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Monte Carlo Simulation, Applied To Risk Assessment Of Projects, With Crystal Ball®

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Abstract
This work aims at presenting the outcomes of using the Monte Carlo simulation analysis in the risk assessment of projects in regards to the management of risks during the activities planned in the scope. To do so, the Crystal Ball® tool, which uses the Monte Carlo simulation based on electronic spreadsheets, was adopted in order to perform simulations, predictions and optimizations with the purpose of supporting decision-making. The study enables to verify the probabilities of occurrence of the calculated values through PERT technique for the duration estimates of a software implementation generic project.
Keywords: *Crystal Ball®. Monte Carlo. Projects. Simulation.*

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I. INTRODUCTION

The risk assessment aims at increasing the probability and impact of positive events and reducing the probability and impacts of negative events in these processes, throughout the whole project (PMBOK, 2013).

The use of Monte Carlo simulation in order to obtain future results is highly feasible. Such simulation is a tool used for decision-making regarding the several types of problem solvings, mainly during situations that involve risk assessment to predict the result of a decision before uncertainties. This simulation when used for managerial problems requires the mathematical modelling of the system to be investigated, standing out the variables and problem 's relevant relations.

The Monte Carlo simulation, which is a technique of discrete events simulation, when applied to the management of projects aims at creating a qualitative analysis that carries out an assessment of occurrence probabilities and impacts of the identified risks. Such risks may be assessed in a quantitative way and a numerical analysis of the effects those risks might have on the project is carried out.

This work aims at presenting the outcomes of using the Monte Carlo simulation analysis in the risk management of projects in regards to the risk assessment during the activities planned in the scope. The increase of deadlines and costs is a frequent issue in the development of projects. The Monte Carlo simulation analyzes the risks and enables to assess quantitatively the likelihood of cost and term increase and can also be used as a decision support tool regarding the launching of a new project.

For the elaboration of this work, the exploratory and explicative research method was used. In order to be more familiar with the subject, it used bibliographic research related to the topic. The current work is justified once it suggests the use of Monte Carlo simulation as a tool to assist the analysis of projects, without significantly adding costs, as well as the lack of having a statistics deeper knowledge, providing the manager a greater sophistication and accuracy of informations, as it is observed the lack in the use of simulations for costs and terms estimates.

Nowadays, there are simulation techniques that are well explored in the risk assessment areas, however, they are little passed on among the project Managers. The uncertainties found in the projects are numerous and to minimize them is a task that very few Managers are aware of. In this context, the simulation techniques arise as an important tool to predict and minimize uncertainties of costs and projects' duration.

As an alternative, the Monte Carlo Simulation, as per segundo Moore (2005), can be largely used in the assessment of projects, in which the risks involved may be expressed in a simple way and easy to read, and the simulations assist the decisions. Thus, the indicators are no longer deterministic and become stochastic and probabilistic.

II. DEFINITION OF PROJECT

According to Dinsmore (2011), the project is a fundamental instrument for all changing activity and generation of products and services. It can involve one single person or even thousands of people, organized in groups and with duration that may vary from some days to several years.

As per Woiler (2008), it is a group of internal and/or external information to the company, collected and processed with the objective to analyze a decision of investment. Under these conditions, the project is not confused with the information, since it is understood as a model that, when incorporating qualitative and quantitative information, attempts to simulate the decision to invest and their operations.
A project is characterized by the temporary effort undertaken with the intention of creating a product, a service or achieving an exclusive result.

1. Temporary: it means that all the projects have well defined beginnings and endings. The end is reached when the project goals are achieved, when it is clear that they are not or they will not be achieved or when the project is no longer necessary and it is closed.
2. Products, services or exclusive outcomes: a project generates exclusive deliveries that are products, services or outcomes. The projects can generate a produced and quantifiable object that can be a final item or a component item, capacity to perform services and results.
3. Progressive elaboration: characteristics of projects that integrate the temporary and exclusive concepts. It means to develop through stages and to carry on through increments, that is, the project scope will be generally described in the beginning and will become more detailed as it develops a more complete understanding of the goals.

In order to facilitate the project 's progressive elaboration and the management control, the projects are divided into phases, which are determined by the characteristics and specific needs of each project and from the management experience, that is, they describe what is necessary to do in the project, Dinsmore (2011). According to (PMBOK, 2013), these phases are: initiation, planning, execution, control and closure.

2.1 MANAGEMENT OF PROJECTS

Managing a project is like putting a puzzle together. Each piece must be properly placed, in a coherent and consistent way, in order to achieve the expected results. This management involves decision-making directly linked to the project goal and to the development and execution processes. as well as the control process of the Dinsmore project (2011).

According to Kerzner (2006), a successful project management demands planning and extensive coordination, that is, the work flow and the project coordination must be horizontally administered. The horizontal organization implies that the work is organized throughout many functional groups permanently interacted, that is, it improves the coordination and communication between subordinates and managers.

"Project management is the applicability of knowledge, skills, tools and techniques in the project activities in order to meet all the requirements (PMBOK, 2013)." Yet, in accordance with (PMBOK, 2013), project management is an integrating venture and such integration requires that each process of the project and the project is properly associated to other process to facilitate its coordination. These processes are agregated into five groups: initiation process group; planning process group, execution process group; monitoring and control process group and closure process group. Esses processos são agregados em cinco grupos: grupo de processo de iniciação, grupo de processo de planejamento, grupo de processo de execução, grupo de processo de monitoramento e controle e grupo de processo de encerramento. 44 processes total.

These 44 processes of the project management groups are organized in nine areas of knowledge: project integration management; project scope management, project duration management; project costs management, project quality management, project human resources management, project communication management; project risk management and project acquisitions management (DINSMORE, 2011).

This work is only delimited to the area of knowledge of risk management.

2.1.1 PROJECT RISK MANAGEMENT

A risk is defined by any event or potential condition that, if consolidated, might positively or negatively affect a project 's object. It has two key dimensions: the probability, which is the chance of happening and the impact, which is the effect on the project, in case of manifestation of the event or risk condition (DINSMORE, 2011).

According to (PMBOK, 2013), the risk management of a project includes processes that deal with identification, analysis, responses, monitoring, control and planning of the project 's risk management. The purposes of managing risks are to increase the probability and the impact of positive events and to reduce the probability and the impact of negative events to the project.

The management of risks must be initiated after the planning, that is, the project must have already defined its goal, planned the deliveries, the quality, the schedule, the estimate of costs or the result projection, which means, a concluded project proposal, whereas these information are needed as basis for the risk management (SALLES, 2009).

Once the plan that will guide all the actions related to the risk management is established, the risk identification process must be presented. This process can be seen as critical, since only the known and identified risks may be suitably measured (CARVALHO, 2005). The objective of this identification process is to create a refined list of what can threaten or cause opportunities in relation with the project's goal.

2.1.2 PROJECT'S RISK ASSESSMENT

In accordance with Salles (2009), every risk presents a related probability which is not zero, considering zero as the assurance of non-occurrence of the event, and neither 100%, which is the fact will surely happen, and if it happens, it will cause an impact. The seriousness of the risk can be measured in two ways, which are not mutually exclusive, through the qualification or quantification and can be complementarily used.

In the qualitative analysis, the impact and the probability of risks are identified and assessed so that, later, they are classified according to its individual potential and prioritized due to its potential effect for the project as a whole. While quantitative analysis is characterized through measurement, numerical analysis of probabilities, impact of risks uniquely and numerical projections for the project as a whole, the most common analysis and quantitative techniques are the sensitivity analysis, decision tree and simulation methods (DINSMORE, 2011).

III. SIMULATION

In 1972, the first simulation languages appeared, such as IBM, GPSS and Fortran. It developed from 1982 to 1984 with the first environments for the simulation in micro computers. From 1980 to 2008 with simulation environments for practically all environments handily used for modeling, analyzing and assessing (STRACK, 1984)

Prado (2010), assures that: "simulation is a problem solving technique through the analysis of a model that describes the behavior of the system using a digital computer".

A system can be defined as: "a group of interrelated parts that when connected, act as per the standards established upon inputs in the sense of producing outputs" (HARDING, 1972). It may be easily divided into subsystems and relate one subsystem to another.

According to Harding (1972), the systems can be classified in two groups: pode-se classificar os sistemas em dois grupos: the deterministic systems and the probabilistic ones. The Deterministic Systems are those exactly predictable and work in accordance with the rules. However, the Probabilistic Systems are those that can only be foreseen through probabilities, which the operation rules are not exactly determined.

The systems are used in the construction of the models used in simulations. A model can be defined, according to Strack (1984), as the "representation of an object, system, or idea is any other way, but the identity itself." It is known that each model has its own characteristics, therefore, there are no available rules for its construction. Although, in order to build a good model, its evolutive characteristic must be taken into consideration. It is essential to start in a simple way and evolve for a greater elaboration, increasing the degree of complexity regarding the proposed objectives.

Such an approach is carried out through modeling, which is the ability to analyze the problem, considering the essential aspects, to select and modify the basic hypothesis that characterize it and make them better (STRACK, 1984).

From the fifties, with the advent of the first computers, "the idea of the Monte Carlo Method was expanded for the solution of more general probabilistic problems, just like the case of the queues; this way, the Monte Carlo simulation had been born" (GAVIRA, 2003).

3.1 THE ADVANTAGES AND DISADVANTAGES OF SIMULATION

According to Law (2007), some of the advantages of adopting the simulation are: to allow the estimate of an annual system development under different operational conditions; to enable the comparison of alternative proposals of systems or operational policies in order to verify what is better adapted to the requirements; to permit a better control on the experimental conditions even before implementing them; and to enable the study of a system for an extended period in relatively short time.

As per Turrioni (2012), some of the disadvantages of using simulation are: the high cost to acquire softwares or using expert consultants; a lot of time being wasted and benefits not being immediately available; necessity of a significant amount of data.

3.2 MONTE CARLO SIMULATION

Monte Carlo simulation emerged in 1949 with the article *The Monte Carlo Method* written by the Mathematicians John von Neumann and Stanislaw Ulam. According to Ulam, the name of the method was given in honor to his uncle who used to often go to the Monte Carlo casino, which contrasts with the idea of direct association with the repetitive and random nature of the casino's roulette, for instance. Although this method was previously known, its use was indeed initiated with the advent of calculators and computers, osice it is a numerical method (SOBOL, 1994).

The Monte Carlo Simulation is a numerical method that enables the resolution of mathematical problems through the simulation of random processes. This methodology is considered mathematically better than the resolution through equations, which would make this problem complex in a way that could not be expressed by a simple analytical solution. One peculiarity found in the Monte Carlo simulation is the very simple structure of its algorithm. Following the rule, first, a program elaborated to perform a random event. After, this event is repeated several times in a way each experience is independent on the others and the outcome average of all events is taken. The other peculiarity is the statistical uncertainty is generally proportional to $\sqrt{D/N}$,having D as a constant and N as the number of events. This formula indicates that in order to reduce the error by 10 times, it is necessary to increase N 100 times (PALACIO, 2010).

According to Freitas (2008), when using this kind of simulation, two fundamental points must be considered. One is that data must be artificially generated by a random numbers generator and the other is the frequency distribution of the variable in interest. Still, according to Freitas (2008), a random number generator must be able to generate independent values and they must be uniformly distributed in a range from 0 a 1.

As per Vose (1996), the main advantages of the Monte Carlo simulation are:

i. the distributions of the variables probabilities do not need to exact, they can be approximate;
ii. correlations and other independencies may be modelled;
iii. the math level involved in the simulation is not very high;
iv. there are softwares commercially available;
v. the highest levels of accuracy can be achieved by the increase of the iteration numbers;
vi. complex mathematical calculations can be easily included;
vii. the method is widely acknowledged as a valid technique so that the results can be easily accepted;
viii. changes in the model can be quickly made.

Nowadays, the Monte Carlo simulation is a methodology often used in the risk assessment field in order to assess the variability of the studied characteristics, under different scenarios, also to quantify the risks of certain events, besides to be used on the models related to probabilistic events (PALACIO, 2010).

3.2.1 MONTE CARLO SIMULATION AND THE PROJECT'S RISK MANAGEMENT

According to Palacio (2010), Van Slyke was the pioneer to propose the use of the Monte Carlo simulation within the projects management in the sixties. Slyke was motivated by the perception of some limitations in the existing management tool hitherto, such as, CPM (*Critical Path Method*) and PERT (*Project Evaluation and Review Technique*). As per Hirschfeld (1978), the planning with the o PERT/CPM methods is carried out through a network, in which a logical sequence of the plan is presented in order to achieve a specific goal. In this network, it is inserted the tasks' duration for an analysis of time optimization e/or cost and programing.

Van Slyke (1963) takes into consideration the unexpected phenomenon that occurs during the execution of a project, for instance, the random variables in runtime of an activity. In the Monte Carlo simulation, the runtime of an activity appears as a distribution function of probability of a certain activity.

Therefore, in the Monte Carlo simulation N consecutive samples are randomly created in terms of cost or time, a random variable, which will be analyzed in a statistical model, later known as a distribution of probability for a determined project risk. Each sample corresponds to a method iteration. Thus, Monte Carlo simulation provides a value estimation of time or cost expected as an error for such estimation, which is inversely proportional to the iteration number. That is, the synthesis of the Monte Carlo simulation is to establish a distribution of probability (model) in which a random variable (time or cost) responds to the risk analyzed and to sample this variable as many times as possible (PALACIO, 2010).

As in any other project, there are many identified risks, in the Monte Carlo simulation, the random variables are numerous and in order to get the result of several random variables simulation, it is necessary to sum up these variables for each iteration. In order to guarantee that the simulation is accurate, the independence or non-linearity of the random variables is very necessary. That involves that the simulated risk events are also independent (PRADO, 2010).

So that the results achieved have high standards, it is necessary that the model choice, that is, the best distribution of probability for each risk analyzed is taken into consideration. The ideal is to have a historical basis of project risks in general. From this basis, it is possible to use statistical methods or softwares of curves fitting to find the distribution of probabilities that better represents a certain historic (PALACIO, 2010).

In the lack of historical data, it is possible to investigate whether the traditional modelings can be applied or to use a triangular distribution or Beta-PERT, in which three parameters are necessary: a value of time/cost in which the risk is minimum; other value in which the risk is maximum and a third one in which the risk is more likely (PALACIO, 2010).

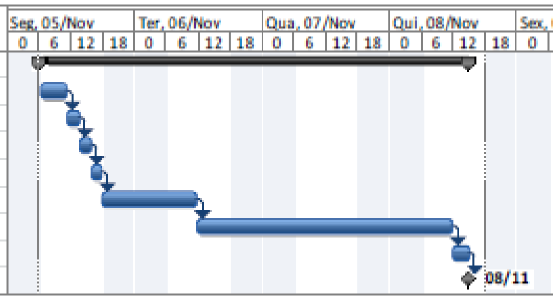
IV. THE APPLICATION OF THE MONTE CARLO SIMULATION IN A PROJECT'S RISK MANAGEMENT

This study aims at verifying the Monte Carlo Simulation performed by AGUIAR, 2010, which assures that the Monte Carlo simulation is carried out in a simple project, without division by delivery and its structure refers to the implementation of a standard software product. The study seeks to present a certainty percentage for the duration of the project.

The study used the software named Crystal Ball®, which is a tool that deals with simulations and predictions through Microsoft Excel. Crystal Ball® was developed by Oracle® and is available for downloading in the manufacturer website with a 14-day-test version.

In the schedule proposed by Aguiar (2010) as follows, the activities to be followed for the implementation of a product is presented and used by software companies for management of quality. Data related to the project are based on the historical information from many executions with different clients. However, a model for the implementation of any software can not be considered.

Id		Modo da	Nome da tarefa	Duração
1			**Implantação de um produto padrão**	**3,6 dias**
2			Primeiro contato com cliente	2 hrs
3			Levantamento do ambiente de TI do cliente	1,5 hrs
4			Nivelamento do Ambiente de Ti	2,25 hrs
5			Instalação do produto	1,75 hrs
6			Testes e Homologação	3,1 hrs
7			Capacitação e treinamentos	16 hrs
8			Liberação de documentos sobre a implanta	2,2 hrs
9			Finalização da implantação	0 dias



Picture 1. Gantt graphis and the analyzed projects' duration.
Source: Adapted from Aguiar, Alves and Henning (2010)

4.1 MODEL DEVELOPMENT

Starting from the proposed schedule, seven main activities are listed, from the finalization project mark, which has no duration, the ID and the Name of the Task, are still informed for each activity, the estimated duration, the best and the worst case for each activity, see picture 2. The F column, PERT, calculates an estimation for the duration of an activity through the following equation:

$$PERT = \frac{((Estimated\ Dur.\ x\ 4) + B.Case + W.Case)}{6}$$

Estimated Dur. = Estimated Durationção
B.Case = Best Case
W.Case = Worst Case

A	B	C	D	E	F	G	H
ID	Nome da tarefa	Duração estimada (em horas)	Melhor caso (em horas)	Pior caso (em horas)	PERT (em horas)	Simulação (em horas)	Tipo de Distribuição
1	Primeiro contato com o cliente	2	1,6	2,4	2,00		Triangular
2	Levantamento do ambiente de TI do cliente	1,5	1,4	3	1,73		Triangular
3	Nivelamento do ambiente de TI	2,25	2,1	5	2,68		Triangular
4	Instalação do produto	1,75	1,4	2,1	1,75		Triangular
5	Testes e Homologação	3,1	1,5	4	2,98		Triangular
6	Capacitação e treinamentos	16	15,9	18,1	16,33		Triangular
7	Liberação de documentos sobre a implantação	2,2	1,9	3,12	2,30		Triangular
8	Finalização da implantação				0,00		
	TOTAL	**28,8**	**25,8**	**37,72**	**29,79**		

Picture 2: Chart with the project's activities and their terms estimations
Source: elaborated by the author.

In the G column (Simulation), the input variables are described for the simulation, in which Crystal Ball® names as Assumptions. H column (Type of Distribution), indicates which is the best distribution for the data. For this study, only the triangular distribution will be used, though, since there is no historical data available that works as a basis to another kind of distribution.

All the information regarding the estimations of the activities are expressed in hours and based on Aguiar's original study (2010), with the exclusion from this basis, the PERT column.

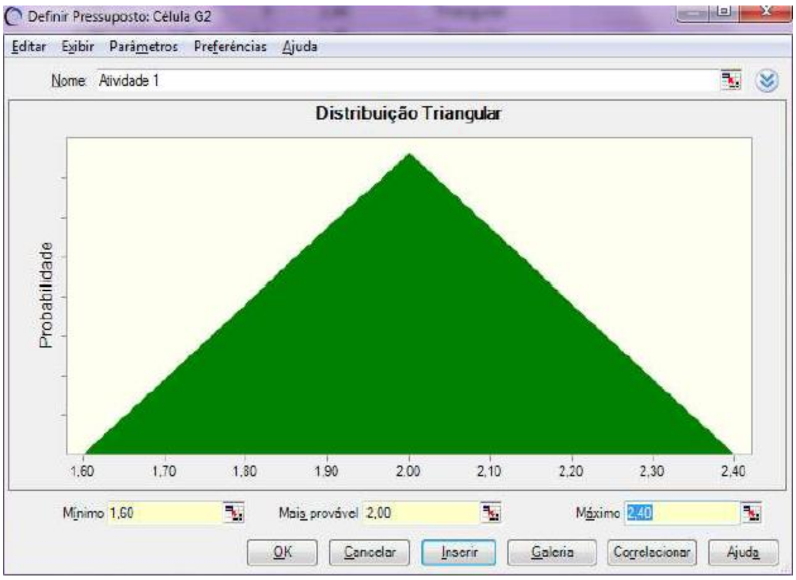
4.2 IDENTIFICATION OF UNCERTAINTIES

According to Aguiar (2010), this step is very important, since, from it, all the modeling will use the identified variables. If any variable is wrongly defined, it might jeopardize all the models, implying wrong decisions in the project. For this study, the uncertainties are related to the duration of each activity individually which might compromise the duration of the project as a whole, after all, the activities have a relation of ending-beginning, that is, an activity will only start when the previous one ends. Yet, Aguiar (2010), mentions that "the duration of a project can be used as uncertainty, but rather as the result of a sum of uncertainties identified in this case". Therefore, each activity becomes an input variable in the software. See following picture:

A	B	C	D	E	F	G	H
ID	Nome da tarefa	Duração estimada (em horas)	Melhor caso (em horas)	Pior caso (em horas)	PERT (em horas)	Simulação (em horas)	Tipo de Distribuição
1	Primeiro contato com o cliente	2	1,6	2,4	2,00	0	Triangular
2	Levantamento do ambiente de TI do cliente	1,5	1,4	3	1,73	0	Triangular
3	Nivelamento do ambiente de TI	2,25	2,1	5	2,68	0	Triangular
4	Instalação do produto	1,75	1,4	2,1	1,75	0	Triangular
5	Testes e Homologação	3,1	1,5	4	2,98	0	Triangular
6	Capacitação e treinamentos	16	15,9	18,1	16,33	0	Triangular
7	Liberação de documentos sobre a implantação	2,2	1,9	3,12	2,30	0	Triangular
8	Finalização da implantação				0,00		
	TOTAL	28,8	25,8	37,72	29,79		

Picture 3: Project data after the definition of all variables of input.
Source: author's elaboration

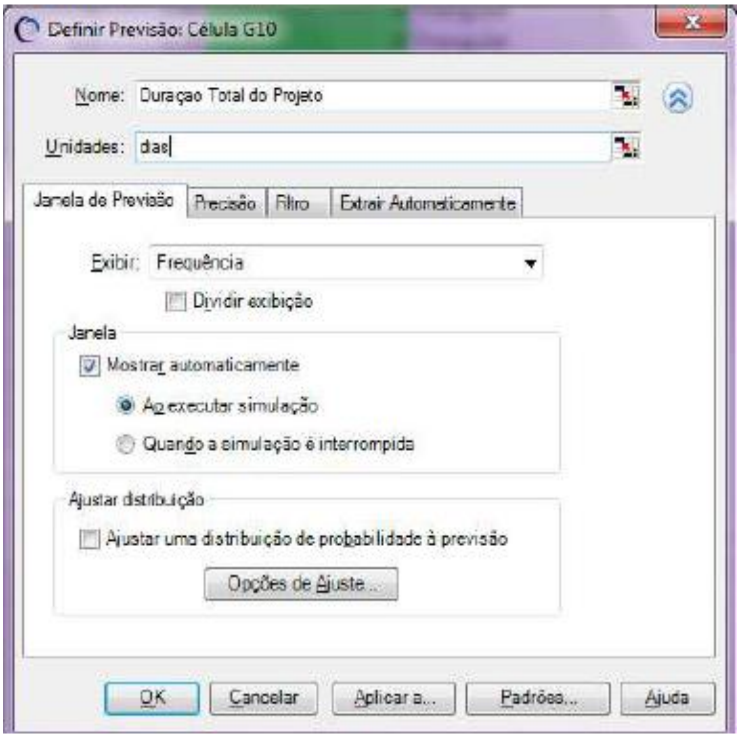
In the original study, the authors identified what type of distribution fit better for each activity, since they owned the history of a single one of them. In this study, all the activities were identified by the triangular distribution due to only having the values of the Best Case (Min), the Most Likely and the Worst Case (Max). Picture 4 shows an example of configuration of one of the input variables, the variable representing activity 1.



Picture 4: Input variable configuration.
Source: author's elaboration

4.3 IDENTIFICATION OF ANALYSIS OR OUTPUT VARIABLES

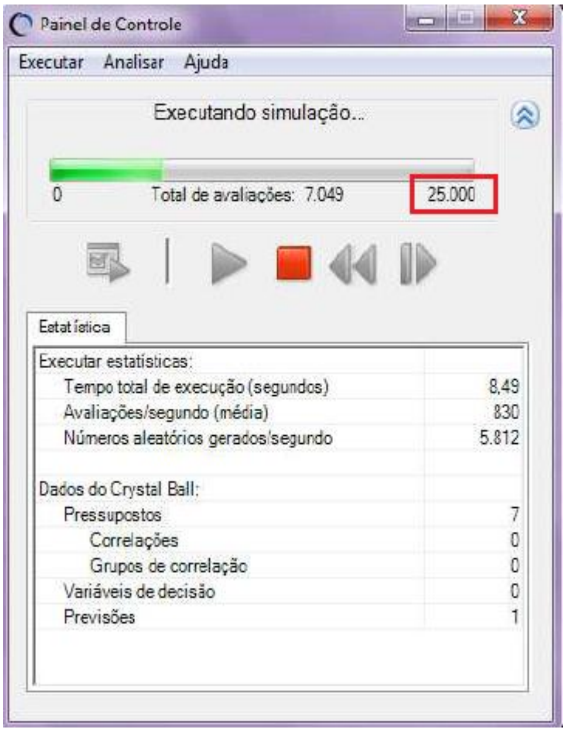
The variable analyzed in this study, what the software names as "Prediction", was the full duration of the project before the individual simulations of each activity. To do so, the formula "SOMA(G2:G8)" was used from Excel to sum up the simulation values of each activity. The values calculated for each iteration were saved in the software for further analysis, as shown in picture 5.



Picture 5: Output variable configuration. Project's full duration.
Source: author's elaboration

4.4 THE SIMULATION

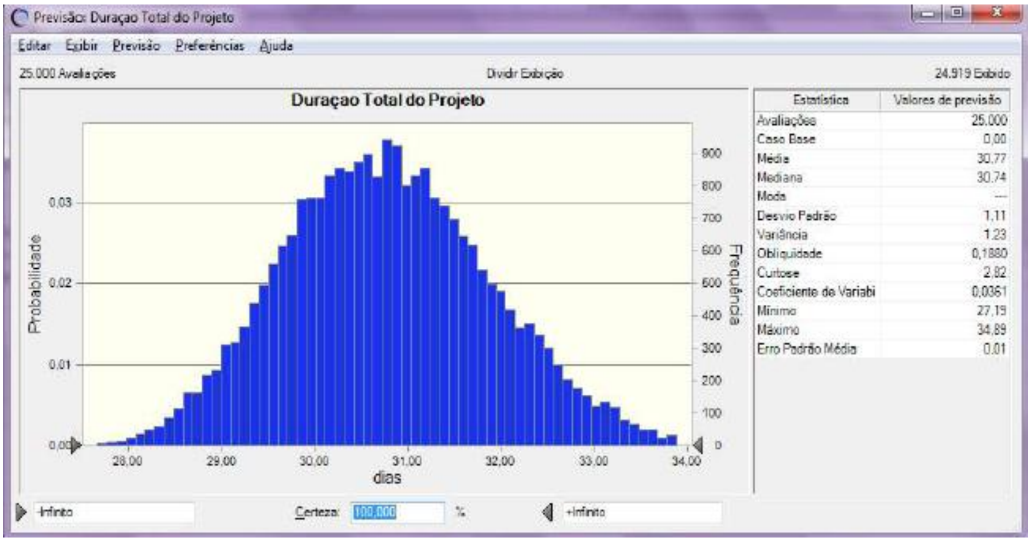
The next step for the simulation was to use the Crystal Ball® option for execution. The amount of repetitions can interfere in the final result of the simulation, however, according to Aguiar (2010), the execution with ten thousand repetitions is a high number and will result in a regular distribution. like the output variable. In any event, the number of repetitions can be easily configured and for this study, 25.000 repetitions were used, as observed in picture 6.



Picture 6: Simulation execution control panel.
Source: author's elaboration

4.5 SIMULATION ANALYSIS

After the simulation had been carried out, it was possible to obtain data like: the frequency graphic, the minimum, average and maximum duration of the project, median, variance and standard deviation, among other information shown in picture 7.



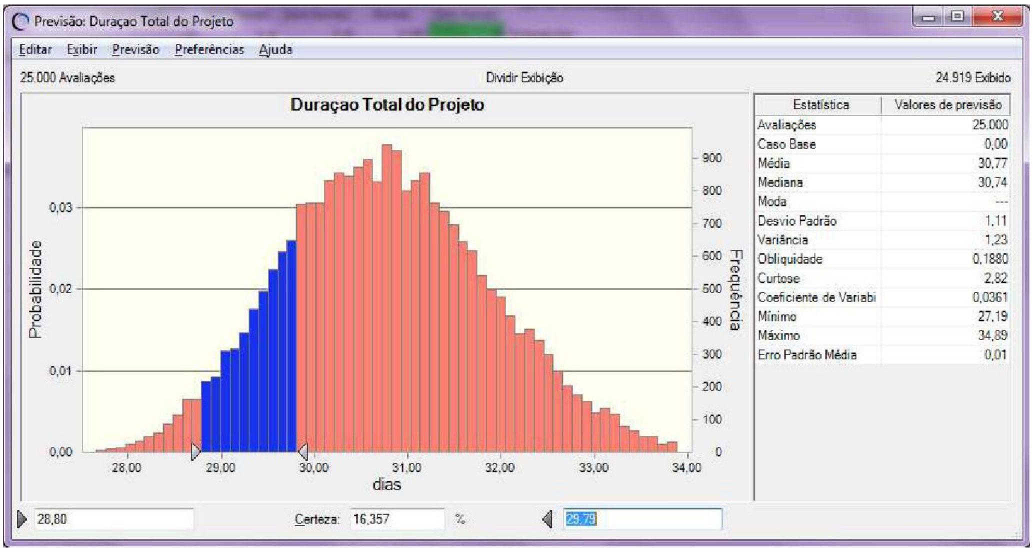
Picture 7. Frequency graphic and output variables statistics
Source: author's elaboration

The simulation made it possible to observe that the average obtained regarding the full duration of the project was 30,77 hours. This duration is greater than the expected duration of 28,8 hours and the one calculated by PERT, was 29,79 hours, as per picture conforme 3.

The minimum value found in the simulation for the duration of the project was 27,19 hours, which is greater than the D column summation, the best case in picture 3. The maximum value found in the simulation was 34,89 hours, which is less than the summation of the E column, the worst case in picture 3. So, it is concluded that the chance of all activities to be the worst or the best cases in the same repetition is respectively 0%.

In the Crystal Ball®, it is still possible to define a range for the verification of the certainty percentage and vice-versa, as seen on the bottom of the window shown in picture 7.

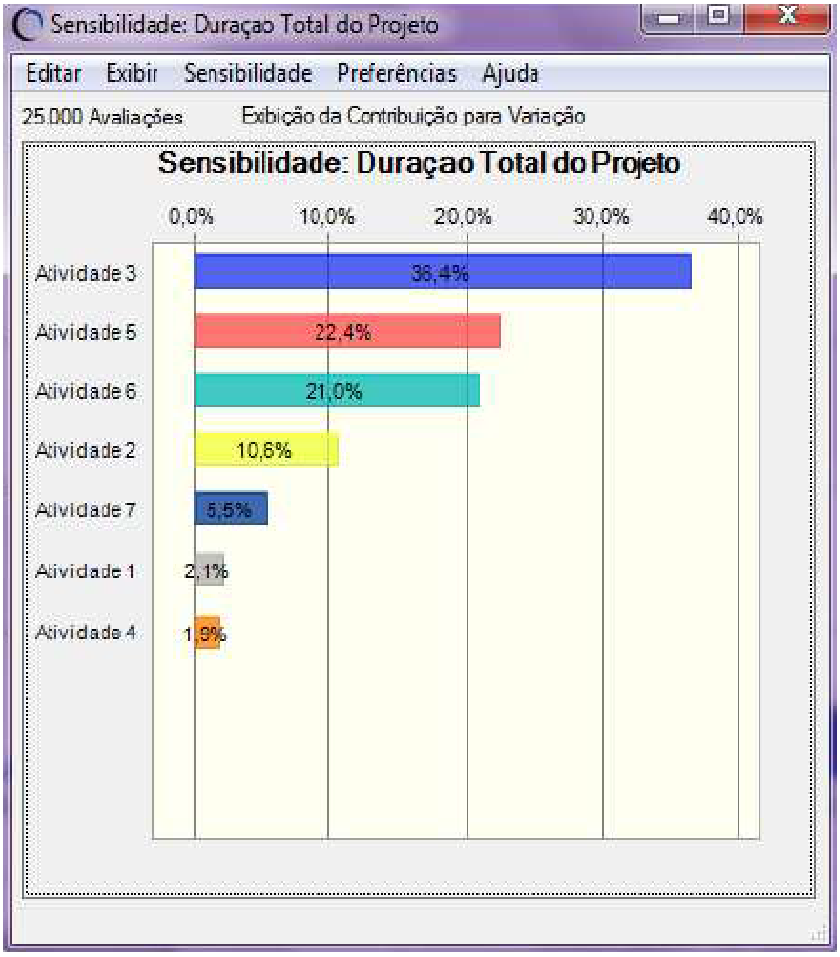
The chance of the project to end between the estimated duration and the one calculated by PERT is 16,357%, as found in picture 8.



Picture: Frequency graphic illustrating the certainty percentage among two values.
Source: author's elaboration

4.6 DECISION MAKING

The simulation will not guarantee 100% certainty the duration of the activities, but it provides supplies so that the activities' term risk is mitigated. Before this scenario is presented by the simulation, it is possible to work along with the factors that may positively or negatively influence the duration of each activity or even make a time contingency reserve for the project. Crystal Ball® makes it possible to analyze which input variables can better contribute for the prediction of the project's duration through the sensitivity graph as seen in picture 9.



Picture 9: Sensitivity Graph of input variables
Source: Author 's elaboration.

V. CONCLUSION

By means of this study, it was possible to realize that the occurrence probability of the values calculated by the estimated duration or by PERT is low. Thus, if the Monte Carlo simulation was used in the elaboration of schedules, it would be possible to develop projects with better performance of terms and even costs. However, it highlights that the construction of a good simulation model is essential for its accurate use.

The Crystal Ball® software is an easy-to-use tool. e mostrou uma ferramenta de fácil utilização. It shows functionality and can be very handy in terms of management of duration risks and activities' cost.

Another prominence point is that the simulation must be used as a support and not as the absolute truth. The simulation is an extremely powerful tool, however, it should not be considered the only source of information on its own.

It can be seen as possible to carry out other studies from this one, because its literature is extensive, especially regarding the use of other softwares or other types of projects.

In conclusion, the deterministic models tend to be replaced by the probabilistic ones, and the level of uncertainty in the decision process will decrease. This reduction, on the other hand, will provide benefits for the decision making process in the management of projects.

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