Reflexion on Emergent Earned Value Schedule Methods

Tiago Moreira and José Figueiredo

***Abstract*—This work aims to reflect on the turnover process between two phases of a power plant construction project - erection and commissioning. Using real data from the project, we propose a new turnover process. Our approach uses recent earned value based schedule methods and try to ensure a more effective commissioning regarding main schedule priorities. We believe that in consequence we are able to reduce the project duration and improve the client-contractor relationship on site. Our contribution to the improvement of this field intends to be multiple: First, we warn for potential mistakes while enquiring the project schedule performance using traditional approaches, namely on projects facing different productivity rates during their lifecycle. Second we demonstrate how emergent earned schedule method improves this monitoring process. Finally, to overcome the problem we faced during our power plant construction project to calculate and communicate the "to complete schedule performance index" in time units, we propose a new approach. Our new approach was validated with real data from the real project.**

***Index Terms*—Earned Value Systmes (EVM), Schedule Performance, Commissioning, Forecasting, Turnover**

I. Introduction

This work is focused on the turnover process between the erection and commissioning activities on site. This process became relevant as these activities tended to overlap on site in order to reduce the overall project duration. This phenomenon commonly called "fast-tracking" is reasonably accepted to speed up almost any kind of project but requires a fairly management process and depends on effective feedback and feed-forward communication [1]. So, some clarifications and changes were the goal of our work.

Our work is concerned with EVM monitoring and controlling methods that would "ensure the commissioning main schedules priorities" by accurately monitor erection works and forecast the commissioning start-up works. These processes have priority because they have significant impact on the overall turnover process. Besides, we tried to shed some light on two important subjects, regarding our experience on the power plant construction project: accurately assess the subcontractors schedule performance and clearly communicate the required future performance to accomplish the commissioning main schedule priorities.

We begin by situating our research on the Turnover operation (Section 2), we then describe in very compact way our literature review (Section 3), we proceed with a method overview (Section 4), we invested in applying and rezoning on the respective results of using traditional EVM and EVM with extensions, (Section 5), after a simulation using different systems we applied the method to the turnover process (Section 6), we introduced some new concepts and explored them in our simulation (Section 7), and finally draw some conclusion in Section 8.

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II. Turnover Problems Overview

Our experience in a power plant construction project allowed us to conclude that some turnover process problems were jeopardizing the turnover process main goals accomplishment. Indeed, the different languages spoken by erection and commissioning teams, the difficulty to keep track of inspected erection systems that allow an accurate turnover process progress status, and finally a lack of monitoring and control method that underpins an accurate end-of-erection forecasting method, harm significantly the commissioning schedule priorities and difficult the client representatives integration within the turnover process activities. Furthermore, without a user-friendly tool enabling and facilitating the communication and the record of all energised systems, the actual communication process to ensure safety-commissioning works seems to be significantly poor. Finally, the end-of-erection follow up tool proved to be inadequate to manage more than 4000 different points requesting re-work, clarifications or changes.

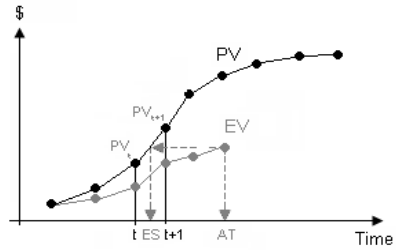

Fig. 1. Earned scheduling

III. Compact Literature Review

After an extensive literature review based on works of [1]-[5] we concluded that the Earned Value Management was the most suitable method as it provides a clear quantitative picture of the project status and provides means to extrapolate project final duration [6]. See Figure 1.

Though Earned Value Management has been widely considered as one of the most effective monitoring and controlling methods [3], [7], [8] and [9], we realised an unexpected shortcoming regarding its schedule performance management ability, namely for projects running behind schedule. To overcome this problem, additional literature review drove us to recently deployed EV management

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methods, namely the Planned Value [14], Earned Duration [10] and [11] and Earned Schedule [12] and [13]. These different researchers published their approaches as an attempt to calculate the planned duration of work remaining (PDWR), each one referring to three different situations assuming a future performance factor (PF) regarding the project past performance. Table 1 resumes these scenarios and includes those stressed by [14] and [15]. The forecasting formulas under study will be based on the three last scenarios presented on Table 1. Due to a great number of different notations, acronyms and formulas used by these authors, we followed the language used by Vanhoucke [16].

TABLE I: PLANNED DURATION OF WORK REMAINING REGARDING THE PROJECT SITUATION

Scenario	Forecasting Method		
	Anbari (2003)	Jacob (2003)	Lipke (2003)
PDWR PF=1	EAC(t)PV1	EAC(t)ED1	EAC(t)ES1
PDWR PF=SPI	EAC(t)PV2	EAC(t)ED2	EAC(t)ES2
PDWR PF=SCI	EAC(t)PV3	EAC(t)ED3	EAC(t)ES3

IV. METHOD OVERVIEW

This section tests the accuracy of the methods presented earlier to forecast commissioning start-up works. First, we modeled the erection and commissioning activities using MS Project. Then, we gathered the "progress and status reports" of each erection system and updated our MS Project master plan with this data. Finally, these results were exported to MS Excel with the help of a "Visual Basic for Applications Macro", and key EV metrics and performance measures were calculated to enable the application of the planned value, earned duration, and earned schedule methods, earlier referred. The next application example is based on the Water Steam Cycle systems and Balance of Power Plant systems (WSC-BOP), which encompasses 19 independent systems. Though the WSC-BOP had project duration (PD) of 33 weeks and a budget at completion (BAC) of 8.957.524 euros, the Real Duration (RD) was 40 weeks and the Final Cost (FC) was 11.812.314 euros. See Fig. 2.

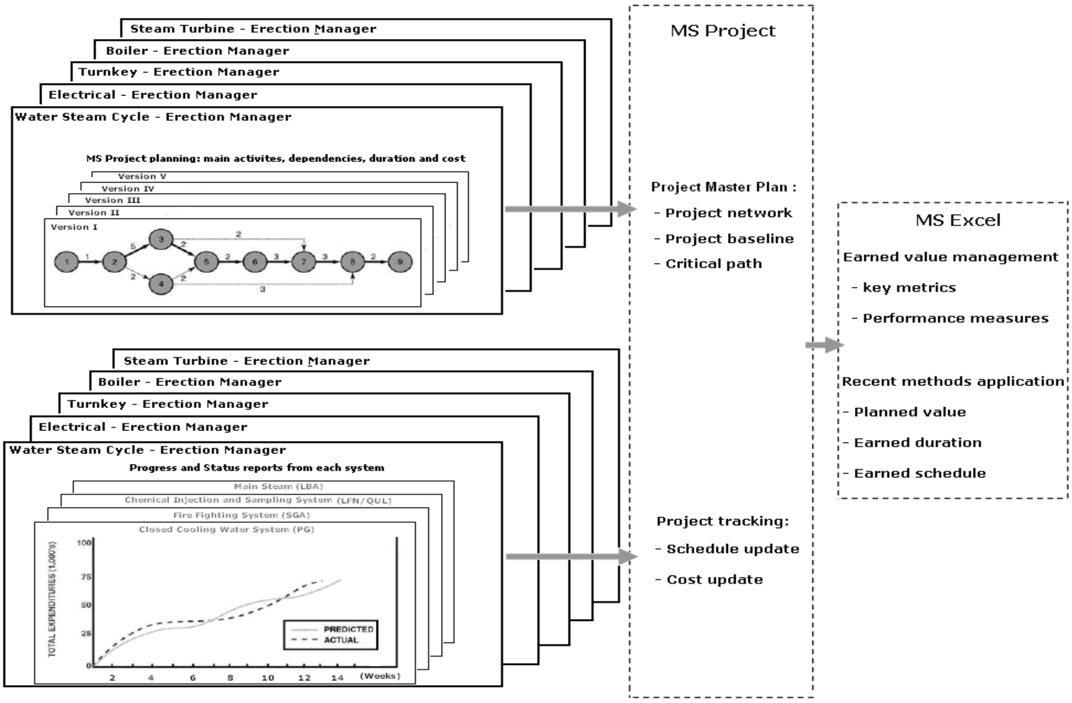

Fig. 2. Method overview

V. RESULTS FROM THE STUDY

We compared the traditional Schedule Variance (SV) defined in PMBOK [17] and the recently proposed SV(t) [12]. We conclude that SV(t) outperforms the SV because, contrarily to SV, it correctly highlights the poor schedule performance by the end of the project, namely a delay around 7 weeks. We compare the traditional Schedule Performance Index (SPI) [17] and the recently developed SPI(t) [12]. We conclude that SPI(t) outperforms SPI as it unveils, contrarily to SPI, the deterioration of the project performance by a negative trend until the end of the project.

To analyze the forecasting accuracy of each method regarding the three different scenarios in Table 1, it was used the Mean Absolute Percentage Error (MAPE) (Equation 1) between the forecasted value (FV) for each period of analysis and the Real Duration (RD) of the project, i.e. 40 weeks.

$$MAPE = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{RD - FV_t}{RD} \right| \quad (1)$$

Firstly, regardless of scenarios, the Planned Value, Earned Duration and Earned Schedule methods behave similarly only during the first and middle stages of the project. Secondly, as the turnover process team has to perform the "3 weeks look ahead schedule", as stated in the official power plant construction project contract, which is obviously done during the latest stages of the project, we enquired the last third of the project duration and concluded that Earned Schedule method outperforms all the other methods, regardless of scenarios and reaches a MAPE of 2,49% when PF follows a SPI(t) trend.

TABLE II: MAPE FOR EACH PROPOSED SCENARIO

		MAPE	
		Overall project life	From Week 22 onwards
P.F. =1	$EAC(t)_{PV1}$	8,29%	9,53%
	$EAC(t)_{ED1}$	3,78%	4,29%
	$EAC(t)_{ES1}$	5,66%	3,90%
P.F.= SPI	$EAC(t)_{PV2}$	185,71%	9,38%
	$EAC(t)_{ED2}$	183,79%	5,64%
	$EAC(t)_{ES2}$	63,87%	2,49%
P.F.= SCI	$EAC(t)_{PV3}$	323,76%	22,11%
	$EAC(t)_{ED3}$	98,21%	8,14%
	$EAC(t)_{ES3}$	51,88%	7,54%

This test unveiled an unexpected shortcoming of the Earned Duration (ED) method for projects running ahead of schedule, as the values were sometimes smaller than AD. Finally, we stressed the unreliable results of Planned Value method proving to be an unreliable method to forecast the end-of-erection and commissioning start up works. See Table II.

VI. FORECASTING METHOD'S EFFECT ON TURNOVER

We performed a simulation study encompassing 19 systems that are part of the WSC-BOP system and analysed the referred methods through a set of metrics aimed at mirroring the turnover process main goals. See Fig. 3.

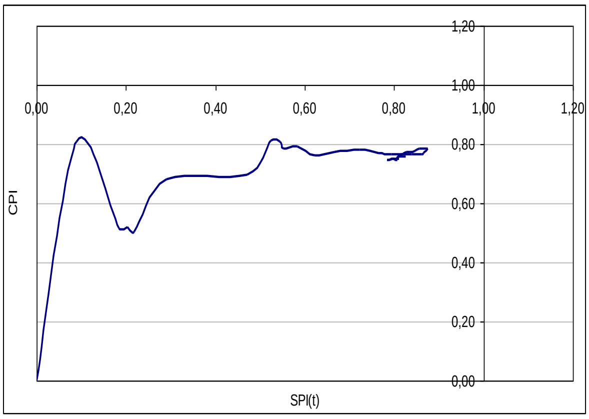

Fig. 3. Poor performance of WSC-BOP system

Walk down preparation - measures the turnover process efficiency improvement as it gauges the time needed to prepare the inspection of each system before the official turnover. In practice the turnover process team will start working on a certain system and will include it in the "3 weeks look ahead schedule" if Equation 2 is satisfied. Later, the Walk down preparation WDP is calculated by the difference between the week erection works finished – planned duration (PD) -and first inspection (FI) scheduled (Equations 3 and 4).

$$\lceil EAC(t) \rceil - AD \leq 3 \tag{2}$$

$$FI = \begin{cases} 0 \ \ if \ \ \lceil EAC(t) \rceil - AD > 3 \\ AD \ \ if \ \ FI = 0 \wedge \lceil EAC(t) \rceil - AD \leq 3 \end{cases} \tag{3}$$

$$WDP = PD - FI \tag{4}$$

$$WI = \begin{cases} \lceil EAC(t) \rceil \ \ if \ \ FI = 0 \vee \lceil EAC(t) \rceil > WI(t-1) \\ WI(t-1) \ \ if \ \ FI > 0 \wedge \lceil EAC(t) \rceil \leq WI(t-1) \end{cases} \tag{5}$$

$$WBEET = WI - PD \tag{6}$$

Finally, the CI (number of cancelled inspections) measures the ability to avoid erroneous end-of-erection estimates. During this test, a cancelled inspection was considered to be any modification done in the "3 weeks look ahead schedule".

$$CI = \begin{cases} 0 \ \ if \ \ FI = 0 \\ CI + 1 \ \ if \ \ \lceil EAC(t) \rceil > WI(t-1) \end{cases} \tag{7}$$

We can conclude that the EAC(t)ES2 outperforms the EAC(t)ED2 method as it requests a lower average number of weeks to prepare the systems' walk-down (WDP), namely 2,58 weeks needed against 3,47 weeks when using the EAC(t)ED2. Furthermore, the EAC(t)ES2 method also gives a better average result regarding the number of cancelled inspections (CI), namely 0,21 against an average value of 0,26 when using the EAC(t)ED2. On the other hand, EAC(t)ED2 method gives slightly better results regarding the time commissioning teams have to wait to launch their activities after the end-of-erection works (WBEET). See Table III.

TABLE III: SIMULATION RESULTS

Metrics	EAC(t)ES2	EAC(t)ED2
WDP	2,58	3,47
WBEET	1,89	1,53
CI	0,21	0,26

We would like to stress the fact that those results are average results and they obviously hide some important situations in which the forecasting output is significantly different from a possible scenario "without any forecasting tool". So, using the EAC(t)ES2 and EAC(t)ED2 methods ensured a WDP smaller than 5 weeks for 94,74% and

84,21%, respectively. The WBEET metric points out that the gap between end-of-erection and commissioning start up works for 73,68% and 89,47% of the systems was smaller than 3 weeks when using the EAC(t)ES2 and EAC(t)ED2 methods respectively. Finally, the CI metric shows that 84,21% (using EAC(t)ES2) and 73,68% (using EAC(t)ED2) of the systems' inspections were never cancelled which is undoubtedly an interesting result.

Finally, we enquired the meaningfulness of EAC(t)ES2 and EAC(t)ED2 by simulating and comparing them with the "rule-of-thumb" procedure of turnover process. Due to a lack of method to monitor the erection works, the turnover process team used to schedule the turnover process preparation works when the initial planned date for a certain percentage of systems' completeness was reached. Thus, we created four different scenarios assuming a percentage of systems' completeness at 85%, 90%, 95% and 98%. Then we calculated the WDP, WBEET and CI metrics for each scenario and compared them with EAC(t)ES2 and EAC(t)ED2 results.

We concluded that both EAC(t)ES2 and EAC(t)ED2 outperform the "rule of thumb" used by the turnover process team despite of the scenario, as they enable the turnover process team to reduce the values of both WDP and CI metrics. Regarding the WBEET metric the EAC(t)ES2 and EAC(t)ED2 methods do not seem to give better average results than the traditional approach applied by the turnover process team. Indeed, using the common turnover process approach ensures a WBEET always lower than 3 weeks while using the EAC(t)ES2 and EAC(t)ED2 this value occurs only 73,68% and 89,47% of the times, respectively.

TABLE IV: STATISTICAL DISTRIBUTION OF WBEET, WDP AND CI

	WDP	
Weeks	$EAC(t)_{ES2}$	$EAC(t)_{ED2}$
[1;2]	52,63%	21,05%
[3;5]	42,11%	63,16%
[6;7]	5,26%	15,79%
	WBEET	
Weeks	$EAC(t)_{ES2}$	$EAC(t)_{ED2}$
0	15,79%	21,05%
1	15,79%	21,05%
2	42,11%	47,37%
3	26,32%	10,53%
	CI	
Number of Cancelled Inspection	$EAC(t)_{ES2}$	$EAC(t)_{ED2}$
0	84,21%	73,68%
1	10,53%	26,32%
2	5,26%	0,00%

This difference may be relevant for those systems that require an early turnover because they belong to the critical path, or have a high criticality index [18] or crucially index [19]. However, our experience showed us that the critical path systems in this kind of PPCP counts for less than 20% of the total erection systems, meaning that the application of EAC(t)ES2 or EAC(t)ED2 might result in an overall significant improvement. See Table Ⅳ.

VII. Beyond Recent Earned Value Developments

As already referred in the literature for projects running behind schedule, an opposed behavior of SV and SV(t) is expected by the end of the PD (10), (16) and (17). However, the WSC-BOP system example unveils an unexpected behavior for SV and SV(t) which starts 8 weeks before the planned PD. Indeed, between Week 25 and Week 33, though the SV increases, stressing an improvement of the project performance as the difference between the planned work and the work performed decreases, the SV(t) decreases stressing a project performance drop. To understand if there is a flawed behavior of SV (PMBOK, 2008) or SV(t) [12] behind this problem we propose the following approach: instead of focusing on the units of work produced during one week we will enquiry the amount of time earned by producing those units (ET/U). Note that in our example the analysis timeframe was always 1 week. We introduce some new concepts to facilitate the comprehension of our experiment, see Table Ⅴ, and then we apply them on the WSC-BOP example and highlight the main conclusions.

TABLE V: PROPOSED METRICS

Metric	Notation	Formula
Planned Work	PW	$PV_{AD} - PV_{AD-1}$ (Eq. 7)
Earned Work	EW	$EV_{AD} - EV_{AD-1}$ (Eq.8)
Planned Time per Unit	PT/U	$\frac{TimeFrame\ Analysis}{PW_{AD}}$ (Eq. 9)
Earned Project Duration	EPD	$\sum_{W=1}^{AD} (EW \times PT/U)_W$ (Eq. 10)
Schedule Variance Index	SV_{ET}	$EPD - AD$ (Eq. 11)
Earned Time	ET	$EPD_{AD} - EPD_{AD-1}$ (Eq.12)

First, having week 25 as an example, see Table Ⅵ, it can be figured out that by the end of week 25 the earned project duration (EPD) is 21,18 weeks (Equation 11) which means that all the planned work until week 21 has already been accomplished and 18% of the planned work from week 22 is accomplished. This helps us understanding in which moment of the project execution work we are. See Table 5.

VIII. Conclusions

Firstly we concluded that the turnover process disability to monitor and control erection works and to forecast commissioning start-up works had a straightforward impact on the project duration, on client-contractor relationship on site and an indirect impact on project's quality and cost.

Then we concluded that Earned Value Management is the most suitable monitoring and controlling method regarding the specificities of turnover process and erection activities of the described type.

Hence, we propose SV(t) and SPI(t) rather than the traditional method SV and SPI, respectively. We also concluded that ES method, under the assumption of PF=SPI(t), is the most reliable method to forecast the commissioning start-up works, and also that EAC(t)ES2 outperforms the EAC(t)ED2 as it reduces the number of weeks needed to prepare inspections, cancelled inspections and improves the relationship with the client.

TABLE VI: PROPOSED METRICS' RESULTS

Actual Duration	21	22	23	24	25
SV	-2,83	-2,73	-2,97	-3,44	-3,82
EPD	18,17	19,27	20,03	20,56	21,18
ET	0,92	1,10	0,76	0,54	0,62
PV	6.323.990	6869.406	7.330.101	7.726.470	8.039.769
EV	4.805.990	5.337.109	5.712.842	6.049.401	6.423.944
PW	627.536	545.951	469.695	387.369	313.300
EW	400.564	530.118	375.734	336.558	374.544
PT/U	0.0016	0.0018	0.0021	0.0026	0.0032

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