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Highlights of Earned Value Analysis in Construction Projects

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Abstract. Construction projects are typically carried out under high-risk conditions and managers are forced to handle a great deal of uncertainty during the construction process. The Earned-Value Analysis is a control technique that provides early warnings of performance by quantitative measures, enabling timely corrective actions to ensure project success. This method was developed to control and adjust the project's baseline during execution. The objective of this article is to discuss the main implications of using EVA in construction projects through a case study. Results proved the applicability of the method in the construction industry. The various indicators generated allow managers to make forecasts for optimistic, realistic, and pessimistic scenarios, having the opportunity to correct any deviations in advance. In addition to forecasts, benchmarking data can be generated for the planners or companies responsible for the project, thus increasing the accuracy of future projects.

Introduction

The construction industry stands out as one of the most relevant sectors of the economy [1], especially in developing countries, which depend directly on its services for the evolution of national infrastructure. The large capital traditionally invested in the sector, mostly employed in the execution phase [2], and the size of the real state developments, which demand intensive labor for their construction, contribute significantly to the progress of nations. However, construction projects are typically carried out under high-risk conditions [3], and, considering the heterogeneous and unique nature of most developments [4], managers are forced to handle a great deal of uncertainty during the construction process [5]. As a result, it is not uncommon for scope changes to occur during project development. A project is considered successful when it achieves all the objectives defined in its initial planning, that is, it has achieved the desired performance, according to the schedule and with predetermined costs [4]. However, in the real world, results achieved through the process begin to gradually deviate from the approved schedule and cost baselines [2] and need to be realigned to it. Delays and cost overruns are the main effects of projects whose implementation has not been properly managed [1,2,5]. According to Vanhoucke and Shtub [6], “the best plan is based on forecasts and is subject to forecast errors” and, therefore, the adoption of a systematic monitoring and control technique capable of dealing with the uncertainties inherent to the construction activity is essential.

Currently, different project control tools are used in the construction industry, and even so, projects run over budget and behind schedule [7]. This is because traditional methodologies are based only on comparative analysis between two parameters, the planned and the current [5], but do not report any current performance trends to forecast future performance. The Earned-Value Analysis (EVA) is a control technique that provides early warnings of performance by quantitative measures, enabling timely corrective actions to ensure project success [7-9]. This method was developed to control and adjust the project's baseline during execution [10]. For this reason, it is also called deviation analysis, and it is currently considered one of the most advanced techniques for tracking the progress of projects [5,7,11-13]. Therefore, the purpose of this article is to discuss the main implications of using EVA in construction projects. Considering that most of the literature on the subject is theoretical, it was decided to use a case study, aiming to demonstrate the applicability of the method in real construction work. The remainder of this paper is structured as follows: Section 2 presents the conceptual background of the research, based on a review of the previous studies on EVA. Section 3 describes the case study approach employed in this paper. Section 4 presents the research findings and discusses research implications. Finally, Section 5 summarizes the conclusions and exposes work limitations and directions for further research.

Earned Value Analysis

The concept of Earned Value was formally introduced as a cost control tool by the US Department of Defense (DoD) in the late 1960s [8]. The development of the methodology was sponsored by government agencies, to improve the management of war projects [14]. In 1967, an approach of thirty-five criteria was developed and entitled Cost/Schedule Control Systems Criteria (C/SCSC), which were used to ensure consistency in performance reports prepared for ongoing projects. In 1996, it was revised and renamed Earned Value Analysis [2]. Since then, the technique has been applied without major changes, not only in government and defense agencies but also in several other sectors, such as oil and gas, manufacturing, pharmaceutical, construction, among others [2,14].

Many authors have dedicated themselves to the study of the practical application of EVA in these different industries. De Marco and Narbaev [15], conducted a study in the European construction industry and concluded that the technique is not yet fully developed in this region. Bagherpour [16], proposed the use of fuzzy logic to deal with the uncertainties inherent in the process of forecasting future scenarios, improving the accuracy of the results. Moslemi-Naeni et al. [17], developed a new Fuzzy-EVA model for the same purpose. Table 1 defines each of these variables and expresses their respective formulas. Table 2 summarize the meanings of the numerical results of each indicator.

Table 1 – EVA parameters information

Shortcut - Definition	Formula	Shortcut - Definition	Formula
PV - Planned Value	-------	**BAC -** Budget at Completion	-------
AC - Actual Cost	-------	**TCPI -** To Complete Performance Index	$\text{TCPI} = \frac{(\text{BAC} - \text{EV})}{(\text{BAC} - \text{AC})}$
EV - Earned Value	-------	**EAC_O. -** Estimate at Completion – Optimistc Scenario	$\text{EACo} = \text{BAC} - \text{EV}$
CV - Cost Variance	$\text{CV} = \text{EV} - \text{AC}$	**EAC_r. -** Estimate at Completion – Realistic Scenario	$\text{EACr} = \frac{(\text{BAC} - \text{EV})}{\text{CPI}}$
SV - Schedule Variance	$\text{SV} = \text{EV} - \text{PV}$	**EAC_p. -** Estimate at Completion – Pessimistic Scenario	$\text{EACp} = \frac{(\text{BAC} - \text{EV})}{(\text{CPI x SPI})}$
CPI - Cost Performance Index	$\text{CPI} = {}^{\text{EV}}/_{\text{AC}}$	**ETC -** Estimate to Complete	$\text{ETC} = \text{EAC} - \text{AC}$
SPI - Schedule Performance Index	$\text{SPI} = {}^{\text{EV}}/_{\text{PV}}$	**VAC -** Variance at Completion	$\text{VAC} = \text{BAC} - \text{EAC}$

Table 2 – Meaning of the numerical results of CV, SV, CPI and SPI

Variances	**< 0**	**= 0**	**> 0**
CV	cost is over budget	cost is right on planned	cost is under budget
SV	ahead of schedule	schedule is right as planned	behind schedule
Index	**< 1**	**= 1**	**> 1**
CPI	spending more than planned	on budget	spending less than planned
SPI	performing less than planned	on schedule	performing more than planned

Methods

The methodological approach considered in this paper was a case study referring to the construction of a residential building. Initially, the planning of activities was carried out, taking into account the executive sequence of services and the resources necessary for their execution, thus creating the Work Breakdown Structure (WBS). Based on the WBS and the actual budget developed for the work, the resources contained in the budget were allocated on schedule using MS Project software, resulting in a complete schedule. To simulate the physical progress of the construction services execution, a random number generator was applied. For this purpose, the RANDBETWEEN function of the Microsoft Excel software was used, which generates random numbers for a given range of values. The results of using this function, after being properly weighted, will correspond to the percentage of progress for each task (Tables 3 and 4).

Table 3 – Weight table

Random Values	1 to 2	3 to 11	12 to 20	21 to 35	36 to 80	81 to 95	96 to 100
Corresponding Percentage	0%	40%	65%	85%	100%	110%	120%

Table 4 – Simulation result and percentage progress after weighting

Stage 1	SR	WP	Stage 2	SR	WP	Stage 3	SR	WP	Stage 4	SR	WP
Week 1	37	100%	**Week 16**	82	110%	**Week 32**	56	100%	**Week 47**	86	110%
Week 2	54	100%	**Week 17**	27	85%	**Week 33**	82	110%	**Week 48**	89	110%
Week 3	12	65%	**Week 18**	30	85%	**Week 34**	97	120%	**Week 49**	96	120%
Week 4	35	85%	**Week 19**	5	40%	**Week 35**	44	100%	**Week 50**	95	110%
Week 5	54	100%	**Week 20**	25	85%	**Week 36**	35	85%	**Week 51**	39	100%
Week 6	9	40%	**Week 21**	37	100%	**Week 37**	53	100%	**Week 52**	6	40%
Week 7	93	110%	**Week 22**	70	100%	**Week 38**	85	110%	**Week 53**	16	65%
Week 8	40	100%	**Week 23**	94	110%	**Week 39**	79	100%	**Week 54**	47	100%
Week 9	36	100%	**Week 24**	98	120%	**Week 40**	85	110%	**Week 55**	22	85%
Week 10	15	65%	**Week 25**	52	100%	**Week 41**	91	110%	**Week 56**	94	110%
Week 11	68	100%	**Week 26**	64	100%	**Week 42**	82	110%	**Week 57**	64	100%
Week 12	10	40%	**Week 27**	52	100%	**Week 43**	46	100%	**Week 58**	33	85%
Week 13	69	100%	**Week 28**	78	100%	**Week 44**	31	85%	**Week 59**	86	110%
Week 14	17	65%	**Week 29**	10	40%	**Week 45**	97	120%	**Week 60**	9	40%
Week 15	72	100%	**Week 30**	68	100%	**Week 46**	46	100%	**Week 61**	80	100%
			Week 31	25	85%				**Week 62**	93	110%
Average		**85%**			**91%**			**104%**			**93%**

Notes: SR – Simulation Results; WP – Weighted Progress

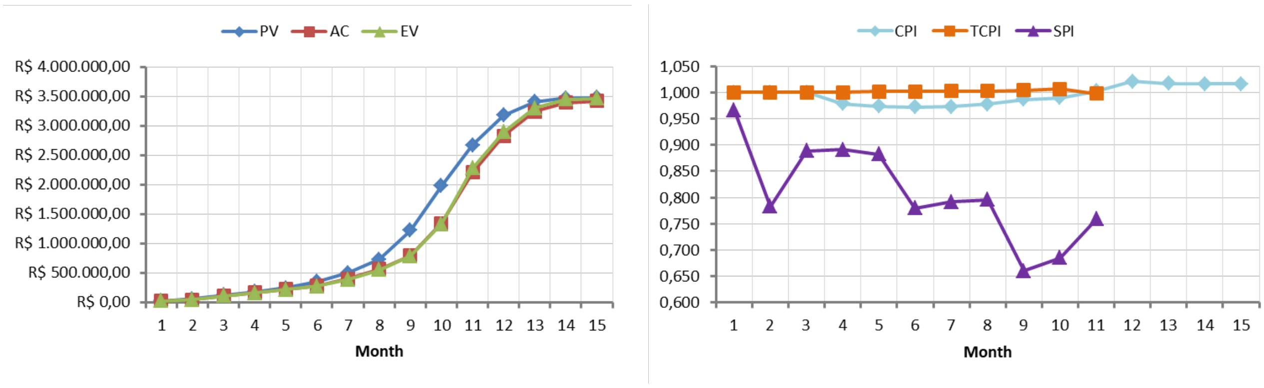
The correct analysis of the project was possible with the development of a cost baseline in Microsoft Project software. It was developed by adding all the costs allocated for each month of work and distributing it over the expected period and is graphically represented in the form of an S-curve. This curve will be used to monitor the current and future project performance [2]. The data from the EVA analysis is then typically put into graphical form to facilitate the communication progress. Considering that during the development of a project, at any time, some activities are completed, some have not yet started and others have already started but have not yet been completed [9], the EVA was then applied in four steps, simulating the construction stages at 25%, 50%, 75% and 100% of the expected duration, and the data and indicators generated were analyzed.

Results and Discussion

Stage 1 - 25% of expected duration - The analysis takes place at the end of the 15th week, during the 4th month when the work should have an evolution of 4.52% and costs R$157,325.20. However, what was actually found was 4.03% progress and $143,186.40. The EV in the period was R$140,122.62. It is noticed that the variation between the AC and the EV is derisory in the fourth month. Although the values are below the PV, this does not mean that the work is saving, on the contrary, it illustrates a CV of -2.19% and an SV of -10.93%. These values represent that 2.19% more was spent than foreseen in the budget for the services carried out in the period, and 10.93% of the planned work was not carried out. The delay in general did not generate a greater loss in terms of cost, because activities planned for the period (earth and foundation works) have a low cost about the work as a whole. But as these activities are part of the critical path, the impact on time was perceived. Performance indicators reveal that the project is spending more than it should at this stage, and the cost projections for the three scenarios considered indicated that: in an optimistic scenario the project will cost R$3.480.770,41, in a realistic scenario it will cost R$3.553.746,66, and in a pessimistic scenario it will cost R$3.972.454,47. For the schedule forecast, the number of days remaining was considered, divided by the SPI on the date, and added to the end of the measured week. In this case, 350 days were left, which when divided by the SPI of 0.89, results in 370 days remaining to completion. As 15 weeks have passed, the end is scheduled for the 68th week of the 16th month.

Stage 2 - 50% of expected duration - The analysis takes place at the end of the 31st week, during the 7th month. During this period, the average progress was 91%, better than the first one (85%), but still lower than the previously forecast. In the simulation, the progress continued below 100% and, therefore, the physical progress was 12.13% against 15.24% of the expected. In this stage, the project spent R$431,278.85 when an expenditure of R$530,054.02 was expected, and the EV of the performed tasks was R$421,850.34. The variations remain the same as in the previous stage, AC<PV and the EV<AC. However, during this period the variances increased, CV dropped to -2.24% and SV dropped to -20.41%. Indicators show that the loss concerning the initial budget has decreased compared to the previous stage, as well as the CPI is slightly lower than the TCPI, indicating that cost recovery is possible. On the other hand, SV increased considerably. With 50% of the estimated time already elapsed, the project points to a delay. It is interesting to point out that the activities contained in the period have a higher cost in relation to the previous period, but as the average evolution was higher, the cost difference was not so marked. The difference regarding the deadline was once more perceived, due to delay in critical path activities. The cost projections for the three scenarios considered indicated that: in an optimistic scenario, the project will cost R$3.487.135,14, in a realistic scenario it will cost R$3.555.434,65, and in a pessimistic scenario it will cost R$4.356.773,70. It can be seen that the pessimistic forecast is quite exaggerated due to the very low SPI. The finish forecast was calculated in the same way as in the previous stage, and the result is an estimated finish for the 70th week of the 16th month.

Stage 3 - 75% of expected duration - The analysis takes place at the end of the 46th week, during the 11th month. During this period, the random average progress was 104%, and for the first time during this simulation, the progress in the period exceeded what was planned. Even so, it was not possible to compensate for the delay in the physical progress of the works, which resulted in 48.63% carried out against 64.05% planned for the period. An amount of R$1,686,787.90 was spent, against the forecasted R$2,227,541.06, but EV was R$1,691,166.86, which means that what has been produced has cost less than it should have, pointing out possible savings concerning the budgeted amount. Fig. 1b illustrates that during the eleventh month, for the first time, the CPI surpasses the TCPI. The explanation for the increase in CPI is because the third stage of the expected duration is the period in which most of the project's expenses are concentrated. As the actual evolution was better than planned, it was possible to recover the loss in relation to the budgeted amount in previous periods. Performance indicators reveal that SPI increased again until 0,759. The cost projections for the three scenarios considered indicated that: in an optimistic scenario, the project will cost R$3.473.327,67, in a realistic scenario it will cost R$3.468.701,75, and in a pessimistic scenario it will cost R$4.003.857,47. Due to the recovery of the CPI, both the Realistic and the Pessimistic scenarios decreased significantly, approaching the Optimistic one. The forecast now indicates an estimated completion for the 68th week.



(a) (b)

Fig. 1 – Perfomance indicators

Stage 4 - 100% of expected duration - The 100% predicted duration milestone would occur on week 62 during the 15th month. However, due to the accumulation of delays related to past stages, the work was not completed on time, requiring a new simulation. The results were properly weighted according to Table 3. On the expected completion date, physical progress was 99.58%, and reached 100%, according to the new simulation, in two more weeks, totaling 64 weeks of the project. Until week 62, the project presented an AC of R$3,407,288.76 and an EV of R$3,462,971.00 (Fig. 1a). PV is equal to the total value foreseen in the budget, as the project should have finished in this period. EV remains above the AC, which shows savings in the services performed. Furthermore, it is very close to BAC, with an absolute SV of R$-14,735.63 indicating that there is little work to be done. In this final step, some indicators are no longer needed since SPI tends to 1 and TCPI tends to 0 at the end of the project. Therefore, CPI was plotted alone to best show the economy, which was R$57,186.4. This value represents a percentage CV of 1.64% (Fig. 1b).

At the end of the project, comparisons can be made to show the differences and problems highlighted by the various indicators. A total duration of 311 days was estimated in the initial planning of the project, but in practice, it was 320 days, a delay of 2.86%. These two extra weeks would generate several problems for the construction company, whose evaluation was not part of the scope of this work, such as the dissatisfaction of potential buyers of the property, who will receive the apartments after the agreed deadline. The cost projections made each month throughout the project, for the three scenarios considered. Due to a very low SPI until week 11, the pessimistic forecast is very different from the others, and it is not possible to consider it as a possible value. As the work showed economy, it was to be expected that the forecast that came closest during the entire period would be Optimistic.

Conclusions

This study aimed to demonstrate the use of EVA for a real construction project, simulating the progress of the services performed. The results proved the applicability of the method to control projects in the construction industry. The various indicators generated allow managers to make forecasts for optimistic, realistic, and pessimistic scenarios, having the opportunity to correct any deviations in advance. In addition to forecasts, benchmarking data can be generated for the planners or companies responsible for the project, thus increasing the accuracy of future projects. However, it is important to emphasize that the positive aspects generated by the technique are only reliable if preceded by well-detailed budgets, adequate planning, and well-defined scope.

Although EVA models can effectively provide reliable forecasts, some authors have been reporting some limitations that should be considered, and some may serve as a stimulus for future work. Tzaveas et al. [10], concluded that EVA has not been as successful in assessing schedule performance, since when the schedule is about 66% complete, EVA schedule performance metrics become unreliable. Zhong and Wang [11] stated that EVA ignores the difference between critical and non-critical activities and the restraints of the critical activities in the whole project, distorting the indicators. Then, the integration of EVA with other methods, such as fuzzy logic, logarithm linear transformation, and non-linear cost profiling is encouraged to investigate which one best fits the criteria in question. Current research can be extended in several directions to approaches the methodology to real-life EVA applications in the construction industry. However, one of the most promising lines of research is the integration of EVA with Building Information Modeling (BIM), in its 4D and 5D dimensions. This application can improve the efficiency of monitoring project cost and deadline control and should be incorporated in future work.

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