A Proposal for the Improvement of Project's Cost Predictability using Earned Value Management and Historical Data of Cost – An Empirical Study

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***Abstract*—This paper proposes an extension of the EVM technique through the integration of historical cost performance data of processes as a means to improve the predictability of projects cost. The proposed technique was evaluated through an empirical study, which evaluated the implementation of the proposed technique in 17 software development projects. The proposed technique has been applied in real projects with the aim of evaluating the accuracy and variation of the CPI_{Acum} and consequently the EAC. Then it was compared to the traditional technique. Hypotheses tests with 90% significance level were performed, and the proposed technique was more accurate and more stable (less variation) than the traditional technique for calculating the Cost Performance Index - CPI and the Estimates at Completion - EAC.**

Keywords: Earned Value Management, Cost Performance Index - CPI, Measurement and Analysis, High Maturity

I. INTRODUCTION

Currently, PMI estimates that approximately 25% of global GNP is spent on projects and that about 16.5 million professionals are directly involved in project management worldwide. This volume of projects and changes in the global scenario, increasingly competitive, generate the need for faster results, with higher quality, lower costs and shorter times [13].

To assess whether or not a project will achieve its cost and time objectives, various measures are collected during its execution, and various performance indexes are produced and periodically analyzed. When deviations above tolerable are found in some performance index, corrective actions are implemented in order to improve them. Among the main techniques to analyze cost and time performance, the Earned Value Management - EVM - is considered the most reliable [9].

EVM is a technique that integrates scope, time and cost data for measuring project performance and predicts its final cost and time based on the current team performance. The technique gained great importance when, in 1967, the U.S Department of Defense started requiring its use as a means to control the costs of contracted projects. [10].

Several formulae derived from EVM measurements are available and have been studied in the past 15 years [9].

However, traditional management methods are not sufficient to predict the performance of processes involved in current and future projects. [4].

Particularly in Software Engineering some model references like CMMI-Dev [15] and ISO/IEC 12207 [8] requires the gathering of measures and a development of indicators of the most important processes, responsible for achieving the business goals of organization.

This paper proposes an improvement in the EVM, it can be used like a performance model to predict the final cost of software projects, based in the CPI historical data of some processes.

II. EARNED VALUE MANAGEMENT – EVM

The earned value management technique allows the calculation of variances and performance indices of cost and time, which generate forecasts for the project, given its performance to date, making the implementation of actions aimed at correcting any deviations possible. This allows manager and project team to adjust their strategies, make balances based on goals, in the current performance of the project, in trends, as well as in the environment in which the project is being conducted [1].

According to [12], EVM plays a crucial role in the success of projects, responding to managerial issues that are considered critical, such as: i) how efficiently are we using our time?, ii) when the project will be finalized? iii)) how efficiently are we using our resources? iv) how above or below the budget it will be at the end of the project, given the current productivity of the team?

EVM is based on three basic measures, which are derived to generate other measures and performance indexes. These basic measures are: i) Planned Value - PV_{Acum}: which represents the Planned Costs accumulated up to a certain date, ii) Earned Value - EV_{Acum}: which represents the Budgeted Cost of Work Performed by a certain date, and iii) Actual Cost -

AC_{Acum} : which represents the Actual Cost of the Work Performed by a certain date. [12].

The basic measures discussed do not allow making cost and time predictions to complete the project and answer the questions previously shown. For this, it is necessary to generate performance indexes, among which the most used are Schedule Performance Index - SPI_{Acum} and Cost Performance Index - CPI_{Acum}.

The SPI is an indicator of actual progress compared to planned progress of a project [13]. It shows how efficiently the project team is using their time [1], and is calculated by:

$$SPI_{Acum} = \frac{EVAcum}{PVAcum}, \quad (1)$$

CPI is a measure of the work performed compared to the actual cost or progress achieved in the project. [13]. It shows how efficiently the project team is using their resources [12], and is calculated by:

$$CPI_{Acum} = \frac{EVAcum}{ACAcum}, \quad (2)$$

CPI_{Acum} is considered the most critical EVM index because it measures the cost efficiency of the work performed [13], and can be used to provide a cost projection.

As the project progresses, the project team can develop a forecast for the Estimate At Completion - EAC, which may be different from the Budget At Completion - BAC, based on project performance [18]. EAC provides the final cost estimation and is given by the following equation (where the premise is that the cost performance will remain the same):

$$EAC = \frac{BAC}{CPIAcum}, \quad (3)$$

Thus, the CPI_{Acum} is used to two purpose: i) to measure the cost efficiently (only analyzing the index), or to ii) make cost projections, thought EAC (see equation 3).

The Figure 1 illustrates the measures and indexes discussed as well as the projections that may be made from indexes shown and Table 1 illustrates the other components of the earned value management technique that were not discussed and / or will not be used in the context of this work, but are important to your understanding.

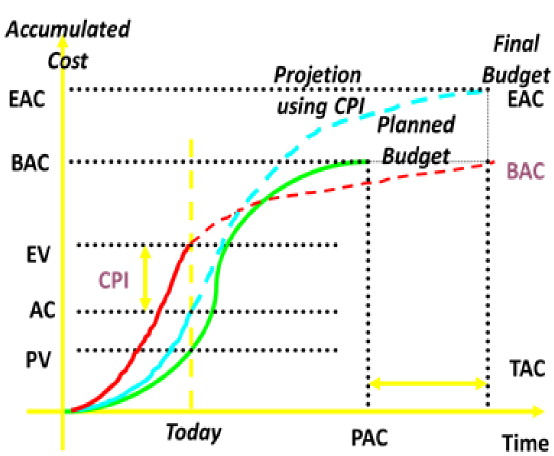

Figure 1 –Measures and performance indexes

TABLE 1 –OTHER EQUATIONS AND DEFINITIONS OF THE EVM TECHNIQUE

Equation	Definition
$BAC = \sum PV$	Budget At Completion, represents the baseline of the project cost.
SAC or PAC	Schedule At Completion or Plan At Completion, represents the final time to complete the project.
$TAC = PAC / SPI_{Acum}$	Time At Completion represents the time projection calculated based on SPI.
$EAC = AC_{Acum} + BAC – EV_{Acum}$	When the premise is that CPI_{Acum} is equal to 1.
$EAC = AC_{Acum} + [(BAC – EV) / (CPI_{Acum} \times SPI_{Acum})]$	When one desires to consider both CPI_{Acum} and SPI_{Acum} indexes

Related works are presented by Solomon [17] that evaluated which elements of the EVM technique has corresponding specific practices in the CMMI. These elements were then used to improve the implementation of specific practices of process areas in the levels 2 and 3 of the CMMI. Solomon [18] also proposed an extension of EVM that can be applied to IT projects. He used quality data of projects to improve its cost projection.

III. PROBLEM DESCRIPTION

The Earned Value Management technique makes use of the CPI to make cost projections at the end of the project. This index is the subject of several discussions on its applicability and reliability to make projections, as reported in works carried out by [2], [6], [9] and [24].

The major focus of the discussion is the CPI_{Acum} stability. Finding out whether the CPI_{Acum} is stable or not is important because it is used to make cost projections ($EAC = BAC / CPI_{Acum}$).

According to [3], stability can be defined as a state of statistical control that provides with a high degree of confidence, the performance prediction of some variable in the immediate future.

Florac [5] states that the stability of a process is considered by many as the core of the management of processes, and it is essential for companies to produce products according to what has been planned and to improve processes in order to produce better and more competitive products.

A study reported in [2] evaluated the CPI_{Acum} stability of several projects of the Department of Defense (DoD), and found that the index was stable after 20% of project execution. This study [2] generalized the result, concluding that any project could use the EVM technique reliably, after 20% of project execution. This information was used as a criterion for retaining or canceling projects in the U.S. government, which showed CPI_{Acum} below 0.9 after 20% of project execution, because according to the study, the stability of the index was evidence that a project with poor CPI was unrecoverable (note that the upper and lower limits defined here, by DoD, represents a specification limit. They are not a natural limit of the process. Thus, the stability of the CPI_{Acum} is discussed here in terms of the customer or as specification limit).

However, several other studies have questioned the generalization of these results in different contexts (projects developed outside the scope of DoD), and showed different results, i.e., they showed instability in cost performance indexes for most of the project [6], [9], [21], [24].

Claiming that the CPI_{Acum} is unstable and varies widely during the execution of a project avoids making accurate projections of cost estimate at the end of the project (EAC), unless one knows or has any expectation that this variation is due to factors already known.

The proposal of improving the earned value management technique presented in the next section is based on the premise that any project is composed of a set of processes, which have different performances. This assumption was confirmed by several studies reported in [5], [14] and [11] and by results shown in Table 2.

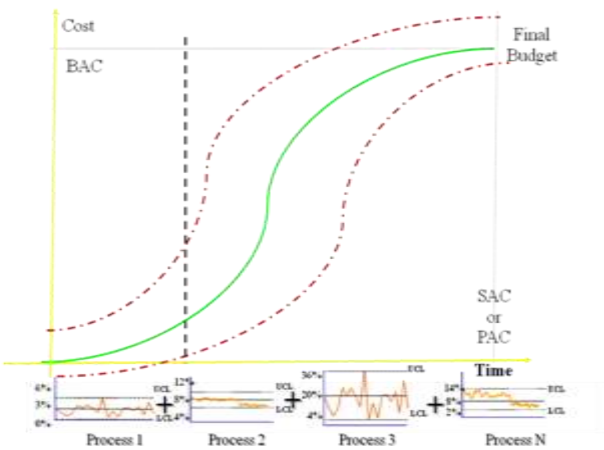

Figure 2 – Justification for the CPI instability

Thus, one reason for the CPI_{Acum} instability is the natural variation of the processes used, as illustrated in Figure 2, which shows that the CPI_{Acum} is actually the result of the performance of different processes, thus, it is not expected that the CPI_{Acum} is constant or equal to 1, but that varies due to the implementation of each specific process. Thus, it is possible to compose an equation that considers the historical performance data of processes, which have not yet been executed in the present project, (but will be futurely executed in the project), increasing the cost predictability, even for projects with unstable CPI_{Acum}.

IV. PROPOSAL OF THE HISTORICAL EVM

The CPI_{Acum} can be used with two purposes: i) to measure the cost efficiency (only analyzing the index), or ii) to make cost projections through EAC (see equation 3). This proposal shall be used only to perform cost projections using the EAC.

If it is obvious that in the Budget At Completion - BAC is no longer viable, the project manager must prepare an Estimate at Completion - EAC. Developing an EAC forecast involves finding estimates or forecasts of future events and conditions for the project based on information and knowledge available at the time of prediction. Information on work performance includes past performance of the project and any information that could impact it in the future [13].

This paper proposes the integration of the EVM with CPI_{Acum} historical data of processes. This integration consists in gathering and using the CPI_{Acum} historical data of each process of the software lifecycle, with traditional measures of the EVM technique, calculated separately to each process.

The CPI_{Acum} historical performance of the processes is important because it will be used to predict the future behavior of the project CPI_{Acum}, which consists of the individual performance of each process.

Thus, given its performance and each EVM individual measure of processes, it is possible the equation below to calculate the CPI_{Acum} projected to the final of project execution:

$$\mathbf{CPI_{Exp}} = \frac{EVAcumProject + \sum_1^N (BACPN - EVAcumPN) + \sum_1^N BACPN}{ACAcumProject + \sum_1^N (ACExpected\ PN - ACAcumPN) + \sum_1^N (ACExpected\ PN)} \qquad (4)$$

Where:

- $\mathbf{EV_{AcumProject}}$ **and** $\mathbf{AC_{AcumProject}}$**:** are respectively the traditional EV_{Acum} and AC_{Acum} of the project, that can be calculated using the traditional EVM equations;
- $\mathbf{BAC_{PN}}$**:** can be calculated adding every PV activities of the process. It can be calculated using the equation below:
  - $$\mathbf{BAC_{PN}} = \sum_1^N PV\ Activity\ N\ of\ Process\ PN \qquad (5)$$
- $\mathbf{EV_{AcumPN}}$ **and** $\mathbf{AC_{AcumPN}}$**:** are respectively the EV_{Acum} and AC_{Acum} of each process. It can be calculated adding every EV and AC of executed activities of the process, like the equation (5) presented previously;
- $\mathbf{AC_{Expected\ PN}}$: is the AC_{Acum} expected by each process after it be executed. The $AC_{Expected\ PN}$ use the historical CPI_{Acum} of each process and can be calculated using the equation below:
  - $$\mathbf{AC_{Expected\ PN}} = \frac{BAC\ PN}{Historic\ CPI\ of\ PN} \qquad (6)$$

This equation represents an evolution in relation to the preliminary first version that was evaluated through project simulations and the results were presented in [19] and [20]. Now it new version was evaluated through an empirical study. The methodology used in the empirical study and the results will be presented in the next sections.

V. PREPARATION

Measures from 17 software development projects were collected among March 2009 and January 2010. According to [4], in addition to collecting basic measures, information on the characteristics of projects must be recorded, such as total estimated size, programming language used, profile of the project team, development environment and process version used. This information will allow grouping the measures collected into different project categories, maintaining homogeneity among members of each group. If the group is not homogeneous, the analyses can be compromised and lead to inappropriate conclusions.

Thus, projects that were part of this study had the following characteristics:

- They were from the same client, which was a multinational telecommunications company,
- They used a lifecycle model, which included 4 processes, namely: i) the Elaboration of Use Case Tests - UCT, ii) the implementation of functional requirements - IMP, iii) testing of these functional requirements - TES, using test cases produced and iv) correction of reported errors - COR;
- They were developed using the same technology (MS Visual Basic and Active Server Pages) and
- They were developed by professionals of similar profiles, which were interspersed among the projects.

All size, effort and cost estimates of projects evaluated were performed using the Use Cases technique [16] after the development and validation of documents of use cases, approved by the client and the development team.

As the largest cost component in a software project are the hours required for product development, all the basic measures and traditional EVM indexes were calculated based on estimated hours and actual hours, measured after the execution of activities.

For each activity planned in the projects, planned costs - PV (through the estimated effort for the execution of the activity) and actual costs (through real effort calculated after performing the activity) were calculated. Based on this information and on the project progress, CPI's$_{Acum}$ for processes and for the project as a whole were calculated.

TABLE 2 – PROJECT INFORMATION

	CPI$_{Acum}$ of Processes				Periods	
Projects	**UCT***	**IMP***	**TES***	**COR***	**Period**	
Project 01	2,02	1,48	1,62	2,95	11/03/09 a 01/04/09	**P1**
Project 02	2,48	4,46	3,43	2,98	16/03/09 a 06/04/09	
Project 03	1,84	-	2,71	1,53	23/03/09 a 16/04/09	
Project 04	1,75	1,14	1,85	7,05	26/03/09 a 17/04/09	
Project 05	3,90	4,30	1,06	1,06	20/04/09 a 19/05/09	
Project 06	1,54	-	1,50	1,85	20/04/09 a 19/05/09	
Project 07	1,46	1,22	1,08	1,61	20/04/09 a 13/06/09	
Project 08	1,98	1,61	1,81	2,17	29/04/09 a 15/05/09	
Project 09	-	2,43	1,43	1,00	29/04/09 a 20/05/09	
Project 10	1,98	1,77	2,39	2,14	21/05/09 a 09/06/09	**P2**
Project 11	2,20	1,67	2,20	10,0	15/06/09 a 30/06/09	**P3**
Project 12	1,19	1,23	4,34	2,50	29/06/09 a 10/07/09	
Project 13	3,31	2,32	3,10	N.D.**	29/07/09 a 10/08/09	**P4**
Project 14	2,24	4,37	2,40	1,85	11/08/09 a 20/08/09	
Project 15	1,01	1,48	-	1,54	12/08/09 a 20/08/09	
Project 16	-	1,90	5,25	3,44	21/08/09 a 04/09/09	**P5**
Project 17	3,78	1,33	3,08	2,57	01/09/09 a 18/09/09	

(*) Note: data of CPI$_{Acum}$ of: i) Elaboration of Use Case Test, ii) Implementation of requirement, iii) Test and iv) Correction of bugs, respectively.

(**) Note: Non Defined – N.D. There was no bug in this project and consequently no effort to fix them.

The CPI$_{Acum}$ determined at the end of execution of each process of the lifecycle of projects, as well as the duration of each project is shown in Table 1.

The proposed technique uses CPI$_{Acum}$ historical data in each utilized process in a software-lifecycle model to perform safer CPI$_{Acum}$ projections. Projects participating in this study were executed on different dates, and therefore were considered different periods for performing statistical analyses and for data availability for the performance of projections using this technique. During the study, each specific period used the average CPI$_{Acum}$ of the processes of projects previously executed.

VI. VALIDATION TECHNIQUE

One of the aims of this study was to answer the following question: "*Does the earned value management traditional technique have higher EAC accuracy and lower CPI variation than the earned value management with historical performance?*"

Variation means that repeated measurement values are grouped together and exhibit little dispersion. According to [13] accuracy means that the measured value is very close to the correct value.

Thus, to measure the accuracy of the techniques, the EAC (Estimate At Completion) of each technique in each activity of the projects evaluated was compared with the AC (Actual Cost) measured at the end of the project execution using the equation bellow:

$$Error_{EAC\ Activity(N)} = \frac{EACActivity(N)}{ACFinal}, \quad (7)$$

The average error shown by each technique in relation to the final AC calculated was also evaluated, using the equation bellow:

$$Average\ Error_{EAC} = \frac{\sum_1^N Error\ EAC\ Activity(N)}{N} \quad (8)$$

To measure the variation of the techniques, the CPI$_{Acum}$ variation was evaluated, which was calculated by the techniques, in relation to the last CPI$_{Acum}$ estimation, or, how much the CPI$_{Acum}$ estimation varied in relation to the previous one using the equation bellow:

$$Variation\ CPI_{Activity(N)} = \frac{CPIActivity(N)}{CPIActivity(N+1)} \quad (9)$$

The variation was measured by project activities, and for the hypotheses testing, the average variation of projects was calculated using the equation bellow:

$$Average\ Variation = \frac{\sum_1^N Variation\ CPIActivity(N)}{(N-1)}, \quad (10)$$

The EAC Error and CPI variation was calculated to both technique (traditional and the proposed technique).

Thus, the following hypotheses were established to evaluate the accuracy of the techniques:

- **H0**$_{Accuracy}$: the traditional earned value management technique provides accuracy equal to the traditional earned value management technique with historical performance. ($Error_{EACTrad.} - Error_{EACHist.} = 0$)
- **H1**$_{Accuracy}$: the traditional earned value management technique provides accuracy lower than the traditional earned value management technique with historical performance.($Error_{EACTrad.} - Error_{EACHist.} > 0$)

A similar hypothesis was identified and tested to evaluate the CPI_{Acum} variation in both techniques.

The techniques shown in section iv were assessed through an empirical study, in which the goal was to measure the variation and accuracy of both techniques and compare them.

At the end of each time of execution, historical data of processes (CPI_{Acum} in each process as seen in the table 1) were collected, analyzed and used through the proposed technique to calculate a new performance cost index CPI_{Hist} (equations 4 to 6). The average error of each project showed in the figure 3, was calculated using the equations 7 and 8.

Figure 3 shows on X axis each of the 8 projects evaluated, and on Y axis, the average errors of $EAC_{Hist.}$ and $EAC_{Trad.}$ for each project. The gain of accuracy using the proposed technique was 57.7% compared to the traditional technique in project 16, represented as point 7 in Figure 3, and 11.3% lower than the traditional technique in project 13, represented as point 04, also in Figure 3.

No errors were collected from the 9 first projects, since they were supposed only to form the historical-data basis to perform index projections for the second period projects.

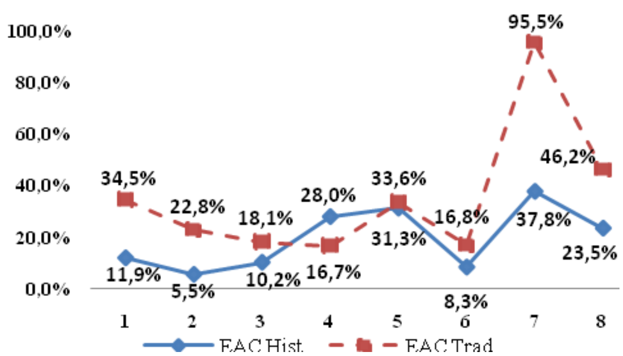

Figure 3 – Average error (Accuracy of techniques)

The project 13 (point 4 in the Figure 3) presented the worst accuracy among the evaluated projects, when the proposed technique was used. This result occurred because the "Correction" process was not executed, since the project did not have any bug (see Table 2). Since the process was not executed, the AC_{Final} of the project was lower then expected, and consequently the CPI_{Acum} was greater than expected. The worst result displayed by the proposed technique in this project was caused by an abnormal behaviour in a specific process.

Figure 4 show the average variation in the techniques. The average variation of each project showed in the figure 4, was calculated using the equations 9 and 10. It could be observed that the proposed technique showed no average variation greater than the traditional technique in any project in any of the periods tested, even when the historical database was still small.

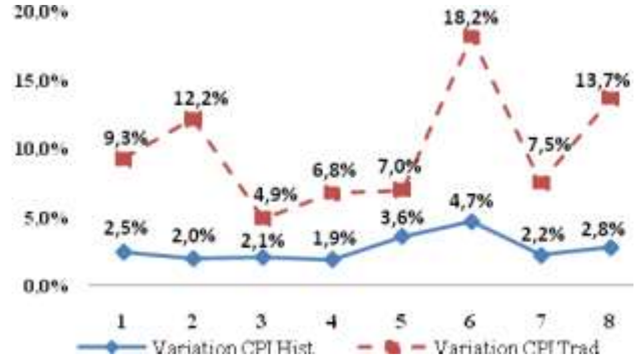

Figure 4 – Average Variation of CPI_{Acum}

In attempt to evaluate the previously shown hypotheses, statistical tests based in the data of the figures 3 (EAC_{Trad} and EAC_{Hist}) and 4 (CPI_{Trad} and CPI_{Hist}) were performed to confirm that the differences in accuracy and variation found in applying the proposed techniques were significant. The Action tool was used to perform the hypotheses tests of T paired samples, with significance level of 90%.

TABLE 3 – ACCURACY AND VARIATION HYPOTHESIS TEST

Hypothesis	Tests	T	*P*	Conclusion
H0$_{Accuracy}$	$Error_{EAC.Trad.} - Error_{EAC.Hist.} = 0$	2,219	0,03	Refute H0
H0$_{Variation}$	$Variation_{CPI.Trad} - Variation_{CPI.Hist.} = 0$	5,26	$5{,}8 \times 10^{-4}$	Refute H0

The analysis of data in table 3 and figures 3 and 4 allows inferring that the proposed technique provides greater accuracy in cost estimations, considering the average error of EAC, and lower variation in CPI_{Acum}.

VII. VALIDITY THREATS

According to [22] the internal validity observes if the treatments really cause the expected results. In this study, the expected results are: i) decrease the CPI_{Acum} variability and consequently the EAC variability and ii) Decrease the error in the EAC estimate. Both expected results were achieved with the application of the proposed technique.

However, it's necessary to consider that, the technique was validated through an empirical study using industry data. This data were from only one software factory with similar projects.

The proposed technique suggests a similar scenario for your application (data of projects that were executed using defined and stable processes, and preferentially with the same technology). However it is important a more widely study with more companies, in different domain of application.

According to [22], the conclusion validity evaluates the statistical significance. The main problem in this study is the number of available projects to conduct the hypothesis test. This is a known problem in Software Engineering. Thus, the result cannot be considered conclusive, but just a clue that the technique works. Before using the technique the company it's recommended to make a similar study, intending to determine if the proposed technique provides better results to its projects.

VIII. CONCLUSION

This paper described the evolution of the EVM technique. The proposed technique integrates historical data of cost performance as a mean to improve the project cost predictability. An empirical study was carried out based on data from 17 projects of a software factory with the aim of identifying whether the technique showed better accuracy and variation in CPI and EAC compared to the traditional technique. To evaluate the proposed technique, several hypothesis tests about the research questions shown in section vi were performed.

The empirical study showed that the proposed technique is more accurate and more stable (less variation) than the traditional technique, when using historical database with CPI_{Acum} of each lifecycle process. All hypothesis tests conducted with historical database composed of at least 9 projects showed significant results, at 90% significance level.

As future works, we propose the use of the proposed technique in other companies, with different contexts, in order to generalize the results obtained here.

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