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Evaluation of EVM/ES forecasting methods in hospital construction projects

Evaluación de métodos de pronóstico EVM/ES en proyectos de construcción hospitalaria

Flavio R. Durón González*[1] http://orcid.org/0000-0002-4840-9230
Luis Arturo Rivas Tovar* http://orcid.org/0000-0002-5186-9895
Magali Cárdenas Tapia** http://orcid.org/0000-0003-1657-9320

* Instituto Politécnico Nacional, ESCA-UST, MÉXICO
** Instituto Politécnico Nacional, ESCA-Tepepan, MÉXICO

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Abstract
The objective is to evaluate 22 time and 12 cost forecasting methods based on Earned Value (EVM/ES) under three assumptions of future performance and in terms of the opportunity, accuracy, and stability of the forecasts. Little attention has been paid in the literature to future performance assumptions and evaluation under these parameters. Method: A total of 6,951 entry data points were used applying statistical measures of error and dispersion based on empirical evidence from 34 hospital construction projects in Mexico. Findings: Using contractor payment estimates as Actual Cost (AC), the more predictive time forecasting methods are those under the assumption that future performance will be as planned and, for cost, under the SPI(t) Schedule Performance Index. Relevance: The research shows the conditions under which the diverse methods offer timely and realistic predictions to be used as a reference in the monitoring and control of hospital construction projects. The limitation of the research consists of using durations and costs from completed projects without considering the possible changes formalized in contractual modifications throughout project's execution. Future research using EVM/ES input data from the project owner's perspective is suggested.
Keywords: *Earned Value (EVM/ES); Estimates at Completion (EAC's); healthcare infrastructure*

Resumen
El objetivo es evaluar 22 métodos de pronóstico del tiempo y 12 del costo, basados en el Valor Ganado (EVM/ES), bajo tres supuestos de desempeño futuro y en términos de la oportunidad, precisión y estabilidad de los pronósticos. En la literatura se ha puesto poca atención en los supuestos de desempeño futuro y en la evaluación bajo estos parámetros. Método: se utilizaron 6,951 datos de entrada empleando medidas estadísticas de error y dispersión a partir de la evidencia empírica de 34 proyectos de construcción hospitalaria en México. Resultados: empleando las estimaciones como Costo Actual (AC), los métodos de pronóstico del tiempo con mayor grado de predicción son aquellos bajo el supuesto de que el desempeño futuro será como fue planeado y, en los del costo, conforme al índice de desempeño del tiempo SPI(t). Relevancia de los hallazgos: la investigación permite conocer las condiciones bajo las cuales los métodos ofrecen predicciones oportunas y cercanas a la realidad para ser utilizadas como referente en el seguimiento y control de proyectos de construcción hospitalaria. La limitación de la investigación consiste en emplear duraciones y costos de proyectos concluidos sin considerar los posibles cambios formalizados en convenios a lo largo de la ejecución. Se sugieren futuras investigaciones empleando datos de entrada al EVM/ES desde la perspectiva del dueño del proyecto.
Palabras clave: Valor Ganado (EVM/ES); pronósticos (EAC's); construcción hospitalaria

[1] ***Correspondence author:***
Universidad Pedagógica y Tecnológica de Colombia UPTC, Colombia
e-mail: fdurong9600@alumno.ipn.mx

1.Introduction

The decrease in hospital healthcare capacity in Mexico (Instituto Nacional de Estadística, Geografía e Informática, 2022), *the scarcity of economic resources allocated to the creation of this type of infrastructure, the recurrent increase in execution schedules and construction costs with respect to the initial plans (Auditoría Superior de la Federación, 2012), (Auditoría Superior de la Federación, 2012) and the characteristics of this type of projects with frequent changes in scope, are elements that constitute the context in which hospital construction projects are developed and allow us to recognize the importance and difficulties for their monitoring and control.*

Undertaking remodeling and expansion projects of existing medical units is one of the most viable options (Rahmat, 1997); (Seth et al., 2010). And, on the other hand, the effectiveness of control lies in the ability of project managers to forecast the real duration and the final cost, being necessary to evaluate the time and cost forecasting methods and to know the conditions under which they offer more timely and closer to reality predictions (Kim, 2007).

Existing research in the literature examines forecasts based on a single performance variable (time or cost), considers that future performance will follow the trend of current performance and little research considers future performance according to the original plan (Batselier and Vanhoucke, 2015); they evaluate forecasts in terms of accuracy and opportunity (Kim, 2007), being necessary to include stability measures (Mejía, 2013)*, since the most accurate forecasting method is not necessarily the most stable (Wauters and Vanhoucke, 2015). Classifying and ranking forecasts could fill the need for professional practice guidelines on which methods to use (Willems and Vanhoucke, 2015).*

This research evaluates time and cost forecasting methods based on EVM/ES metrics with empirical evidence from 34 completed hospital remodeling and expansion projects (34UM Program), undertaken by the most important health and social security institution in Mexico (the owner of the 34UM Program).

The research is conducted in three categories of analysis: 1) the schedule and cost performance of locally and centrally managed projects; 2) the evaluation of time and cost forecasting methods in terms of opportunity, accuracy, and stability; 3) the aspects that influence the forecasting capability of the methods.

The following sections present the concepts that define Earned Value EVM/ES and aspects identified in the literature that affect the predictive ability of the forecasting methods. We then present the results of the three categories of analysis in the case study by identifying the best forecasting methods.

1.1 Earned Value Method (EVM/ES)

Earned Value methodology is very useful for project monitoring and control as it incorporates time and cost performance variables into a single tool/technique (Bakr, 2004); (Project Management Institute, 2017).

Fleming and Koppelman point out that EVM/ES compares planned work (PV) to what has been earned or completed (EV) and to what has been spent (AC), to determine whether schedule and cost performance are as planned (De Koning and Vanhoucke, 2016), see (Figure 1(a)).

In the literature there are several models and criteria for the use of EVM from the perspective of the project/program owner that can be found in diverse public entities in the United States (Department of Energy-OAPM, 2014); (National (Aeronautics and Space Administration, 2013); (National Defence Industrial Association, 2014); (United States Air Force, 2007). Monitoring project/program costs in accordance with these models involves the agreement between project/program owner and contractors to report their costs as a result of internal control processes.

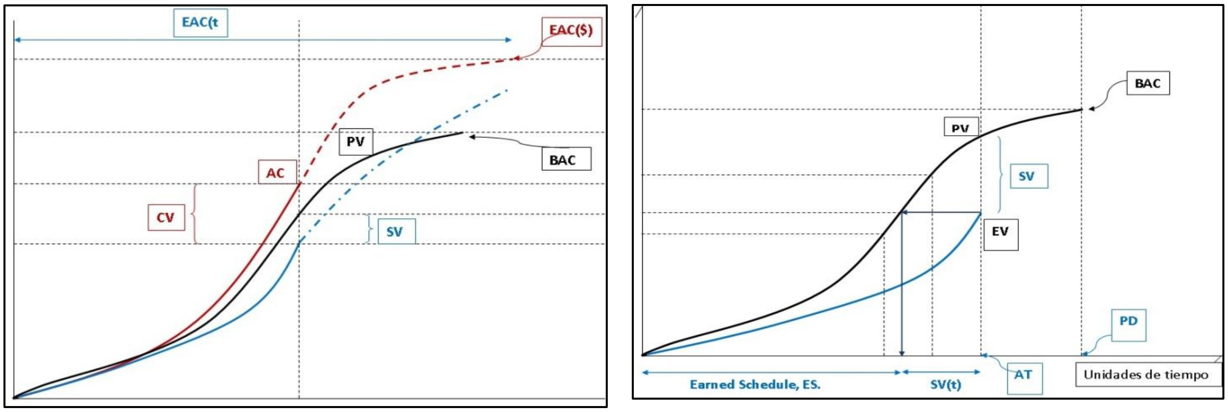
Performance metrics according to EVM consist of variations, indexes, and forecasts (Project Management Institute, 2011). *For forecasts or Estimates at Completion (EAC) there are several calculation methods based on current project performance (AC, Actual Cost; AT, Actual Time) and assumptions about future time and cost performance (PDWR, Planned Duration of Work Remaining; PCWR, Planned Cost of Work Remaining). Defined by the following equations* (Vanhoucke, 2014) *(Equation 1); (Equation 2):*

Estimated cost at Completion. $$\boldsymbol{EAC_{(\$)} = AC + PCWR} \quad (1)$$

Estimated time at Completion. $$\boldsymbol{EAC_{(t)} = AT + PDWR} \quad (2)$$

Thus, forecasts are a function of the assumptions under which the duration and cost of the remaining work PDWR and PCWR are calculated (Vanhoucke, 2014), the specific characteristics and the current status of the project (Anbari, 2003); (Christensen et al., 1995).

Assumptions of future performance are taken into account through the use of Performance Factors (PF): according to plan (PF=1); according to current schedule or cost performance (PF=SPI, PF=SPI(t), or PF=CPI); according to current schedule and cost performance (PF=SCI or PF=SCI(t)) (Vandevoorde and Vanhoucke, 2006).



(a) (b)

Figure 1*. Input data for (a) EVM, and (b) ES (Project Management Institute, 2011)*

Earned Schedule (ES) is used for time monitoring based on time units (Lipke, 2003). *EVM and ES are considered to be part of a single technique/tool, as ES uses the input data from EVM (Vanhoucke, 2014). Earned Schedule is a measure of the time in which the Earned Value (EV) should have occurred with respect to the Planned Value (PV), see (Figure 1 (b))*

ES emerges as an alternative to correct the anomalous behaviour of metrics based on monetary units SV and SPI, whereby the indexes report an apparent improvement in schedule performance from the second half of the execution of projects with delays to completion (Lipke, 2003). *Thus, ES, based on time units, has positioned itself as one of the most reliable alternatives for schedule monitoring (Buyse and Vandenbussche, 2010); (Crumrine, 2013).*

1.2 Time and cost forecasting based on EVM/ES metrics.

Stability of CPI, SPI and SPI(t) indexes leads to timely and accurate EAC(t) time and EAC($) cost forecasts throughout the project life cycle (Mitchell, 2007). *It is measured against performance indexes at project/program completion and are considered stable when the variation is +-10% De Koning and Vanhoucke, 2016).*
Some authors suggest that index stability is reached after 20% of project progress (Fleming and Koppelmn, 2002), while others indicate that stability could be reached after 50% (Kim, 2007), and even after 90% /Buyse and Vandenbussche, 2010). (Kim, 2007) adds that EVM-based forecasts show instability at the beginning of the project because there is little performance data available at that time and early warnings are reliable only after performance has stabilized, but no one knows when it stabilizes.

De (Koning and Vanhoucke, 2016) studied project characteristics and index stability. They point out that stability is reached earlier when the project duration is increased, or when the performance measurement intervals are shorter (5% of the planned duration), with no relationship between stability and the size of the project budget.

SPI(t) index has advantages over SPI in the calculation of forecasts, as it provides earlier warnings (Crumrine, 2013) and allows more accurate forecasts, although they can sometimes generate false alarms Kim and Kim, 2014)**.**

Using updated baselines (PMB, Performance Measurement Baseline), according to the authorized chang*es in the project/program, allows performance indexes to reach stability earlier and forecasts to show less dispersion compared to the use of non-updated PMB (Buyse and Vandenbussche, 2010). They add that the worst forecast method with updated PMB can be more accurate than the best forecast method with non-updated PMB.*

It is important to pay attention to the assumptions on which each method is based (Booz et al., 2016). For example, better time forecasts are obtained with updated and non-updated PMB under the assumption that future performance will follow the trend as planned (PF=1), and best cost forecasts are obtained with updated PMB considering the performance factor

PF=SPI(t), that is, the best cost forecast is based on the Schedule Performance Index (Batselier and Vanhoucke, 2015). These authors add that the assumption considering 80% CPI and 20% SPI(t) exhibits remarkably good opportunity and accuracy and that the opportunity and accuracy exhibited by the time forecasts is slightly better than that exhibited by the cost forecasts.

Research shows that index stability is achieved at different times during execution and that some methods exhibit better forecasts than others. Because of the above, there is no single best deterministic forecasting method that is accurate and superior for all projects and in all types of circumstances (Jack, 2010); (Kamil, 2005), as cited in (Wheelwright, 1995); (Trahan, 2009), as each project is unique and the performance of forecasting methods is fundamentally project-specific (Kim, and Kim, 2014).

(Kim, 2007) suggests using different equations based on the varying situations and adds that the accuracy of the forecasts would be driven by the similarity of project characteristics. The simultaneous use of several forecasting methods provides a wide range of possible forecasts from which estimates can be rationalized at completion (Kostelyk, 2012)*, as forecasts are fundamentally judgmental tools that support project managers in making informed decisions in a timely manner (Kim and kim, 2015).*

2. *Materials and research method*

The 34UM Program consisted of the remodeling and expansion of 34 emergency medical areas (34 projects) with 45,000 m^2 *total construction area, performed between 2011-2012, improving 11% of the physical infrastructure of the Program's owner and geographically distributed throughout the country.*

Using data from this set of projects, quantitative research was carried out based on descriptive statistical analysis of completed projects.

Input data consisted of planned production (PV), progress reported during project execution (EV) and contractor payment estimates (AC) following the criteria of (Diaz, 2014). They were obtained from three sources: 34UM Program owner, the Transparency Institute (INAI-Mexico) and External Supervision. Twenty-two schedules of the original contract and 35 amended schedules resulting from modification agreements were obtained; 11 financial closures of contracts; and 59 reports on a weekly basis (2,006 at project level reports) monitoring the progress of the projects from July 15, 2011, to January 18, 2013.

The validity of the PV, EV and AC data was verified based on (Trahan, 2009). Data with missing periods were calculated by linear interpolation following the criteria of (Mitchell, 2007), and inconsistencies were corrected according to the criteria of (Depatment of Energy-OAPM, 2014), avoiding modifying reports from periods prior to the one in which the inconsistency occurred. Starting with 7,197 data, corrections were made to 6.3% to finally use 6,951 points for the calculation of performance metrics based on (PMI, 2011) and (Vanhoucke, 2014). The tabular information made it possible to obtain a total of 261 graphs for data analysis.

Data capture, processing and analysis were performed using Microsoft Excel© spreadsheets. Twenty-nine cases were analysed, including groups of projects and individual projects, organized according to available information and research interests. Two cases with complete information from all three sources served to analyse alternatives to the input data from the perspective of the project/program owner.

*The equations for the calculation of each forecasting method are grouped according to the three assumptions of future schedule and cost performance (see the Appendix). In this research, combinations of indices that are not part of the theoretical basis of the methods were explored, e.g., between SPI($) and SPI(t), and PF=0.80*SPI+0.20*CPI is added.*

The evaluation of the forecasting methods in terms of accuracy was performed based on the Mean Absolute Percentage Error (MAPE) and Mean Percentage Error (MPE), and stability with the standard deviation over the monitoring periods following the criteria of (Vanhoucke, 2014). Vanhoucke points out that opportunity refers to the time window over which precision and stability are evaluated, to detect whether the forecasting methods provide reliable values at certain stages of the project.

The forecasting methods were classified and ranked by assigning a value of 1 to the method considered to have the best performance for each case of analysis; for each method, the average score obtained in the cases of analysis was obtained; and the method or methods with the lowest score were considered to be the best see (Table 1).

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3. Results and discussion

3.1 Schedule and cost performance in the 34UM Program

The S-Curves in (Figure 2) show the behaviour of the 34UM Program based on ***PV*** *with an updated PMB, original contract PV,* ***EV*** *progress and AC based on contractor´s payment Estim.*

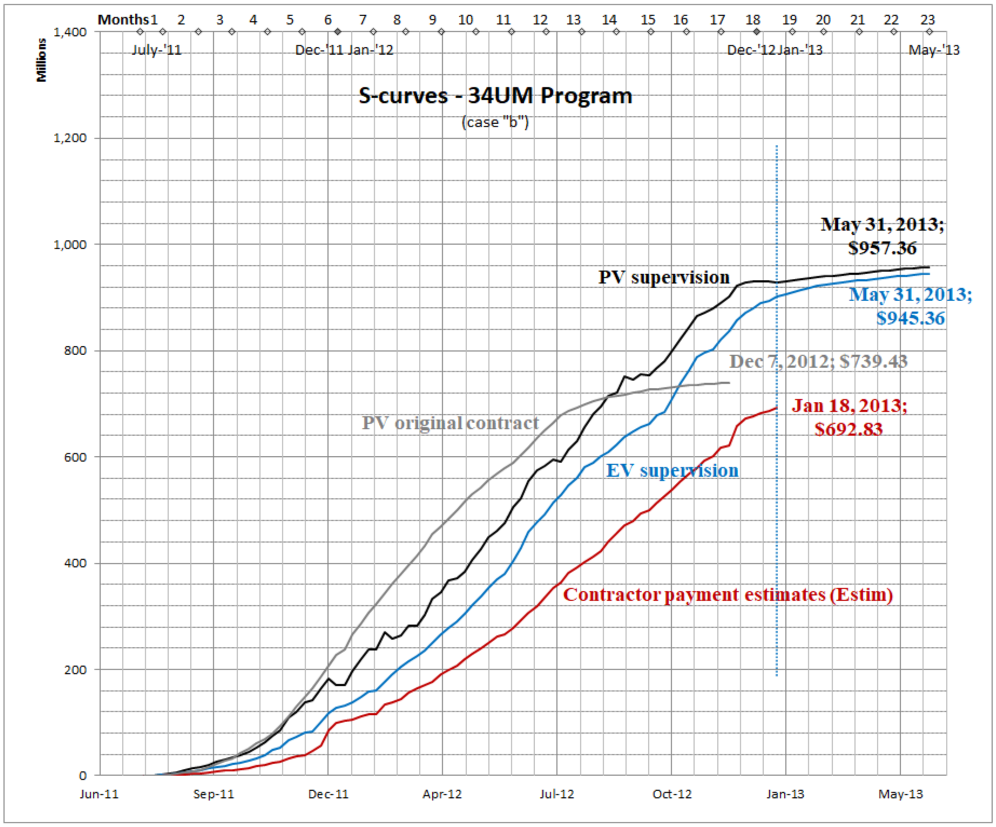

Figure 2*. S-curves of the 34UM Program performance (own elaboration)*

Real duration exceeded the planned duration by 178 days (34.7%) and the planned cost was exceeded by 27.8%. Projects managed at the central level exceeded the planned duration by 68.1% and cost by 33.6%; those managed at the regional (local) level exceeded duration by 19.1% and cost by 23.4%.

Time forecasts at the Program level exhibited instability from the beginning up to 40% of the Actual elapsed Time (AT), characteristic behaviour in index-based forecasts (Kim, 2007). With updated PMB, EAC[6] exhibited forecasts with accuracy within +-5% of the real duration, with a timeliness as early as 51.5% of (AT). That is, in the middle of the Program planned duration the method alerted about the possible completion date.

*Reliable cost forecasts were obtained late near real completion. With updated PMB, EAC[27] presented forecasts with accuracy within +-5% of actual cost, with a timeliness from 92.9% of EV progress. (Figure 3) shows the increase in time and cost for each project. The letter "****C****" distinguishes those managed at the central level and "D" distinguishes those managed at the regional (local) level.*

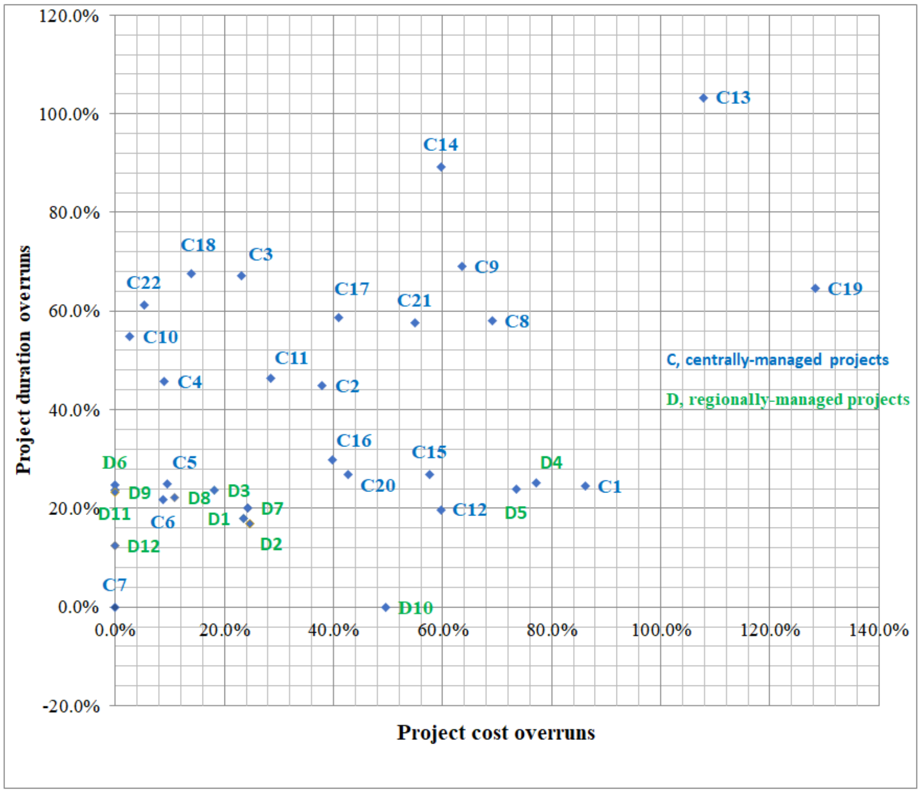

Figure 3. *Time and cost overruns according to the entity managing the contracts (own elaboration)*
*Contracts with increases of more than 30% of the time and 80% of the cost were managed at the central level (**C**), suggesting that contract management at the regional or local level is preferable.*

3.2 Evaluation of time and cost forecasting methods

(Table 1) presents a summary of the best time and cost forecasting methods based on the classification and ranking indicated in the research method. A lower score means a more favorable evaluation.

Table 1. *Ranking of the best positioned schedule and cost forecasting methods (own elaboration)*

Forecasting method	Cases grouping several projects (34UM program, SUB11 & SUB13)		Cases at individual project analysis (K1 – P5)	
	PMB updated	PMB non-updated	PMB updated	PMB non-updated
Schedule forecast				
[16] EAC(t)ES1 PF = 1	2.3	9.7	1.4	6.4
[8] EAC(t)ED1 PF=1	2.8	10	3	7.3
[9] EACED1 PF=1	3.8	10	3.5	5.6
[1] EAC(t)PV1 PF=1	4.3	16.7	3.7	10.6
[14] EAC(t)ED3 PF = 0.8SPI(t) + 0.2CPI	13	3	8.5	11.4
[15] EACED3 PF = 0.8SPI + 0.2CPI	16.3	3.3	12.3	5.8
[10] EAC(t)ED2 PF = SPI(t)	14.8	3.3	13.3	13.9
[17] EAC(t)ES2 PF = SPI(t)	13.3	4	11.5	6.6
Cost forecast				
[28] EAC($) PF=SPI(t)	1.3	1	5	4
[23] EAC($) PF=1	3	4	1.5	3.6
[25] EAC($) PF=SPI(t)	6	2	6.2	3.7
[27] EAC($) PF=SPI	1.8	9	7.6	5
[31] EAC($) PF = SPI * CPI	5.8	3	9.7	8.1
[34] EAC($) PF = 0.2SPI(t) + 0.8CPI	6.5	8	5.3	7

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Best time forecasting methods are those under the assumption that future performance will follow the behavior of how it was planned (PF=1), according to the results obtained by (Buyse and Vandenbussche, 2010). Best cost forecasting methods are based on the SPI and SPI(t) time performance indexes according to the findings of (Batselier and Vanhoucke, 2015).

The time forecasting method with highest degree of predictability (in 69% of the cases analyzed) is the Estimate at Completion EAC[16], based on the assumption (PF=1). Reliability in terms of accuracy and stability was consistently achieved from 50% of progress. Average accuracy: MAPE[16]=6.13%; MPE[16]=1.55%; Average stability: 5.3% with respect to the Real Duration (RD). Recommended for use with updated baselines (PMB).

$$EAC(t)_{[16]} = AT + (PD - ES) \qquad (1)$$

The cost forecasting method with the highest degree of predictability (in 72% of the cases analyzed) is the Estimate at Completion EAC[28], based on the assumption PF=SPI(t). Reliability in terms of accuracy and stability was consistently achieved from 60% of progress. Average accuracy: MAPE[28]=15.78%; MPE[28]=-0.82%; Average stability: 17.0% with respect to Real Cost (RC). Recommended for use with updated or non-updated baselines (PMB).

$$EAC(\$)_{[28]} = \frac{BAC}{SPI_{(t)}} \qquad (2)$$

The results show that there is no single best forecasting method that is the most accurate and superior for all projects under all circumstances, according to (Jack , 2010), (Kamil, 2005) and (Trahan, 2009).

3.3 Aspects influencing the forecasting capability of the methods

Four aspects to be considered were identified throughout the research: the PV, EV and AC input data; the reliability of the SPI(t) performance index; the use of updated and non-updated PMBs; and the stability of the performance indexes due to changes/rescheduling of PMBs and variations in project progress with respect to the plan.

With PV and EV data, as usually reported in professional practice and, AC=Contractor Payment Estimates, it is possible to obtain reliable cost forecasts from the SPI and SPI(t) Schedule Performance indexes see (Table 1), although in this alternative the CV and CPI metrics are not useful to reflect cost performance correctly see (Figure 2).

It was confirmed that the SPI(t) index proposed by (Lipke, 2003) is stable towards project completion and corrects the anomaly exhibited by the SPI index. The point of divergence between SPI and SPI(t) was found at a progress EV=75.8% with respect to the original Budget at Completion (BAC) and at an elapsed time AT=74.7% of the initially planned duration.

It is more convenient to use updated PMBs, since they provide a greater number of forecasting methods with values close to the Real Duration or Real Cost.

(Figure 4) shows the schedule performance, performance indexes and project duration forecast in two opposite cases: project C13 with unstable PMB as a result of four rescheduling and significant variations between progress and plan; project D3 with stable PMB throughout its execution, as a result of no rescheduling and project progress being close to plan.

The upper graphs show an unstable PMB where for every elapsed day AT (straight line) the days gained (ES) exhibit staggering with sustained periods of no progress, and a stable PMB with progress very close to plan.

The graphs in the center show the behavior of CPI and SPI(t). With unstable PMB, SPI(t) index exhibits instability with the sawtooth effect reported by (Henderson , 2006).

When rescheduling/changes in the baseline occur, the variations and indexes experience "peaks", as the baseline update puts the progress on schedule, showing recovery in performance, while forecasts in the same periods show "valleys", bringing the forecasted duration closer to the real duration.

In the case of ideal performance (graphs on the right), the stability of CPI and SPI(t) results in all time forecasting methods being accurate within the +-5% threshold with respect to the Real Duration, as of 39.1% and 38% progress of the Planned Duration.

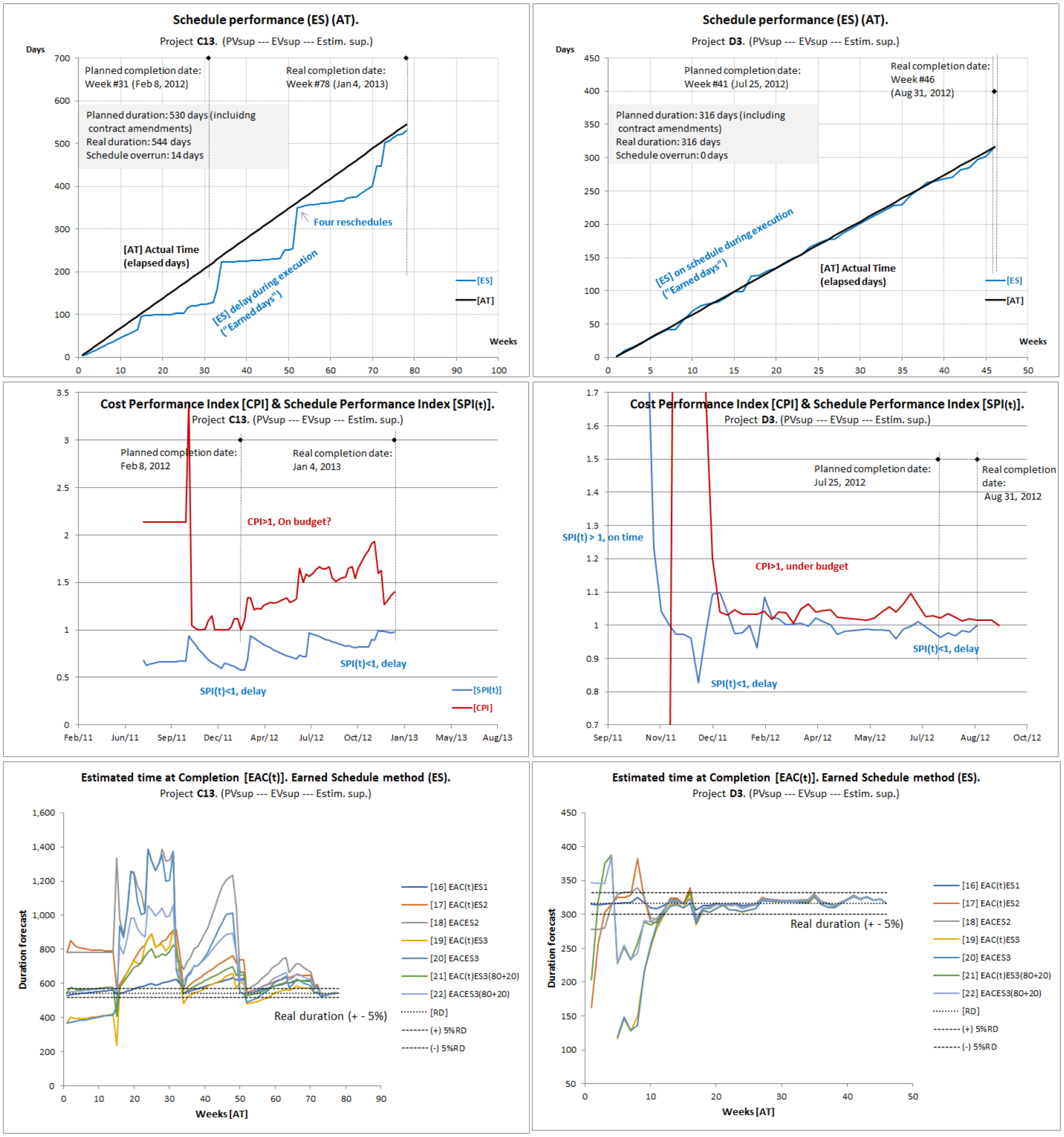

Figure 4. *Project C13 (unstable PMB), Project D3 (stable PMB). (Own elaboration)*

4.Conclusions

The EVM/ES performance indicators provide relevant information to the project manager for decision making according to (Bakr, 2004); (Project Management Institute, 2017), allowing in the case study to evaluate the performance of the contract administration units. Thus, local supervision is associated with compliance in time and cost as opposed to project management at the central level.

In terms of opportunity, accuracy, and stability, according to (Batselier and Vanhoucke, 2015), time forecasting methods exhibited better performance than cost forecasting methods. Better forecasts were found with updated baselines as they

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presented lower dispersion (Buyse and Vandenbussche, 2010). With AC=Contractor Payment Estimates, the best time forecasting method is EAC[16], under the assumption that future performance will be as planned accordingly to (Buyse and Vandenbussche, 2010), and should be complemented with EAC[14] y EAC[15]; the best cost forecasting method is EAC[28], based on the Schedule Performance Index SPI(t) accordingly to Batselier & Vanhoucke, 2015 and should be complemented with EAC[23].

A limitation of this research is the use of the Planned Duration (PD) and Planned Cost (PC) with the values they took once the projects were completed. PD and PC in practice vary as changes in the project baseline are authorized during execution.

The use of the contractor payment estimates as Actual Cost (AC) resulted in the Cost Performance Index (CPI) not being able to identify the cost overruns in which most of the 34UM projects incurred, so future research is suggested to use the input data to the EVM/ES based on the proposal of (Valderrama and Guadalupe, 2010).

Authors contributions.

Data collection and statistical analysis, first draft, Flavio R. Durón-González. Research design, review of findings and final revision, Luis Arturo Rivas-Tovar. Verification of results and support in statistical work, Magali Cárdenas-Tapia.

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Appendix

Time forecasting methods evaluated in the research, adapted from (Vanhoucke , 2014).

***Planned Value Method* (PVM)**	
Time Variation TV = (EVcum - PVcum) * PD / BAC	
PF = 1	
[1] EAC(t)PV1	= PD – TV
PF = SPI; SPI(t); CPI	
[2] EAC(t)PV2	= PD / SPI(t)
[3] EACPV2	= PD / SPI
PF=SCI; SCI(t)	
[4] EAC(t)PV3	= PD / (SPI(t) * CPI)
[5] EACPV3	= PD / (SPI * CPI)
[6] EAC(t)PV3(80+20)	= PD / (0.8 SPI(t) + 0.2 CPI)
[7] EACPV3(80+20)	= PD / (0.8 SPI + 0.2 CPI)
***Earned Duration Method* (EDM)**	
PF = 1	
[8] EAC(t)ED1	Si AT < PD, EAC(t)ED1 = PD + AT * (1 - SPI(t))
	Si AT > PD, EAC(t)ED1 = AT * (2 - SPI(t))
[9] EACED1	Si AT < PD, EACED1 = PD + AT * (1 - SPI)
	Si AT > PD, EACED1 = AT * (2 - SPI)
PF = SPI; SPI(t); CPI	
[10] EAC(t)ED2	Si AT < PD, EAC(t)ED2 = PD / SPI(t)
	Si AT > PD, EAC(t)ED2 = AT / SPI(t)
[11] EACED2	Si AT < PD, EACED2 = PD / SPI
	Si AT > PD, EACED2 = AT / SPI
PF=SCI; SCI(t)	
[12] EAC(t)ED3	Si AT<PD, EAC(t)ED3 = (PD/SCI)+AT*(1-1/CPI) Where: SCI = SPI(t)*CPI
	Si AT>PD, EAC(t)ED3 = AT*(1-1/CPI+1/SCI) Where: SCI = SPI(t)*CPI
[13] EACED3	Si AT < PD, EACED3 = (PD/SCI)+AT*(1-1/CPI) Where: SCI = SPI*CPI
	Si AT > PD, EACED3 = AT*(1-1/CPI+1/SCI) Where: SCI = SPI*CPI
[14] EAC(t)ED3(80+20)	Si AT < PD, = (PD/SCI)+AT*(1-1/CPI) Where: SCI = 0.8SPI(t)+0.2CPI
	Si AT > PD, = AT*(1-1/CPI+1/SCI) Where: SCI = 0.8SPI(t)+0.2CPI
[15] EACED3(80+20)	Si AT < PD, = (PD/SCI)+AT*(1-1/CPI) Where: SCI = 0.8SPI+0.2CPI
	Si AT > PD, = AT * (1 - 1/CPI + 1/SCI) Where: SCI = 0.8SPI+0.2CPI