Performance control considering risks for construction projects

Control del desempeño de proyectos de construcción considerando riesgo

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***Resumen*— La toma de decisiones durante la ejecución de los proyectos es de vital importancia para el éxito de los mismos. Para facilitar ese proceso se ha desarrollado el método de Gestión del valor ganado (EVM), que integra el alcance, tiempo y costo, para medir el desempeño del proyecto e identificar variaciones con el plan original del mismo. Identificando variaciones en el desempeño el Gerente de proyectos debe realizar los correctivos necesarios para reorientar el proyecto.**

Sin embargo, siendo un método determinístico la menor variación es considerada un problema de desempeño, lo que es objeto de críticas actualmente. El propósito de este artículo es proponer un método basado en EVM para identificar rangos de control de tiempo y costo que permitan al Gerente de Proyecto determinar cuándo se deben tomar correctivos. La propuesta fue validada en un proyecto del sector construcción, mostrando su utilidad.

***Palabras clave*— Análisis de riesgos, Análisis de Valor Ganado, Gestión de proyectos, Simulación Monte Carlo.**

***Abstract*— Making decisions during the building phase of a project is much important for their success. To support that process, it has developed the Earned Value Management system which considers scope, time and cost to measure the project performance and to identify variances from the original plan. By identifying performance variances, the Project Manager has to do corrective actions for correcting the course of the project.**

The EVM is a deterministic method so any variance reported is considered a performance problem that needs to be attended. This characteristic is currently considered a weakness of the method for being applied in daily operations. The paper presents an EVM-based method for controlling time and cost that allows the project manager to determine when really needed corrective actions are. The proposal was applied in a construction project to evaluate its utility.

***Index Terms* — Earned Value Management, Monte Carlo Simulation, Project Management, Risk Analysis.**

I. Introduction

CONSTRUCTION industry is an economic activity that impacts development and growth in countries, so reaching an efficient performance in this industry have positive nationwide social, commercial and infrastructure impacts.

In Colombia, construction industry is usually a driver for economic growth. As can be seen in the table I, construction industry growth has been usually higher than national Colombian growth. Construction industry is classified in buildings (residential and not residential) and infrastructure (roads, dams, bridges, railways).

TABLE I.
CONSTRUCTION INDUSTRY GROWTH. SOURCE: [1], [2], [3]

	2014	2015	2016
Colombia GNP	4,6%	3,1%	2,0%
Construction industry	9,9%	3,9%	4,1%

Infrastructure projects are usually developed by public work contracts while building projects are developed by private entities. This nature of the project highlights a difference between those types of projects, infrastructure projects look for the common welfare while building projects look for financial utilities [4].

Although construction projects can look for different goals, they are complex and prone to time delays and cost overruns [5]. In Colombia, over 50% of the building projects ends with cost overruns while over 80% of the projects ends with time delays between 3 and 80 days [6]. Time delays are evidence of a common problem in building construction industry in Colombia where making decision is based on intuition and personal experience [7].

To avoid time delay and cost overruns, there are project management tools, however very few companies apply any to improve control and monitoring [4]. One tool is the Earned Value Management (EVM), a method to measure the performance of the project by converting in monetary units the work done, time used and costs invested [8]. It also identifies deviations from initial plan and estimates final performance of the project [9]. It is a method promoted internationally as a control tool [10], however some weaknesses have been identified [11].

The main limitation is related to the deterministic nature of the model. The EVM does not consider the range of possible

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results and the probability to meet the objectives of the project [12].

Variability environment has been considered in the literature by several means. Statistical procedures such as Shewhart charts [13], [14]; Schedule buffers [15]; Fuzzy logic [16], and Monte Carlo Simulation [17], [18], [19].

Variability can also be included by doing qualitative analysis. This analysis allow to build a ranking of risks considering probability and impact, and it has been used in construction projects with Modal Analysis of Effects and Failures (MAEF), fuzzy logic and multicirteria analysis (MCDA) [20], [21], [22], [23], [24].

Despite the above literature, the research is related to particular cases so the results cannot be generalized, and the integration EVM and risk is not completely researched [25]. By the other side, the research on this topic can be considered scarce and more stochastic analysis should be done in future research [26].

After all this, the objective of the research was to propose a non-deterministic method for controlling building construction projects in Colombian uncertainty environment. In addition, the method considers working with part and not all activities of the project, so the project manager can apply it with less effort.

II. METHOD

The proposal to control construction projects considering risks is based on four phases: identification of potential risks, identification of critical risks, identification of critical project activities and building control limits.

To identify potential risks, it is performed a literature review to build a general risk list from research on construction projects in developing countries. The list is later reduced, with help of an expert panel, by extracting those duplicated, obviously included in others and those that do not apply to Colombian construction industry. The result is a general risk list with application to local construction projects. The purpose of this risk list is that the project manager and staff use it to identify potential risks for the project when it is been planned.

The project manager group identifies critical risks through a Modal Analysis of Effects and Failures (MAEF), which establishes Risks Scores and Risk Priority Numbers to build a ranking among risks. The risk score metric uses occurrence and severity evaluation of the risk, while the risk priority number uses occurrence, severity and detection evaluation of the risk. Critical risks for the project are those with high evaluation of both risk metrics. The purpose of this phase is to obtain a raking of potential risks for the project planned. Working high ranked risks helps the project manager to focus on a short list of those with more impact and probability instead of working with a long list of risks that may never be in the project and even would not affect the project.

Next phase of the method is the identification of the critical activities of the project. To do this, it is necessary to establish the relationship or influence among critical risks, already identified, and every activity of the project. The project group estimates the level of influence by a risk score evaluation; and the critical activities are those with higher values. The purpose of this phase is, again, to provide a short list of prioritized activities for analysis.

The last phase of the method is building the control limits for the project. In first place is necessary to identify the risk profile for the duration of critical activities, later the project manager decides the desirable control level for every period (in statistical percentiles). A third task is to simulate the performance of the project for every control period by Monte Carlo Simulation (MCS). The results of every simulation represent the control limit for the project in that moment of the project.

III. RESULTS

To put in practice the method proposed, in first place was decided to narrow the scope. The project was performed in building sub-sector in the city of Cali, to obtain specific and useful results and not general results for building and infrastructure sub-sectors.

Identification of potential risks

As explained in the method section, in first place was performed a literature review. A preliminary list of 519 risks were identified from developing countries as can be seen in the table II.

TABLE II.
SOURCES OF RISKS

Country	Risks	Authors	Country	Risks	Authors
India	45	[27]	Egypt	99	[28]
South Africa	19	[29]	Arabia Saudi	54	[30]
Malaysia	28	[31]	Colombia	55	[32]
Egypt	44	[33]	Colombia	51	[34]
Egypt	50	[35]	Poland	11	[36]
Egypt	63	[37]			

The list was reduced to 106 risks by identifying duplicated and some included in others, and were later evaluated by an expert panel and reduced to 53 risks. The risks were classified in 11 groups as follows:

Owner: slow decision making, interference, lack of experience in construction projects and breach of the contract.

Financial: High cost of equipment, delay in payments, incorrect cost estimation, contractor's financial difficulties and waste in the workplace.

Design: Inadequate consultant experience, delays in tests and inspections by consultants, slow review and approval of designs, reprocess due to design changes, errors and discrepancies in documents and delays in approval.

Contractual: Inappropriate procedures, increase in scope of work, unrealistic inspection methods, errors and discrepancies in the contract and unrealistic schedule imposed in the contract.

Contractor: Ineffective planning and scheduling, frequent change of subcontractors, inappropriate or obsolete construction methods, breach of contract, fraudulent practices and bribes, quality control and guarantee.

Labor: Labor shortage, unskilled labor force, numerous simultaneous activities, strikes, absenteeism, low motivation and workers' morale.

Operational: Shortage of materials, delays in material delivery, material mismanagement, inefficient equipment use, theft of materials, equipment malfunction, accidents and low level of productivity.

Economics: Materials price fluctuation, security and delay in delivering the workplace.

Socials: Damage by vandalism or during alteration of the public order, corruption, delay in mobilization to workplace, traffic control and restrictions in workplace.

Politics: Changes in regulations and laws, slow permits, owner bureaucracy, delay in final inspection and certification by a third party.

Environmental: Contamination and weather impacts (cold, rain, etc.).

Identification of critical risks

For the application of the rest phases of the method, was selected a construction project from the building sub-sector in the city of Cali. A construction company accepted to take part in the research project by providing project information and the group of Engineers as expert panel. The project was already closed but the performance information was available. The project was scheduled for 36.5 weeks but because of some delays it finally took 39.6 weeks. The budget of COP$4,466,967,831 had also cost overruns and costed COP$ 5,055,841,496.

To perform the MAEF analysis, it was followed the proposal of [38] that uses five scales to evaluate likelihood, impact and detection difficulty as seen in the following table.

TABLE III. VALUE GUIDELINES SCALE. SOURCE: ADJUSTED FROM [38]

	Value	Description
Likelihood	5	Very likely to occur
	4	Will probably occur
	3	Equal chance of occurring or not
	2	Probably will not occur
	1	Very unlikely
Impact	5	Major milestone and critical path impact
	4	High milestone and critical path impact
	3	Moderate milestone and critical path impact
	2	Low milestone and critical path impact
	1	Impact insignificant
Detection Difficulty	5	There is no detection method available or known that will provide an alert with enough time to plan for a contingency
	4	Detection method is unproven or unreliable; or effectiveness of detection method is unknown to detect in time
	3	Detection method has medium effectiveness
	2	Detection method has moderately high effectiveness
	1	Detection method is highly effective and it is almost certain that the risk will be detected with adequate time

The expert panel evaluated every risk according to those attributes and it could be calculated the Risks Scores (likelihood and impact) and Risk Priority Numbers (likelihood, impact and detection).

Finally, as proposed by [38], it was performed a dispersion analysis represented by the cross analysis of Risks Scores and Risk Priority Numbers. In this analysis, the risks with high values in both measurements are selected. For the project, it was identified 18 risks that represents the 34% of the total identified. Critical risks identified were:

- Frequent change of subcontractors
- Material mismanagement
- Weather impacts (cold, rain, etc.),
- Inefficient equipment use
- Increase in scope of work,
- Slow permits
- High cost of equipment
- Contractor's financial difficulties
- Lack of experience in construction projects
- Numerous simultaneous activities
- Reprocess due to design changes
- Quality control and guarantee,
- Errors and discrepancies in the contract, Absenteeism,
- Unrealistic schedule imposed in the contract
- Slow decision making
- Delays in material delivery
- Interference by the owner.

Identification of critical project activities

The risk score analysis performed to identify critical activities followed the same procedure as explained before. However, in this case, the likelihood and impact values were estimated considering the influence of every risk over every activity of the project.

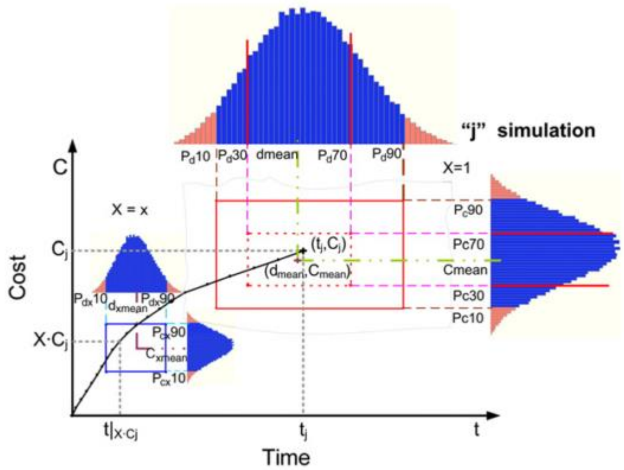
As a ranking, the critical activities were those that the sum of values were greater. Finally, the critical activities identified were: preliminaries, excavation, foundation, and slabs.

Control limits

The risk profile of critical activities is composed by the probabilistic distribution and the metrics mean and deviation.

However as there were not available historic information to build the probabilistic information, it was supposed a normal distribution and the duration and cost information were built by the three value method. The most likely, optimistic and pessimistic time and cost estimations were provided by the experts.

The next step was to decide the control level as suggested by [17]. This is a decision made by the project manager and is defined in percentiles (eg. P10-90 or P30). The graph 1 shows that the decision results in more or less control level that is the same for the whole time project.

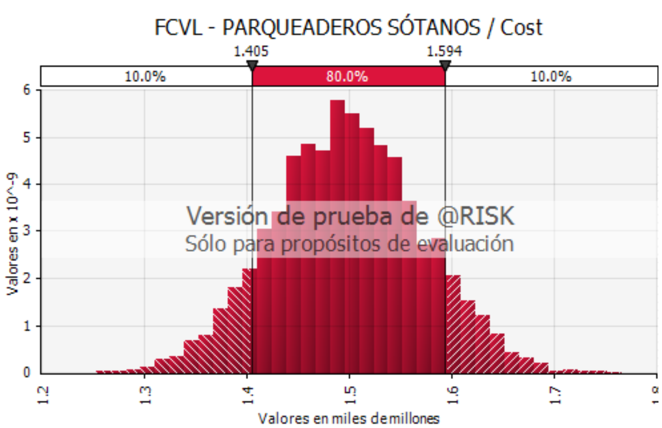


Graph 1 Control level graphical view. Source: [17]

It can be seen how a P10-90 decision represents a flexible level while a P30-70 represents a greater control. For the project it was decided to use both the flexible and strong to explore both decisions. In addition, it was decided to use four control moments, 25%, 50%, 75% and 100%. Finally, it was performed the simulation for every moment to obtain the control limits.

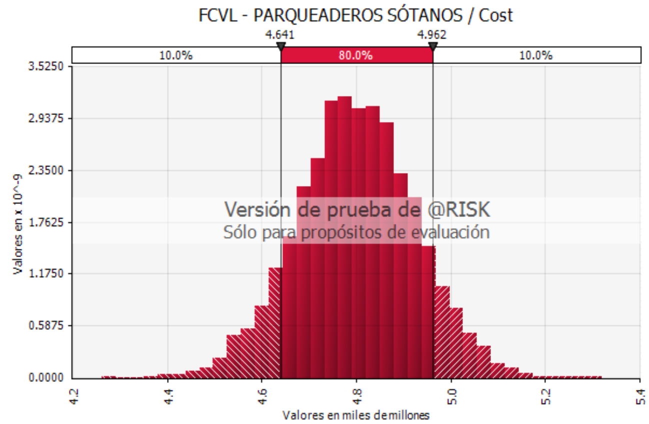
One of the outputs of the MCS is the probabilistic distribution of the variable analyzed. So in this research it was obtained a distribution for duration and cost in every control moment with every control politics. In the following graph can be seen one of those results while the rest is presented in a table. The graph shows the distribution of cost for P10-90 in 100% of advance.

The main result is the identification of the control limit. As example it can be seen in graph 2, that the control level in the first moment of control is between COP$ 1,405 million and COP$ 1,594 million. This means that under the P10-90 control level if the cost of the project is between them, it is considered under control.



Graph 2 Cost distribution for 25% advance in P10-90 control

By the other side, the graph 3 shows that the control level in the last period of simulation is between COP$ 4,641 million and COP$ 4,962 million. This means that under the P10-90 control level the project should cost inside that range to be considered under control.



Graph 3 Cost distribution for 100% advance in P10-90 control

Another finding of the research project is that the budget of COP$ 4,467 million estimated had less than 10% of success probability. An optimistic estimation considering that the project manager had less than 10% of chance to do the project in that budget. By the same way, it can be seen that the final cost of the project of COP 5,055,841,496 is over the control limit.

The following table shows results of all simulations, cost and duration for every simulation of control level. The table also shows the planned and real performance data of the project. The results showed in the table are understood in the following way.

For example, if using a control level P10-90 and the Project were in 50% of advance, the cost should be between COP$ 2,328 and COP$ 2,557 million to be considered under control. However, in that moment the real cost was COP$ 2,921 over the control limit, so the manager should make decisions to solve the overrun. By the other way, for the same 50% advance the project should be between 20.7 and 22.6 weeks but it was in the 26.6 weeks.

TABLE IV. Control Limits For P10-90 And P30-70 For Cost And Duration.

Cost (million pesos)						
%Advance	Planned	Pc10	Pc90	Pc30	Pc70	Real
0%	0	0	0	0	0	0
25%	1.504	1.408	1.585	1.461	1.532	1.873
50%	2.470	2.328	2.557	2.392	2.489	2.921
75%	3.359	3.467	3.736	3.545	3.655	3.918
100%	4.467	4.641	4.962	4.736	4.867	5.056
Duration (weeks)						
%Advance	Planned	Pc10	Pc90	Pc30	Pc70	Real
0%	0	0	0	0	0	0
25%	14,7	14,9	16,5	15,3	16	20,3
50%	21	20,7	22,6	21,1	21,9	26,6
75%	25,6	27,4	29,6	27,9	28,8	32,5
100%	36,5	37,03	40,53	38,05	39,52	39,6

It was already said that the Project finished with time delay and cost overrun, however it can be seen in the table that the project had problems not only at 100% of advance but also during the 25%, 50% and 75%.

In another analysis, comparing the P10-90 and the P30-70 control limits, the results of the project during the four moments of advance, were always out of control. However, the P10-90 limit, a more flexible politics, shows problems less notorious and even at the end of the project, it could be considered under control, 39.6 weeks less than the limit of 40.5 weeks.

This analysis highlights a phenomenon related to the optimistic estimation by project planners. The budget and schedule planned were under the limits estimated by the simulation for any percentile. While the Budget was COP$ 4.467 million, the analysis considering uncertainty estimated COP $ 4.962/4.867 million. By the other side, project duration was planned by 36.5 weeks while the probabilistic analysis estimated 4.5/39.5 weeks. As time and cost planned are usually early estimates of the future, they results to be optimistic predictions as some authors have discovered [39].

In an analysis by periods, it was found the same. It could be noticed that the performance estimated when planning was out of the control limits. The planned cost was under limits after 50% of advance in both percentiles while the time was under limits in 255, 75% and 100% of P10-90 since 25% of advance in P30-70.

By the other side, it has to remember that the methodological proposal considered to use some activities and not all for the simulations. As a way to validate if that strategy is useful, it was decided to build the control limits by simulating all activities of the project. With help of the expert panel the information needed was obtained for all activities of the project. The results of the simulations are shown in the table V.

TABLE V. CONTROL LIMITS FOR ALL ACTIVITIES

Cost (million pesos)						
%Advance	Planned	Pc10	Pc90	Pc30	Pc70	Real
0%	0	0	0	0	0	0
25%	1.504	1.405	1.594	1.460	1.537	1.873
50%	2.470	2.321	2.563	2.393	2.494	2.921
75%	3.359	3.480	3.769	3.562	3.681	3.918
100%	4.467	4.626	4.973	4.729	4.873	5.056
Duration (Weeks)						
%Advance	Planned	Pd10	Pd90	Pd30	Pd70	Real
0%	0	0	0	0	0	0
25%	14,7	14,86	16,77	15,39	16,17	20,3
50%	21	20,66	23,04	21,33	22,29	26,6
75%	25,6	27,55	30,03	28,22	29,25	32,5
100%	36,5	36,8	41	37,99	39,76	39,6

The results of considering the risk in all activities was that the control limits were modified. However when comparing every data obtained it was found that the variations were minimum and the major difference found was 1.9%. In addition, the control ranges grew although at the end the behavior was understood in the same way, the project was always out of control.

IV. CONCLUSIONS

Time and cost are the base for planning and controlling projects, however the consideration of uncertainty adds elements to be considered by Project manager. Introducing variability in the analysis allow managers to know the deviations from planned values in a framework that considers normal variability and even performance trends.

The construction of the list of risks is a phase in the method that won be necessary to plan every project. However, as it was developed by an expert panel, it is necessary to continue enriching it with more experts included.

The application of the method does not need more information or work than included in scheduling, control and risk management. What is needed is the expertise of the project managers to analyze risks and with some basic knowledge of Monte Carlo simulation, to build the control limits.

The identification of activity risk profiles needs historic information or expert knowledge to calculate or estimate the probabilistic distribution, mean and deviation. So, having a method for selecting some critical activities for the simulation allows to apply the method with less effort. The analysis of the results applying the simulation to all activities showed few differences to using only critical activities.

Although the tool for control is the establishment of the time and cost limits, the operation of the tool can be used easily in a tabular or graphic way. However, the identification of trends is easier in the graphic format.

The results of the project show that the success of the method is based on the considerations of project managers, the experts in every case. The knowledge and experience about risks and probabilistic analysis, and the decision about the level of control, rigid or flexible, are the real base of the application of the method. Although the method was put in practice in a real construction project, more application in real projects would help to get general conclusions.

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