibility is particularly beneficial in educational settings for enabling students to acquire practical skills in employing quantitative risk management tools without a steep learning curve.

Using MCSimulRisk® not only optimises students' time, but also enhances learning outcomes by fostering a deeper understanding of risk and uncertainty concepts in projects. This tool allows practical exercises with complex scenarios that would otherwise be challenging to model with traditional software. This means that students learn to use analytical tools and they can develop a remarkable ability to analyse and interpret results, make data-driven decisions and justify their choices based on solid reasoning.

In the professional realm, MCSimulRisk® serves as a viable alternative for those who need to conduct risk analyses but, for various reasons, do not have access to commercial software. With a web-based version currently being developed, the tool aims to become accessible to a larger audience by allowing use without installing Matlab®. This feature extends MCSimulRisk®'s adoption possibilities in different contexts, from academic to corporate environments, by offering a robust and accessible solution for project risk simulation and control.

Purpose of MCSimulRisk®

MCSimulRisk® was created to address students' educational challenges in risk management and quantitative analysis courses. The tool facilitates practical learning without needing advanced Excel® programming skills, which often act as a significant barrier when using commercial software. As a result, MCSimulRisk® enables users to focus on risk analysis and result interpretation by optimising both study and practice time. Furthermore, students and professionals can employ the specialised Monte Carlo simulation software to tackle projects of any complexity because it allows the intuitive and accessible modelling of uncertainties and the analysis of complex project networks.

What Does MCSimulRisk® Do?

MCSimulRisk® uses Monte Carlo simulation, a widely utilised modelling technique in project management, to quantify risk impacts and to analyse project behaviour in various uncertainty scenarios. This simulation method generates multiple scenarios based on probability distributions to calculate total duration, cost and other relevant project outcomes. These scenarios are created from user-defined input data, such as time and cost probability distributions for each activity and their precedence relationships. As a result, MCSimulRisk® provides a detailed project behaviour analysis by helping to identify and mitigate potential risks before they negatively impact project development.

This tool also allows users to integrate specific risks into the project model, and to classify these risks based on their likelihood and the impact they may have on project duration and costs. This is achieved by selecting the probability distributions that model uncertainty associated with each activity or set of activities. MCSimulRisk® also enhances the visualisation of results by offering probability distribution graphs, planned value curves, among other visual representations.

Key Features of MCSimulRisk®

Some of the features that stand out in MCSimulRisk® are the following:

1. **Integration of Multiple Uncertainties:** Unlike other commercial tools, MCSimulRisk® includes various types of uncertainty in risk analysis modelling, including randomness, stochasticity, and epistemic uncertainty. This comprehensive modelling approach offers a more realistic representation of project risks by covering a more comprehensive range of possible scenarios
2. **Intuitive Interface:** Although developed in Matlab®, MCSimulRisk® features an accessible and user-friendly interface. Users do not need advanced programming skills to operate the tool. The interface allows for the easy definition of project activities, the establishment of precedence relationships, and the selection of probability distributions and types of uncertainty
3. **Sensitivity and Criticality Analysis:** MCSimulRisk® calculates sensitivity indicators, such as the Criticality Index (CI) and the Cruciality Index (CrI), to evaluate which activities are the most likely ones to impact project duration and cost. This feature is

essential for helping users to prioritise activities based on their importance and associated risks

4. **Project Control in Uncertain Environments:** The tool includes advanced methodologies for project control in uncertain environments, such as cost and schedule control indices (SCoI and CCoI) and the ARI. These methodologies enable real-time risk monitoring and the comparison of project progress to original estimates
5. **Data Export:** MCSimulRisk® allows users to export simulation results and generated data to Excel® (.xlsx) files for further analysis outside the Matlab® environment. This feature is handy for reporting and documentation by facilitating data-driven communication and informed decision making

What Can MCSimulRisk® Be Used For?

MCSimulRisk® is a versatile tool that can be applied to various project management areas. In the educational field, it facilitates the teaching of risk analysis and uncertainty management by providing students with a practical platform to explore different risk scenarios and their impacts. Exercises conducted with MCSimulRisk® help students to better understand theoretical risk concepts and to develop analytical skills for informed decision making.

In the professional sphere, MCSimulRisk® can assess and manage project risks across any sector by enabling project managers to anticipate potential issues and to plan contingencies. Users can perform sensitivity analyses to determine how different risk factors affect the project and can use this information to prioritise resources and efforts. By incorporating advanced monitoring and control methods, MCSimulRisk® also allows for real-time project management by adjusting expectations and making informed decisions based on identified risks.

Results That MCSimulRisk® Can Deliver

The results generated by MCSimulRisk® provide a comprehensive view of project risks. These include:

- **Probability distribution curves** for the total cost and duration of the project, which enables users to assess the likelihood of meeting deadlines and budgets
- **Sensitivity and criticality indicators** that identify the most significant activities in risk terms
- **Planned value graphs and SRB/CRB curves** show the project's risk progression and allow baseline schedules and costs to be compared
- **Stochastic control scenarios** to evaluate project status and to make necessary adjustments based on the risks that emerge while project is underway

- **Export options for results in Excel®-compatible formats** by facilitating the creation of detailed reports and presentations

In summary, MCSimulRisk® is more than simulation software; it is a comprehensive risk analysis tool designed to enhance teaching and learning in project management and to support uncertainty analysis in real-world contexts. Given its intuitive interface and ability to manage multiple uncertainty types, MCSimulRisk® becomes an essential resource for education, research and professional practice in risk management. By facilitating the modelling of complex scenarios and enabling detailed project risk analysis, MCSimulRisk® offers an analytical tool and a rich learning experience that prepare users to face real-world challenges in project management. This user manual aims to guide readers in effective MCSimulRisk® use by maximising its potential for their specific needs in risk analysis and project planning.

To start with

Information About This Version

This is MCSimulRisk® V2.0, compatible with the Windows operating system.

Matlab® does not support cross-compilation. A programme compiled in Windows can only be run in Windows.

This version is developed using Matlab® R2023a. The users who intend to run MCSimulRisk® must have this specific version of Matlab® installed on their computer. Otherwise, they will need to download and install the specific Runtime for the Matlab® version in which the application was compiled (R2023a). If a user installs a later Matlab® Runtime version, it will not execute the compiled applications from earlier versions. However, many versions can be installed simultaneously on the same computer.

How to Get Help

Free technical support is available to all the registered users of MCSimulRisk® with a current maintenance plan. To ensure you are registered, please sign up online at www.insisoc.uva.es/MCSimuRisk/register

General Application Execution Instructions

To ensure that the MCSimulRisk® application runs properly, the following requirements must be met:

- You must have installed the equivalent Runtime version in which the application was compiled
- Place the MCSimulRisk.exe file in the same directory/folder as the .xlsx file of the project you wish to run

Double-click MCSimulRisk.exe to open a new command window. Follow the on-screen instructions or use the pop-up menus to make the most all the functionalities that MCSimulRisk® offers.

Pre-Setup

On the download page (www.insisoc.uva.es/MCSimuRisk/download), you will find the following files:

- ***MCSimulRisk.exe*** – The executable file for the application
- ***ProjectTask.xlsm*** – A macro-enabled Excel® workbook
- ***Matlab® Runtime R2023a (9.14)*** – It allows you to run compiled Matlab® applications or components without installing MATLAB on your computer

To download and install the Matlab® Runtime (you can also find it on the official Matlab® website: https://es.mathworks.com/products/compiler/matlab-runtime.html):

- Click on version R2023a (9.14) for the Windows 64-bit platform from the table on the webpage. The Matlab® Runtime version must match the Matlab® version used to compile the application
- Save the Matlab® Runtime installer file on the computer where you intend to run the application or component
- Double-click the downloaded zip file, locate the installer (setup.exe), run the .exe file and follow the installation wizard instructions

ProjectTask.xlsm is a macro-enabled Excel® workbook that helps you to set up your project. In the "Define the Project" section, you will be guided to properly configure your project before running simulation. Once the project is correctly configured, convert the .xlsm file (macro-enabled Excel® workbook) into an .xlsx file (Excel® workbook).

MCSimulRisk.exe can only read data from an Excel® (.xlsx) file and not from other file types. Additionally, they must be located in the same directory on the same storage path in the system.

Warning Icons

Throughout this manual, various icons appear. Each one has a different meaning:

Warning: In this case, users should pay special attention to the indicated point because it could affect correct application functioning or be relevant for appropriate project configuration.

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To work with MCSimulRisk®, two base applications are required: Matlab®, the programming environment in which MCSimulRisk® is developed; Excel®, the spreadsheet software used to configure the project.

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Additionally, MCSimulRisk® is a registered trademark with No. M4223848 dated 19 March 2024, and held by the University of Valladolid.

Block 1. Define the project

This section aims to set up the project to be analysed. A supporting file is used in the .xlsm format (a macro-enabled Excel® workbook) to do this. This file includes preprogrammed macros that efficiently adapt the project to the identified activities and risks.

This file with MCSimulRisk must be converted into the .xlsx format (Excel® spreadsheet), which is the format compatible with the data-reading application.

This section is divided into two parts:

1. **Spreadsheet Configuration:** this initial step is to prepare the spreadsheet by enabling the necessary tables to define the project. The required matrices for entering critical data are automatically generated depending on the project's characteristics (number of activities and identified risks)
2. **Entering Project Data:** the second step is to outline how to input project data (durations, costs, risks, and precedence relationships) onto the configured spreadsheet. Once the data entry is complete, the file is ready to be used as a data source in MCSimulRisk

This process ensures that all the relevant project data are well organised and ready for efficient analysis in MCSimulRisk.

1.1 Setting Up the Project Template

Step 1: Open the "ProjectTask.xlsm" file

Start by opening the "**ProjectTask.xlsm**" file, a macro-enabled Excel® workbook. This file serves as the base for creating the **.xlsx** file where the project information to be simulated in MCSimulRisk is to be encoded.

If you see the message "**ADVERTENCIA DE SEGURIDAD: Las macros se han deshabilitado**", click "**Habilitar contenido**" (see Fig. 1.1). This ensures that the macros programmed in the file properly function.

Step 2: Enter the Main Project Parameters

Next you must input the main project parameters:

- **Number of project activities (No. of activities):** Enter the number of activities that make up the project in the "**No. of activities**" field. Then click the "**Generate Activities**" button. The associated macro automatically generates the corresponding activities based on your entered number (see Fig. 1.2).

Fig. 1.1 *Initial view of the application. Warning message to enable macros*

When you click "**Generate Activities**", a **precedence matrix** is also created that defines the precedence relationships between project activities. Activity **A0** corresponds to the fictitious initial activity, while the last generated activity is the fictitious final activity. This final activity is bigger than the total number of project activities.

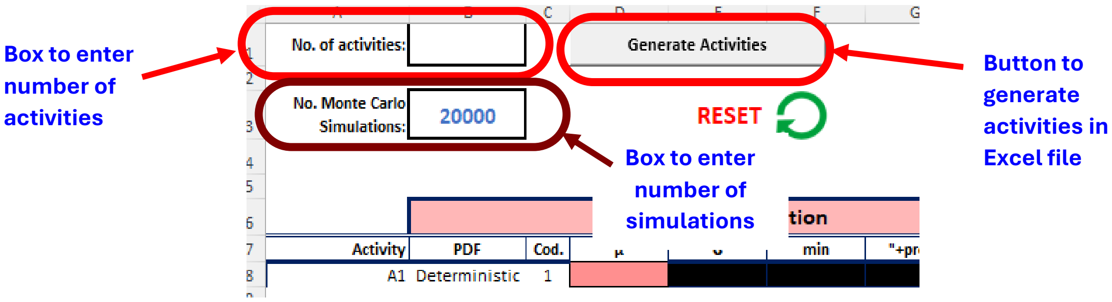


Fig. 1.2 *Entering number of activities and simulations*

- **Number of Monte Carlo Simulations (No. of Monte Carlo Simulations):** The system runs 20,000 simulations by default. However, this value can be adjusted to suit your needs by entering a different number in the corresponding field.

- **Number of Duration Risks (No. of duration risks):** Enter the project's identified duration risks in the "No. of duration risks" field. Then click the "Generate Risks Duration" button (see Fig. 1.3). This action automatically triggers the associated macro to generate the specified number of duration risks.

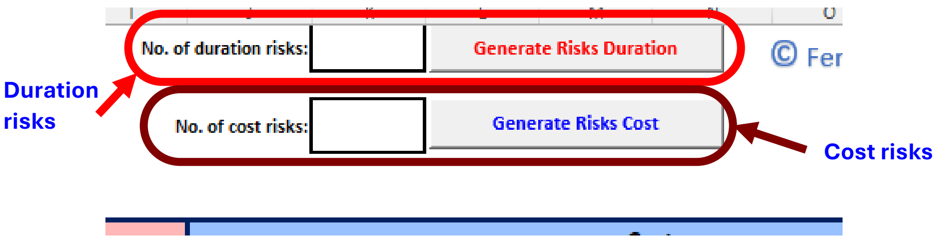


Fig. 1.3 *Entering the number of cost and duration risks*

For each identified duration risk, the macro generates two rows: one for probability of occurrence and another for the impact on project duration.

Additionally, if the number of duration risks exceeds zero, clicking "Generate Risks Duration" automatically extends the precedence matrix by incorporating duration risks as activities into the project. This ensures risks to be correctly sequenced (see Fig. 1.4).

Activity A0 remains the fictitious initial activity in the updated precedence matrix. At the end of the matrix, the fictitious final activity (Af) is added, along with the risks identified as activities.

Precedence Relationship Matrix

Predecessors →								R1	R2	R3	
Successors ↓		A0	A1	A2	A3	A4	A5	A6	A7	A8	Af
	A0	0	0	0	0	0	0	0	0	0	0
	A1										
	A2										
	A3										
	A4										
	A5										
R1	A6										
R2	A7										
R3	A8										
	Af										

Fig. 1.4 *Unfilled precedence relationship matrix. Example of a project with five activities and three duration risks*

- **Number of Cost Risks (No. of cost risks):** Enter the project's identified cost risks in the "No. of cost risks" field. Then click the "Generate Risks Cost" button, and the corresponding macro automatically generates the cost risks based on the number you entered (see Fig. 1.3). For each cost risk, two rows are generated: one for probability of occurrence and another for the impact on project duration.

  Additionally, clicking "Generate Risks Cost" creates a Correlation Matrix for risks (see Fig. 1.5). In this matrix, you can set correlations between identified risks.

Risk Correlation	R1	R2	R3	R4	R5
R1					
R2					
R3					
R4					
R5					

Positive value ('1') means positive correlation (e.g. '1' in (Ri,Rj) means that Rj will occur only if Ri occurs).
Negative value ('-1') means negative correlation (e.g. '-1' in (Rm,Rn) means that Rn will occur only if Rm does NOT occur).

Fig. 1.5 *Risk Correlation Matrix, unfilled. Example of a project with three duration risks and two cost risks*

Important: Even if the number of duration or cost risks is zero, you must indicate this in the respective fields ("**No. of duration risks**" and "**No. of cost risks**") and follow these steps in the right order:

1. *Enter "No. of activities" + click on "Generate Activities"*
2. *Enter "No. of duration risks" + click on "Generate Risks Duration"*
3. *Enter "No. of cost risks" + click on "Generate Risks Cost"*

By completing these steps, the result is a similar template to that shown in Fig. 1.6. For a project with five activities, three duration risks and two cost risks, the template includes:

- A section for encoding project activities (duration and cost)
- A section for encoding identified risks (duration and cost risks)
- The project's precedence matrix includes duration risks as activities
- The Risk Correlation Matrix

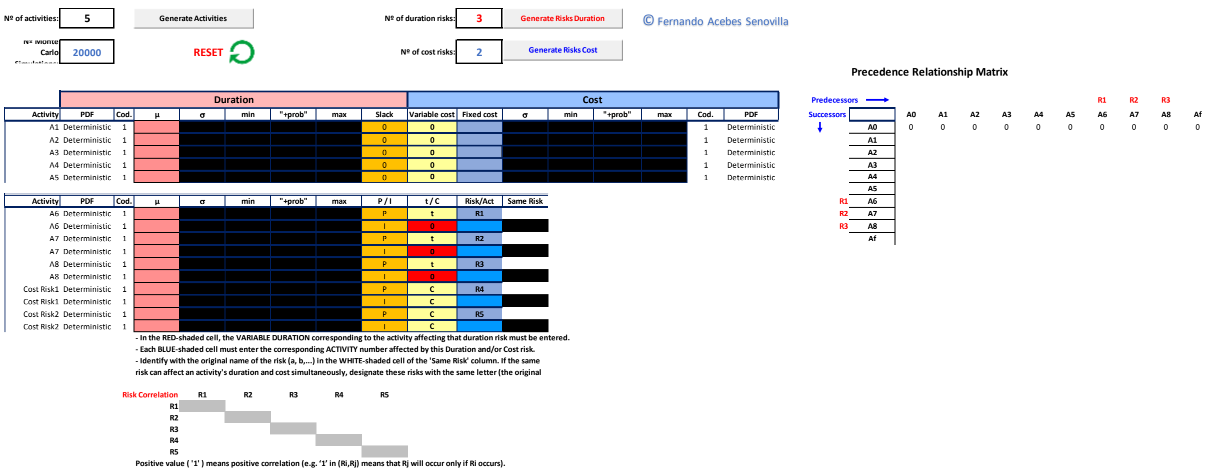


Fig. 1.6 *Base template generated for project data entry. Example of a project with five activities, three duration risks and two cost risks*

RESET Function

The spreadsheet has a button labelled "RESET" that clears the entire table and restores it to its initial state (see Fig. 1.7).

Fig. 1.7 *'RESET' button for restoring the spreadsheet*

Saving the File

Once the base template for encoding project data is generated (see Fig. 1.6), it is essential to save the file in the .xlsx format with the project name (see Fig. 1.8). Otherwise MCSimulRisk is unable to read data.

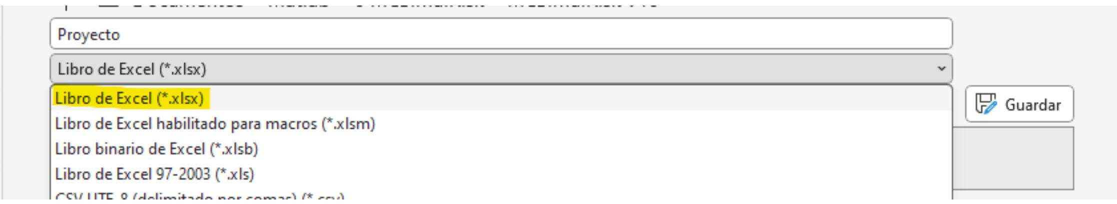


Fig. 1.8 *"Save As" instruction for the Excel® workbook (*.xlsx)*

Caution: Do not save or overwrite the .xlsm file because you would lose the ability to reuse it as a model for future projects.

If you make a mistake when entering number of activities, duration risks or cost risks, click "**RESET**" and re-enter data correctly. Failure to do so may cause macros to malfunction, which can affect the generation of the tables needed to define the project.

1.2 Defining Activities and Risks

You now have a base file in the Excel® (.xlsx) format where you can encode all the project data. In the previous section, you generate this file based on number of activities, duration and cost risks. This section inputs all the relevant data for these variables (activities and risks).

We start by entering the duration data for project activities. To illustrate the process, a **Sample Project** is used to clarify each step.

1.2.1 Definition of the Sample Project

The sample project consists of **five activities** (see Table 1.1). Each activity is identified by its duration and cost, which may be subject to uncertainty. This means that both **duration and cost** can take random values based on a probability distribution function that must be encoded on the Excel® sheet.

Table 1.1 *Definition of project activities: duration and cost*

Id Activity	Precedents	Duration (t.u.)					Cost (m.u.)					
							Variable cost u.m./u.t.	Fixed cost				
		pdf type	Parameters	P_1	P_2	P_3		pdf type	Parameters	P_1	P_2	P_3
A0 (start)												
A1	-	Normal	(μ, σ)	6	0.8		85	Deterministic	μ	110		
A2	-	Deterministic	μ	14			100	Deterministic	μ	55		
A3	A1	Uniform	(min, máx)	5.5	8.5		75	Uniform	(min, máx)	70	90	
A4	A1	Triangular	(min, +prob, máx)	15	16	23	60	Triangular	(min, +prob, máx)	45	50	55
A5	A2, A3	Triangular	(min, +prob, máx)	7	9	14	95	Triangular	(min, +prob, máx)	60	65	80
A6 (end)	A4, A5											

In Table 1.1, activities are identified by their ID in the first column. The second column specifies the precedence relationships for each activity by indicating the preceding activities required before each one can start.

Subsequent columns describe the critical data for activities. For each activity, the probability distribution function (e.g., normal, uniform, triangular, etc.) that defines its behaviour is specified. Next the characteristic parameters of each distribution function are provided. For normal distribution, these parameters are the mean (μ) and standard deviation (σ); for uniform distribution, the minimum (min) and maximum (max) values are used.

The final group of columns relates to the project **cost** parameters. Cost is divided into:

- **Variable cost,** associated with activity duration
- **Fixed cost,** independent of duration

As fixed costs can also be subject to randomness, fields are included to encode this uncertainty in a similar way to activity duration.

Regarding precedence, the sample project follows an **AON** (Activity On Node) diagram or project graph (see Fig. 1.9). This diagram includes fictitious activities A0 (Initial Activity) and A6 (Final Activity), along with the sequence of project activities.

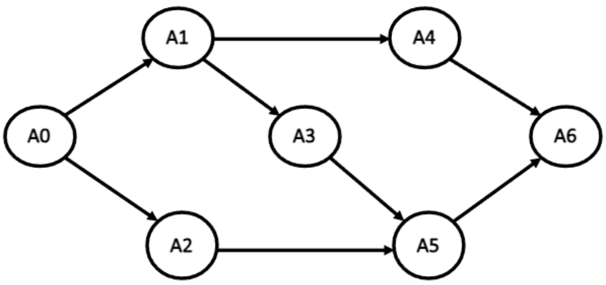


Fig. 1.9 *Project graph for the sample project*

To complete this example, four identified risks in the project are considered (see Table 1.2). Of these, three affect the duration objective (Ra, Rb, and Rc) and two impact the cost objective (Rb and Rd). Risk Rb impacts both project duration and project cost.

In Table 1.2, along with the description and ID of each risk, the impacted activity, probability of risk occurring and potential impacts are included. For each risk, a probability distribution function (PDF) is defined to model its behaviour (e.g., normal, uniform, triangular, etc.), along with the parameters characterising the function. For instance, for normal distribution, parameters would be the mean (μ) and standard deviation (σ); for uniform distribution, they would be the minimum (min) and maximum (max) values.

Table 1.2 *Definition of the identified risks in the project*

Risk Description	Risk Id	Impacted Activity	Probability		Impact Duration		Impact Cost	
			PDF	Parameters	PDF	Parameters	PDF	Parameters
-	Ra	A1	Unif.	[0.08 0.25]	Unif.	[2 5]	-	-
-	Rb	A4	Unif.	[0 0.02]	Unif.	[2 5]	Unif.	[230.5 691.50]
-	Rc	A5	Unif.	[0.08 0. 25]	Unif.	[0.5 2]	-	-
-	Rd	A2	Unif.	[0.02 0. 08]	-	-	Unif.	[230.5 691.50]

In this example, uniform probability distribution functions are used to model the probability of risks occurring and their potential impacts on duration and cost.

1.2.2 Incorporating Activity Duration Data

Having defined project activities, you enter data on the Excel® sheet, '**Pyto_ejemplo.xlsx**'. On this sheet, activities are numbered and coded (A1, A2, A3, etc.).

You firstly select the type of probability distribution function that represents the behaviour of each activity duration (column '**PDF**' in Fig. 1.10). By default, all activities are configured with a deterministic duration (the equivalent to Bernoulli distribution). By clicking on the corresponding cell, you can choose a different distribution function from the following options: Deterministic, Uniform, Normal, Triangular, Beta-Pert or Lognormal (see Fig. 1.10).

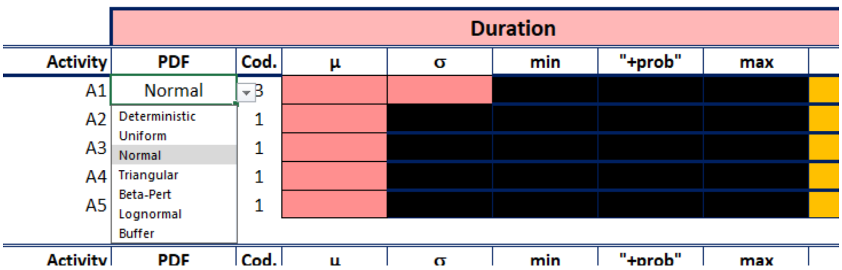


Fig. 1.10 *Selecting the probability distribution function for duration.*

After selecting the desired distribution function (Normal in this example), the function code in the 'pdf' column is updated, and the fields where parameters need to be entered change colour. This makes it easier to input the corresponding values. For activity A1, set at Normal distribution, the coloured fields are for the mean (μ) and standard deviation (σ).

Following the sample project, you select the various probability distribution functions for all the activities and complete the relevant fields by entering the numerical values in the highlighted cells (see Fig. 1.11).

			Duration						
Activity	PDF	Cod.	μ	σ	min	"+prob"	max	Slack	V
A1	Normal	3	6	0.8				0	
A2	Deterministic	1	14					0	
A3	Uniform	2			5.5		8.5	0	
A4	Triangular	4			15	16	23	0	
A5	Triangular	4			7	9	14	0	

Fig. 1.11 *Sample project template with activity duration data filled in*

MCSimulRisk operates according to Finish-to-Start (FS) logic, which means that a successor activity starts immediately after its predecessor finishes. The delay between these activities is zero, which means that there is no waiting time. In this case, **slack** is zero.

A column named 'Slack' takes a value of 0 by default, which indicates that the successor activity starts immediately after the predecessor finishes. However, you can modify this cell to introduce slack:

- **Positive slack:** If you enter a positive value, the successor activity's start is delayed in relation to the end of its predecessor
- **Negative slack:** If you enter a negative value (Slack < 0), the successor activity starts before its predecessor finishes

1.2.3 Incorporating Activity Cost Data

Having defined activity durations, including their uncertainties, you can input the **cost** data for each activity. Cost is divided into two components: variable cost and fixed cost.

- **Variable cost:** measured in monetary units per time unit (e.g., €/day). The total cost of an activity is directly proportional to its duration, multiplied by this cost factor
- **Fixed cost:** it is independent of activity duration, which means that it remains constant no matter how long it takes. However, fixed costs can be random. If the value is not deterministic, and may vary under certain conditions, you can configure it using a probability distribution function

Based on the **Sample Project** data, you can input the cost data for activities. The process for selecting the probability distribution function that represents the fixed cost of each activity is similar to that for duration. Here you select the desired function by clicking the '**PDF'** cell (see Fig. 1.12).

Fig. 1.12 *Selecting the probability distribution function for cost*

After selecting the distribution function, the cells for the parameters to be entered are automatically shaded. For instance, in Fig. 1.12 when choosing the Triangular distribution to model the fixed cost of activity A4, the cells for parameters min (minimum), +prob (most probable) and max (maximum) are shaded. Then you need to input numerical values. You can also notice that the code (**Cod**.) identifying the distribution function changes, which MCSimulRisk uses internally.

After entering all the cost data for the **Sample Project**, the completed template looks like that shown in Fig. 1.13.

	Cost							
	Variable cost	Fixed cost	σ	min	"+prob"	max	Cod.	PDF
	85	110					1	Deterministic
	100	55					1	Deterministic
	75			70		90	2	Uniform
	60			45	50	55	4	Triangular
	95			60	65	80	4	Triangular

Fig. 1.13 *Sample project template with activity cost data filled in*

1.2.4 Incorporating Precedence Relationships

It is not enough to simply input activity durations, costs and risks to conduct Monte Carlo simulation and to obtain accurate graphical and numerical results. It is essential to identify when activities are executed in the project; that is, their sequence or precedence relationships. These data are inputted into the MCSimulRisk application through the precedence matrix, as illustrated in Fig. 1.4.

The matrix is automatically generated when you input number of activities and number of risks (particularly duration risks) using a specific macro that handles this task.

A **duration risk** that affects an activity becomes an additional activity placed inside a series after the impacted activity. If the risk materialises, it affects that activity's duration and potentially causes a delay (if it is a threat) or an advance (if it is an opportunity). This impact functions similarly to an added activity in the sequence.

Therefore, when defining the project's **precedence relationships**, it is crucial to consider duration risks conclude them in the Precedence Matrix.

A **cost risk** that affects an activity does not influence precedence relationships. The project cost is independent of its structure. In any case, the total project cost is calculated as the sum of activity costs, regardless of their sequence.

The Precedence Matrix must include risks that impact duration. In the **Sample Project**, Fig. 1.14 shows how the identified risks relate to the activities they can impact. For instance, duration risk Ra might affect activity A1, while risk Rb (including the duration and cost components)may impact activity A4.

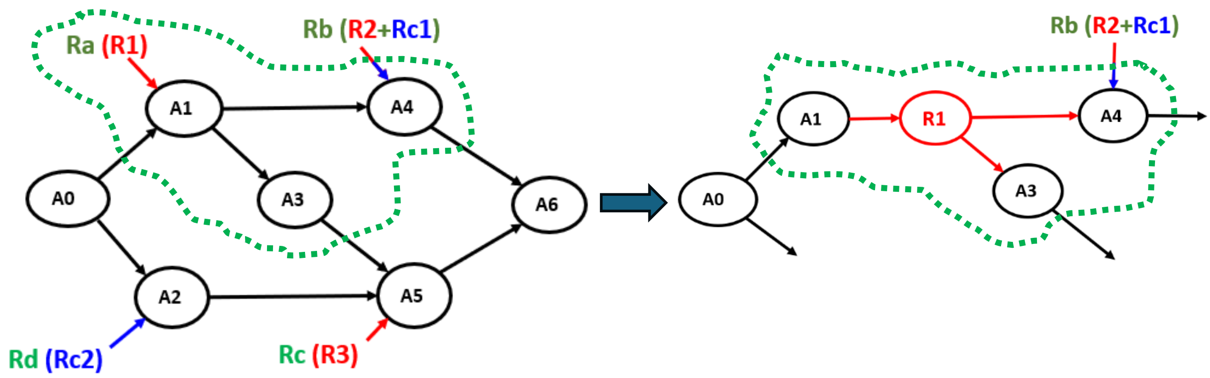


Fig. 1.14 *Risks included in the sample project and the R1 equivalence in the project network*

The right side of Fig. 1.14 show the interpretation of duration risk **R1** (corresponding to risk Ra, which has no cost component) in the project network. This risk helps to establish the precedence relationships between activities. Risk R1, which may impact the duration of activity A1, is sequenced in series with A1. This means that the successor activities of A1 have R1 as their predecessor.

This exact procedure applies to other risks affecting project duration, such as risk R2 (duration component of risk Rb) and risk R3 (which corresponds entirely to risk Rc).

It is important to note that cost risks, such as Rd (or the cost component Rc1 in risk Rb), do not affect the sequencing of project activities.

By considering these considerations, you can complete the **Precedence Matrix** shown in Fig. 1.4. A '1' is placed inside the appropriate cells to identify successor and predecessor activities according to the project definition.

You complete the matrix using the data in Table 1.1, which shows the preceding activities and the project's Activity On Node (AON) diagram (Fig. 1.14).

Example of precedence relationships for some activities:

- For activity A1, both Table 1.1 and Fig. 1.14 indicate that it has no predecessors. So, its predecessor is A0 (initial activity). You place a '1' in the row for A1 and the column for A0
- For activity A2, it is also indicated that its predecessor is the initial activity (A0). You place a '1' in the row for A2 and the column for A0

- For activity A3, Table 1.1 shows that its predecessor is A1. However, as risk R1 can impact A1, risk R1 becomes the predecessor activity of A3. Thus, in the Precedence Matrix, you place a ‘1’ in the row for A3 and the column for R1 (A6), and another ‘1’ in the row for R1 (A6) and the column for A1, because A1 is R1’s predecessor.

Following this same procedure for all activities and duration risks, you complete the Precedence Matrix as shown in Fig. 1.15.

Precedence Relationship Matrix

	Predecessors →							R1	R2	R3	
Successors ↓	**Precedents**	**A0**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**Af**
	A0	0	0	0	0	0	0	0	0	0	0
	A1	1									
	A2	1									
	A3							1			
	A4							1			
	A5			1	1						
R1	**A6**		1								
R2	**A7**					1					
R3	**A8**						1				
	Af								1	1	

Fig. 1.15 *Precedence matrix for the sample project, including identified risks*

The **Precedence Matrix** can be interpreted in two ways: by looking for predecessor activities or successor activities per activity.

- To find the **predecessors** of an activity, review the matrix rows. For example, activity A5 has A2 and A3 as predecessors
- • To identify **successor** activities, review the matrix columns. The cells containing a ‘1’ indicate the successor activities of the corresponding activity. For example, activity A1 has R1 (coded as A6) as its successor

Error Validation Rule:

- Every activity, including the initial activity (A0), must have at least one **successor**, except for the final activity (Af)
- Every activity, including the final activity (Af), must have at least one **predecessor**, except for the initial activity (A0)

1.2.5 Incorporating Risks

The next step is to input risks into the generated base template. In the beginning, you enter the number of duration risks and cost risks, and click the corresponding button to generate them (see Fig. 1.3). The macros embedded in the spreadsheet create the necessary fields for all the risk information, and two rows are produced for each identified risk for both duration and cost.

If a risk affects both duration and cost, it is split into two risks: one is specific to duration and the other to cost. Calculations are then made to unify these impacts as a single original risk.

a) Incorporating Duration Risks

Two rows are generated for each identified duration risk. The first row contains information about the probability of the risk occurring, while the second row details the potential impact on duration. Fig. 1.16 illustrates the two rows created for the same duration risk and the defining fields.

Activity	PDF	Cod.	µ	σ	min	"+prob"	max	P / I	t / C	Risk/Act	Same Risk
A6	Deterministic	1						P	t	R1	
A6	Deterministic	1						I	0		

Fig. 1.16 *Duration risk model and defining fields on the Excel® sheet*

The first column, '**Activity'**, refers to the coding assigned to the duration risk. Each duration risk receives a consecutive number following the last project activity. This coding is crucial because it is used to complete the precedence matrix. Each duration risk behaves like an activity in series with the activity that it might impact.

As they refer to the same risk, both rows generated for a single risk share the same code (e.g., 'A6' in Fig. 1.16).

The '**PDF'** column specifies the type of probability distribution function that describes the risk's behaviour. The first row corresponds to the risk's probability of occurrence, and the second row refers to the potential impact on duration. This column is paired with '**Cod**.' by automatically assigning a code for the selected distribution function. Clicking the distribution type cell opens a dropdown menu with options like Deterministic, Normal, Uniform, Triangular, among others, which allow you to appropriately represent the risk's behaviour. By default, the Excel® sheet selects 'Deterministic' with code 1, but you can choose a different one if necessary.

The subsequent fields contain the parameters that define each selected distribution function. These are the same fields used to define activity durations (see Fig. 1.10). When you select a distribution function, cells are shaded to indicate where to input the appropriate values; e.g., for the 'Deterministic' function (a Bernoulli-type distribution), the mean value (µ) field is highlighted. Conversely, for the 'Uniform' distribution, the 'min' and 'max' fields are shaded because these are needed to define that distribution.

The '**P/I'** field is informational, which indicates that the first row refers to the probability (P) of the risk occurring, while the second row contains information about the risk's impact (I).

The **'t/C'** field contains information about the variable cost of the activity affected by the risk. In the probability row (the first of the two rows generated for each risk), the cell shows 't'. This means that the risk is related to time or duration. A red-shaded cell is displayed in the impact row (second row), where you must input the variable cost of the affected activity. This cost can be found in the activity cost definitions (see Fig. 1.13).

It is important to remember that a risk with an impact on an activity's duration can either shorten or prolong duration, and can consequently affect the variable cost. Longer duration results in higher costs, while shorter duration lowers costs.

The following section shows that the 't/C' field is also used for cost risks.

Additionally, the Excel® template includes the following informational message at the bottom of the risk data entry table: "In the RED-shaded cell, the VARIABLE DURATION corresponding to the activity that affects that duration risk must be entered".

In the '**Risk/Act'** column, risks are consecutively numbered, starting with duration and cost risks. Numbering begins with risk 'R1' (see Fig. 1.16). This number is indicated in the first row of each risk, and corresponds to its probability. In the second row (showing the impact), you must indicate the activity number affected by the risk in the blue-shaded cell.

The Excel® sheet also includes the message: "*Each BLUE-shaded cell must contain the corresponding ACTIVITY number affected by this duration and/or cost risk*".

The '**Same Risk'** column provides information about the risks that affect the project's duration and cost. A unified code is assigned for the risks that impact both objectives. In the first row of each risk (related to probability), you should assign an alphabetical code (e.g., a, b, c, etc.) to name each duration risk. Coding starts with 'a' for the first duration risk and sequentially continues.

For cost risks, if a risk affects both duration and cost, use the same letter for both risks. This allows the system to treat them as a single risk. You do not need to input information in the second row of this column (related to impact), as this cell is shaded black.

The Excel® sheet also includes the message: "Identity with the risk's original name (a, b, etc.) in the WHITE-shaded cell of the 'Same Risk' column. If the same risk can simultaneously affect an activity's duration and cost, designate these risks with the same letter (the original risk)".

b) Incorporating Cost Risks

The information needed to input cost risks is similar to that used for duration risks. As shown in Fig. 1.17, the fields to be completed use the same Excel® sheet and columns.

Activity	PDF	Cod.	µ	σ	min	"+prob"	max	P / I	t / C	Risk/Act	Same Risk
Cost Risk1	Deterministic	1						P	C	R4	
Cost Risk1	Deterministic	1						I	C		
Cost Risk2	Deterministic	1						P	C	R5	

Fig. 1.17 *Cost risk model and defining fields on the Excel® sheet*

As with duration risks, two rows are generated for each identified cost risk. However, no activity code is assigned because cost does not impact the precedence relationships between activities. Instead cost risks are sequentially numbered (Cost Risk).

By selecting the most appropriate probability distribution function, you should model the cost risk's probability (first row) and impact (second row), and then fill in the relevant parameters for the chosen function.

The '**P/I**' and '**t/C**' columns are informational, and you do not require to input any values. In the '**Risk/Act**' column, select the activity that the cost risk may impact by entering the activity number in the blue cell. Finally, assign the appropriate alphabetical code to the identified risk in the' **Same Risk'** column. As explained earlier, use the same letter for both if a cost risk is associated with a previously coded duration risk.

Fig. 1.18 shows the table containing the Sample Project's duration and cost risk information, with the corresponding parameters detailed in Table 1.2.

Activity	PDF	Cod.	μ	σ	min	"+prob"	max	P / I	t / C	Risk/Act	Same Risk
A6	Uniform	2			0.08		0.25	P	t	R1	a
A6	Uniform	2			2		5	I	85	1	
A7	Uniform	2			0		0.02	P	t	R2	b
A7	Uniform	2			2		5	I	60	4	
A8	Uniform	2			0.08		0.25	P	t	R3	c
A8	Uniform	2			0.5		2	I	95	5	
Cost Risk1	Uniform	2			0		0.02	P	C	R4	b
Cost Risk1	Uniform	2			230.5		691.5	I	C	4	
Cost Risk2	Uniform	2			0.02		0.08	P	C	R5	d
Cost Risk2	Uniform	2			230.5		691.5	I	C	2	

- In the RED-shaded cell, the VARIABLE DURATION corresponding to the activity affecting that duration risk must be entered.
- Each BLUE-shaded cell must enter the corresponding ACTIVITY number affected by this Duration and/or Cost risk.
- Identify with the original name of the risk (a, b,...) in the WHITE-shaded cell of the 'Same Risk' column. If the same risk can affect an activity's duration and cost simultaneously, designate these risks with the same letter (the original risk).

Fig. 1.18 *Modelling the Sample Project's duration and cost risks*

In the **Sample Project**, three duration and two cost are identified risks. Each duration risk is coded with a consecutive activity number (A6, A7, and A8), starting from the last activity in the project (A5).

The risks' probability and impact are modelled using uniform distribution functions. Although other distributions could have been chosen, the uniform distribution is suitable for representing epistemic risks where the exact probability or impact level is unknown. Stil, a range can be estimated within which values may vary. Any value within that range has an equal probability of occurring.

In the '**Risk/Act'** column, you indicate the activity that each risk may impact. In the '**t/C'** column, you record the variable cost of the activities affected by duration risks. For example, the first duration risk (A6), which could impact activity A1, has a variable cost of 85 monetary units per time unit (u.m./u.t.), and is reflected in the 't/C' column and in the second row corresponding to this risk.

Finally, the '**Same Risk'** column shows four distinct risks (Ra, Rb, Rc, and Rd). It also highlights that risk R2 (coded as A7) is the same as R4 (Cost Risk1), which implies that risk Rb can affect both the duration objective (R2) and the cost objective (R4).

1.2.6 Completing the Correlation Matrix

By default, all the identified risks are considered independent, which means that no correlation exists between them. However, in some cases, there may be a relation between risks.

Risk correlation in a project refers to how the occurrence of one risk can influence the probability of another risk occurring. If two risks correlate, the occurrence of one may increase or decrease the probability of the other. There are two main types of correlation:

- **Positive Correlation:** when the occurrence of one risk increases the probability of another risk occurring. For instance, delaying the delivery of materials (risk A) could increase the risk of cost overruns (risk B) due to the need to expedite work or to hire additional staff
- **Negative Correlation:** when the occurrence of one risk decreases the probability of another. For example, improving staff training (risk C) might reduce the probability of execution errors (risk D)

Understanding the correlation between risks is essential for prioritising them and planning more effective responses. Focusing on highly correlated risks can help to more efficiently prevent multiple problems. The **Correlation Matrix** must be completed to incorporate correlation/s into the simulation model (see Fig. 1.19).

Risk Correlation	R1	R2	R3	R4	R5
R1					
R2					
R3					
R4					
R5					

Positive value ('1') means positive correlation (e.g. '1' in (Ri,Rj) means that Rj will occur only if Ri occurs).
Negative value ('-1') means negative correlation (e.g. '-1' in (Rm,Rn) means that Rn will occur only if Rm does NOT occur).

Fig. 1.19 *Risk Correlation Matrix*

Completing the Correlation Matrix is unnecessary in the **Sample Project**, where risks are independent. MCSimulRisk provides a default matrix for independent risks.

If there is a positive correlation between two risks, it should be reflected in the matrix by marking a '1' (positive) in the corresponding cell. For example, if duration risk R3 always occurs when risk R1 occurs, they positively correlate. To encode this relation, a '1' is placed in the cell (R1, R3). An informational legend at the bottom of the matrix states: "Positive value ('1') means positive correlation (e.g., '1' in (Ri, Rj) means that Rj occurs only if Ri does)."

Conversely, if there is a negative correlation, which means the occurrence of one risk implies that another does not occur, this is represented in the matrix with a ‘-1’ (negative). For instance, if cost risk R5 does NOT occur when risk R2 does, they negatively correlate. In this case, a ‘-1’ is placed in the cell (R2, R5). The legend at the bottom of the matrix explains: “Negative value (‘-1’) means negative correlation (e.g., ‘-1’ in (Rm, Rn) means that Rn occurs only if Rm does NOT)”.

It is important to note that the **Correlation Matrix** reflects the relations between risks; it does not include information about probabilities or impacts. That information is provided in the risk definition table. For instance, if the cell (R1, R3) contains a ‘1’, risk R3 only occurs if risk R1 does. The risk definition table specifies that the probability of R3 is P3, and the probability of R1 is P1. As these events are dependent, the final probability of R3 occurring is the product of both probabilities: $Pf(R3)=P1 \times P3$.

Block 2. MCSimulRisk commands

This second section explains the commands and tools provided by **MCSimulRisk** for conducting a **Quantitative Risk Analysis** using Monte Carlo simulation for any type of project.

To ensure that the properly application works and you can run the simulation, the following requirements must be met:

- **Matlab® version 2023a** must be installed
- You must install the corresponding Runtime for Matlab® 2023a if Matlab® is not installed

Additionally, you must ensure that the following files are in the same folder or directory (see Fig. 2.1):

- The executable file **MCSimulRisk.exe** (version 2023a)
- The project spreadsheet (**.xlsx**) that you wish to simulate

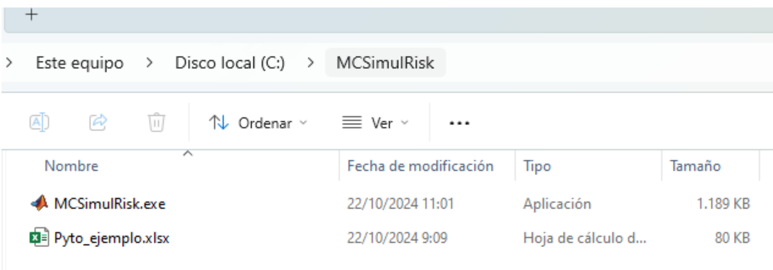


Fig. 2.1 *Executable .exe and Example Project (.xlsx)*

Once these requirements are fulfilled, double-click on the MCSimulRisk.exe file to launch the application. A **command screen** opens and displays the initial relevant information. Please note that there may be a brief delay before the text appears.

Patience: Remember that a slight delay may occur before the text is displayed.

When the program runs, the main application screen (command window) appears, initially showing an informational message (see Fig. 2.2). Along with this, a small pop-up window opens to prompt you to enter the name of the .xlsx file in which you have modelled and saved your project for simulation (see the centre of Fig. 2.2).

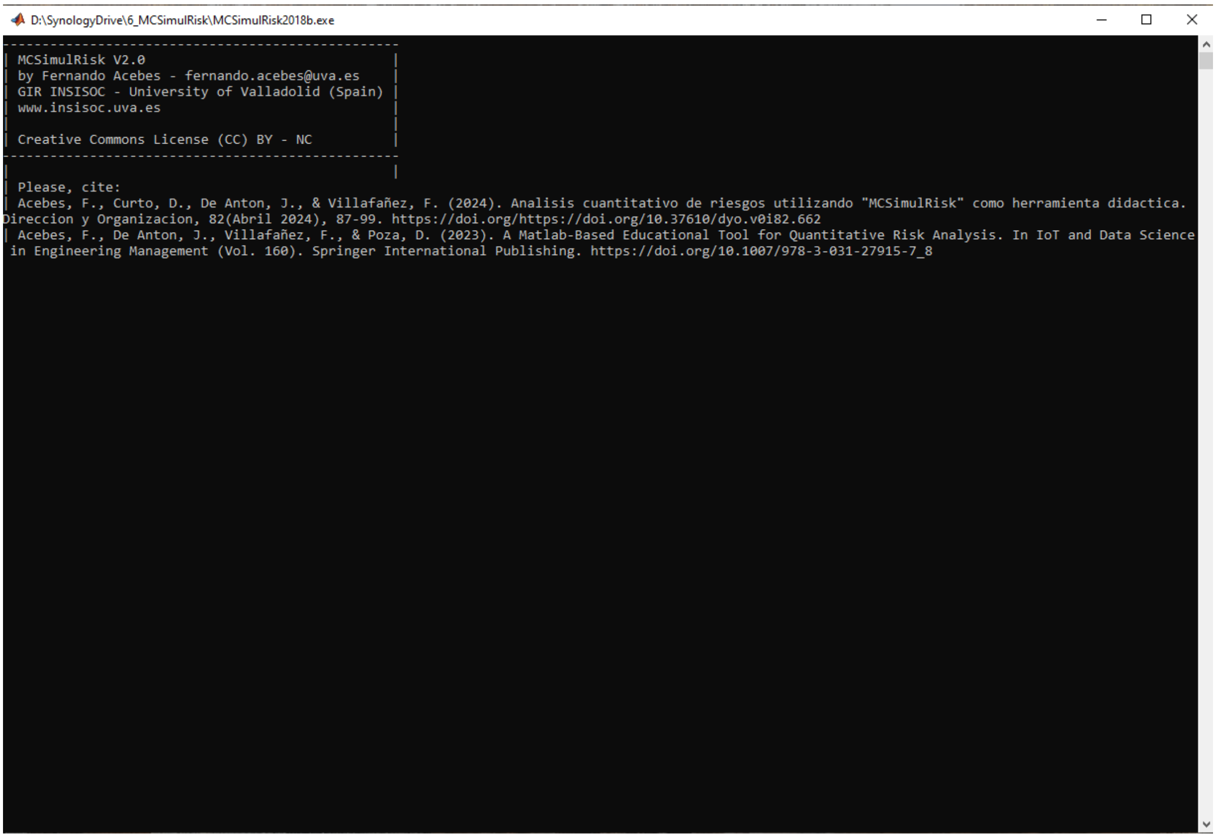


Fig. 2.2 *Main command screen with the project selection window*

Enter the name of the .xlsx file where you saved the project that you want to simulate and click ‘OK’ (see Fig. 2.3).

The name entered in the pop-up window (excluding the extension) must exactly match the file name. If the name does not match, an automatic Matlab error message appears indicating that the file cannot be opened due to a problem with Excel®’s data reading function (e.g., “Unable to open file ‘incorrect_name.xlsx’”).

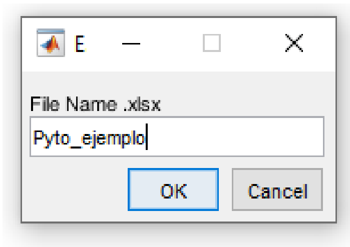


Fig. 2.3 *Pop-up window requesting the file name to be simulated*

Once you have correctly entered the Excel® project file name (e.g., for Sample Project: ‘Pyto_ejemplo’), the initial calculations are performed and the following information appears on the screen (see Fig. 2.4):

1. **Matrix of Possible Project Paths (Including Risks):** this matrix shows the different routes in the project by considering the identified risks. These routes do not necessarily represent critical paths that determine the project's maximum duration, but all the possible paths based on the project's precedence network configuration
2. **Matrix of Possible Project Paths (Excluding Risks):** this matrix excludes the identified risks and shows the possible routes in the project without considering those risks by calculating all paths based on the precedence network of activities

```
The matrix of possible project paths (including Risks) is
     1     6     3     5     8
     1     6     4     7     0
     2     5     8     0     0

The matrix of possible project paths (without Risks) is
     1     3     5
     1     4     0
     2     5     0

The Serial / Parallel project indicator is: SP = 0.50

The Activity distribution AD indicator is: AD = 0.50

The Topological float TF indicator is: TF = 0.75

The Planned Project Duration is 23 time units
The Planned Project Cost is 4610 monetary units

The mean value of the Project Duration is 25.684
The variance of the Project Duration is 4.110
The mean value of the Project Cost is 4925.695
The variance of the Project Cost is    7.0455e+04

Percentile     Duration       Cost
   5.0         22.803        4545.460
  10.0         23.244        4613.787
  15.0         23.604        4661.990
  20.0         23.903        4701.690
  25.0         24.193        4737.069
  30.0         24.462        4773.346
  35.0         24.714        4805.206
  40.0         24.964        4836.328
  45.0         25.225        4866.874
  50.0         25.475        4898.848
  55.0         25.743        4930.006
  60.0         26.006        4964.429
  65.0         26.275        4999.823
  70.0         26.577        5038.808
  75.0         26.896        5081.789
  80.0         27.272        5131.623
  85.0         27.724        5187.252
  90.0         28.363        5264.721
  95.0         29.421        5401.482
  100.0         35.854        6632.431
```

Fig. 2.4 *Initial project information*

3. **Network Topology Indicators**. Topological indicators provide quantitative measures that describe the project network's structure and characteristics. These indicators enable a more precise and objective analysis of the network's topology. Some of the commonest indicators include:

   – **Series/Parallel Indicator (SP):** it assesses whether the network resembles more of a series or parallel structure on a scale from 0 to 1. If **SP = 0**, then all the activities are in parallel. If **SP = 1**, the network is entirely in series. Intermediate values indicate mixed structures. This indicator also determines the maximum number of levels in the network, defined by the longest chain of activities in series

   – **Activity Distribution (AD):** this measures how activities are spread across the network levels on a scale from 0 to 1. If **AD = 0**, activities are evenly distributed across all levels. If **AD = 1**, a single level contains the maximum number of activities, while the other levels contain only one activity each

   – **Topological Float (TF):** it indicates how many activity levels can be shifted without exceeding the network's maximum level (defined by SP) on a scale from 0 to 1. If **TF = 0**, the network is fully dense and no activity can move. If **TF = 1**, there is a chain of activities without a float to define the network's maximum level, while other activities have the maximum possible float

4. **Planned Project Values.** The initial planned values for the project's total duration and cost are displayed

5. **Critical Duration and Cost Statistics.** The **mean** and **variance** of the total duration and cost are calculated and presented after Monte Carlo simulation

6. **Duration and Total Cost Percentiles.** Duration and total cost percentiles (in increments of 5) are provided. They derive from Monte Carlo simulation to help to assess the project's variability and risk

Additionally, a main menu appears in a pop-up window showing all the available options in MCSimulRisk (see Fig. 2.5).

In the following sections of this manual, each option in the main application menu is explained in detail. The purpose of each option is described, along with the graphical and numerical results that can be obtained.

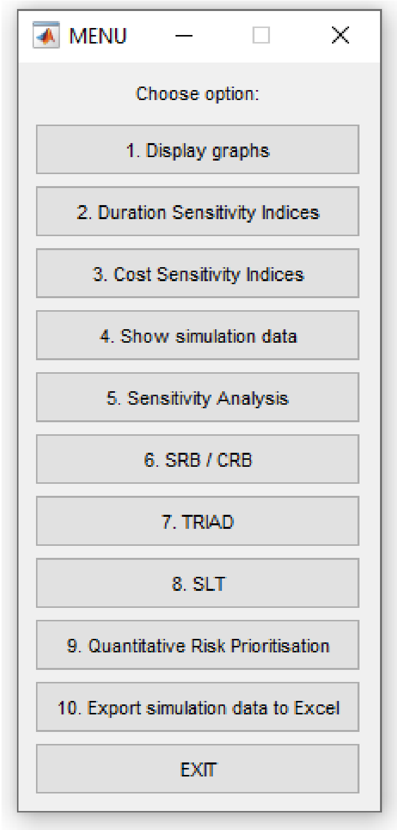


Fig. 2.5 *MCSimulRisk main menu*

2.1 Display graphs

The first option on the main menu, '1. Display graphs', allows you to generate the project's primary graphical representations. Clicking on '1. Display graphs' opens a second dropdown menu (see Fig. 2.6) entitled "Select the graph you want to represent:", where you can choose from the available graph options.

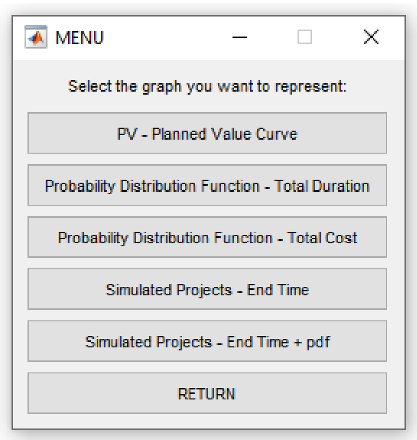


Fig. 2.6 *Menu '1. Display graphs'. Available options*

The graphical representation menu offers several options you can select:

2.1.1 PV – Planned Value Curve

The **PV Curve (Planned Value)** is an essential graphical representation in project management that shows the relation between time and planned cost. Also known as the “S curve” due to its characteristic shape, this graph illustrates the cumulative budget over the project’s life cycle. The PV Curve is a baseline for comparing actual progress to planned progress, which helps managers to visually and effectively identify cost and schedule deviations (see Fig. 2.7).

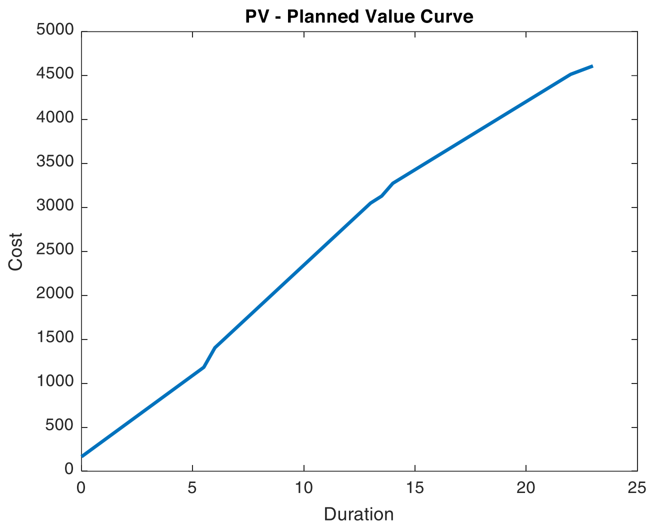


Fig. 2.7 *Planned Value (PV) curve*

2.1.2 Probability Distribution Function – Total Duration

Based on multiple simulations, the **probability distribution function (pdf)** for the project’s total duration is a histogram that displays the frequency or probability of different completion times. Along with the **cumulative distribution function (cdf),** this graph allows you visualise the accumulated probability of completing the project before a specific date, which facilitates deadline-related decision making and risk management (see Fig. 2.8a).

2.1.3 Probability Distribution Function – Total Cost

The **probability distribution function (pdf)** for the project’s total cost is a histogram that shows the frequency or probability of various possible costs based on multiple simulations. When combined with the **cumulative distribution function (cdf),** this graph helps to visualise the accumulated probability of executing the project within a specific budget to enhance cost-related decision making and risk management (see Fig. 2.8b).

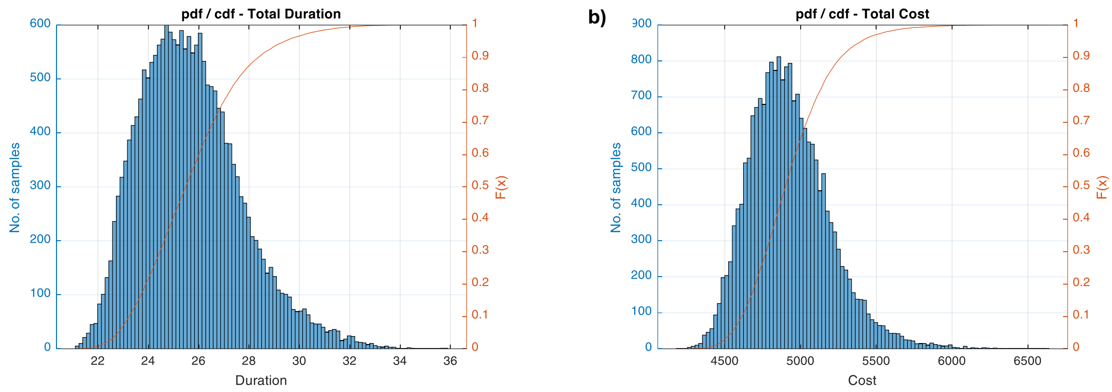


Fig. 2.8 *Probability Distribution Function (pdf) and Cumulative Distribution Function (cdf). a) Total duration. b) Total cost*

2.1.4 Simulated Projects – End Time

The **scatter plot** of the total duration and cost for a series of simulated projects illustrates the relation between these factors upon project completion. Each point on the graph represents a simulated project, with duration on the horizontal axis and cost on the vertical axis. This graph enables you to visualise patterns or correlations between time and cost. This helps with the identification of potential risk scenarios or deviations in future projects (see Fig. 2.9a).

2.1.5 Simulated Projects – End Time + pdf

In Fig. 2.9b, **histograms** (probability distribution functions) for the total duration on the horizontal axis and the total cost on the vertical axis are included in the time and cost scatter plot for simulated projects.

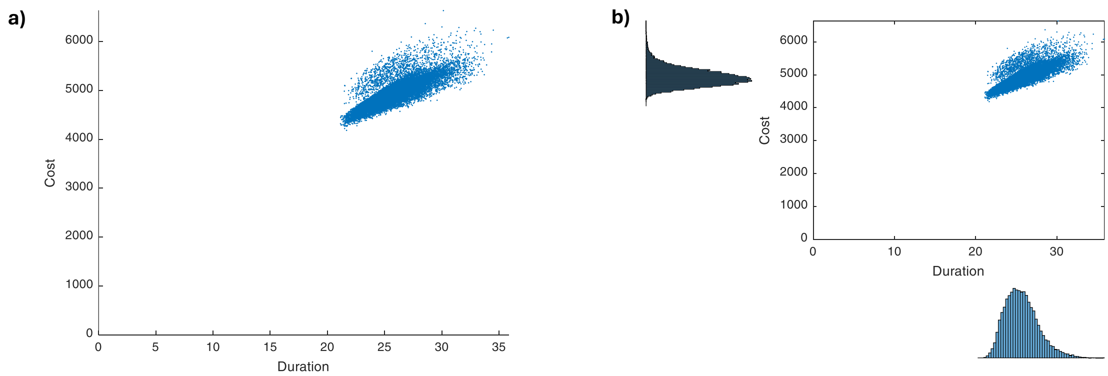


Fig. 2.9 *Time-Cost scatter plot. a) Time-Cost scatter cloud. b) Includes probability distribution functions*

This graph (Fig. 2.9b) allows you to observe the relation between the scatter points in the Cartesian space (duration and cost) and the corresponding distribution functions.

2.1.6 RETURN

This secondary menu can return to the main menu (see Fig. 2.5).

2.2 Duration Sensitivity Index

The next option on the main menu is '2. Duration Sensitivity Index'. It allows you to calculate and visualise the critical sensitivity indicators for the project's duration. Clicking this option opens a secondary menu entitled '**Select the sensitivity index to be displayed**:', showing the different available sensitivity indicators (see Fig. 2.10).

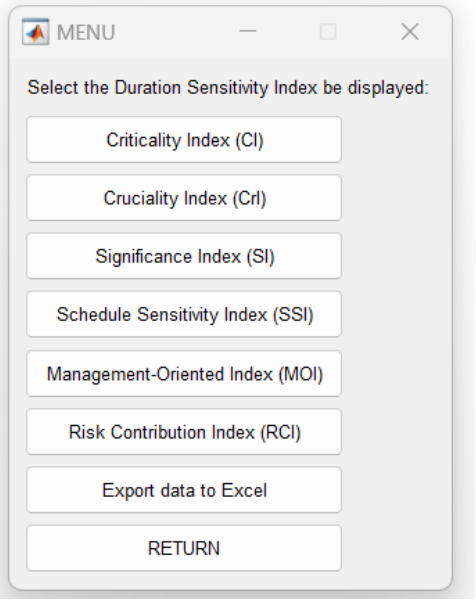


Fig. 2.10 *'2. Duration Sensitivity Index' Menu. Available options*

Duration sensitivity indicators are valuable for analysing how various tasks affect the total project duration. As not all activities have the same impact on schedule, it is crucial to identify those that can significantly influence the completion time. Using Monte Carlo simulations, these indicators provide a precise view of the uncertainty and risk associated with project duration.

This analysis is helpful in complex projects with multiple dependencies, where minor changes in one task can lead to significant deviations in the overall timeline. Sensitivity indicators help project managers to identify the activities that require tighter control by optimising schedule management and decision making.

Below is an overview of the options in the duration sensitivity indicators submenu.

This manual does **NOT include** the formulas used to calculate these indicators; it focuses on explaining how MCSimulRisk presents them and how to use them.

2.2.1 Criticality Index (CI)

Also known as the **Criticality Index**, this indicator shows how often an activity appears on the project's critical path. A high value indicates that activity is critical in most scenarios and any delay directly impacts total duration, which requires closer monitoring (see Fig. 2.11a).

2.2.2 Cruciality Index (CrI)

The **Cruciality Index** measures the correlation between an activity's duration and the total project duration. A high value means any change in this task's duration significantly impacts the schedule. This indicator highlights the vital tasks that can affect the timeline if delayed (see Fig. 2.11b).

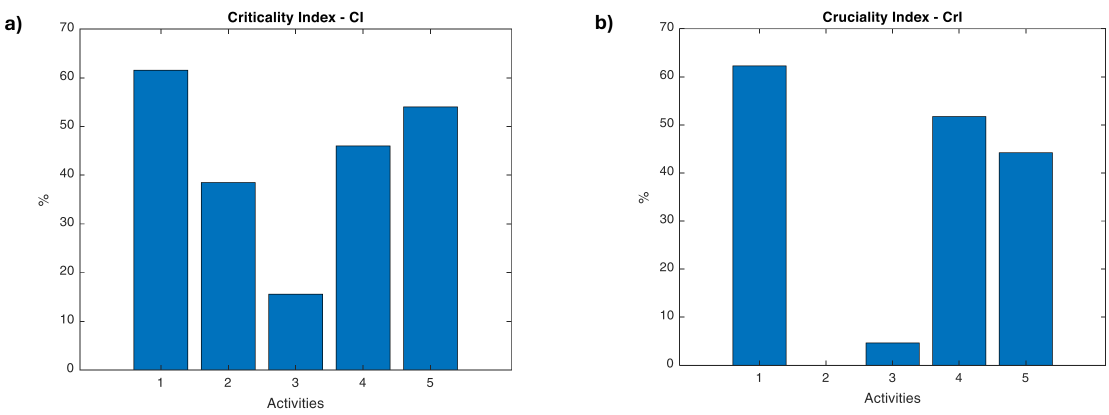


Fig. 2.11 *Representation of Indicators for the Sample Project: a) Criticality Index (CI). b) Cruciality Index (CrI)*

2.2.3 Significance Index (SI)

The **Significance Index** indicates how important an activity is for overall project duration. It assesses the potential impact of a delay in that activity on the entire project (see Fig. 2.12a).

2.2.4 Schedule Sensitivity Index (SSI)

The **Schedule Sensitivity Index** combines the probability of an activity being on the critical path with the impact of its variability on the project's total duration. The SSI is the most realistic indicator for prioritising activities based on sensitivity (see Fig. 2.12b).

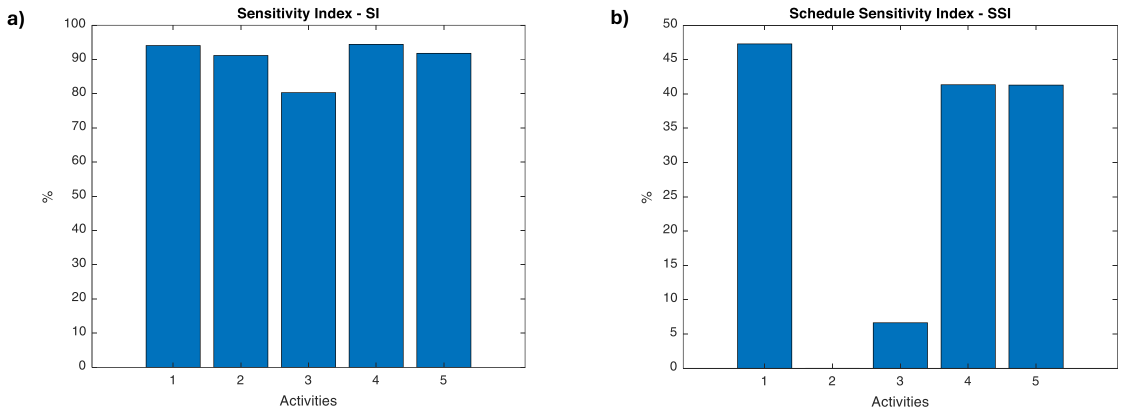


Fig. 2.12 *Representation of Indicators for the Sample Project: a) Significance Index (SI). b) Schedule Sensitivity Index (SSI)*

2.2.5 Management-Oriented Index (MOI)

The Management-Oriented Index evaluates the relative importance of an activity in terms of its impact on the project's total duration. This indicator goes beyond criticality and considers how a task should be strategically managed. It incorporates information about the project network's structure (see Fig. 2.13a).

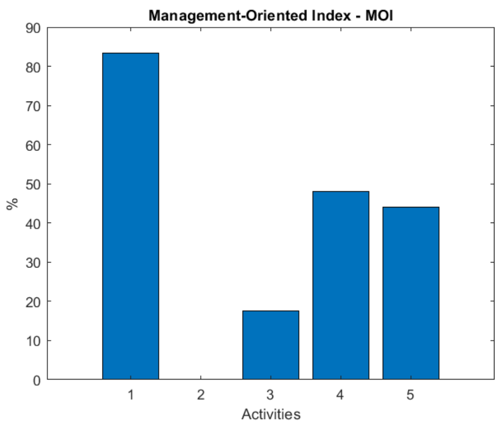


Fig. 2.13 *Representation of Indicators for the Sample Project: a) Management-Oriented Index (MOI). b) Risk Contribution Index (RCI)*

Clicking on any option in the "2. Duration Sensitivity Index" menu allows the corresponding graphs to be displayed in a pop-up window. Additionally, the numerical values of each selected indicator are presented on the screen, along with the graphical representation.

In Fig. 2.14, you can see the numerical results (in %) displayed for the **Sample Project** after selecting each sensitivity indicator.

```
The Criticality Index of the project activities is (CIa1 CIa2 ...):
   62.1200   37.9300   15.2500   46.8700   53.1550

The Cruciality Index of project activities is (CrIa1 CrIa2 ...):
   61.8107       NaN    6.0313   50.4047   45.4834

The Significance Index (SI) of project activities is (SI1 SI2 ...):
   94.0659   91.1450   80.3498   94.4751   91.8237

The Schedule Sensitivity Index (SSI) of project activities is (SSIa1 SSIa2 ...)
   48.2077         0    6.5449   42.2612   41.1599

The Management-Oriented Index (MoI) of project activities is (MOIa1 MOIa2 ...):
   83.4163         0   17.6503   48.0479   43.9902

The Risk Contribution Index (RCI) of project activities is (RCI1 RCI2 ...):
    0.7670         0         0    0.0375    0.2025
```

Fig. 2.14 *Numerical results of sensitivity indicators displayed on screen*

2.2.6 Export data to Excel®

This option is available on the ”2. Schedule Sensitivity Index” menu and allows you to export the numerical data of all the sensitivity indicators to an Excel® spreadsheet. Having this data in an external file facilitates any further analysis and the possibility of reprocessing or graphing it later. It is not necessary to view graphs before exporting.

Selecting this option generates an Excel® file named “**Ind_sensibilidad.xlsx**” that contains the values (in %) for each indicator related to every project activity. The file is saved in the exact location as MCSimulRisk.exe executable.

If an Excel® file named “**Ind_sensibilidad.xlsx**” already exists and you attempt to export again, an error message appears in a pop-up window stating that a file with the same name already exists in that location (see Fig. 2.15).

2.2.7 RETURN

This option on the secondary menu allows you to return to the main menu (see Fig. 2.5).

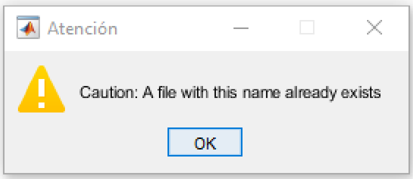


Fig. 2.15 *Error message displayed when attempting to export data to Excel® if a file with the same name already exists*

2.3 Cost Sensitivity Index

The next option on the main menu, '**3. Cost Sensitivity Index'**, is used to calculate and display the leading cost sensitivity indicators for the project. Clicking this option opens a secondary menu entitled '**Select the cost sensitivity index to be displayed:**' showing the different available sensitivity indicators (see Fig. 2.16).

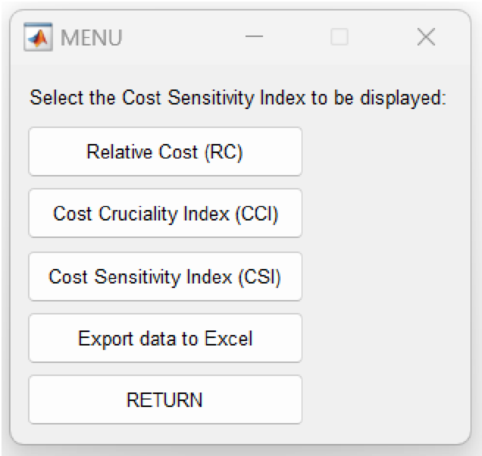


Fig. 2.16 *'3. Cost Sensitivity Index'* Menu. Available options

Cost sensitivity indicators allow you to analyse how variations in individual activities affect the total project cost. These indicators are crucial for identifying which tasks or components are at higher risk of causing cost overruns and, therefore, which require stricter management. Like the duration sensitivity indicators, these are calculated using simulations, such as Monte Carlo, to evaluate multiple cost variability scenarios.

However, there is a crucial difference: the total project cost is obtained as the sum of the costs of all the activities, regardless of their position in the activity network after eliminating the concept of a "critical path" in cost terms.

The options in the cost sensitivity indicators submenu are described below:

2.3.1 Relative Cost (RC)

The **Relative Cost** indicator shows the importance of each activity based on its contribution to the project's total cost. It measures how much an activity's cost represents compared to the total cost. An activity with a high relative cost implies significant investment in that task, which necessitates careful management due to its impact on the overall budget (see Fig. 2.17a).

2.3.2 Cost Cruciality Index (CCI)

The **Cost Cruciality Index** measures the correlation between an activity's cost and the project's total cost. This index reflects how variations in the cost of a specific task affect the overall budget. A high CCI value indicates that any deviation in the cost of that task (regardless of it being an increase or decrease) considerably impacts the project's total cost (see Fig. 2.17b).

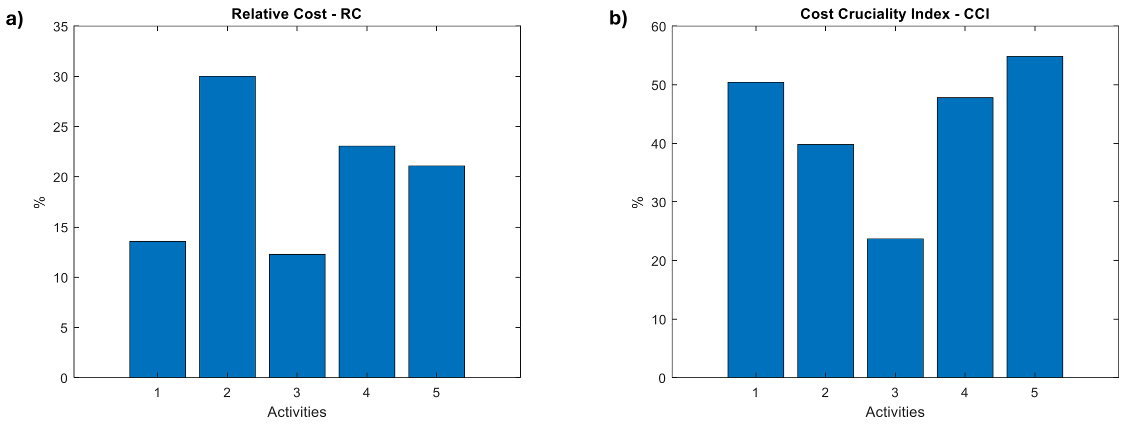


Fig. 2.17 *Representation of cost indicators for the sample project: a) Relative Cost (RC). b) Cost Cruciality Index (CCI)*

2.3.3 Cost Sensitivity Index (CSI)

The **Cost Sensitivity Index** indicator is defined similarly to the schedule indicators. The CSI combines an activity's Relative Cost (RC) and variability. It is calculated by weighting the relative cost of the activity with the ratio between the standard deviation of the activity's cost and the standard deviation of the project's total cost (see Fig. 2.18).

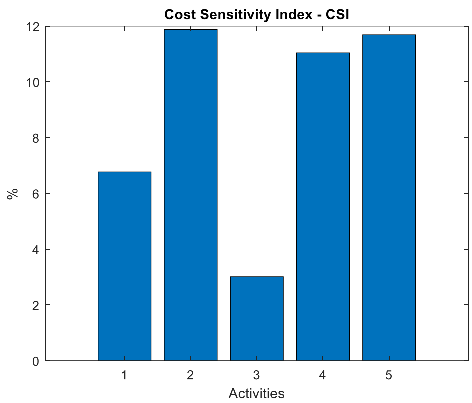


Fig. 2.18 *Representation of the Cost Sensitivity Index (CSI) for the sample project*

By clicking on any option on the "3. Cost Sensitivity Index" menu, the corresponding graphs are displayed in a pop-up window. Additionally, the numerical values of each indicator are shown on the screen along with the graph.

Fig. 2.19 shows the **Sample Project**'s numerical result (in %) on the application screen after selecting each cost sensitivity indicator.

```
The Relative Cost Index of project activities is (RCa1 RCa2 ...):
   13.5948   29.9836   12.2709   23.0588   21.0919

The Cost Cruciality Index of project activities is (CCIa1 CCIa2 ...):
   50.1770   37.8379   25.0722   47.6103   55.3352

The Cost Sensitivity Index of project activities is (CSIa1 CSIa2 ...):
    6.8412   11.6949    3.0263   11.0202   11.8369
```

Fig. 2.19 *Numerical results of cost sensitivity indicators displayed on screen*

2.3.4 Export data to Excel

The '3. Cost Sensitivity Index' submenu includes an option to export the numerical data for all the cost sensitivity indicators to an Excel spreadsheet. You do not need to view the graphs before exporting. This option creates an Excel file named "**Ind_sensibilidad_coste.xlsx**" that contains the values (in %) for each indicator related to every project activity. The file is saved in the exact location of the **MCSimulRisk.exe** application.

If an Excel file named "**Ind_sensibilidad_coste.xlsx**" already exists and you try to export it again, a pop-up window displays an error message that indicates that a file with the same name already exists.

2.3.5 RETURN

This option allows you to return to the main menu (see Fig. 2.5).

2.4 Show simulation data

The next option on the main menu enables calculations to determine the **total duration and cost** for a specific percentile or, conversely, to calculate the corresponding percentile for a given total duration or cost. To access this functionality, click on '4. Show simulation data' on the main menu. A secondary menu entitled 'Select the desired option to be calculated:' appears with the available calculation options (see Fig. 2.20).

Although the application provides information on the total durations and costs for all the quintiles (percentiles in multiples of five; see Fig. 2.4), you might need these values or their inverses for other specific percentiles. This option makes it easy to obtain these results.

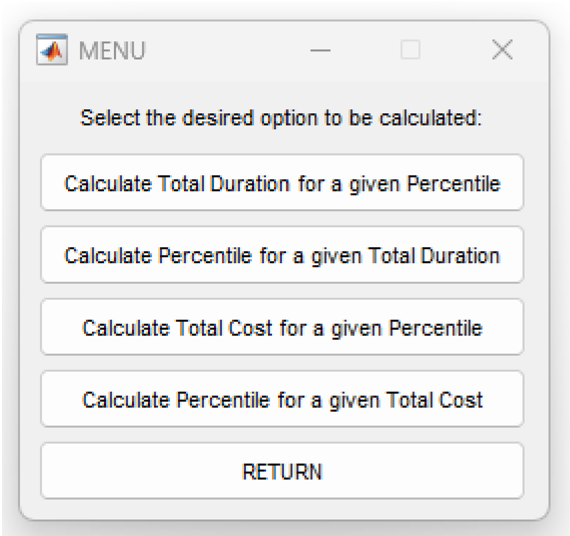


Fig. 2.20 *'4. Show simulation data'* Menu. Available options

2.4.1 Calculate Total Duration for a given Percentile

This calculates the total project duration for a specified percentile. This option opens a pop-up window that asks for the desired percentile (see Fig. 2.21a). Enter the percentile as a percentage (e.g., '73'). When clicking '**OK'**, total duration is displayed in time units (u.t.) (e.g., 26.764 u.t.; see Fig. 2.21b).

a)

b)

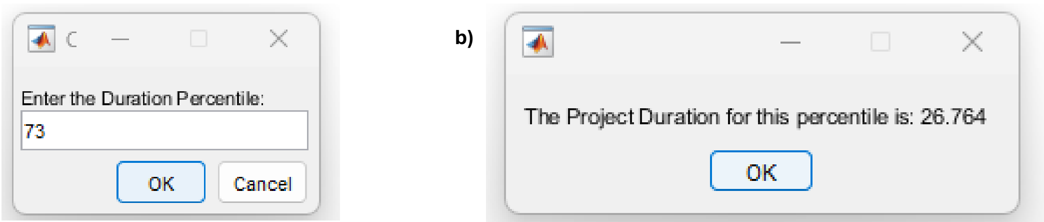


Fig. 2.21 *Calculating the duration for a specified percentile: a) Input data window. b) Result window*

2.4.2 Calculate Percentiles for a given Total Duration

This option calculates the percentile corresponding to a specified total project duration. Selecting this opens a pop-up window that requests total duration (see Fig. 2.22a). Enter duration in u.t. (e.g., '27'). After clicking '**OK'**, the resulting percentile is shown (e.g., P76.38) (see Fig. 2.22b).

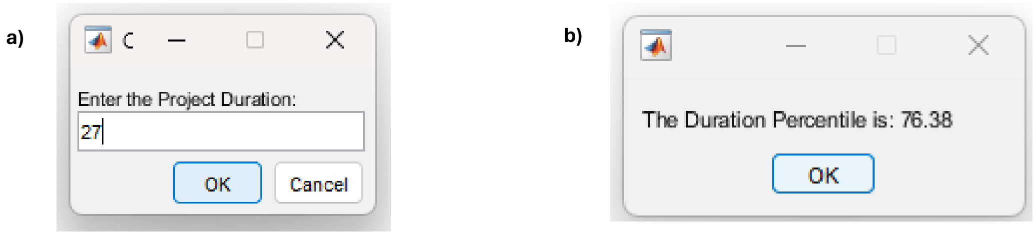


Fig. 2.22 Calculating the percentile for a given total duration: a) Input data window. b) Result window

2.4.3 Calculate Total Cost for a given Percentile

This calculates the total project cost for a specified percentile. This option opens a pop-up window asking for the percentile (see Fig. 2.23a). Enter the percentile as a percentage (e.g., '78'), and click '**OK'** to display the total cost in monetary units (u.m.) (e.g., 5108.843 u.m.; see Fig. 2.23b).

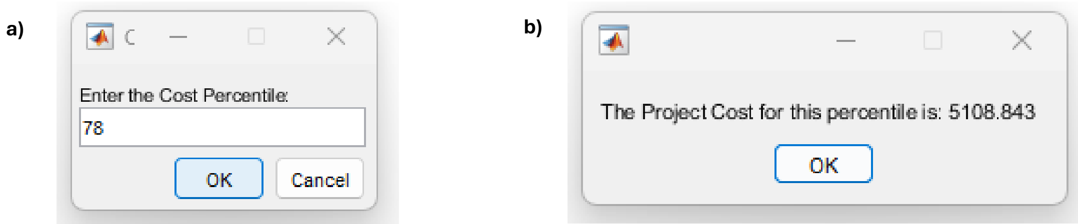


Fig. 2.23 Calculating the total cost for a given percentile: a) Input data window. b) Result window

2.4.4 Calculate Percentile for a given Total Cost

This option calculates the percentile corresponding to a specified total cost. Selecting it opens a pop-up window to request the total cost (see Fig. 2.24a). Enter the cost in u.m. (e.g., '5100'). Clicking '**OK'** displays the resulting percentile (e.g., P77.03; see Fig. 2.24b).

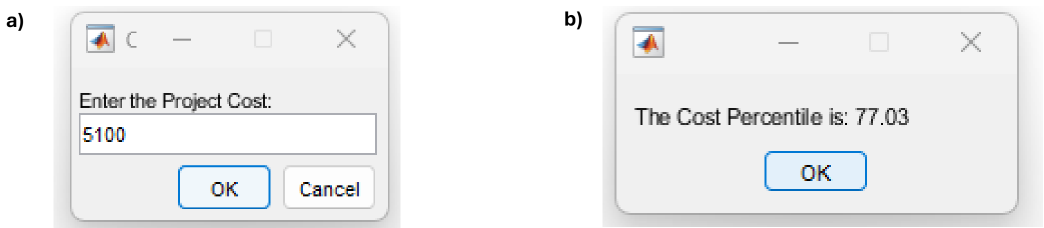


Fig. 2.24 Calculating the percentile for a given total cost: a) Input data window. b) Result window

2.4.5 RETURN

This option returns you to the main menu (see Fig. 2.5).

2.5 Sensitivity Analysis

A **sensitivity analysis** of project activities is a technique that assesses how changes in one independent variable or more can affect the overall project outcome. This analysis is crucial for identifying the most critical factors that influence performance and evaluating the project's robustness in the face of risks and uncertainties.

The '5. Sensitivity Analysis' option on the main menu is used to conduct this type of analysis. Selecting it opens a secondary menu entitled 'Select the desired Sensitivity Analysis option:'. It displays two types of sensitivity analysis that can be performed (see Fig. 2.25).

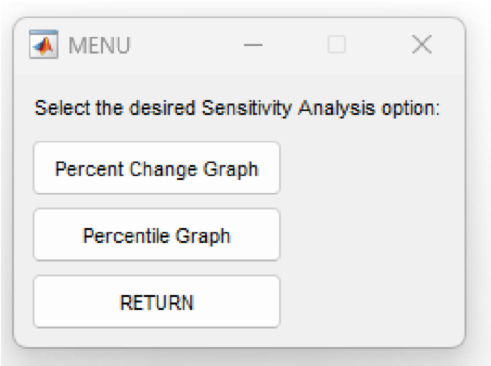


Fig. 2.25 *'5. Sensitivity Analysis' Menu. Available options*

Based on the original project, where activity durations and costs are subject to uncertainty, and risks are modelled through probability distribution functions, a sensitivity analysis is performed by consecutively modifying the duration of each activity, while leaving other variables unchanged. Activity durations can be adjusted in two ways: by assigning a new value based on a percentage of the original value (predefined) or by using a specific percentile (internally programmed).

2.5.1 Percent Change Graph

During each simulation, the activity duration is adjusted to a percentage of its original value:

$$d_f A_{i_j} = dA_i \cdot \%_j$$

where $d_f A_{i_j}$ is the final duration of activity A_i in simulation j; dA_i is the original duration of activity A_i and $\%_j$ is the percentage applied in simulation j. Percentages are: ***%j = {0.1, 0.25, 0.5, 0.95, 1, 1.05, 1.1, 1.5},*** expressed as decimals.

The uncertainty associated with the modified activity is calculated proportionally to the new duration value.

Clicking “**Percent Change Graph**” (Fig. 2.25) opens a pop-up window that asks for the desired percentile for the sensitivity analysis and the option to represent it for the mean value. The window is entitled “**Enter the Percentile for Sensitivity Analysis**” (see Fig. 2.26).

Given the inherent uncertainty in project activities and the identified risks, analysing only the mean value may be insufficient. In some cases, it is necessary to represent sensitivity results at a specific percentile to better capture the impact of uncertainties.

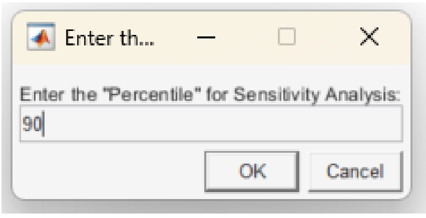


Fig. 2.26 *Input window for ‘Percentile’ data for sensitivity analysis graphs*

Once calculations are complete, MCSimulRisk displays a new secondary menu (Fig. 2.27).

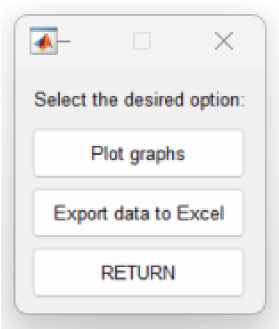


Fig. 2.27 Secondary sensitivity analysis menu

The available options include:

- **Plot graphs**. They graphically represent the sensitivity analysis results. Graphs are divided into two types: **spider plot and tornado plot**.
    - **Spider Plot**: it visually displays all the variables in a linear format. The horizontal axis represents the percentage variation in activity duration, while the vertical axis shows the output variable (total duration, total cost, standard deviation). The graph illustrates the evolution of each variable in relation to the others.
    - **Tornado Plot**: it shows the impact of different variables on a critical outcome using bars. The horizontal axis represents the output variable (total duration or cost, standard deviation), and the vertical axis lists each activity. The plot

highlights the values obtained for each activity and provides a clear view of their relative impact.

The resulting spider graphs include (Fig. 2.28):

– Mean activity duration / Percentage duration (Fig. 2.28a)

– Mean activity cost / Percentage duration (Fig. 2.28b)

– Activity duration at the selected percentile / Percentage duration (Fig. 2.28c)

– Activity cost at the selected percentile / Percentage duration (Fig. 2.28d)

– The standard deviation of activity duration / Percentage duration (Fig. 2.28e)

– The standard deviation of activity cost / Percentage duration (Fig. 2.28f)

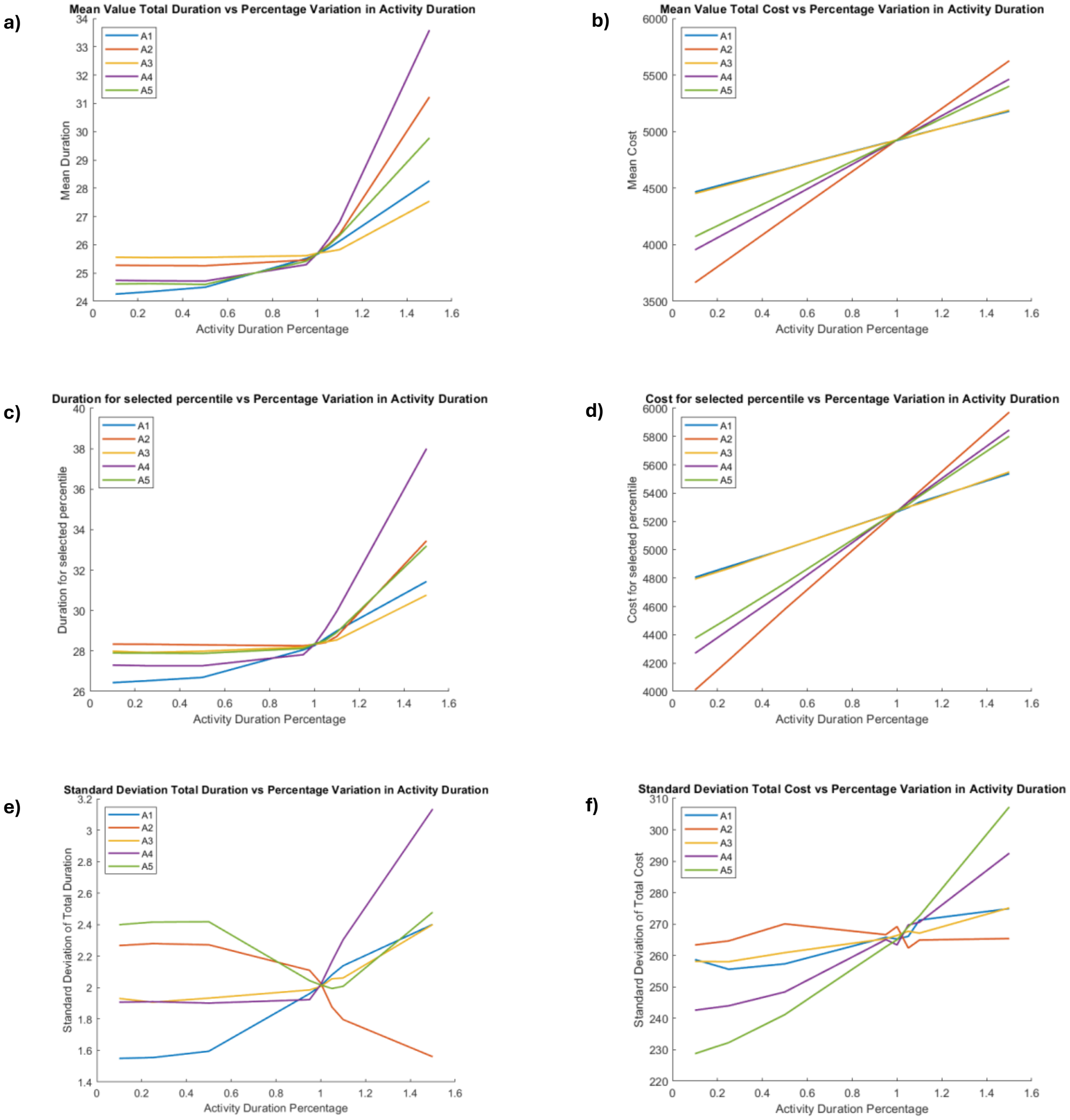


Fig. 2.28 *Spider graphs for the sensitivity analysis "Percent Change Graph"*

The generated tornado graphs are as follows (Fig. 2.29):

- Mean activity duration/Activity Duration Percentage (Fig. 2.29a)
- Mean activity cost/Activity Duration Percentage (Fig. 2.29b)
- Activity duration at the chosen percentile/Activity Duration Percentage (Fig. 2.29c)
- Activity cost at the chosen percentile/Activity Duration Percentage (Fig. 2.29d)
- The standard deviation of activity duration/Activity Duration Percentage (Fig. 2.29e)
- The standard deviation of activity cost/Activity Duration Percentage (Fig. 2.29f)

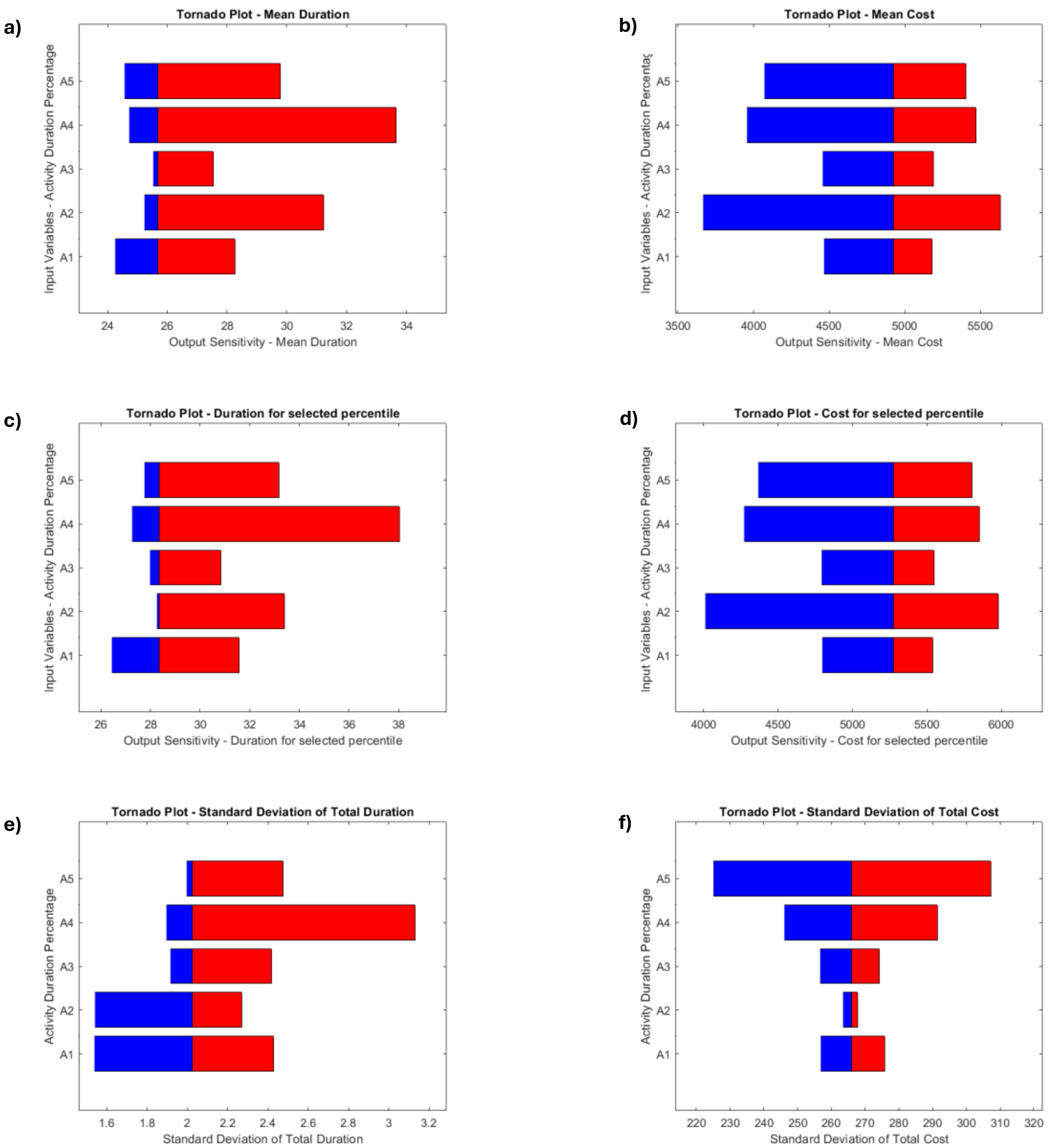


Fig. 2.29 Tornado graphs for the sensitivity analysis "*Percent Change Graph*"

- **Export data to Excel®**. On the secondary sensitivity analysis menu (see Fig. 2.27), you can export the numerical data from the analysis to an Excel® spreadsheet. It is not necessary to view graphs before exporting. Selecting 'Export data to Excel®' generates an Excel® file named "**Sen_Analys_percent.xlsx**", which includes multiple sheets, one for each selected graph containing the corresponding data for each activity and duration percentage (see Fig. 2.28 and Fig. 2.29). The Excel® file is saved in the exact location of the MCSimulRisk.exe application.

  If a file named "**Sen_Analys_percent.xlsx**" already exists and you attempt to export again, a pop-up window displays an error message indicating that a file with the same name already exists in that location.

- **RETURN.** This option allows you return to the previous menu (see Fig. 2.25).

2.5.2 Percentile Graph

During this analysis, the activity duration is adjusted based on a specific percentile of the value range from simulation:

$$d_f A_{i_j} = P_j dA_i$$

where $d_f A_{i_j}$ is the final duration of activity A_i in simulation j, and $P_j dA_i$ is the jth percentile of the duration of activity A_i.

The set percentiles used to adjust the original duration of activity A_i during each j simulation are: P_j = ***{P1, P5, P10, P25, P50, P75, 9P0, P95, P99}***.

The uncertainty associated with the modified activity is calculated proportionally to the new duration value.

Clicking "**Percentile Graph**" (see Fig. 2.25) opens a pop-up window that asks for the desired percentile for the sensitivity analysis, with the option to represent it for the mean value (see Fig. 2.26). After calculations, MCSimulRisk displays a new secondary menu in a pop-up window (see Fig. 2.27).

The options available on the new menu are:

- **Spider graphs**. The generated spider graphs include (Fig. 2.30):
  - Mean activity duration / Percentage activity duration (Fig. 2.30a)
  - Mean activity cost / Percentage activity duration (Fig. 2.30b)
  - Activity duration at the chosen percentile / Percentage activity duration (Fig. 2.30c)
  - Activity cost at the chosen percentile / Percentage activity duration (Fig. 2.30d)
  - The standard deviation of activity duration / Percentage activity duration (Fig. 2.30e)

– The standard deviation of activity cost / Percentage activity duration (Fig. 2.30f)

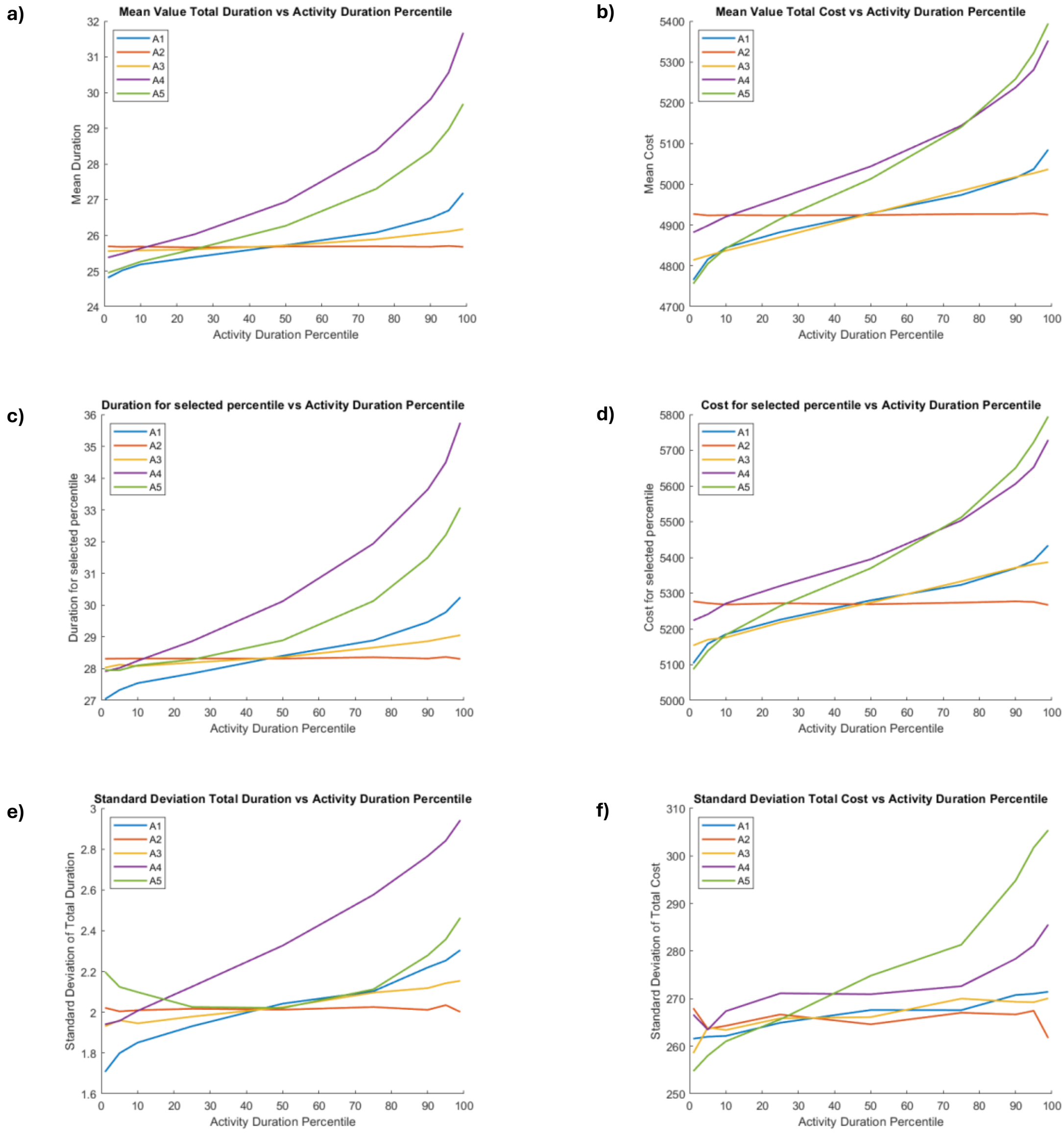


Fig. 2.30 *Sensitivity analysis spider charts "Percent Change Graph"*

- **Tornado Graphs.** The generated tornado graphs include (Fig. 2.31):
  - Mean activity duration / Percentage activity duration (Fig. 2.31a)
  - Mean activity cost / Percentage activity duration (Fig. 2.31b)
  - Activity duration at the chosen percentile / Percentage activity duration (Fig. 2.31c)
  - Activity cost at the chosen percentile / Percentage activity duration (Fig. 2.31d)
  - The standard deviation of activity duration / Percentage activity duration (Fig. 2.31e)
  - The standard deviation of activity cost / Percentage activity duration (Fig. 2.31f)

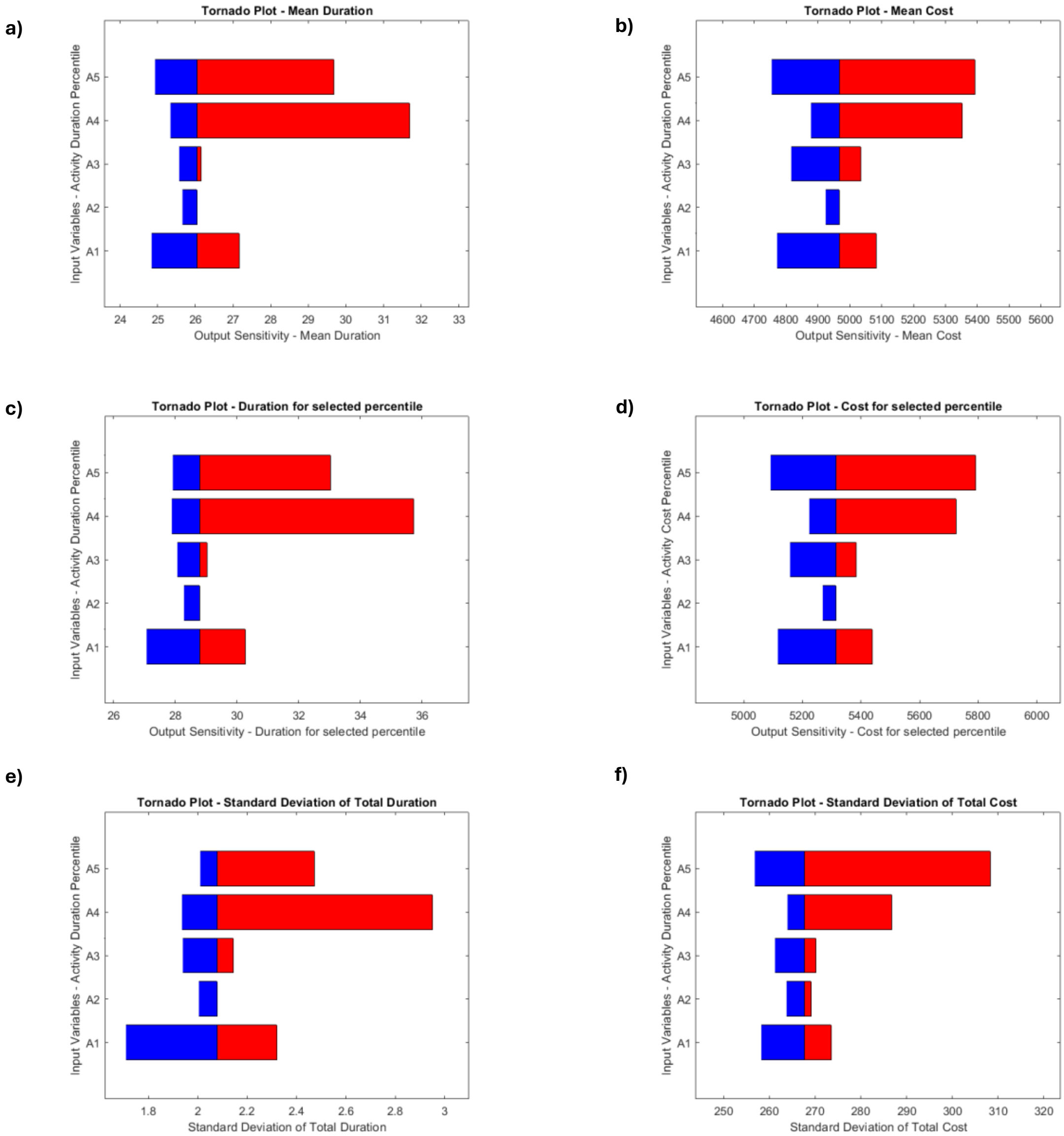


Fig. 2.31 *Tornado graphs for the sensitivity analysis "Percent Change Graph"*

- **Export data to Excel®**. On the secondary sensitivity analysis menu (Fig. 2.27), you can export the numerical data from the analysis to an Excel® spreadsheet. It is not necessary to view graphs before exporting. Selecting this option generates an Excel® file named "**Sen_Analys_percentile.xlsx**" containing multiple sheets with the data for each selected graph (see Fig. 2.30 and Fig. 2.31). Each sheet includes the data related to each activity and duration percentages. The file is saved in the exact location of the **MCSimulRisk.exe** application.

If a file named "**Sen_Analys_percentile.xlsx**" already exists and you attempt to export again, a pop-up window displays an error message indicating that a file with the same name already exists in that location.

- **RETURN.** This secondary menu option allows you return to the previous menu (Fig. 2.25).

2.5.3 RETURN

This option allows you to return to the main menu (Fig. 2.5).

2.6 SRB / CRB

SRB (Schedule Risk Baseline) and **CRB** (Cost Risk Baseline) are risk baselines proposed by Pajares and López-Paredes (2011)[1] that represent the evolution of risk, measured through variance, in both schedule and cost as the project progresses. These curves are used in a methodology to calculate project monitoring and control indicators: the **Schedule Control Index (SCoI)** and the **Cost Control Index (CCoI)**. These indicators enable project management that accounts for uncertainty.

By selecting '6. SRB / CRB' from the main menu (Fig. 2.5), you can generate and obtain the numerical values from this methodology. Clicking this option opens a pop-up window that prompts you to input the time interval for calculations, with the default value set at '**1**' time unit (**u.t.**) (see Fig. 2.32)**.**

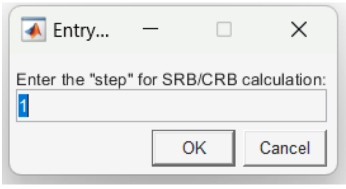


Fig. 2.32 *Pop-up window requesting time interval for SRB/CRB calculations*

After performing calculations, MCSimulRisk displays a new secondary menu (Fig. 2.33) offering options to plot SRB/CRB curves, export data to an Excel® file or return to the main menu.

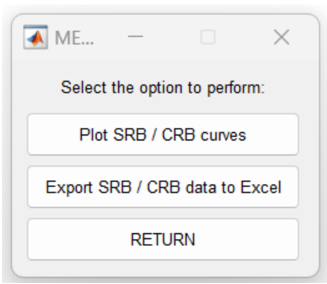


Fig. 2.33 *SRB/CRB secondary menu*

[1] Pajares, J., & López-Paredes, A. (2011). An extension of the EVM analysis for project monitoring: The Cost Control Index and the Schedule Control Index. International Journal of Project Management, 29(5), 615–621. https://doi.org/https://doi.org/10.1016/j.ijproman.2010.04.005

2.6.1 Plot SRB/CRB curves

Selecting this option displays the following project indicators on the screen (see Fig. 2.34):

- ***Schedule Risk Value*** **(SRV)**. This represents the planned project's total schedule risk, measured as the area under the SRB curve. It quantifies the risk in project duration using the absolute variance of the total duration from start to completion as planned
- ***Unitary Schedule Risk Value*** **(SRVu)**. This is the unitary value of duration risk, expressed as a fraction. It allows for comparisons between projects of different sizes or uncertainty levels, and is calculated by dividing the SRV by the project's maximum duration risk value
- ***Cost Risk Value*** **(SRV)**. This indicates the planned project's total cost risk, which is also measured as the area under the CRB curve. It quantifies the risk in terms of the absolute variance of the total cost from project start to planned completion

```
Schedule Risk Value (SRV)
   46.4028

Unitary Schedule Risk Value (SRVu)
    0.5017

Cost Risk Value (CRV)
   8.6710e+05

Unitary Cost Risk Value (CRVu)
    0.6747
```

Fig. 2.34 *Project risk indicators relative to SRB/CRB*

- ***Unitary Cost Risk Value*** **(SRVu)**. This is the unitary value of cost risk, expressed as a fraction. It compares projects of different scales regarding duration, cost and uncertainty. It is calculated by dividing the **CRV** by the project's maximum cost-risk value

Selecting "Plot SRB/CRB curves" from the menu (Fig. 2.33) generates graphs showing the evolution of both the schedule risk (Schedule Risk Baseline – **SRB**) and cost risk (Cost Risk Baseline – **CRB**) according to the planned project execution (see Fig. 2.35).

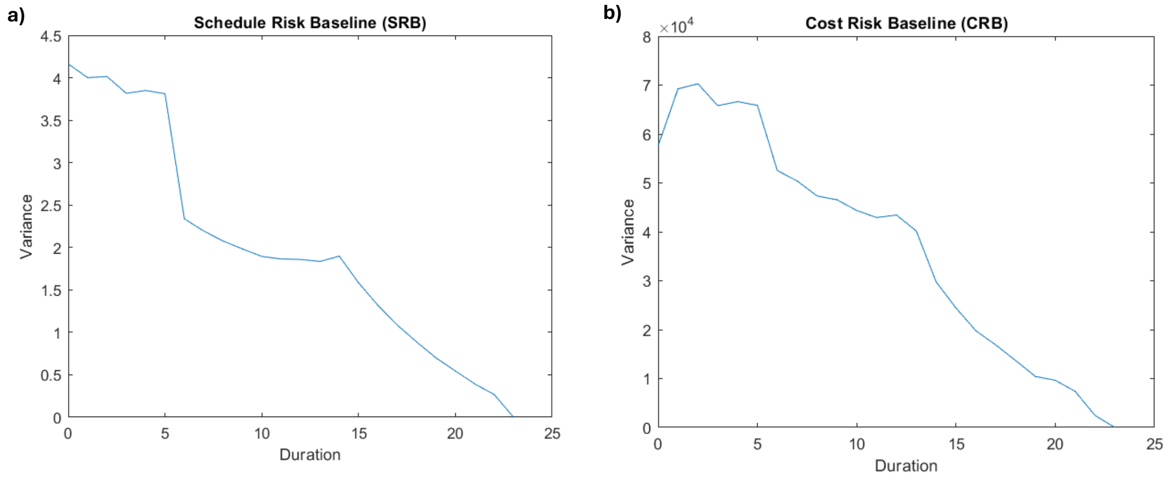


Fig. 2.35 *Project risk evolution curves: a) Schedule Risk Baseline - SRB. b) Cost Risk Baseline - CRB*

2.6.2 Export SRB/CRB data to Excel®

From the **SRB/CRB** secondary menu (Fig. 2.33), you can also export the numerical data related to the risk indicators, based on the SCoI/CCoI methodology, to an Excel® file. It is not necessary to view graphs to proceed with the export. Selecting this option creates an Excel® file named "**SRB_CRB.xlsx**", which includes two sheets: one with the SRB and the RB indicator data; another with the **SRV, SRVu, CRV** and **CRVu** indicators. The file is saved in the exact location of the **MCSimulRisk.exe** application.

If a file named "**SRB_CRB.xlsx**" already exists and you attempt to export again, a pop-up window shows an error message indicating that the file already exists in that location.

2.6.3 RETURN

This option allows you to return to the main menu (see Fig. 2.5).

2.7 TRIAD

The '7. TRIAD' option on the main menu enables the generation of graphical and numerical representations of the **TRIAD** methodology proposed by Acebes et al. (2014)[2]. This

[2] Acebes, F., Pajares, J., Galán, J. M., & López-Paredes, A. (2014). A new approach for project control under uncertainty. Going back to the basics. *International Journal of Project Management*, *32*(3), 423–434. https://doi.org/https://doi.org/10.1016/j.ijproman.2013.08.003

methodology enhances project monitoring and control in uncertain environments by improving management compared to previous methods.

When you select this option, **MCSimulRisk** performs the necessary calculations and displays a pop-up window entitled “Select the option to perform:” (see Fig. 2.36). It allows you to choose between obtaining graphs or exporting data to an Excel® file.

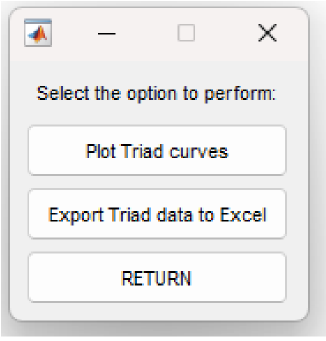


Fig. 2.36 *TRIAD secondary menu*

2.7.1 Plot TRIAD curves

Clicking this option reveals the graphs used in the TRIAD methodology for project monitoring and control. Two of these graphs focus on project duration (see Fig. 2.37a), while the other two focus on cost control (see Fig. 2.37b).

Fig. **2.37a** displays the percentile curves for the planned project duration (P10, P30, P50, P70, and P90), along with the planned value curve, at each point (duration, % project completion). During execution, the project’s current control point (current duration, current % completion) is plotted, which allows the identification of the corresponding execution percentile.

Fig. **2.37b** shows the **Time Schedule Variance** (TSV), a key indicator in this methodology. TSV is calculated as the difference, upon each % completion, between the percentile value (or the ongoing project value) and the planned value. The graph displays TSV curves for the percentiles on a (% completion, TSV) diagram. To monitor the project in real time, the control point is positioned at the current % completion, along with the corresponding TSV value.

Fig. **2.38a** presents the percentile cost curves for the planned project (P10, P30, P50, P70 and P90), along with the planned value curve at each point (% cost completion, total cost). During project execution, the control point (current % cost completion, current cost) is plotted to determine which cost percentile the project falls in at that time.

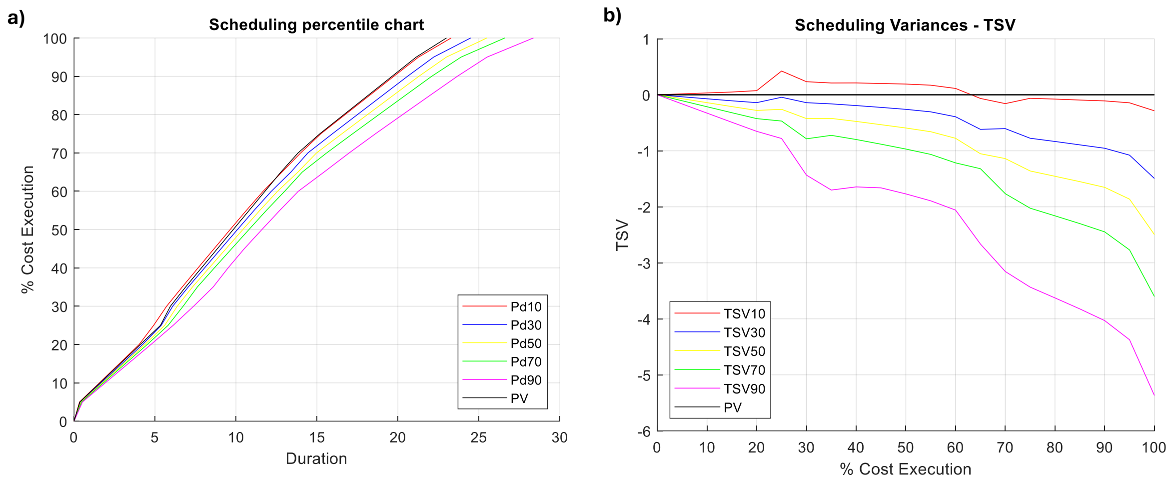


Fig. 2.37 *Project duration TRIAD Curves: a) Percentile curves. b) TSV curves*

Fig. **2.38b** illustrates the **Time Cost Variance** (TCV) indicator that this methodology defines. TCV is calculated as the difference, upon each % completion, between the percentile value (or the ongoing project value) and the planned value. The graph plots TCV curves for the percentiles on the (TCV, % completion) axis. To monitor the project at a specific time, the control point is plotted upon current % cost completion, along with the corresponding TCV value.

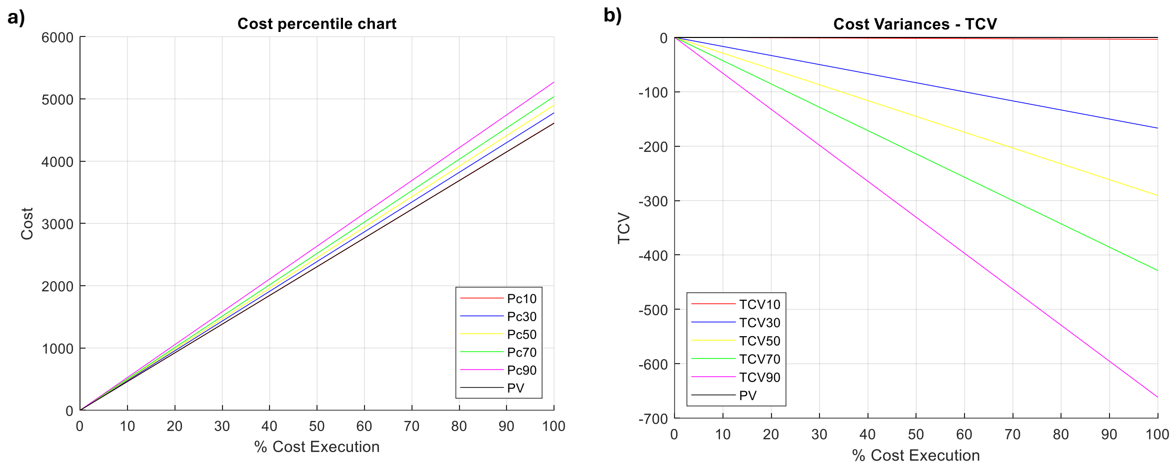


Fig. 2.38 *Project cost TRIAD curves: a) Percentile curves. b) TCV curves*

2.7.2 Export Triad data to Excel®

On the **TRIAD** secondary menu (see Fig. 2.36), you can export the numerical data for the TRIAD graphs and indicators to an Excel® file. It is not necessary to generate graphs before exporting. Selecting this option creates an Excel® file named "**Triad.xlsx**", which includes the data needed to produce the graphs shown in Figs. 2.37 and 2.38 (percentile curves for duration and cost, TSV and TCV curves). The file is saved in the exact location of the **MCSimulRisk.exe** application.

If a file named "**Triad.xlsx**" already exists and you attempt to export again, a pop-up window displays an error message indicating that the file already exists in that location.

2.7.3 RETURN

This option allows you to return to the main menu (see Fig. 2.5).

2.8 SLT

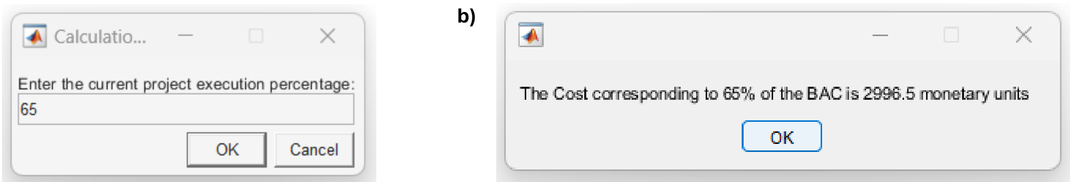
The '8. SLT' option on the main menu provides graphical and numerical representations of the **SLT (Statistical Learning Techniques)** methodology proposed by Acebes et al. (2015)[3]. This methodology significantly advances project monitoring and control in uncertain environments.

SLT compares planned and simulated projects at two key points: upon project completion and the current execution time. By utilising advanced machine learning techniques, these representations and numerical data allow the percentile to be identified at which the ongoing project stands and to estimate the final duration and cost.

Upon selecting this option, **MCSimulRisk** displays a pop-up window that prompts you to enter the current percentage of project execution to be monitored, with the message: "Enter the current percentage of project execution:" (see Fig. 2.39a). After entering data and clicking '**OK**', an informational window displays the corresponding Budget Upon Completion (**BAC**) for the entered % of execution (see Fig. 2.39b).

Subsequently, once calculations are complete, a new pop-up window entitled: "Select the desired option:" appears (see Fig. 2.40) and offers the choice of viewing the SLT methodology graphs or exporting data to an Excel® file.

a) b)



[3] Acebes, F., Pereda, M., Poza, D., Pajares, J., & Galán, J. M. (2015). Stochastic earned value analysis using Monte Carlo simulation and statistical learning techniques. International Journal of Project Management, 33(7), 1597–1609. https://doi.org/https://doi.org/10.1016/j.ijproman.2015.06.012

Fig. 2.39 *SLT methodology: a) Input percentage of execution. b) Result pop-up window*

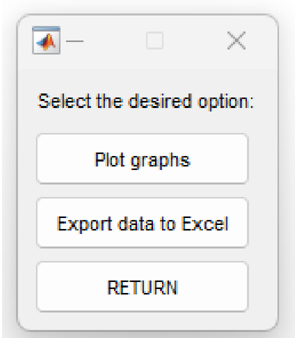


Fig. 2.40 *SLT secondary menu*

2.8.1 Plot graphs

Clicking this option displays the specific graphs used in the SLT methodology for project monitoring and control (see Fig. 2.41).

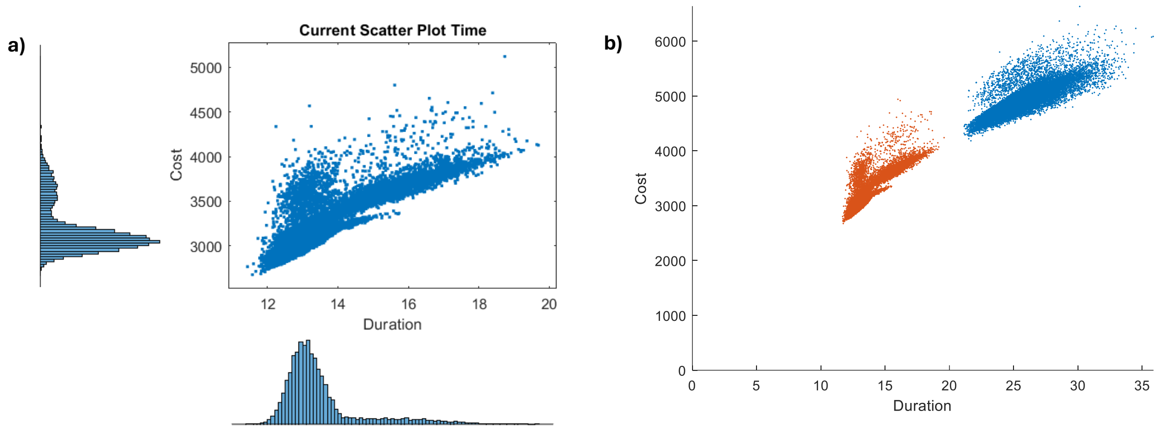


Fig. 2.41 *SLT methodology curves: a) Scatter plot of projects at the control point. b) Scatter plot of the simulated projects at the control point and project completion. c) Simulated projects at the control point with and without delay. d) Simulated projects at the control point with and without cost overrun*

Fig. 2.41a shows a Scatter Plot of the planned and simulated projects at the control point, which correspond to the entered % of project execution on a Cartesian Duration-Cost diagram.

Fig. 2.41b compares the simulated projects at two times: at the control point (red scatter points, according to the % of execution) and upon project completion (blue scatter points).

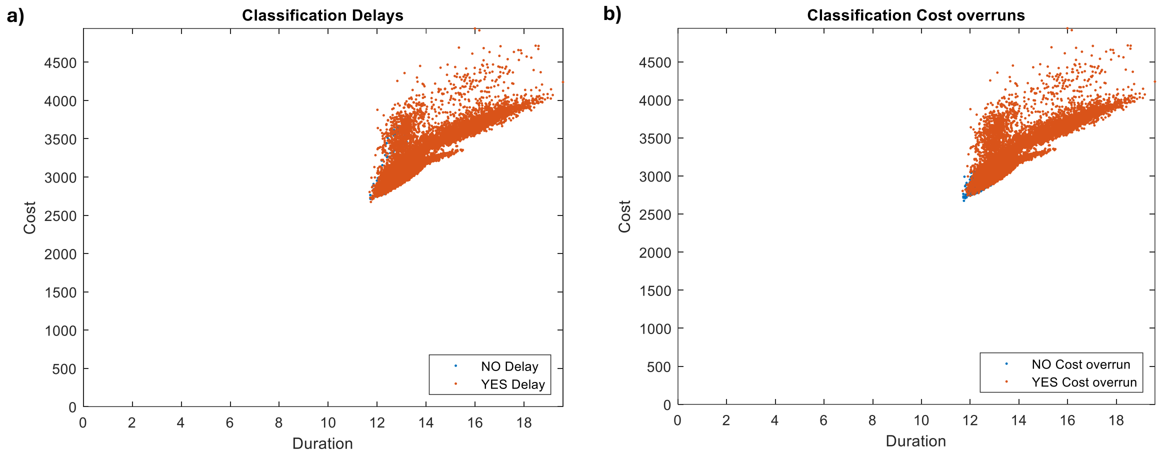


Fig. 2.42 *SLT Methodology Curves: a) Simulated projects at the control point with and without delay. b) Simulated projects at the control point with and without cost overrun*

Fig. 2.42a distinguishes simulated projects at the control point: those expected to be delayed compared to the initial plan (in red) and those that are not delayed (in blue).

Fig. 2.42b differentiates the simulated projects at the control point: those expected to incur a cost overrun compared to the plan (in red) and those that so not (in blue).

2.8.2 Export data to Excel®

On the **SLT** secondary menu (see Fig. 2.40), you can export the numerical data related to the SLT graphs and indicators to an Excel® file. It is not necessary to generate graphs beforehand. Selecting '**Export data to Excel'** creates an Excel® file named "**SLT.xlsx**" that contains all the information needed to produce the graphs shown in Fig. 2.41.

The **first tab** of the Excel® file includes data from 20,000 simulations performed by the application with the following variables: duration and cost at the current control point, duration and cost at the final execution point, delay indicator (1 = yes, 0 = no), cost overrun indicator (1 = yes, 0 = no), final delay (compared to the plan) and final cost (compared to the plan). The **second tab** contains the duration and cost data for the actual ongoing project. The file is saved in the same directory as the **MCSimulRisk.exe** application.

It is recommended using these data in statistical programmes, such as 'R' or 'Python', to address classification and regression problems. This enables you to determine the execution percentile of the actual project and to estimate the total duration and cost.

If a file named "**SLT.xlsx**" already exists and you attempt to export again, the application displays an error message indicating that the file already exists in that location.

2.8.3 RETURN

This option allows you to return to the main menu (see Fig. 2.5).

2.9 Quantitative Risk Prioritisation

The '9. Quantitative Risk Prioritisation' option on the main menu (see Fig. 2.5) enables the prioritisation of identified project risks. Instead of using a traditional probability-impact matrix, **MCSimulRisk** applies the **QRP (Quantitative Risk Prioritisation)** methodology developed by Acebes et al. (2024)[4] to generate a prioritised list of risks based on their relevance to the project's duration and cost objectives.

When selecting this option, the application prompts you to enter a percentile to calculate priorities. This value reflects the risk aversion level because probability distribution functions require this level to perform calculations. A pop-up window appears entitled "Enter the Percentile for Quantitative Risk Prioritisation" in which you should input the desired percentile (see Fig. 2.43).

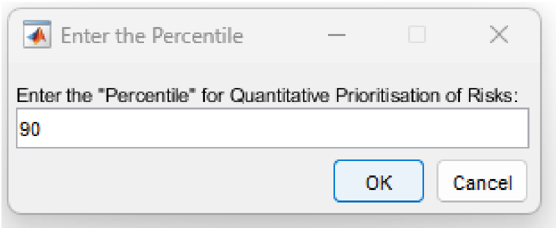


Fig. 2.43 *Window for inputting percentile for calculations*

Having entered the percentile and clicked '**OK'**, the application displays the total project duration and cost corresponding to that percentile (see Fig. 2.44). These values are used internally to effectively prioritise risks.

```
The Project Duration for this percentile is    28.3039

The Project Cost for this percentile is    5.2674e+03
```

Fig. 2.44 *Informational text displayed on the command screen*

After calculations, a pop-up window entitled "Select the desired option" appears (see Fig. 2.45). This window displays the risk prioritisation results on the screen or you can export numerical data to an Excel® file.

[4] Acebes, F., González-Varona, J. M., López-Paredes, A., & Pajares, J. (2024). Beyond probability-impact matrices in project risk management: A quantitative methodology for risk prioritisation. Humanities and Social Sciences Communications, 11(1), 670. https://doi.org/10.1057/s41599-024-03180-5

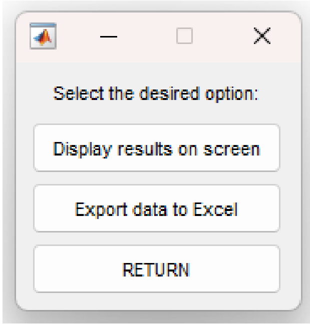


Fig. 2.45 *QRP secondary Menu*

2.9.1 Display results on the screen

To view the risk prioritisation results using the QRP methodology, click "Display results on the screen" on the secondary menu (see Fig. 2.44). Two lists are presented:

1. **Disaggregated Risk Table:** this list treats risks as independent. It firstly includes all the risks that affect duration, followed by those that impact cost. If a risk affects both objectives, it is broken down into two separate risks. Risks are numerically coded (R1, R2, etc.) (see Fig. 2.46)
2. **Quantitative Prioritisation of Risk:** On this list, the risks that impact both duration and cost are unified with alphanumeric codes (Ra, Rb, etc.). This list is the more relevant one.

Disaggregated_Risk_Table =

5×5 table

	Duration_without_R	Cost_without_R	Difference_Duration_without_R	Difference_Cost_without_R	Same_Risk
R1	27.34	5179.9	0.96419	87.579	1
R2	28.247	5262.7	0.056912	4.7414	2
R3	28.168	5243.5	0.13575	23.938	3
R4	28.304	5255.8	0	11.628	2
R5	28.304	5221.8	0	45.583	4

Quantitative_Prioritisation_of_Risks =

4×4 table

	Duration_Diff	Ranking_Dur	Cost_Diff	Ranking_Cost
Ra	0.96419	1	87.579	1
Rb	0.056912	3	16.37	4
Rc	0.13575	2	23.938	3
Rd	0	4	45.583	2

Fig. 2.46 *Risk prioritisation results shown on the command screen*

In the Example Project (see Table 1.2 and Fig. 1.18 in the 'Pyto_ejemplo.xlsx' file), it is observed that Ra only affects duration and corresponds to R1; Rb impacts both duration and cost, and is split into R2 (duration) and R4 (cost); Rc only affects duration; Rd only affects cost and corresponds to R3 and R5, respectively.

The first list shows a table with rows for each disaggregated risk. The initial columns display the project's total duration and cost after removing each risk compared to the original values (Fig. 2.43). The final column indicates how disaggregated risks are grouped on the second list.

On the second list impacts are aggregated. For example, as **Ra** corresponds to R1, the differences in duration and cost are identical. **Rb** combines risks R2 and R4. The difference in duration is calculated by adding only the relevant components (R2), while the cost impact includes the indirect contribution from R2 and the direct component from R4. So total cost impact for Rb is the sum of both components: 16.37 (4.7414 from R2 and 11.628 from R4).

The list also ranks risks based on their impact on duration and cost.

2.9.2 Export data to Excel®

On the **QRP** secondary menu (Fig. 2.45), you can export the quantitative prioritisation data to an Excel® file named "**EvCuantRiesg.xlsx**". It is not necessary to view results on the screen before exporting. The file includes the data shown on the screen (see Fig. 2.46) and is saved in the exact location of the **MCSimulRisk.exe** application.

If a file with that name already exists and you attempt to export it again, a message appears indicating that it already exists.

2.9.3 RETURN

This option allows you to return to the main menu (see Fig. 2.5).

2.10 Export simulation data to Excel®

The '10. Export simulation data to Excel' option allows you to export Monte Carlo simulation data to an Excel® file named '**Datos_sim.xlsx'**. The generated file includes six tabs with the following information:

- **'Possible Paths with Risks'**. A matrix of possible project paths, including risks. This matrix shows all the potential routes in the project network based on precedence relationships, but they do not necessarily represent critical or the longest paths
- **'Possible Paths without Risks'**. A matrix of possible project paths, excluding risks. It calculates all the possible routes after removing the identified risks

- **'Percentiles'**. Percentiles of total duration and cost are calculated at five-percentile intervals following Monte Carlo simulation
- **'PV Curve'.** Duration and cost values form the planned (**Plan Value – PV**) curve
- **'Simulation Data'.** Detailed simulation data for the specified number of simulations (20,000 by default). This includes the duration of each activity (with risks treated as activities), the fixed costs for each activity and the project's total duration and cost
- **'Topological Indicators'.** Network topological indicators that provide insights into the project's structure. This includes the Series/Parallel Indicator (SP), Activity Distribution (AD) and Topological Float (TF)

Let's assume that a file named "**Datos_sim.xlsx**" already exists, and you attempt to export again. In this case, a pop-up window displays an error message indicating that the file already exists in the exact location.

2.11 EXIT

This option, available from the main menu (see Fig. 2.5), terminates and closes the application.