A STOCHASTIC RISK ANALYSIS THROUGH MONTE CARLO SIMULATION APPLIED TO THE CONSTRUCTION PHASE OF A 600 MW GAS TURBINE PLANT

Fahimeh Allahi[(a)], Lucia Cassettari[(b)], Marco Mosca[(c)]

[(a),(b),(c)] DIME, Scuola Politecnica, University of Genoa
Genoa, ITALY

[(a)] allahi@ dime.unige.it, [(b)] cassettari@dime.unige.it, [(c)] marcotulliomosca@gmail.com

ABSTRACT

Construction projects are characterized by great uncertainty. Appropriate risk analysis techniques are required to estimate the adequate coverage level against the occurrence of extra costs to increase the progress of the project in the tenders. The project margin increases when an excessive provision leads to a more comprehensive coverage of the risks.
The purpose of this research is to apply an innovative analysis method based on Monte Carlo Simulation (MCS) to a real project to demonstrate the advantages of a study in a stochastic regime. The amount of contingency determined by the proposed approach is more accurate compared with the previous method used by the company. In the illustrated application, MCS has been applied even to the study of the work progress status.

Keywords: Contingency, Stochastic Risk Analysis, Monte Carlo Simulation, Construction Project.

1. INTRODUCTION

A risk is an uncertain event or condition that, if it occurs, has an effect on at least one of the project objectives. Contingency cost is the estimated amount of budget or time setting aside to cover the total risk of projects (Project Management Institute 2013; Association for Project Management 2008; Eldosouky, Ibrahim and Mohammed 2014). Fundamentally, contingency cost is an essential reservation for uncertainties in the projects (Thompson and Perry 1992) and it is demonstrated the total financial obligation for the project manager (Baccarini and Love 2014). The procedure of project risk management consists of identifying, quantitative and qualitative risk analysis, response planning and mitigating risks which are caused the successful of the project (Maytorena, Winch, Freeman and Kiely 2007). By applying a risk analysis method such as the Monte Carlo Simulation (MCS), PERT, Failure Models and Effect Analysis (FMEA), decision trees and sensitivity analysis (PMBOK® Guide 2013; Muriana and Vizzini 2017; Baccarini 2005; Bakhshi and Touran 2014), the estimated contingency amount can be obtained. As an example, while a project contains tasks with risk factors, PERT method can determine the risk of overcoming the estimated time. Furthermore, the MCS has been applied in the study of the stochastic system behavior by means of its reproduction in a controllable environment. It is defined as a mathematical model that consists of the equations that describe the relationships between the components of the system parameters and their bond. The purpose is to verify the performance of the system in the face of certain inputs, to gather information on its output and make possible predictions. The MCS is used when it is not possible to analyze the object system analytically to make an estimate of the entire output probability distribution. The basic steps for the application of the Monte Carlo method can be described as follows:

- Identification of external factors
- Model definition
- Allocation of probability distributions
- Settings of the simulations and performance of the experiments
- Verification of results

This proposed methodology for risk management and project control allows working in a stochastic regime that increases the progress of the project.
The research is structured in the following steps: the next part illustrates a description of the company and the different phases of the project. In addition the MCS analysis is applied for the contingency provision. In the last part, the analysis and the obtained results from the application of the methodology to an installation of four gas turbines 600MW are described.

2. RISK ANALYSIS METHOD FOR THE CASE STUDY

The proposed method is applied in the EPC project (turnkey system) of an international Construction Company with over 30,000 employees in seven plants. The organizational structure of the Company is quite complex, considering the high number of employees, 2,937 units and the wide range of functions which require an ordering and management on many different correlated levels. In the recent years, the Company has taken steps to strengthen the operational methodologies and tools to support the management. The EPC contract

had involved the design and construction of a power plant in open cycle "turnkey" 600 MW in Egypt. The control unit is composed of four equipped units with four gas turbines that are totally designed and constructed by the Company.
The Company usually carried out a Risk Analysis so structured:

1. Identification of the activities needed to complete the job order, thus creating a list of tasks and their dependencies (prior and subsequent activities) and the necessary resources (in the construction phase are the work hours to complete that particular task);
2. Analysis of environmental conditions that may affect the site's activities (socio-political situation, type of customer, logistical constraints, local workforce specialization);
3. Mitigation of the risk of delayed timing and consequently the risk of overcoming the cost of the site budget by increasing the percentage of time and therefore the resources planned in the initial ideal program. The ideal program is modified by finding suitable multipliers "K" that vary according to the environmental analysis result. This step allowed the Company to have a more realistic forecast (Figure 1).

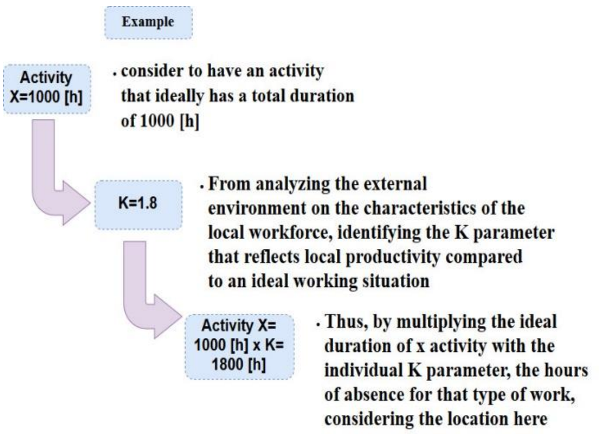


Figure 1: Example of the Company's Risk Management approach

The Authors applied MCS to manage the phase of development of the project, which is stochastic, with the aim of reducing the risks of delay of the contractual delivery date. In particular, risk analysis has been applied to two different phases of the project:

1. The phase of bid
2. The work progress control

2.1. The Phase of Bid

This phase is a fundamental activity to estimate the price of the order to success in the project. It is important to note that the methodology will be applied only to the construction phase, which it is allocated about 30% of the total project budget.

In the following, the main steps of the methodology for the bid phase, entitle:

• Identification of necessary data to the model;
•Applying Monte Carlo analysis for the contingency provision.

2.1.1. Identification of Necessary Data to the Model

When the total required budget for the construction phase is determined, it should be split into the different program activities. Allocation budget to the individual activities is done by taking into account the specific characteristics of each activity such as the duration, the type of processing, the fixed costs and the variable costs. Table 1 presents the identified weight percentage of the total required budget for each activity.

Table 1: Weight Percentage of the Total Required Budget for Some Tasks

Task	Weight	Task	Weight
Excavation for turbine Hall unit 1-4	0.86%	Fuel oil plumps shelter install.	0.81%
Foundation Hall including half of unit 1-4	1.95%	Compressor install	1.00%
Stack unit 1-4 foundations	0.59%	Fogging system install	1.38%
G.T. 1-4 foundations	3.11 %	Underground instrument	7.36%
Steel struct. turbine hall 1-4	2.05%	Cable ways and install	2.93%
Local control system (half) elevation 1-4	1.70%	Yard area and finishing HVAC	8.05%
Main transformer G.T. 1-4 foundations	3.42%	GIS subs. and cable connection	2.31%

In order to obtain the necessary input data for the simulator and acquire an accurate estimation, it has been switched from a deterministic analysis to a stochastic one.
Each activity was then associated with a probability distribution taking into account both the optimistic case, in which the allocated budget is not fully spent, and the bad case, where the execution of the activity requires the allocation of an extra budget .
The most suitable probability density function starting from a 3-point-estimate containing minimum value, maximum and most likely value, is the Triangular Distribution. Therefore, each activity is then assigned with a triangular distribution and the Table 2 is obtained.

Table 2: Applying the Triangular Distribution to Each Task

Weight of single task	Triangular Distribution		
	Min	Real	Max
0.86%	0.77%	0.86%	1.16%
1.95%	1.76%	1.95%	2.63%
0.59%	0.53%	0.59%	0.80%
3.11 %	2.80%	3.11%	4.20%
2.05%	1.85%	2.05%	2.77%
1.70%	1.53%	1.70%	2.30%
3.42%	3.08%	3.42%	4.62%
1.38%	1.24%	1.38%	1.86%
6.04%	5.44%	6.04%	8.23%
2.39%	2.15%	2.39%	3.23%
2.95%	2.66%	2.95%	3.98%
2.21%	1.99%	2.21%	2.98%
1.28%	1.15%	1.28%	1.73%
1.97%	1.67%	1.97%	2.71%

2.1.2. Applying Monte Carlo Analysis for the Provision Contingency

By using the described input data, it is possible to apply the Monte Carlo method. In addition, to apply a number of experimental runs on the model to obtain the valid results, the method of the Mean Square Pure Error (MSPE) in the repeated run (Mosca, Bruzzone and Cassettari 2009; Cassettari, Giribone and Mosca 2010; Cassettari, Mosca and Revetria 2012; Mosca, Giribone, Revetria, Cassettari and Cipollina 2008) should be done. Furthermore, Figure 2 presents the MSPE curves necessary to identify the sample size in order to obtain the statistical stabilization both of Mean Square Pure Error of the Mean (MSPEMED) and Mean Square Pure Error of the Standard Deviation (MSPESTDEV). It occurs at around 1000 runs. Therefore, the MCS results obtained using @RISK with the features of 5 reps and 10,000 runs are shown in Figure 3.

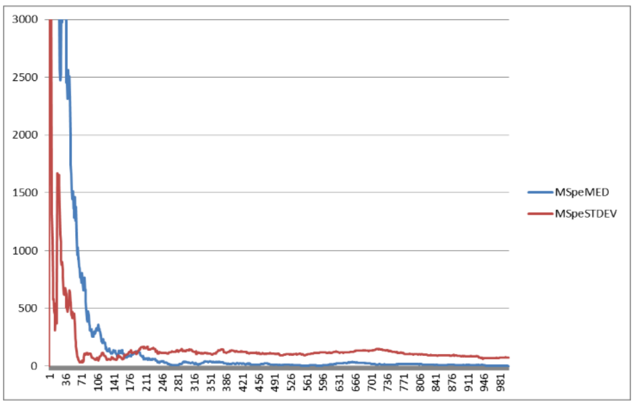


Figure 2: MSPE Curve for the Input Data

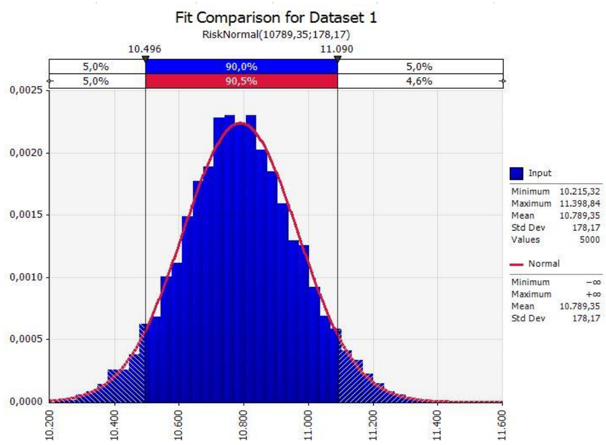


Figure 3: Monte Carlo Simulation by @ Risk Sofware

The obtained probability distribution curve covers a range of between € 10.2mn and € 11.6mn. In order to have an 80% coverage probability, the Company should therefore allocate an amount of not less than 11m euros, representing about 8% of the total value of the order.

2.2. The Phase of the Work in Progress Control

The main risk of this phase are the delays that may be the result of various reasons. Following are cited some of the main causes involving delays in the pipeline:

- Equipment failures;
- Errors on the part of employees;
- Weather conditions;
- Delays in the procurement of materials.

The objective of the proposed risk analysis to the phase of the progress management is to identify the likelihood of unexpected upstream in order to have the possibility to make changes to the program and the construction budget to complete the project within the deadline. This is crucial as the excess of the end date of the project involves huge penalties from the customer.

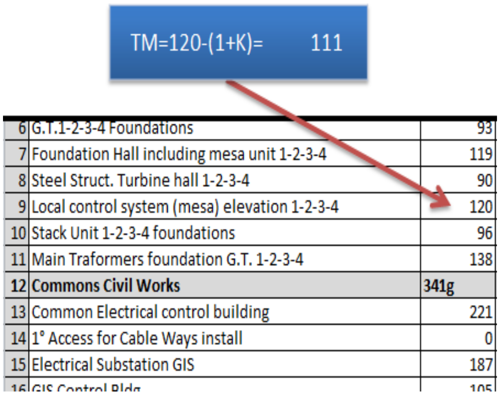
The main steps of the applied methodology to the phase of the advancements management are:

- Study of the Construction program and data identification
- Identification of the critical path

2.2.1. Study of Construction Program and Data Identification

To define the necessary input date for the simulator, each activity should be associated with a real deterministic time. As mentioned above the Company was used to augment the actual time with an incremental time by means of a standard percentage of increase K. Therefore, the first step was to eliminate the effect of the coefficient K and consequently to identify the most likely duration "TM" (an average duration that does not take account of external factors (Figure 4)).

Once the average time is obtained it is possible to transform the duration of each activity from deterministic to stochastic. The next step is to decide what type of probability distribution to use. It has opted for a non-symmetrical triangular distribution for all activities.
However, the variability of the duration of the activity was differentiated according to the characteristics of the project task.
In particular, for all civil works to take into account the impacting weather variability on outdoor works, it is considered intervals as follows:
Max duration = TM * 1.4
Min duration = TM * 0.8
As for the electro-mechanical assemblies, the following extreme values are considered:
Max duration = TM * 1.2
Min duration = TM * 0.9


TM=120-(1+K)= 111

6	G.T.1-2-3-4 Foundations	93
7	Foundation Hall including mesa unit 1-2-3-4	119
8	Steel Struct. Turbine hall 1-2-3-4	90
9	Local control system (mesa) elevation 1-2-3-4	120
10	Stack Unit 1-2-3-4 foundations	96
11	Main Traformers foundation G.T. 1-2-3-4	138
12	**Commons Civil Works**	**341g**
13	Common Electrical control building	221
14	1° Access for Cable Ways install	0
15	Electrical Substation GIS	187

Figure 4: Example of the Most Likely Duration Estimation

2.3. Applying Monte Carlo Analysis to Predict the Final Date of the Project

In this phase, the described input data and MCS should apply in the @RISK software with features of 5 reps and 1,000 runs corresponding to the MSPE curves in Figure 5. The MCS has been applied to each of the four critical paths (one for each gas turbine) in order to evaluate the duration of the four units construction.
The MCS risk analysis has been repeated at 5 different instants of time in order to take into account during the progress of the project of the activities which already completed. In addition it recalculates with an increasing level of reliability of the expected date of delivery of the four gas turbines.

- T = 0: from June 1, 2016
- T = 1: from August 31, 2016
- T = 2: from September 30, 2016
- T = 3: from October 31, 2016
- T = 4: from November 30, 2016

Some of the MSPE Curves and MCS results on the different critical path associated with these instants of time are reported in the following.

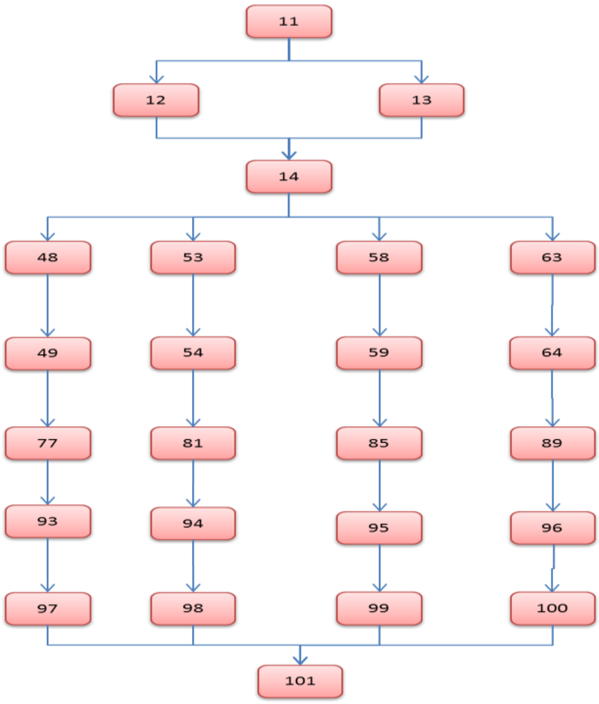


Figure 5: Critical Paths for Each Gas Turbine

Critical path 1 (T=0)

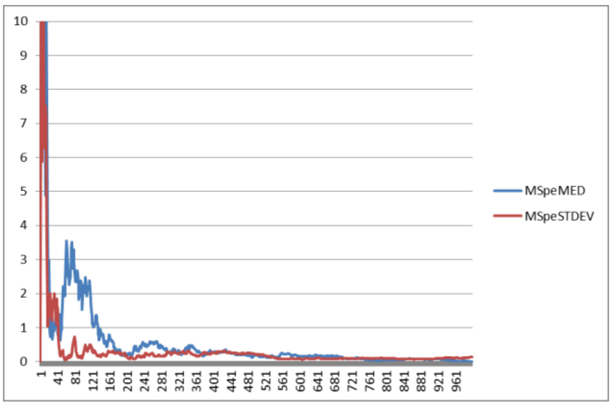


Figure 6: MSPE Curve for Critical Path 1 (T=0)

From T = 0 to T = 1, which is from June to August 2016, the first civil works were completed. There were no major problems or delays and some of activities had been concluded in advance with a positive impact on the overall project duration. In Figure 6 and Figure 7 the results of MSPE and Monte Carlo analysis for Critical path 1 for T = 0 and Figure 8 and Figure 9 for critical path=1 for T=1 are illustrated.

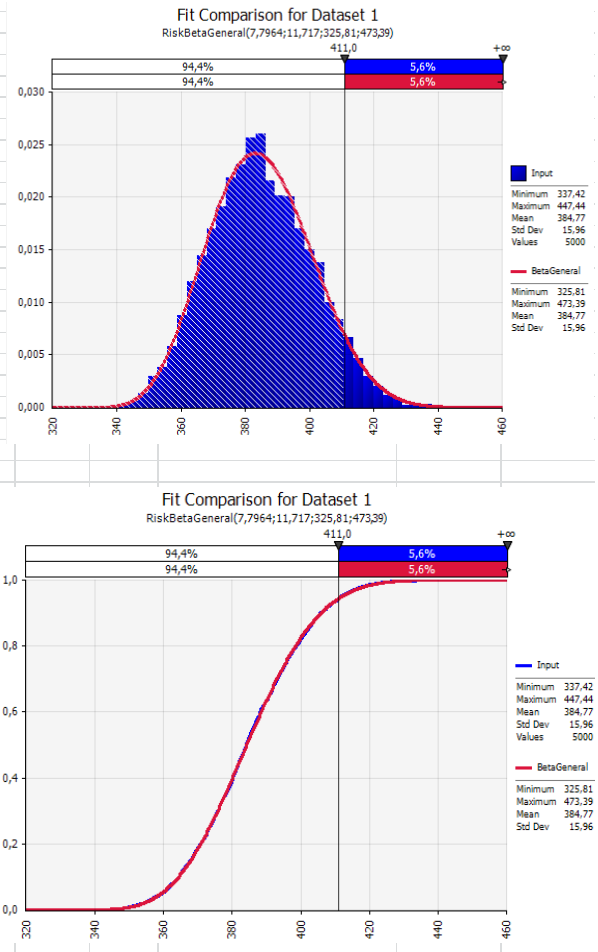


Figure 7: Monte Carlo Simulation for Critical path 1 (T=0)

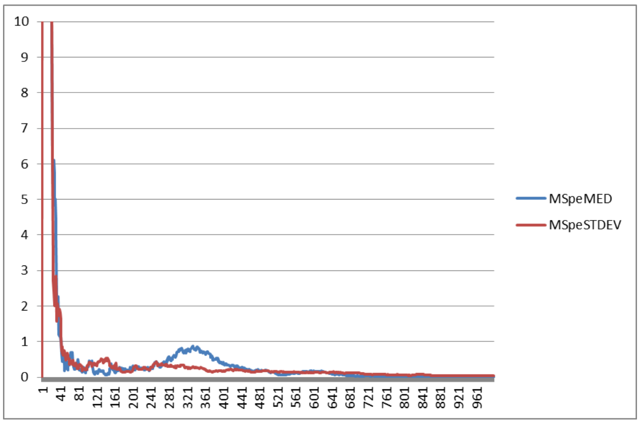


Figure 8: MSPE Curve for Critical Path 1 (T=1)

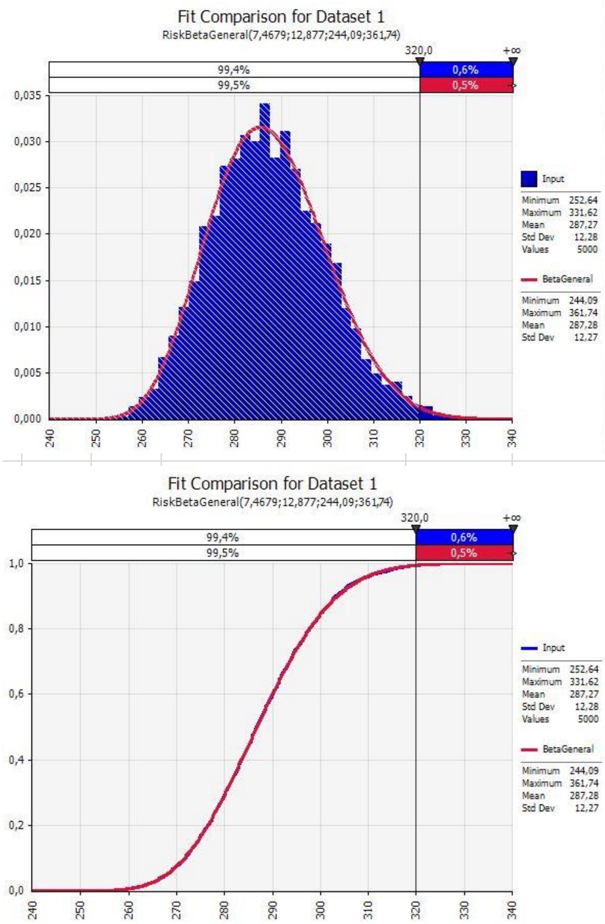


Figure 9: Monte Carlo Simulation for Critical Path 1 (T=1)

From the instant T = 1 to the instant T = 2, i.e. from September to October 2016, the realization of civil works continued. There were no particular problems or delays during the implementation of the program activities.
From the instant T = 2 to T = 3, i.e. from October to November 2016, almost all civil works were completed without any unexpected details, but the obtained time advantage in the first phase of the order had a slight decrease, as shown in the curve of project total cost (Figure 10).

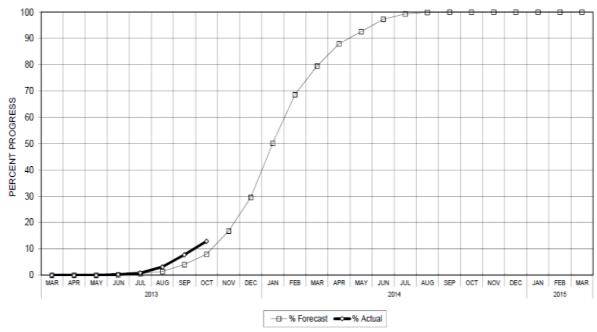


Figure 10: Project Total Cost

From time T = 3 to T = 4 i.e. from November to December 2016 continued the civil works and construction of steel structures of the four gas turbines has started. Although the overall situation of the construction phase has to be in advance of the program yet, the previously accumulated advantage has been greatly reduced.
The progress in the pipeline and the total order curves progress updated at T=4 are illustrated in Figure 11.

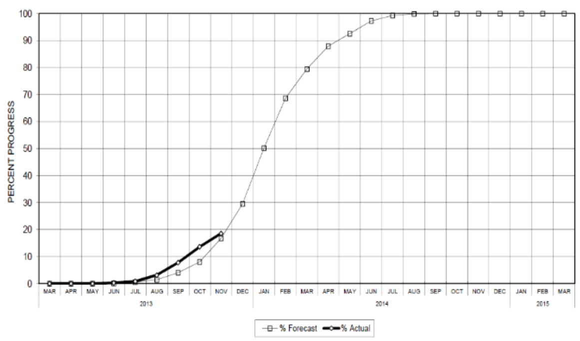


Figure 11: Total Order Curve of Progress

The objective of the proposed risk analysis was to identify for each critical path and each instant of time, the probable date of delivery of the plant and also the respective percentages of risk that the effective date would exceed.
In Particular, the obtained data from the carried out analysis are:

- ΔT: this data indicates the duration in days that divides the current date and the delivery date of the plant (for example, if you consider the time instant T = 2 of the first critical path the ΔT will equal 290 because the days are passing from late September 2016 to August 2017).
- Variability Range

This data indicates the variability of project final date determined by the analysis:

• Optimistic, realistic and pessimistic time
• P(x) delivery on time
• P(x) delayed delivery

Table 3 summarizes all the results just described.
At this point to understand when it would be appropriate to make changes to the program it is necessary to identify an additional element named P(x) threshold.
The P(x) introduces the probability of delay threshold that shows whether or not to make changes to the program of activities. For instance when P(x) threshold > P(x) delayed delivery, the advancements in the pipeline are under control then it will not allowed to make changes to the program. In addition, when P(x) threshold < P(x) delayed delivery, the construction site of the advancements are having significant delays so it is appropriate to begin to change the program by allocating additional resources to make up for lost time.

Table 3: Summary of Progress Simulation Results

Summary of Progress Simulation Results									
ID	Instant time T	N critical path	ΔT in days: Data TOAC - Instantaneous advancement	Variable Range	Optimistic T	Realistic T	Pessimistic T	P(x) delivery on time	P(x) delayed delivery
01	0	1	411	48	337	385	433	94.40%	5.60%
02	0	2	421	49	353	402	451	87.60%	12.40%
03	0	3	432	50	362	412	462	87.40%	12.60%
04	0	4	442	50	376	426	476	81.60%	18.40%
11	1	1	320	47	240	287	334	99.40%	0.60%
12	1	2	330	48	256	304	352	96.90%	3.10%
13	1	3	341	48	266	314	362	97.70%	2.30%
14	1	4	351	50	277	327	377	95.70%	4.30%
21	2	1	290	33	231	264	297	98.60%	1.40%
22	2	2	300	36	245	281	317	93.90%	6.10%
23	2	3	311	36	255	291	327	93.80%	6.20%
24	2	4	321	36	268	304	340	91.40%	8.60%
31	3	1	259	30	204	234	264	99.30%	0.70%
32	3	2	269	33	218	251	284	94.00%	6.00%
33	3	3	280	33	228	261	294	94.10%	5.90%
34	3	4	290	34	251	285	319	92.10%	7.90%
41	4	1	229	26	182	208	234	98.50%	1.50%
42	4	2	239	29	196	225	254	90.90%	9.10%
43	4	3	250	29	206	235	264	89.50%	10.50%
44	4	4	260	30	218	248	278	87.10%	12.90%

The Figure 12 illustrates an example comparing for each instant of time and any critical path with the threshold P(x) delayed delivery:

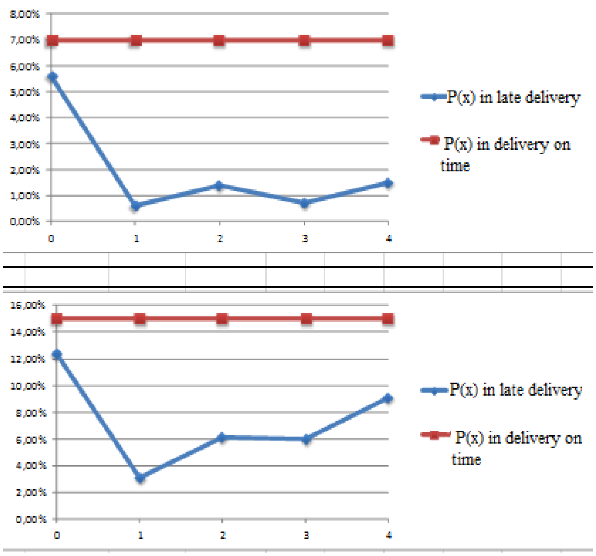


Figure 12: Comparison with the Threshold P(x) for Critical Path 1 (top chart) and Critical Path 2 (bottom chart)

As can be seen from the charts, for the analyzed time period it was not necessary to make changes to the program for any critical path at each instant of time. So it has been concluded that the advances in the pipeline in the period from June 2016 to December 2016 mirrored the predictions made at the
Finally, by the Figure 13, it is understood that how the variability of results decreases with the approaching of the delivery dates. This is very important because it allows the passing of time to identify more accurately the project end date.

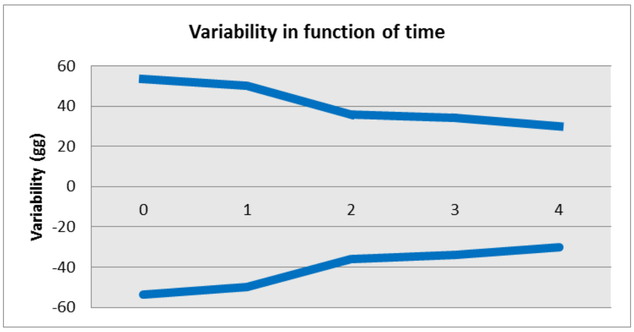


Figure 13: Range of Variability

3. CONCLUSION

The proposed study illustrate the application of a stochastic risk analysis based on Monte Carlo method to a real case study. The study aims to highlight the benefits and results obtained through a stochastic analysis compared to traditional deterministic analysis.

In Particular, two project phases were considered in this research: the process of bid and the phase of work in progress control; Risk Analysis with Monte Carlo method has been applied to both.

The analysis on the first phase has led to the allocation of a contingency equal to 8% of the costs of construction of the plant; this percentage represents a quantitative estimate of all the possible risks that may occur in the pipeline.

The MCS analyzes in the progress phase identified the project final dates for each critical path calculated at five different time instants, from June 2016 to December 2016; This has allowed to verify the evolution of the program and modify the program to avoid penalties. Moreover, it can be understand from the months analyzed showed that was not necessary to change the program of activities.

Finally, it has been possible to note how the variability of the results decreases with the approaching of the implant delivery dates; this aspect is fundamental in order to identify more precisely the final date of the project over time.

REFERENCES

Allahi F., Cassettari L., Mosca M., 2017. Stochastic Risk Analysis and Cost Contingency Allocation Approach for Construction Projects Applying Monte Carlo Simulation. Lecture Notes in Engineering and Computer Science: Proceedings of the World Congress on Engineering 2017, 5-7 July, 2017, London, U.K., pp 385-391.

Association for Project Management, 2008. Interfacing Risk and Earned Value Management. Association for Project Management, UK.

Baccarini D., 2005. Estimating Project Cost Contingency – Beyond the 10% syndrome. Proceedings of Australian Institute of Project Management National Conference. Nov 9th, Victoria (Australian Institute of Project Management, Australia).

Baccarini D., Love P.E.D., 2014. Statistical Characteristics of Cost Contingency in Water Infrastructure Projects. Journal of Construction Engineering and Management, 140(3), 1-9.

Bakhshi P., Touran A., 2014. An overview of budget contingency calculation methods in construction industry. Procedia Engineering 85, 52-60.

Cassettari L., Giribone P.G., Mosca M., Mosca R., 2010. The stochastic analysis of investments in industrial plants by simulation models with control of experimental error: Theory and application to a real business case. Applied Mathematical Sciences, 4(76), 3823–3840.

Cassettari L., Mosca R., Revetria R., 2012. Monte Carlo Simulation Models Evolving in Replicated Runs: A Methodology to Choose the Optimal Experimental Sample Size. Mathematical Problems in Engineering, 2012, 0-17.

Eldosouky I.A., Ibrahim A.H., Mohammed H.E., 2014. Management of construction cost contingency covering upside and downside risks. Alexandria Engineering, 53(4), 863–881.

Maytorena E., Winch G.M., Freeman J., Kiely T., 2007. The influence of experience and information search styles on project risk identification performance. IEEE Trans. Engineering Management, 54 (2), 315–326.

Mosca R., Giribone P., Revetria R., Cassettari L., Cipollina S., 2008. Theoretical Development and Applications of the MSPE Methodology in Discrete and Stochastic Simulation Models Evolving in Replicated Runs. Journal of Engineering, Computing and Architecture, 2(1), 1934-7197.

Mosca R., Bruzzone G.A., Cassettari L., Mosca M., 2009. Risk analysis for industrial plants projects: An innovative approach based on simulation techniques with experimental error control. Proceedings of 21st European Modelling and Simulation Symposium, EMSS 2009.

Muriana C., Vizzini G., 2017. Project risk management: A deterministic quantitative technique for assessment and mitigation. International Journal of Project Management, .doi: 10.1016/j.ijproman.2017.01.010, (In Press, Corrected Proof).

Project Management Institute (PMI), 2013. A guide to the Project Management Body of Knowledge: (PMBOK® Guide). Fifth ed. PMI, Project Management Institute, Newtown Square, PA.

Thompson P.A., Perry J.G., 1992. Engineering construction risks. London, Thomas Telford.Mercer P.A. and Smith G., 1993. Private view data in the UK. 2nd ed. London: Longman.

AUTHORS BIOGRAPHY

Fahimeh Allahi is a Ph.D. student in Industrial Engineering at the University of Genoa- Department of Mechanical Engineering, Production Engineering, and Mathematical Modelling (DIME). Her research field is focused on risk management and Derivate based on Monte Carlo Simulation.

Lucia Cassettari earned her degree in Management Engineering in 2004 at the University of Genoa. She obtained the title of Ph.D. in Mathematical Engineering and Simulation in 2009. She is actually a researcher in University of Genoa-Department of Mechanical Engineering, Production Engineering, and Mathematical Modelling (DIME). Her research field is focused on simulator-based applications for industrial plants with particular attention on the application of DOE and Optimization techniques to industrial plant problems using Simulation. Her main experience is in research projects involving BPR (Business Process Reengineering), Activity Based Management, Cost Control, Logistics, and Decision Support Systems. Her current teaching activity is in the Industrial Plant Management and Planning & Control degree courses.

Marco Mosca earned his degree in Management Engineering in 1999 at the University of Genoa. He obtained the title of Ph.D. in Innovation Management in 2011. He has more than 10 years of working experience: consultant in Accenture, manager in Bombardier Group working in Italy, Switzerland, Austria and Germany and Managing Director of an Italian Manufacturing company. He is now Visiting Professor at Polytechnic School of University of Genoa. His current teaching activity is in the Operations Management degree course.