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A comparison of different project duration forecasting methods using earned value metrics

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Abstract

Earned value project management is a well-known management system that integrates cost, schedule and technical performance. It allows the calculation of cost and schedule variances and performance indices and forecasts of project cost and schedule duration. The earned value method provides early indications of project performance to highlight the need for eventual corrective action.

Earned value management was originally developed for cost management and has not widely been used for forecasting project duration. However, recent research trends show an increase of interest to use performance indicators for predicting total project duration. In this paper, we give an overview of the state-of-the-art knowledge for this new research trend to bring clarity in the often confusing terminology.

The purpose of this paper is 3-fold. First, we compare the classic *earned value* performance indicators SV and SPI with the newly developed *earned schedule* performance indicators SV(t) and SPI(t). Next, we present a generic schedule forecasting formula applicable in different project situations and compare the three methods from literature to forecast total project duration. Finally, we illustrate the use of each method on a simple one activity example project and on real-life project data.

Keywords: Earned value; Earned duration; Earned schedule; Project duration forecasting

1. Schedule performance indicators

Earned Value Management (EVM) is a methodology used to measure and communicate the real physical progress of a project and to integrate the three critical elements of project management (scope, time and cost management). It takes into account the work complete, the time taken and the costs incurred to complete the project and it helps to evaluate and control project risk by measuring project progress in monetary terms. The basic principles and the use in practice have been comprehensively described in many sources (for an overview, see, e.g. [1] or [2]).

Although EVM has been setup to follow-up both time and cost, the majority of the research has been focused on the cost aspect (see, e.g. the paper written by Fleming and Koppelman [3] who discuss earned value management from a *price*-tag point-of-view). Nevertheless, earned value management provides two well-known schedule performance indices, the schedule variance (SV) and the schedule performance index (SPI), to measure project progress. The SV is the difference between the earned value (EV) and the planned value (PV), i.e. SV = EV − PV (for a graphical

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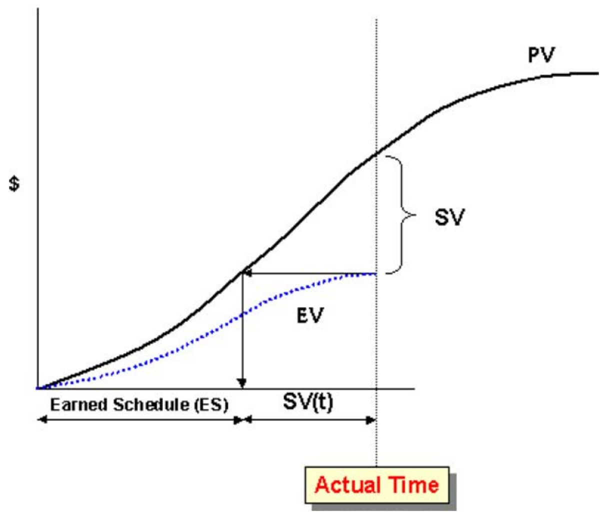

Fig. 1. SV versus SV(t).

presentation, see Fig. 1). Note that the PV is often denoted as the BCWS (Budgeted Cost for Work Scheduled) and the EV as the BCWP (Budgeted Cost Work Performed). The SV measures a volume of work done (i.e. earned) versus a volume of work planned. However, the SV does not measure time but is expressed in a monetary unit. If SV < 0, a lower volume of work has been earned as planned, and the work is behind plan. If SV > 0, a higher volume of work has been earned as planned, and the work is ahead of plan. If SV = 0, the earned work is exactly as planned. At the end of a project, the EV = PV = BAC (budget at completion), and hence, the SV always equals 0. The SPI is the ratio between the earned value and the planned value, i.e. SPI = EV/PV, and is a dimensionless indicator to measure the efficiency of the work. If SPI < 1 (=1, >1), the schedule efficiency is lower than (equal to, higher than) planned. At the end of a project, the SPI is always equal to 1.

The interpretation and the behaviour of the earned value management performance indicators SV and SPI over time have been criticized by different authors [4]. First, the SV is measured in monetary units and not in time units, which makes it difficult to understand and is therefore often a source of misinterpretations. Secondly, a SV = 0 (or SPI = 1) could mean that a task is completed, but could also mean that the task is running according to plan. Thirdly, towards the end of the project, the SV always converges to 0 indicating a perfect performance even if the project is late. Similarly, the SPI always converges to 1 towards the end of the project, indicating a 100% schedule efficiency even in the project is late. As a result, at a certain point in time the SV and the SPI become unreliable indicators, and this “grey time area” where these indicators loose their predictive ability usually occurs over the last third of the project (expressed in percentage completion, see [4]). However, this is often the most critical period where the forecasts need to be accurate, since upper management wants to know when they can move up to the next project stage.

In order to overcome the anomalies with the earned value schedule performance indicators, Lipke [4] introduced the concept of earned schedule (ES). In this method, the earned value at a certain (review) point in time is traced forwards or backwards to the performance baseline (S-curve) or PV. This intersection point is moved downwards on the X-axis (the time scale) to calculate the earned schedule ES (see Fig. 1). Hence, the ES is found by identifying in which time increment of PV the EV occurs. It translates the EV into time increments and measures the real project performance in comparison to its expected time performance. The corresponding schedule performance metrics are:

$$\mathrm{SV}(t) = \mathrm{ES} - \mathrm{AT}, \tag{1}$$

$$\mathrm{SPI}(t) = \mathrm{ES}/\mathrm{AT}, \tag{2}$$

where AT is used to refer to the Actual Time.

In contrast to the SV, the SV(t) is expressed in time units, which makes it easier to interpret. A SV(t) < 0 (>0) indicates the number of time units that the project lags (is ahead of) its expected performance. The behaviour of SV(t) over time results in a final SV(t) that equals exactly the real time difference at completion (while the SV always ends at zero). The same holds for the SPI(t) indicator, which has a final value reflecting the final project schedule performance (while the SPI always equals 1).

2. A generic project duration forecasting formula

Earned value metrics have been widely used to monitor the status of a project and forecast the future performance, both in terms of time and cost. The use of the metrics to forecast a project’s final cost is numerous and is outside the scope of this paper (for an overview, see, e.g. Christensen [5] who reviews different cost forecasting formulas and examines their accuracy). In this section, we elaborate on the use of the metrics to forecast a project’s final duration by different methods. A generic project duration forecasting formula is given by:

$$\mathrm{EAC}(t) = \mathrm{AD} + \mathrm{PDWR}, \tag{3}$$

where EAC(t) is the estimated duration at completion, AD the actual duration and PDWR is the planned duration of work remaining.

We use the EAC(t) metric to refer to any forecasting metric for a project’s total *duration* (note that the abbreviation EAC – without (t) – is usually used in the literature to refer to the *cost* estimate at completion) and the AD metric to refer to the actual duration of the project at the current time instance. Moreover, the PDWR metric is the component that has to be estimated, and heavily depends on the specific characteristics and the current status of the project [1]. In Table 1, we distinguish between six different project situations based on the classification described in [1].

Table 1
The estimated PDWR depending on the project situation (based on Anbari [1])

Situation	Forecasting method			Comments
	Anbari [1]	Jacob [6]	Lipke [4]	
EAC(t) as originally planned	Monitor schedule			The final project duration will be as planned, regardless of the past performance. This situation may be dangerous, as unattended problems mostly do not resolve themselves ("we'll catch up during the commissioning phase")
PDWR is new	Re-schedule			The original project assumptions are no longer valid for the remaining work (due to changed conditions). The use of performance indices to predict is obsolete and a new schedule for the remaining work needs to be developed
PDWR is very high	Re-schedule			Quality problems are irreversible and a lot of extra time is needed to fix the problems (occurs mostly in the late project stage). Stakeholders usually loose their interest in the project ("If this project ever finishes, it would be a miracle")
PDWR according to plan	$EAC(t)_{PV1}$	$EAC(t)_{ED1}$	$EAC(t)_{ES1}$	Past performance is not a good predictor of future performance. Problems/opportunities of the the past will not affect the future, and the remaining work will be done according to plan
PDWR will follow current SPI trend	$EAC(t)_{PV2}$	$EAC(t)_{ED2}$	$EAC(t)_{ES2}$	Past performance is a good predictor of future performance (realistic!). Problems/opportunities of the past will affect future performance, and the remaining work will be corrected for the observed efficiencies or inefficiences
PDWR will follow current SCI trend	$EAC(t)_{PV3}$	$EAC(t)_{ED3}$	$EAC(t)_{ES3}$	Past cost *and* schedule problems are good indicators for future performance (i.e., cost *and* schedule management are inseparable). The SCI = SPI * CPI (schedule cost ratio) is often called the critical ratio index
	Planned value rate	Earned duration	Earned schedule	

The first project situation assumes ideal circumstances and does not require any forecasting since the project is considered to be on plan. The second and third rows refer to project situations where forecasting (i.e. estimating the PDWR) is useless due to the changing conditions or irreversible problems. Hence, in the remainder of our paper, we will focus on the last three possible project scenarios. In these cases, we assume that the PDWR is according to plan (scenario 4), follows the current SPI trend (scenario 5) or follows the current SCI trend (scenario 6). Each forecasting technique described in the three following sub-sections will be discussed from these last three project scenarios point-of-view.

To the best of our knowledge, only three project duration forecasting methods have been presented in literature. In the remainder of this paper, we refer to these methods as the *planned value method* [1], the *earned duration method* [6] and the *earned schedule method* ([4], and further developed by [7–10]). However, the many notations, abbreviations and often confusing metrics used to describe these three methods unnecessarily complicate the comparability of these methods. In order to shed light on the confusing terminology, we summarize the overwhelming amount of synonyms taken from these various literature sources in Table 2. The column labelled with "At Completion indicators" displays the terminology used to refer to Eq. (3). The column labelled with "Assessment indicators" displays the terminology used to measure the additional effort needed to finish the project within the project deadline. The specific calculation of these metrics will be explained in detail in the following three sub-sections.

2.1. The planned value method

The planned value method is described by Anbari [1] and relies on the *planned value rate* which is equal to the average planned value per time period, i.e. PVRate = BAC/PD where BAC is used to denote the budget at completion and PD to denote total planned project duration. This method assumes that the schedule variance can be translated into time units by dividing the schedule variance by the planned value rate, resulting in the time variance TV as follows:

$$\begin{aligned}\mathrm{TV} &= \mathrm{SV}/\mathrm{PVRate} = (\mathrm{SV} * \mathrm{PD})/\mathrm{BAC} \\ &= (\mathrm{EV} - \mathrm{PV}) * \mathrm{PD}/\mathrm{BAC}.\end{aligned} \quad (4)$$

According to the project characteristics (reflected by the last three situations of Table 1), the following forecasting formulas have been derived:

Table 2
Terminology used in comparison papers under study

Baseline	Anbari [1]		Jacob [6]		Lipke[a]	
	SAC	Schedule at completion	PD	Planned duration	PD	Planned duration
Status of the project	PVRate	Planned value rate	ED	Earned duration	ES	Earned schedule
	AT	Actual time	AD	Actual duration	AT	Actual time
	SPI	Schedule performance index	SPI	Schedule performance index	SPI(*t*)	Schedule performance index time
	SV	Schedule variance	SV	Schedule variance	SV(*t*)	Schedule variance time
	TV	Time variance	–	–	–	
	CR	Critical ratio	–	–	SCI(*t*)	Critical ratio time
	TEAC = AT + TETC		*EDAC = AD + UDR*		*EAC(t) = AT + PDWR*	
At completion indicator	TETC	Time estimate to complete	UDR	Unearned duration remaining	PDWR	Planned duration for work remaining
	TEAC	Time estimate at completion	EDAC	Estimate of duration at completion	EAC(*t*)	Estimate at completion time
	–	–	–	–	*IEAC(t) = AT + PDWR/PF*	
	–	–	–	–	IEAC(*t*)	Independent estimate at completion time
Assessment indicator	–	–	TCSPI	To complete schedule performance index	SPI(*t*) to go[b]	To complete schedule performance index for PD
	–	–	–	–	To complete SPI(*t*)[c]	To complete schedule performance index for latest revised schedule (LRS)

[a] The terminology used is based on the presentation by Lipke and Henderson "Earned schedule – an emerging practice" presented at the 16th Annual International Integrated Program Management Conference, November 15–17, Virginia.
[b] The SPI(*t*) to go is equal to the TCSPI (Eq. (15)) or the TCSPI(*t*) (Eq. (22)) of the current paper.
[c] The to complete SPI(*t*) equals the TCSPI-LRS (Eq. (16)) or the TCSPI(*t*)-LRS (Eq. (23)) of the current paper.

- Duration of remaining work as planned

$$\mathrm{EAC}(t)_{\mathrm{PV1}} = \mathrm{PD} - \mathrm{TV}. \tag{5}$$

- Duration of remaining work follows the current SPI trend

$$\mathrm{EAC}(t)_{\mathrm{PV2}} = \mathrm{PD}/\mathrm{SPI}. \tag{6}$$

- Duration of remaining work follows the current SCI trend

$$\mathrm{EAC}(t)_{\mathrm{PV3}} = \mathrm{PD}/\mathrm{SCI}. \tag{7}$$

Note that the terminology of Anbari [1] is somewhat different since he proposes the Time Estimate at Completion (TEAC) and the Time Estimate to Complete (TETC) to refer to the EAC(*t*) and the PDWR (see Table 2).

2.2. The earned duration method

The earned duration method is described by Jacob [6] and extended by Jacob and Kane [11]. The earned duration ED is the product of the actual duration AD and the schedule performance index SPI, i.e. ED = AD ∗ SPI, and hence, the generic "earned duration" forecasting formula is:

$$\mathrm{EAC}(t)_{\mathrm{ED}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ED})/\mathrm{PF}. \tag{8}$$

The performance factor is used to adapt the future performance to the past performance (depending on the project characteristics) and reflects the last three situations of Table 1, as:

- *PF = 1:* Duration of remaining work as planned

$$\mathrm{EAC}(t)_{\mathrm{ED1}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ED})/1 = \mathrm{PD} + \mathrm{AD} * (1 - \mathrm{SPI}). \tag{9}$$

- *PF = SPI:* Duration of remaining work with SPI trend

$$\mathrm{EAC}(t)_{\mathrm{ED2}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ED})/\mathrm{SPI} = \mathrm{PD}/\mathrm{SPI}. \tag{10}$$

- *PF = SCI:* Duration of remaining work with SCI trend (note that this formula is not given in [6])

$$\mathrm{EAC}(t)_{\mathrm{ED3}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ED})/\mathrm{SCI} = \mathrm{PD}/\mathrm{SCI} + \mathrm{AD} * (1 - 1/\mathrm{CPI}). \tag{11}$$

In situations where the project duration exceeds the planned duration, and the work is not yet completed, the PD will be substituted by the AD in the above mentioned formulas. In these cases, the formulas are:

$$\mathrm{EAC}(t)_{\mathrm{ED1}} = \mathrm{AD} + (\mathrm{AD} - \mathrm{ED})/1 = \mathrm{AD} * (2 - \mathrm{SPI}), \tag{12}$$

$$\mathrm{EAC}(t)_{\mathrm{ED2}} = \mathrm{AD} + (\mathrm{AD} - \mathrm{ED})/\mathrm{SPI} = \mathrm{AD}/\mathrm{SPI}, \quad (13)$$

$$\mathrm{EAC}(t)_{\mathrm{ED3}} = \mathrm{AD} + (\mathrm{AD} - \mathrm{ED})/\mathrm{SCI} = \mathrm{AD} * (1 - 1/\mathrm{CPI} + 1/\mathrm{SCI}). \quad (14)$$

An additional assessment metric given by Jacob [6] measures the additional effort needed to finish the project within the project deadline. This corrective action metric related to the schedule performance is called the "To Complete Schedule Performance Index" (TCSPI) and is calculated as:

$$\mathrm{TCSPI} = (\mathrm{PD} - \mathrm{ED})/(\mathrm{PD} - \mathrm{AD}) \quad (15)$$

or

$$\mathrm{TCSPI\text{-}LRS} = (\mathrm{PD} - \mathrm{ED})/(\mathrm{LRS} - \mathrm{AD}). \quad (16)$$

The former measures the additional effort needed to finish the project within the planned duration while the latter measures the effort to finish the project with the latest revised schedule (LRS) duration.

2.3. The earned schedule method

The earned schedule method to forecast project duration has been recently introduced by Henderson [8], and is an extension of the work done by Lipke [4]. Henderson has illustrated the validity of the earned schedule concept by applying it on a portfolio of six projects [7] and on a small scale but time critical information technology software development project [9]. The earned schedule ES can be mathematically expressed as:

$$\mathrm{ES} = \mathrm{N} + (\mathrm{EV} - \mathrm{PV}_N)/(\mathrm{PV}_{N+1} - \mathrm{PV}_N), \quad (17)$$

where N is the time increment of the PV that is less than current PV, PV_N the planned value at time N and PV_{N+1} is the planned value at time $N + 1$.

The generic earned schedule duration forecasting formula is:

$$\mathrm{EAC}(t)_{\mathrm{ES}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ES})/\mathrm{PF}. \quad (18)$$

The performance factor used depends on the project situation:

- *PF = 1:* Duration of remaining work as planned

$$\mathrm{EAC}(t)_{\mathrm{ES1}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ES})/1 = \mathrm{AD} + (\mathrm{PD} - \mathrm{ES}). \quad (19)$$

- *PF = SPI(t):* Duration of remaining work with SPI(t) trend

$$\mathrm{EAC}(t)_{\mathrm{ES2}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ES})/\mathrm{SPI}(t). \quad (20)$$

- *PF = SCI(t):* Duration of remaining work with SCI(t) trend (note that this formula is not given in any of the earned schedule papers)

Table 3
Terminology used in the current paper

	Planned value method		Earned duration method		Earned schedule method	
	$\mathrm{EAC}(t) = \mathrm{AD} + \mathrm{PDWR}/\mathrm{PF}$		$\mathrm{EAC}(t) = \mathrm{AD} + \mathrm{PDWR}/\mathrm{PF}$		$\mathrm{EAC}(t) = \mathrm{AD} + \mathrm{PDWR}/\mathrm{PF}$	
At completion indicators	$\mathrm{EAC}(t)_{\mathrm{PV1}}$	Estimate of duration at completion PF = 1	$\mathrm{EAC}(t)_{\mathrm{ED1}}$	Estimate of duration at completion PF = 1	$\mathrm{EAC}(t)_{\mathrm{ES1}}$	Estimate of duration at completion PF = 1
	$\mathrm{EAC}(t)_{\mathrm{PV2}}$	Estimate of duration at completion PF = SPI	$\mathrm{EAC}(t)_{\mathrm{ED2}}$	Estimate of duration at completion PF = SPI	$\mathrm{EAC}(t)_{\mathrm{ES2}}$	Estimate of duration at completion PF = SPI(t)
	$\mathrm{EAC}(t)_{\mathrm{PV3}}$	Estimate of duration at completion PF = SCI	$\mathrm{EAC}(t)_{\mathrm{ED3}}$	Estimate of duration at completion PF = SCI[a]	$\mathrm{EAC}(t)_{\mathrm{ES3}}$	Estimate of duration at completion PF = SCI(t)[b]
Assessment Indicator	–	–	TCSPI	To complete schedule performance index for PD	TCSPI(t)	To complete schedule performance index for PD
	–	–	TCSPI-LRS	To complete schedule performance index for LRS	TCSPI(t)-LRS	To complete schedule performance index for LRS

[a] This forecasting formula does not appear in Jacob [6], and has been added by the authors.
[b] This forecasting formula does not appear in Lipke [4], and has been added by the authors.

$$\mathrm{EAC}(t)_{\mathrm{ES3}} = \mathrm{AD} + (\mathrm{PD} - \mathrm{ES})/(\mathrm{CPI} * \mathrm{SPI}(t)) = \mathrm{AD} + (\mathrm{PD} - \mathrm{ES})/\mathrm{SCI}(t). \quad (21)$$

The "To Complete Schedule Performance Index" or TCSPI(t) can be calculated as:

$$\mathrm{TCSPI}(t) = (\mathrm{PD} - \mathrm{ES})/(\mathrm{PD} - \mathrm{AD}) \quad (22)$$

or

$$\mathrm{TCSPI}(t)\text{-LRS} = (\mathrm{PD} - \mathrm{ES})/(\mathrm{LRS} - \mathrm{AD}) \quad (23)$$

and measures the additional effort to finish the project within the planned duration or the revised duration, respectively. Remark that the TCSPI(t) and the TCSPI(t)-LRS is denoted as the 'SPI(t) to go' and the 'to complete SPI(t)' in Table 2. The terminology used throughout this section has been summarized in Table 3.

3. Forecasting duration examples

In this section, we illustrate the use of the three forecasting methods on a single-activity project example with and without the presence of a learning curve. Moreover, we apply these forecasting methods on data at a higher WBS-level of three real-life projects from Fabricom Airport Systems, Belgium.

3.1. Forecasting at activity level

In order to illustrate the three forecasting methods, we display the EV metrics of a single activity example for the installation of TFT monitors (Thin Film Transistor). The details are given in Fig. 2, which reveals that, at the third week reporting period (W3), the project is overspent and delayed. We consider two situations: linear and non-linear planned values.

The total project duration for the linear case can be estimated by means of the three forecasting methods as follows. The *Planned value method* calculates the planned value rate as $\mathrm{PVRate} = \mathrm{BAC}/\mathrm{PD} = €\ 35.000/7$ weeks $= €\ 5.000$/week and consequently, the time varience $\mathrm{TV} = \mathrm{SV}/\mathrm{PVRate} = (€\ 12.000 - €\ 15.000)/€\ 5.000$/week $= -0.6$ weeks. The *Earned duration method* relies on the earned duration of week 3 that is equal to $\mathrm{ED} = \mathrm{AD} * \mathrm{SPI} = \mathrm{AT} * \mathrm{SPI} = 3 \times 0.8 = 2.4$ weeks. The performance needed to finish within the planned duration is $\mathrm{TCSPI} = (\mathrm{PD} - \mathrm{ED})/(\mathrm{PD} - \mathrm{AD}) = (7 - 2.4)/(7 - 3) = 1.15$, denoting that for each time unit that we spend on the remaining work, 1.15 time units need to be earned in order to finish on plan. The *Earned schedule method* calculates the earned schedule as $\mathrm{ES} = N + (\mathrm{EV} - \mathrm{PV}_N)/(\mathrm{PV}_{N+1} - \mathrm{PV}_N) = 2 + (12.000 - 10.000)/(15.000 - 10.000) = 2.4$ weeks and consequently, $\mathrm{SV}(t) = \mathrm{ES} - \mathrm{AT} = 2.4 - 3 = 0.6$ weeks and $\mathrm{SPI}(t) = \mathrm{ES}/\mathrm{AT} = 2.4/3 = 0.80$. The performance needed to finish within the planned duration equals $\mathrm{TCSPI}(t) = (\mathrm{PD} - \mathrm{ES})/(\mathrm{PD} - \mathrm{AT}) = (7 - 2.4)/(7 - 3) = 1.15$. Table 4 shows a summary of the forecasted project duration results based on the previously calculated measures and the values for the assessment indicators by each method. All forecasting methods yield similar results, regardless of the method used, except the ED method with a continuing SCI trend. This has also been observed by Jacob and Kane [11], who attribute the

Scope:	Install 350 TFT Monitors (linear, no learning curve)
TAC:	7 weeks
BAC:	€ 35000 (€ 100 / monitor)

	W1	W2	W3	W4	W5	W6	W7
PV	5,000	10,000	15,000	20,000	25,000	30,000	35,000
AC	3,750	9,100	12,750				
EV	3,500	8,500	12,000				
SPI	0.70	0.85	0.80				
CPI	0.93	0.93	0.94				
SCI	0.65	0.79	0.75				
AT	1	2	3	4	5	6	7
ES	0.70	1.70	2.40				
SPI(t)	0.70	0.85	0.80				
SCI(t)	0.65	0.79	0.75				

Scope:	Install 350 TFT Monitors (including learning curve)
TAC:	7 weeks
BAC:	€ 35000 (€ 100 / monitor)

	W1	W2	W3	W4	W5	W6	W7
PV	1,500	4,000	7,500	12,000	18,000	26,000	35,000
AC	3,750	9,100	12,750				
EV	3,500	8,500	12,000				
SPI	2.33	2.13	1.60				
CPI	0.93	0.93	0.94				
SCI	2.18	1.98	1.51				
AT	1	2	3	4	5	6	7
ES	1.80	3.22	4.00				
SPI(t)	1.80	1.61	1.33				
SCI(t)	1.68	1.50	1.25				

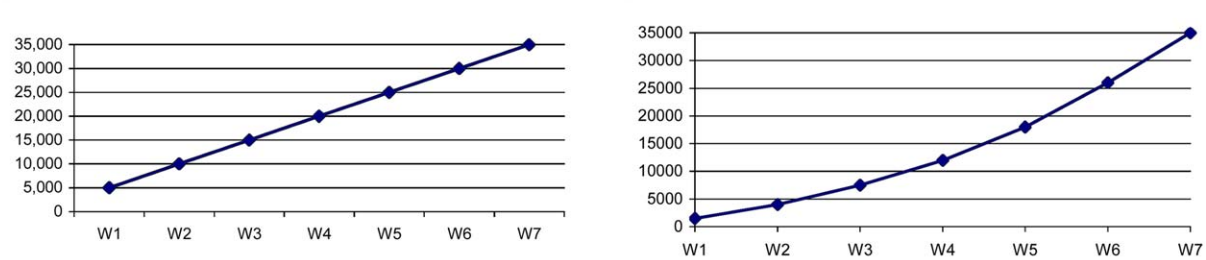

Fig. 2. Earned value metrics on the activity level with (right) and without (left) a learning curve.

Table 4
Forecasted duration (PDWR) and the corresponding assessment indicators (TCSPI and TCSPI(t)) for our example activity project

Case	Linear PV			Non-linear PV		
	Anbari	Jacob	Lipke	Anbari	Jacob	Lipke
PDWR according to plan	7.60	7.60	7.60	6.10	5.20	6.00
PDWR will follow current SPI trend	8.75	8.75	8.75	4.38	4.38	5.25
PDWR will follow current SCI trend	9.30	9.11	9.11	4.65	4.46	5.39
Assesment indicator	×	1.15	1.15	×	0.55	0.75

100% correlation of all methods to the following straightforward reasons:

1. All methods apply the same basic parameters such as EV, PD, PV, ...
2. All methods use linear formulas.
3. The planned values are linear as well.

One could conclude that the three schedule forecasting methodologies have equal validity. However, in a real project environment it is seldom true that the planned value is linear (but rather it has the notorious S-shaped curve). Instead, one can assume a learning curve factor to denote that work efficiency increases over time due to experience and other beneficial factors. Learning curves have been studied in literature from a project scheduling and monitoring point-of-view in [12–18]. The right part of Fig. 2 shows the non-linear PV rate and Table 4 displays the calculated forecasting metrics. As a result, the forecasted durations are no longer identical, but depend on the used method. In our example, the earned schedule method results in the longest forecasted project durations. Jacob and Kane [11] suggest to use of smaller time increments for the reporting periods to approximate a linear model, reducing the possible resulting errors.

3.2. Forecasting at project level

The illustrations and results of this section are drawn from a simplified earned value management approach for managing complex system projects of an airport luggage handling systems at Fabricom Airport Systems in Brussels (Belgium). Weekly meetings with the project team provide the progress data, which is then translated into earned value metrics, according to the pre-defined earned value methods. The data is then rolled-up to monthly values for formal project performance reporting. All calculations and graphs are done by use of a Microsoft Excel spreadsheet. The different schedule forecasting methods will be applied to real project data for three projects. Each project has a different performance, one project is behind schedule but under cost, one project is late with a cost over-run and one project is ahead of schedule but with a cost over-run. The real-life data of the three projects is summarized in Table 5.

Project 1. Re-vamp check-in: The project concerns a revamping of different check-in islands. This project existed mainly out of electrical works (engineering, installation and commissioning) and automation works (programming, implementing and commissioning). The planned duration was 9 months, with a budget at completion of € 360.738. For detailed project data, we refer to Table 6 of the Appendix A. Fig. 3 displays the different earned value metrics. The project was delivered 4 months later than expected, but under budget.

The graph of the SV and SV(t) along the project duration (the left upper graph of Fig. 3) reveals that the SV follows a negative trend till February 2003, followed by a positive trend and finally ending with a zero variation. The SV(t) graph, on the contrary, shows a negative trend along the complete project duration, and ends with a cumulative variation of −4 months, which is exactly the project's delay. A similar effect is revealed in the graph of the schedule performance metrics (the left middle of Fig. 3). During the early and middle stages, both SPI and SPI(t) correlate very well. However, towards the late project stage (at the ca. 75% completion point), the SPI becomes unreliable showing an improving trend while the project is slipping further away. This further performance decline is clearly shown by the SPI(t) indicator.

The forecast of the three different schedule forecasting methods have been applied and displayed at the right of Fig. 3. The graph reveals some repetitive patterns, regardless

Table 5
Our real-life project data for three project at Fabricom Airport Systems

	Project	Category	Budget at completion	Cost at completion	Planned duration	Actual duration
1	Revamp check in	Late finish cost under-run	€ 360,738	€ 349,379	9	13
2	Link lines	Late finish cost over-run	€ 2,875,000	€ 3,247,000	9	12
3	Transfer platform	Early finish cost over-run	€ 906,000	€ 932,000	10	9

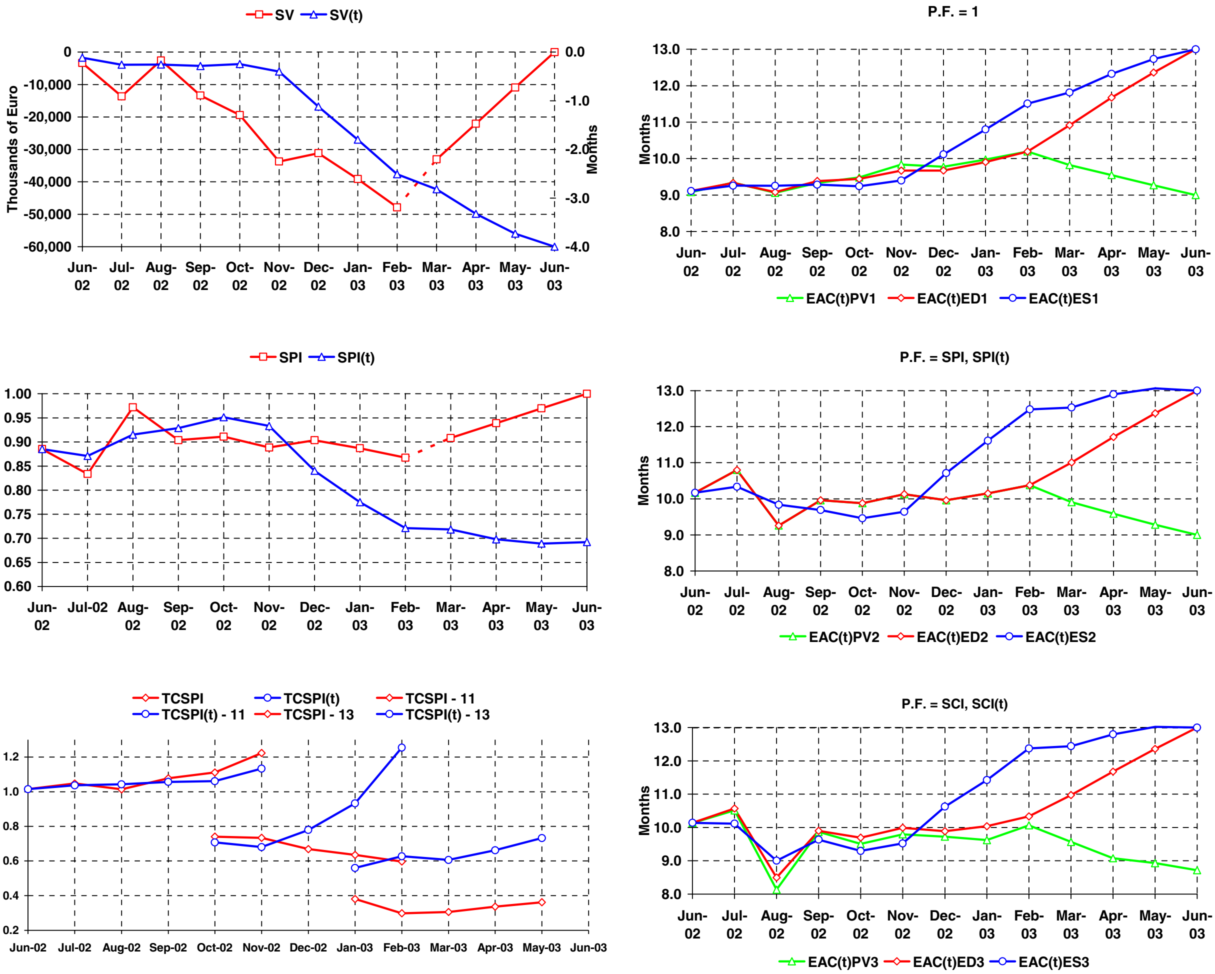

Fig. 3. The earned value metrics for Project 1 "Re-vamp check-in" (late finish, under budget).

of the scenario (see Table 1). First, all methods correlate very well during the early and middle project stages, and produce nearly similar results. Second, the earned schedule method clearly outperforms all other methods during the last project stage reporting periods. Finally, the graphs display bizarre and unreliable results for the planned value rate method once the planned time at completion has been reached, and is therefore not a good duration predictor. The graphs also reveal that the earned schedule method always forecasts a higher project duration, for each of the three scenarios. Moreover, both methods are quasi un-sensitive to the scenarios, which might be explained by the fact that the bad schedule performance (late finish) is compensated by a good cost performance (cost under-run).

The graph in the lower right part of Fig. 3 shows the evolution of the 'to complete schedule performance index' (which are defined in the earned schedule and the earned duration method) over time. These indices show the performance needed to complete the project on time and is given by TCSPI (calculated with the earned duration method) and TCSPI(t) (calculated with the earned schedule method). At the early project stage, both indices produce similar results. Since there were no signs of an improved schedule efficiency at the September 2002 project review, it was decided to take a two-months project delay into account (revised project duration $= 9 + 2 = 11$ months). From this point onwards, the new TCSPI indicators (referred to as "TCSPI-11" and "TCSPI(t)-11") indicators have been computed. After 7 months (the December 2002 project review), the TCSPI-11 indicator show a declining trend, indicating that a lower performance efficiency is needed. However, the TCSPI(t)-11 indicator just started an upward trend, which is a clear indication that improved performance is crucial to finish the project within the revised deadline of 11 months. A revised scenario to allow for a 4-months delay resulted in a revised targeted project duration of 13 months (with new indicators "TCSPI-13" and "TCSPI(t)-13"). The TCSPI-13 continuously shows a lower value compared to the TCSPI(t)-13.

Project 2. Link lines: Table 7 of the Appendix A displays the data of the "link lines" project, which links two piers with fully automated baggage conveying lines. The planned duration was 9 months, and the project finished 3 months later with a cost over-run. Fig. 4 displays the forecasted

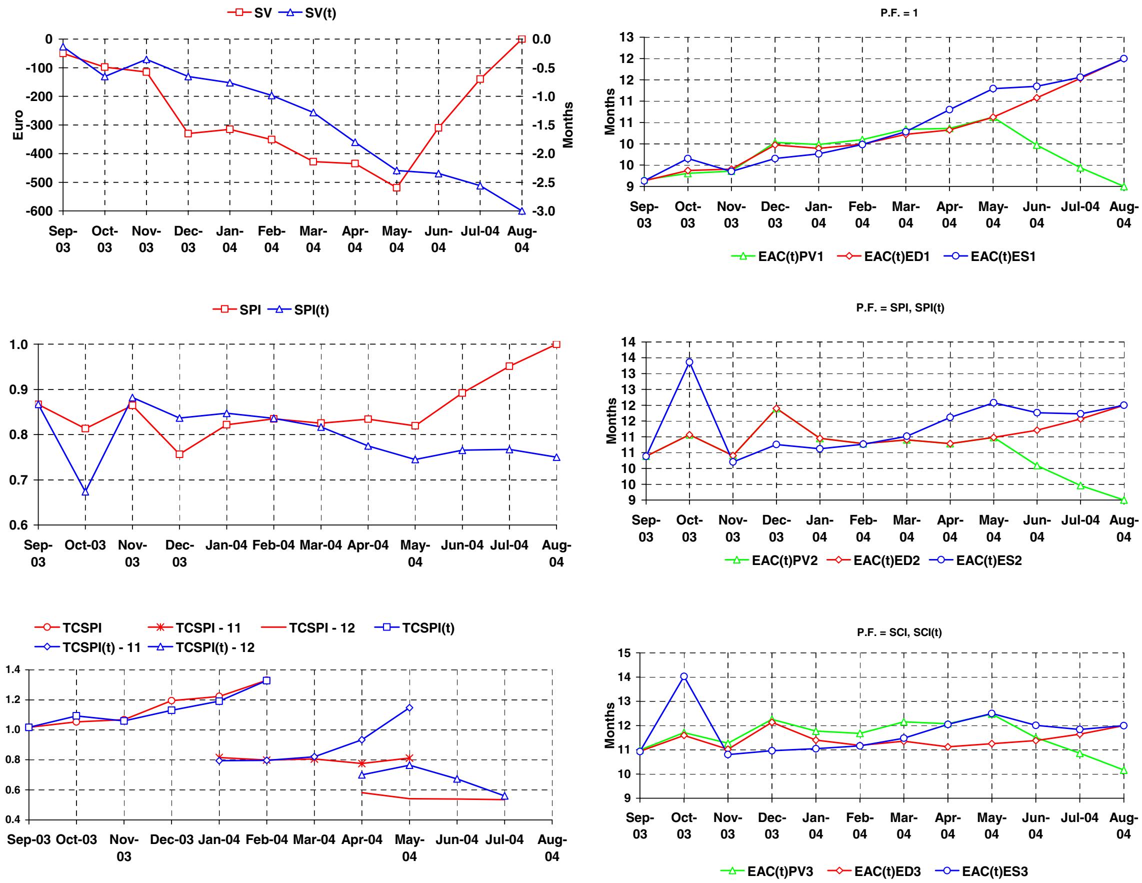

Fig. 4. The earned value metrics for Project 2 "Link lines" (late finish, over budget).

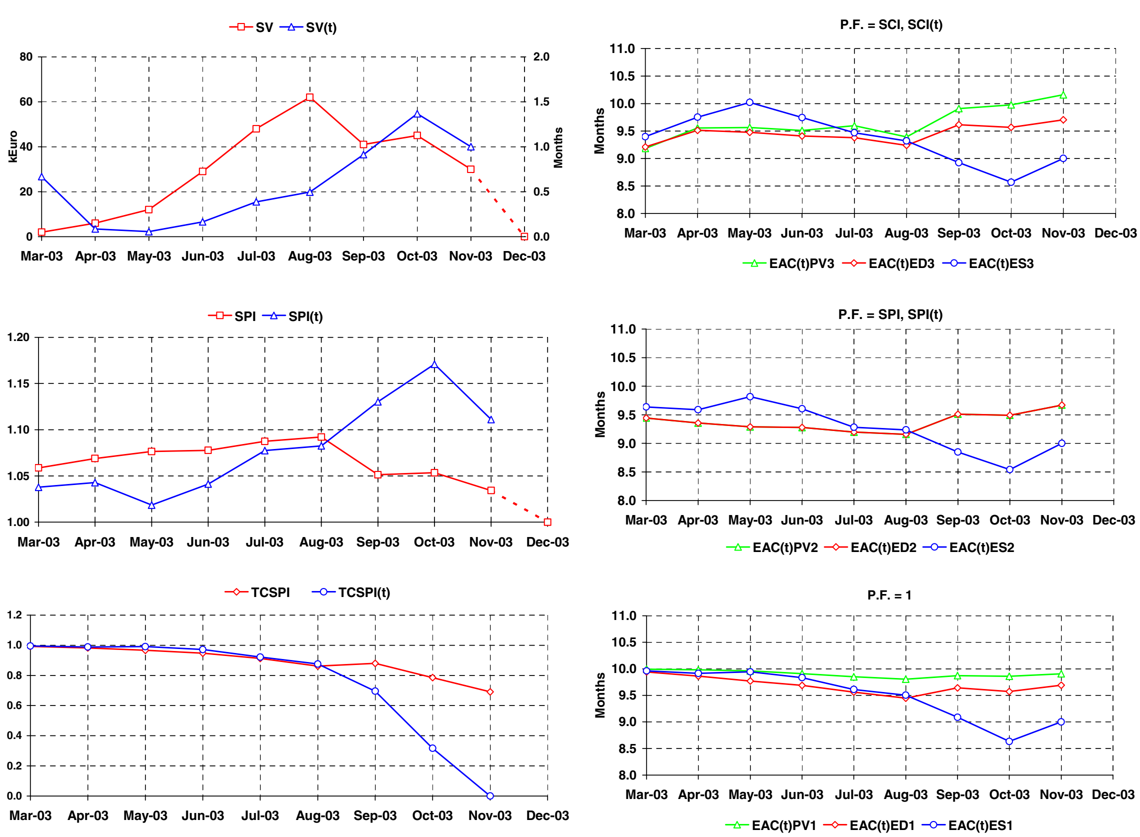

Fig. 5. The earned value metrics for Project 3 "Transfer platform" (early finish, over budget).

results in a similar way as Fig. 3. The graphs reveal that the forecasting methods correlate well for the first two thirds of the project, and show a better performance of the earned schedule method towards the end of the project. A similar behaviour is reflected in the 'to complete schedule performance indices', producing similar results during the early and middle project stages, and an outperforming accuracy for the TCSPI(t)-12 index at the end of the project. As a contrast, the TCSPI-12 shows a decreasing trend (less performance is needed) whilst the project is slipping further away (see Fig. 5).

Project 3. Transfer platform: The third project is a renovation of the transfer baggage conveying system due to changed baggage flows and security issues. This project had a planned duration of 10 months, while it finished within 9 months, with a cost over-run (see Table 8 for details). The graphs confirm the results found by the previous projects. At the late project stage, the planned value rate and the earned duration method give more pessimistic (i.e. longer duration) results and the TCSPI metrics produce higher values than the TCSPI(t). The overestimation of duration and/or the needed efficiency calculated by the earned duration method may cause wrong decision-taking by the upper management.

4. Recommendations and conclusions

In this paper, we compared three different project duration methods using earned value metrics and evaluate them on fictive and real-life project data. We presented a generic formula to forecast the duration of a project and linked them to different project situations. Each method can be further sub-divided into three different forecasting models as a function of the project situation. We applied each method on a fictive single-activity project with linear and non-linear increasing periodic values reflecting the absence or presence of learning curves as well as three real-life project from Fabricom Airport Systems, Belgium. We summarized the often confusing terminology of the different methods in two tables.

The results show a similar forecasting accuracy for each method in the linear planned value case. However, the introduction of learning curves, which is much more realistic in the project world, results in a different forecasting accuracy for the three methods. The three real-life projects reveal that the earned schedule method was the only method which showed satisfying and reliable results during the whole project duration. Consequently, the results confirm the previously found results that the results obtained by the planned value rate and the earned duration method are unreliable at the end of the project. Instead, the earned schedule method seems to provide valid and reliable results along the project's lifespan.

As a conclusion, we believe that the use the planned value method, the earned duration method or the earned schedule method depending on the need and knowledge of the project manager might lead to similar results for project monitoring in the early and middle stages. However, we recommend to shift to the earned schedule method for monitoring project progress at the final stage of the project. Moreover, we recommend to use these schedule forecasting methods at least at the cost account level or at higher levels of the work breakdown structure. This is contradictory to the statements given by Jacob [6] who argues that the schedule forecast metrics should only be used at the level of the activity. Although we recognize that, at higher WBS levels, effects (delays) of non-performing activities can be neutralized by well performing activities (ahead of schedule), which might result in masking potential problems, we believe that this is the only approach that can be taken by practitioners. Indeed, the earned value metrics are set-up as early warning signals to detect in an easy and efficient way (i.e. at the cost account level, or even higher), rather than a simple replacement of the critical-path based scheduling tools. This early warning signal, if analyzed properly, defines the need to eventually "drill-down" into lower WBS-levels. In conjunction with the project schedule, it allows to take corrective actions on those activities which are in trouble (especially those tasks which are on the critical path). Our forecasting results on the three real-life projects demonstrate that forecasting project duration with earned value metrics at higher WBS levels provides reliable early warning signals.

Our future research intensions are 3-fold. In order to generalize the results found in this study, we will test the three earned value concepts (planned value, earned schedule, earned duration) on projects based on a full-factorial simulation experiment, rather than relying on a (small) set of real-life project. Secondly, we aim at combining different methods depending on the risk profile and other characteristics of the project. Finally, we want to link the forecasting methods to their corresponding corrective actions that can be taken. To that purpose, we will rely and extend the work done by Lipke [19].

As a final remark, we cite the letter to the editor of Harvard Business Review from Cooper [20] as a response to the article written by Fleming and Koppelman [3]. In this letter, the author argues that the use of earned value management can be questioned when they are applied in highly complex projects. Due to the cycles of rework, the accuracy of the EVM metrics can be biased, leading to incorrect management decisions. It is our ultimate goal to investigate this research topic and provide an answer on this issue. In doing so, we will rely and extend the partial answer formulated by Lipke [10] who measures the 'effective earned value' when the project is the subject of a vast amount of rework cycles.

Appendix A

Detailed information about the three real-life project at Fabricom Airport systems (see Tables 6–8).

Table 6
Detailed information for project 1 "Re-vamp check-in"

	Jun-02	Jul-02	Aug-02	Sep-02	Oct-02	Nov-02	Dec-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03
AC	25,567	66,293	78,293	124,073	191,367	259,845	285,612	290,843	303,489	316,431	320,690	336,756	349,379
EV	25,645	68,074	89,135	125,244	198,754	268,763	292,469	306,725	312,864	327,694	338,672	349,861	360,738
PV	28,975	81,681	91,681	138,586	218,141	302,478	323,632	345,876	360,738	360,738	360,738	360,738	360,738
SV	−3330	−13,607	−2546	−13,342	−19,387	−33,715	−31,163	−39,151	−47,874	−33,044	−22,066	−10,877	0
CV	78	1781	10,842	1171	7387	8918	6857	15,882	9375	11,263	17,982	13,105	11,359
SPI	0.885	0.833	0.972	0.904	0.911	0.889	0.904	0.887	0.867	0.908	0.939	0.970	1.000
CPI	1.003	1.027	1.138	1.009	1.039	1.034	1.024	1.055	1.031	1.036	1.056	1.039	1.033
SCI	0.888	0.856	1.107	0.912	0.946	0.919	0.925	0.935	0.894	0.941	0.991	1.008	1.033
AD	1	2	3	4	5	6	7	8	9	10	11	12	13
ES	0.885	1.742	2.745	3.716	4.756	5.600	5.881	6.201	6.491	7.183	7.676	8.268	9.000
PD	9	9	9	9	9	9	9	9	9	9	9	9	9
SV(t)	−0.115	−0.258	−0.255	−0.284	−0.244	−0.400	−1.119	−1.799	−2.509	−2.817	−3.324	−3.732	−4.000
SPI(t)	0.885	0.871	0.915	0.929	0.951	0.933	0.840	0.775	0.721	0.718	0.698	0.689	0.692
SCI(t)	0.888	0.894	1.042	0.938	0.988	0.965	0.860	0.817	0.743	0.744	0.737	0.716	0.715
$EAC(t)_{PV1}$	9.083	9.339	9.064	9.333	9.484	9.841	9.777	9.977	10.194	9.824	9.551	9.271	9.000
$EAC(t)_{ED1}$	9.115	9.333	9.083	9.385	9.444	9.669	9.674	9.906	10.194	10.916	11.673	12.362	13.000
$EAC(t)_{ES1}$	9.115	9.258	9.255	9.284	9.244	9.400	10.119	10.799	11.509	11.817	12.324	12.732	13.000
$EAC(t)_{PV2}$	10.169	10.799	9.257	9.959	9.878	10.129	9.959	10.149	10.377	9.908	9.586	9.280	9.000
$EAC(t)_{ED2}$	10.169	10.799	9.257	9.959	9.878	10.129	9.959	10.149	10.377	11.008	11.717	12.373	13.000
$EAC(t)_{ES2}$	10.169	10.334	9.835	9.689	9.461	9.642	10.712	11.611	12.479	12.530	12.897	13.062	13.000
$EAC(t)_{PV3}$	10.14	10.52	8.13	9.87	9.51	9.79	9.73	9.62	10.07	9.57	9.08	8.93	8.72
$EAC(t)_{ED3}$	10.14	10.57	8.50	9.90	9.70	9.99	9.89	10.04	10.34	10.97	11.68	12.36	13.00
$EAC(t)_{ES3}$	10.14	10.12	9.00	9.64	9.30	9.52	10.62	11.42	12.37	12.44	12.80	13.02	13.00
TCSPI	1.014	1.048	1.014	1.077	1.111	1.223							
TCSPI(t)	1.014	1.037	1.042	1.057	1.061	1.133							
TCSPI-11					0.741	0.734	0.669	0.635	0.597				
TCSPI(t)-11					0.707	0.680	0.780	0.933	1.255				
TCSPI-13								0.381	0.299	0.305	0.336	0.362	
TCSPI(t)-13								0.560	0.627	0.606	0.662	0.732	

Table 7
Detailed information for project 2 "Link Lines" (costs in thousands of €)

	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun- 04	Jul-04	Aug-04
AC	344	452	796	1056	1562	1922	2256	2451	2676	2925	3138	3247
EV	325	427	735	1025	1453	1774	2024	2190	2356	2565	2735	2875
PV	375	525	850	1355	1768	2125	2452	2625	2875	2875	2875	2875
SV	−50	−98	−115	−330	−315	−351	−428	−435	−519	−310	−140	0
CV	−19	−25	−61	−31	−109	−148	−232	−261	−320	−360	−403	−372
SPI	0.867	0.813	0.865	0.756	0.822	0.835	0.825	0.834	0.819	0.892	0.951	1.000
CPI	0.945	0.945	0.923	0.971	0.930	0.923	0.897	0.894	0.880	0.877	0.872	0.885
SCI	0.819	0.768	0.798	0.734	0.764	0.771	0.741	0.745	0.721	0.782	0.829	0.885
AD	1	2	3	4	5	6	7	8	9	10	11	12
ES	0.867	1.347	2.646	3.347	4.237	5.017	5.717	6.199	6.706	7.653	8.440	9.000
PD	9	9	9	9	9	9	9	9	9	9	9	9
SV(*t*)	−0.133	−0.653	−0.354	−0.653	−0.763	−0.983	−1.283	−1.801	−2.294	−2.347	−2.560	−3.000
SPI(*t*)	0.867	0.674	0.882	0.837	0.847	0.836	0.817	0.775	0.745	0.765	0.767	0.750
SCI(*t*)	0.819	0.636	0.814	0.812	0.788	0.772	0.733	0.692	0.656	0.671	0.669	0.664
$EAC(t)_{PV1}$	9.157	9.307	9.360	10.033	9.986	10.099	10.340	10.362	10.625	9.970	9.438	9.000
$EAC(t)_{ED1}$	9.133	9.373	9.406	9.974	9.891	9.991	10.222	10.326	10.625	11.078	11.536	12.000
$EAC(t)_{ED1}$	9.133	9.653	9.354	9.653	9.763	9.983	10.283	10.801	11.294	11.347	11.560	12.000
$EAC(t)_{PV2}$	10.385	11.066	10.408	11.898	10.951	10.781	10.903	10.788	10.983	10.088	9.461	9.000
$EAC(t)_{ED2}$	10.385	11.066	10.408	11.898	10.951	10.781	10.903	10.788	10.983	11.209	11.563	12.000
$EAC(t)_{ES2}$	10.381	13.363	10.204	10.756	10.621	10.763	11.020	11.615	12.079	11.760	11.730	12.000
$EAC(t)_{PV3}$	10.99	11.71	11.27	12.26	11.77	11.68	12.15	12.07	12.47	11.50	10.35	10.16
$EAC(t)_{ED3}$	10.93	11.60	11.02	12.14	11.40	11.18	11.35	11.12	11.25	11.38	11.65	12.00
$EAC(t)_{ES3}$	10.93	14.03	10.80	10.96	11.04	11.16	11.48	12.05	12.50	12.01	11.84	12.00
TCSPI	1.017	1.053	1.068	1.195	1.223	1.330						
TCSPI(*t*)	1.017	1.093	1.059	1.131	1.191	1.328						
TCSPI-11					0.815	0.798	0.805	0.775	0.812			
TCSPI(*t*)-11					0.794	0.797	0.821	0.934	1.147			
TCSPI-12								0.581	0.542	0.539	0.536	
TCSPI(*t*)-12								0.700	0.765	0.674	0.560	

Table 8
Detailed information for project 3 "Transfer line" (costs in thousands of €)

	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03
AC	35	95	174	412	623	754	874	932	952	952
EV	36	93	169	402	597	735	839	887	906	906
PV	34	87	157	373	549	673	798	842	876	906
SV	2	6	12	29	48	62	41	45	30	0
CV	1	−2	−5	−10	−26	−19	−35	−45	−46	−46
SPI	1.059	1.069	1.076	1.078	1.087	1.092	1.051	1.053	1.034	1.000
CPI	1.029	0.979	0.971	0.976	0.958	0.975	0.960	0.952	0.952	
SCI	1.089	1.046	1.046	1.052	1.042	1.065	1.009	1.003	0.984	
AD	1	2	3	4	5	6	7	8	9	10
ES	1.038	2.086	3.056	4.165	5.387	6.496	7.912	9.367	10.000	
PD	10	10	10	10	10	10	10	10	10	
SV(t)	0.667	0.086	0.056	0.165	0.387	0.496	0.912	1.367	1.000	
SPI(t)	1.038	1.043	1.019	1.041	1.077	1.083	1.130	1.171	1.111	
SCI(t)	1.067	1.021	0.989	1.016	1.032	1.055	1.085	1.114	1.057	
$EAC(t)_{PV1}$	9.994	9.981	9.962	9.909	9.850	9.806	9.872	9.859	9.906	
$EAC(t)_{ED1}$	9.941	9.862	9.771	9.689	9.563	9.447	9.640	9.572	9.692	
$EAC(t)_{ES1}$	9.962	9.914	9.944	9.835	9.613	9.504	9.088	8.633	9.000	
$EAC(t)_{PV2}$	9.444	9.355	9.290	9.279	9.196	9.156	9.511	9.493	9.669	
$EAC(t)_{ED2}$	9.444	9.355	9.290	9.279	9.196	9.156	9.511	9.493	9.669	
$EAC(t)_{ES2}$	9.636	9.589	9.818	9.604	9.281	9.236	8.848	8.541	9.000	
$EAC(t)_{PV3}$	9.182	9.556	9.565	9.509	9.596	9.393	9.908	9.974	10.160	
$EAC(t)_{ED3}$	9.210	9.513	9.476	9.410	9.379	9.238	9.616	9.568	9.703	
$EAC(t)_{ES3}$	9.396	9.752	10.020	9.744	9.468	9.320	8.925	8.568	9.000	
TCSPI	0.993	0.983	0.967	0.948	0.913	0.862	0.880	0.786	0.692	
TCSPI(t)	0.996	0.989	0.992	0.973	0.923	0.876	0.696	0.317	0.000	

References

[1] Anbari F. Earned value method and extensions. Project Manage J 2003;34(4):12–23.

[2] Fleming Q, Koppelman J. Earned value project management Newtowns Square. PA: PMI; 2000.

[3] Fleming Q, Koppelman J. What's your project's real price tag? Harvard Bus Rev 2003;81(9):20–1.

[4] Lipke W. Schedule is different. The Measurable News 2003(March): 31–4.

[5] Christensen DS. The estimate at completion problem: a review of three studies. Project Manage J 1993;24:37–42.

[6] Jacob D. Forecasting project schedule completion with earned value metrics. The Measurable News 2003(March):1. 7–9.

[7] Henderson K. Earned schedule: a breakthrough extension to earned value theory? A retrospective analysis of real project data. The Measurable News 2003(Summer):13–7. 21.

[8] Henderson K. Further developments in earned schedule. The Measurable News 2004(Spring):15–6. 20–2.

[9] Henderson K. Earned schedule in action. The Measurable News 2005:23–8. 30.

[10] Lipke W. Connecting earned value to the schedule. The Measurable News 2004(Winter):1. 6–16.

[11] Jacob DS, Kane M. Forecasting schedule completion using earned value metrics revisited. The Measurable News 2004(Summer):1. 11–7.

[12] Amor JP. Scheduling programs with repetitive projects using composite learning curve approximations. Project Manage J 2002;33(2): 16–29.

[13] Amor JP, Teplitz CJ. Improving CPM's accuracy using learning curves. Project Manage J 1993;24(4):15–9.

[14] Amor JP, Teplitz CJ. An efficient approximation procedure for project composite learning curves. Project Manage J 1998;29(3):28–42.

[15] Badiru AB. Incorporating learning curve effects into critical resource diagramming. Project Manage J 1995;2(2):38–45.

[16] Lam KC, Lee D, Hu T. Understanding the effect of the learning–forgetting phenomenon to duration of projects construction. Int J Project Manage 2001;19:411–20.

[17] Shtub A. Scheduling of programs with repetitive projects. Project Manage J 1991;22(4):49–53.

[18] Shtub A, LeBlanc LJ, Cai Z. Scheduling programs with repetitive projects: a comparison of a simulated annealing, a genetic and a pair-wise swap algorithm. Eur J Oper Res 1996;88:124–38.

[19] Lipke W. Deciding to act. Crosstalk 2003(December):22–4.

[20] Cooper KG. Your projects real price tag – letters to the editor. Harvard Bus Rev 2003;81(12):122.