Towards a Complete Earned Value Analysis

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Planned vs Actual

A purely "accounting" approach to project tracking involves the monitoring of status by simply comparing actual and planned costs to date. The problem with using the difference between these measures as a sole indicator of project health is that it ignores the level of progress achieved. A greater than planned expenditure at a given stage is not necessarily bad news as it may simply reflect that the project is ahead of schedule in terms of work completed. Similarly, being under budget at a given time may simply indicate that the project is behind schedule.

It is worth noting here that the "actual cost" that should be used here and elsewhere below, is really the "committed cost". Actual cost, in the sense of moneys having been paid usually understates the real situation due to delays within financial system processing.

Earned Value Analysis

'Earned Value Analysis' overcomes the limitation of the simple Actual vs Plan analysis by taking account of progress achieved. All work to be done is assigned a value, essentially the amount budgeted to complete that work.

At any given point in time:

Earned Value (EV)	is the value of the work *actually* completed by that time
Planned Value (PV)	is the value of the work that was *scheduled* to be completed by that time
Actual Cost (AC)	the amount that has been spent by that time (to complete whatever has actually been completed)

Two further parameters are derived from these, namely:

Cost Variance (CV)	the difference between what we had budgeted for completed work (Earned Value) to date and what we have actually spent to complete that work (Actual Cost)

CV = EV - AC

and

Schedule Variance (SV)	the difference between what we had budgeted for the work *actually* completed to date (Earned Value) and what we had budgeted for the work *expected to be* completed to date (Planned Value)

SV = EV – PV

In addition we define the term

Budget Variance (BV)	the difference between planned expenditure at a given time (PV) and actual expenditure at the time (AC)

BV = AC – PV

These quantities can be computed at all levels of the workbreakdown structure.

Example:
Table 1 below shows a situation in which the Planned Value and the Actual Cost for a given date are equal, suggesting we are 'on budget'. However, introduction of the additional measures, with an Earned Value of, say, $5,000, allows us to see that we have earned considerably less value than expected; the negative Cost and Schedule Variances presenting a picture of a project in trouble.

Planned Value (PV)	$10,000
Actual Cost (AC)	$10,000
Budget Variance (BV = AC – PV)	$0
Earned Value (EV)	$5,000
Cost Variance (CV = EV - AC)	-$5,000
Schedule Variance (SV = EV – PV)	-$5,000

Table 1

From this and the relations above, it is clear that the Budget Variance is arithmetically equal to the difference between the Schedule Variance and the Cost Variance, i.e., BV = SV – CV

Thus, Earned Value Analysis extends the simple Actual versus Planned comparison by decomposing the Budget Variance into contributions made to it by variances in schedule and in cost.

Refinements to EVA
The discussion is a little easier if we switch from sums and differences to ratios, beginning with the standard EVA parameters Cost Performance Index (CPI) and Schedule Performance Index (SPI).

CPI is defined as the ratio of Earned Value to Actual Cost

CPI = EV/AC

Earned Value and Actual Cost refer respectively to outputs and inputs relating to the same level of achievement, so CPI can be regarded as an index of efficiency relative to expenditure, i.e., cost efficiency.

Similarly, SPI is defined as the ratio of Earned Value to Planned Value,

SPI = EV/PV

Earned Value and Planned Value refer, respectively, to actual and planned levels of achievement over the same period of time. Hence, SPI can be regarded as an index of efficiency relative to time, i.e., time efficiency.

The analogous ratio, Actual Cost to Planned Value, has no formal definition in EVA, but is defined here as *Budget Performance Index* (BPI).

BPI = AC/PV

Since BPI provides an indication of actual expenditure relative to expected expenditure at a given time point, it can also be interpreted as an indicator of the relative level of resource usage (including procurement activity) to that point.
Combining these indices we have:

SPI = CPI * BPI (1)

This expression for SPI describes the fundamental relation within the time performance of any operation, viz., that it is a function of the efficiency of its inputs, and the rate of their usage.

It highlights two major families of contributing causes of schedule variance:

- Differences in the level of actual resource efficiency from that expected. These might arise from a mis-estimate of skills (resource efficiencies) available or perhaps a mis-estimate the volume of the work required.

- Differences in the level of actual resource activity from that expected. These might result from absenteeism once the job has begun (such as illness or the demands of higher priority work elsewhere) or a variance in start time.

Earned value Analysis therefore provides a window to the relative contributions of these two families of influence factors. In what follows, we shall deconstruct these families further, providing performance indices for specific factors operating within them and so offering better guidance for remedial action.

Refinement 1 : Start Variances

Consider Figure 1a below. Suppose that the Earned Value and Actual Cost (point X) are equal, i.e., CPI = 1. Then the entire shortfall in SPI is due to the low value of BPI, shown by the segment XZ.

A low value of BPI might initially suggest low levels of activity within the task, since the actual rate of expenditure with respect to time is on average less than the planned rate. However, it may be that some, or all, of this shortfall is due to a difference between the task's actual start and its baseline start. It might then be that underlying problems are not related to factors within this particular task and are instead due to those occurring prior to the task's start, such as delayed finishes on precedent tasks.

Operational factors within the task (i.e., factors in play after the task has actually been started) can be assessed more explicitly by comparing EV and AC not with the PV corresponding to the Current Date (point Z) but rather with a *Delay-Adjusted Planned Value* (DPV), corresponding at a time equal to the current date minus the start variance (point Y on Figure 1 b). This is achieved by simply translating the planned value graph in time by this difference, resulting in the dotted line shown.

Figure 1a

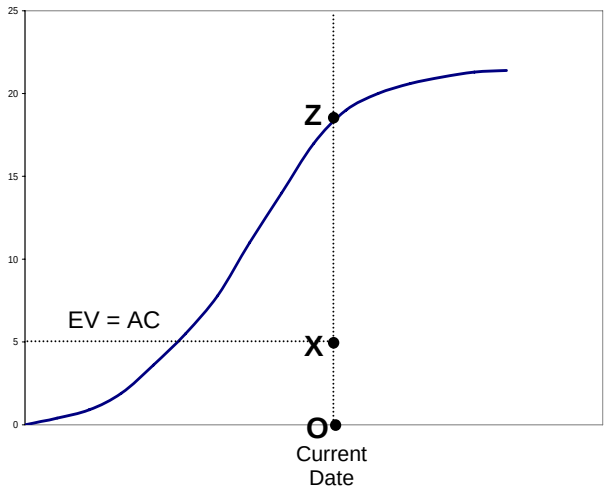
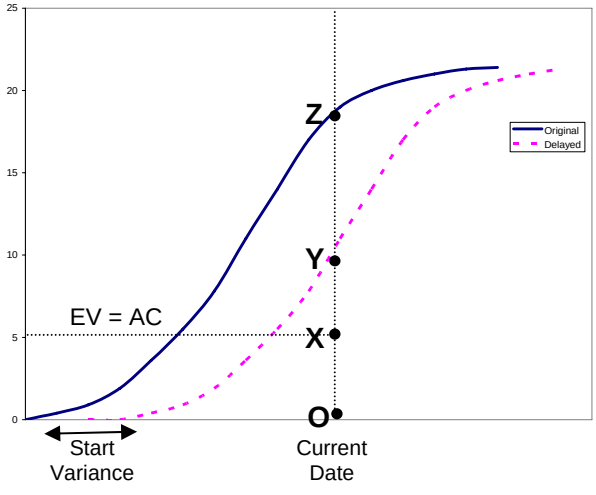


Figure 1b



The value difference YZ represents the effect of the delayed start while the value difference XY represents the effect of relatively less activity than expected since the actual start of the task.

Budget Performance Index (BPI) is defined above as the ratio of Actual Cost to Planned Value. We can now define the '*Activity Performance Index*' (API) as the ratio of the Actual Cost to the Delay-Adjusted Planned Value, i.e.

API = AC / DPV

and the '*Punctuality Performance Index*' (PPI) as the ratio of the Delay-Adjusted Planned Value to (original) Planned Value, i.e.

PPI = DPV / PV

The value BPI, represented by the ratios OX to OZ, consists of a real activity ratio OX to OY and a punctuality factor OY to OZ. That is:

BPI = API * PPI

DPV can be obtained directly from knowledge of the time-value relationship or might be the result of aggregation from lower level entities in the WBS, as discussed below.

We can now modify equation (1) to be become:

SPI = CPI * API * PPI (2)

The interpretation here is that schedule differences can be traced to those occurring in efficiencies (CPI), attendance or activity (API) and punctuality (PPI)

We momentarily revert to absolute values for graphical purposes only. The equation corresponding to (2) above is:

SV = CV + AV + DV (2a)

Where AV is the difference between Actual Costs and the delay adjusted planned value, i.e.

AV = AC – DPV

And DV is a delay variance given by:

DV = DPV - PV

The relative contributions to SV can be clearly seen in the diagrams below:

Figure 2a

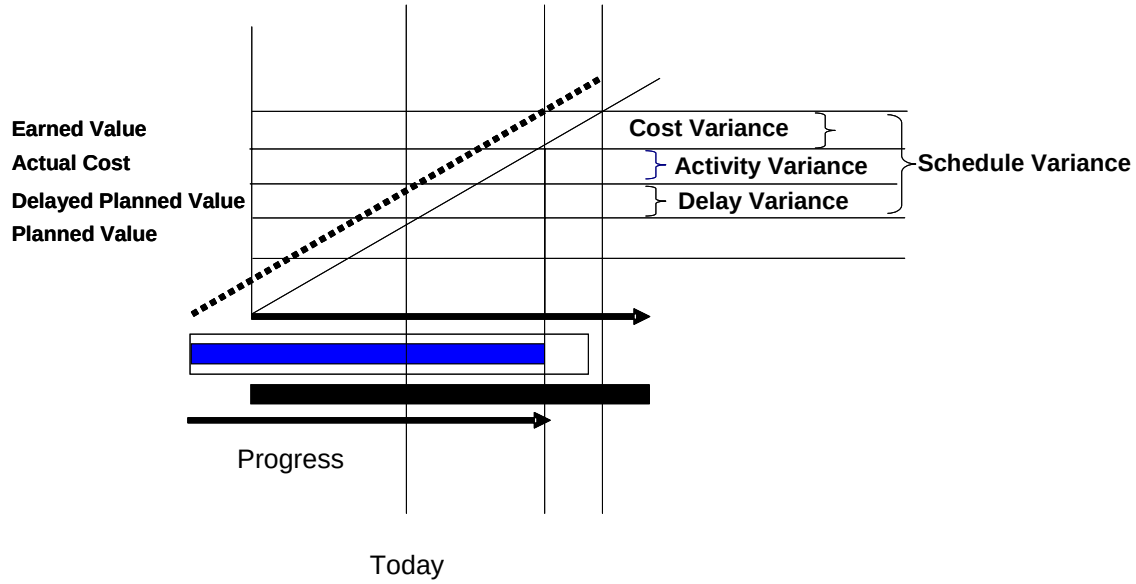
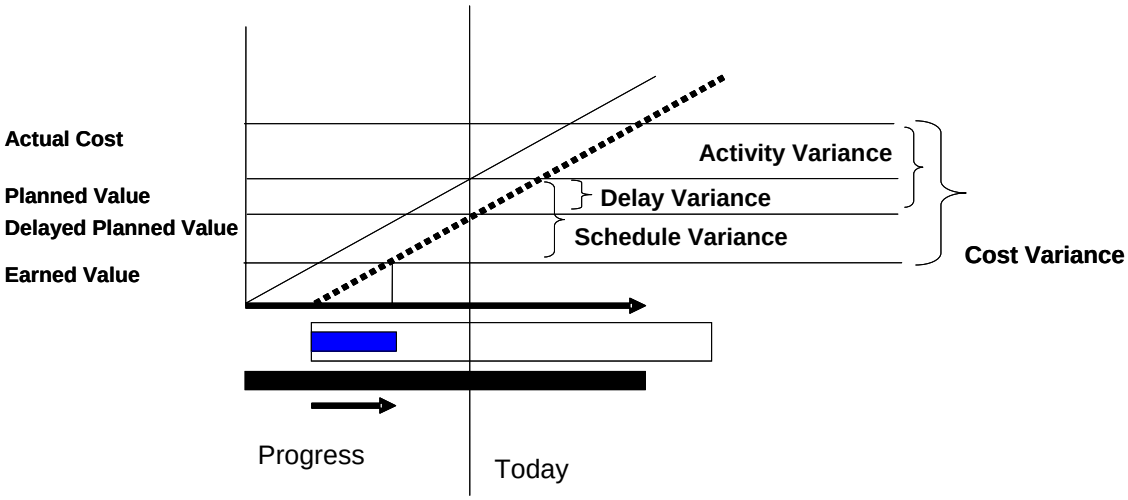


Figure 2b



In Figure 2a, all parameters from equation 2a are positive and therefore re-enforce each other to produce a positive SV. However, in Figure 2b, the task started late and this combined with inefficiency on the job (negative CV) provides for a negative SV, offset somewhat by a higher than expected (and costly) activity variance (positive AV).

It is also useful to define the Duration Variance DRV and the Duration Performance Index (DPI) as

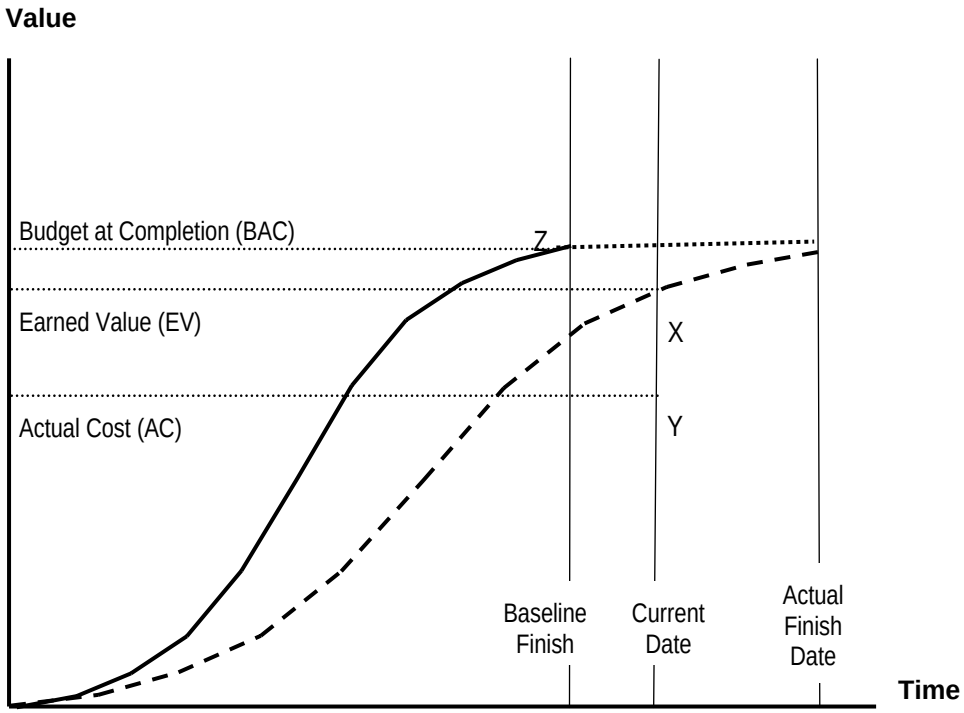
DRV = CV + AV

DPI = CPI * API (3)

This respectively measures the schedule performance of the task without the effects of the delay variance.

Refinement 2: Finish Variances

Figure 3



It is clear that the Value – Time function flattens out to a value of BAC after the Baseline Finish date is passed (point Z on figure 3), and that the Earned Value approaches the same value as the job is completed. It is a well documented deficiency in the definition of SV and SPI that they become zero and one respectively once the task has been completed, regardless of the history of time performance over the duration, thereby masking the sources of any problems from future examination. This problem can be solved by allowing the planned value to grow beyond the baseline finish at a rate equal to the overall average rate of planned value production between the baseline start and the baseline finish, given by quantity
BAC/BD,

where BD is the Baseline Duration of the task.

This is shown in Figure 4 where the Planned Value function is extended at the baseline duration time (point Z) by means of a straight line of slope BAC/BD.
Although theoretically this implies PVs greater than BAC, in practice these are never calculated. Instead we use alternative (but algebraically equivalent) formulations, viz.

SPI = [EV/BAC] / [AD/BD]

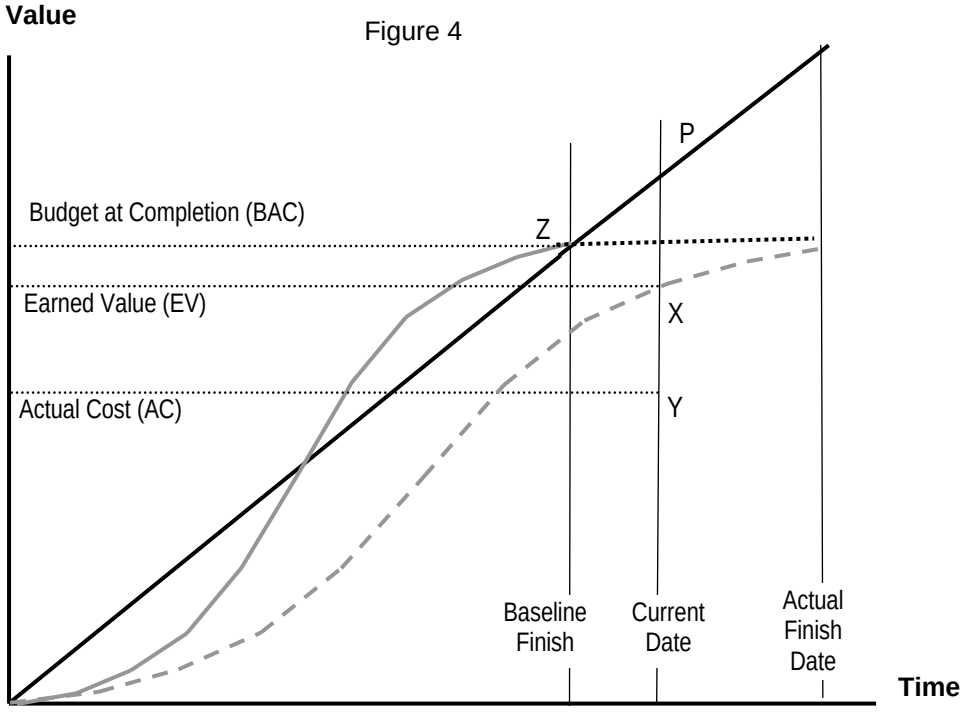
BPI = [AC/BAC] / [AD/BD]

Where AD is the actual duration of the task. CPI calculation remains unchanged.
Formulating the expressions in this way makes it explicit that we are comparing, in the case of SPI, the proportion of value generated and in the case of BPI, the proportion of budget expended with the proportion of duration elapsed.
SPI will always be less than or equal to one since EV is always less than or BAC and AD/BD in the post-Baseline Finish is always greater than one. Further, at the conclusion of the task

SPI = BD/AD

which is now a direct schedule comparison between baseline and actual duration. This is equivalent to other attempts to repair the deficiency in the standard definition of SPI, including the one suggested in [1] (page 18). These alternative formulations of SPI and BPI will allow a finish variance factor to be maintained in later analyses and to be retrieved for historical review:

Figure 4



Refinement 3: Accounting for Incorrect Scope Estimates

Since earned value represents progress to date, an error in the original scope (volume) specification would cause this to be measured against a different set of outputs than those assumed in the baseline. . We assume here that the variation in scope is due to a planning error and not one where a subsequent approved scope variation obtains, i.e., that the variation in required output does not increase or decrease value at completion (BAC).

At this point we need an estimate of how much the scope is increased.
We define the '*Estimate Performance Index*' (EPI) as the ratio of the planned volume of output to the revised volume

If a suitable metric is available we can calculate this increase as

$EPI = N_b/N_f$

where N_b is the planned volume of output and N_f is the revised volume of output. In more complex contexts we will need to estimate this increase using a similar technique to that used to establish progress points within the task. To analyse performance within the task after scope re-estimation has been factored out EV should be adjusted through

EV = EV' * EPI

Now we have

CPI = CPI' * EPI where

CPI' = EV' /AC

So that

SPI = CPI' * EPI * API * PPI (4)

This provides the relative contributions made to schedule changes from changes in efficiency, scope, attendance and punctuality.

Refinement 4: Reflecting Intermediate price changes:

Since the Cost Performance Index is the ratio of Earned Value to Actual Cost, and the growth of the latter could be affected by unplanned price variations. We can remove the (external) effects of unplanned price increases from CPI and BPI by re-calculating the Actual Cost using baseline rather than current rates.
We define '*Actual Cost in Baseline Currency*' (ACBC) as Actual Cost expressed in the currency as it was valued at the baseline rather than currently..
We also define '*Baseline Cost Performance Index*' (BCPI) as the ratio of Earned Value (EV) to ACBC)

BCPI = EV/ACBC

and

BCPI' = EV'/ACBC

The variation of BCPI or BCPI' from 1 provides an assessment of resource efficiency independent of unforeseen price variations. The adjustment factor to be applied is defined to be the '*Rate Performance Index*' (RPI) which is the ratio of costs to date calculated at baseline rates compared to those calculated at current rates, i.e.,

RPI = ACBC/AC

Now we have:

CPI' = BCPI' * RPI

and therefore:

SPI = BCPI' * RPI * EPI * API * PPI

This gives a breakdown of schedule differences in terms of undiluted efficiency, rate and scope changes, activity levels and punctuality.

As a final refinement, notice from its definition that API also carries the effects of price increases. We define '*Baseline Activity Performance Index*' (BAPI) as Activity Performance Index (API) adjusted for rate changes by:

BAPI = API * RPI

So that finally we have

SPI factored into four fundamental and measurable components:

SPI = BCPI' * EPI * BAPI * PPI (5)

Where:

BCPI'	is a measure of resource efficiency independent of scope and price change
EPI	is a measure of the quality of the estimate for the task
BAPI	is a measure of the activity or attendance on the task independent of price change
PPI	is a measure of the punctuality of the task

In addition we have:

RPI	a measure of price increase from that anticipated in the baseline.
DPI	a measure of the schedule performance without start variance.
BPI	a measure of the level of activity to date over the task.
API	a measure of the level of activity, without start variance.

Sample Calculations[1]

Ref.	Variable	Value	Description	Formula
	Current Date	Day 7	Seven days have elapsed since the baseline start	
	Baseline Duration	10 d	Original baseline duration	
S	BAC	10000	Budget at Completion	
	Percent Complete	50%	Progress to date	
S	EV	5000	Earned Value	

[1] PV and EV are assumed to behave as a linear function of time with a slope of $1000 per day.

S	PV	7000	Planned Value	
S	AC	6000	Actual Cost	
S	CV	-1000	Cost Variance	EV-AC
S	SV	-2000	Schedule Variance	EV-PV
+,S	CPI	0.8333	Cost Performance Index	EV/AC
S,*,**,+	SPI	0.7142	Schedule Performance Index	EV/PV
	Actual Start	Day 3	Started 2 days after baseline start	
	DPV	5000	Delayed Planned Value (excluding 2 day delay)	
*	PPI	0.7142	Punctuality Performance Index	DPV/PV
**,+	API	1.2	Activity Performance Index	AC/DPV
	BPI	0.8571	Budget Performance Index	AC/PV
+	DPI	1	Duration Performance Index	CPI*API
	Nb	100	Baseline Output Units required	
	Nf	110	Forecast Output Units required	
*	EPI	0.9090	Estimate Performance Index	Nb/Nf
	EV'	5500	Earned Value modified for scope	EV/EPI
**	CPI'	0.9166	Cost Performance Index modified for scope	EV'/AC
	Orig. Currency Value	1	Value of Dollar at time of baseline setting	
	Current Curr. Value	0.95	Current Value of Dollar	
	ACBC	5700	Actual Cost expressed in original currency values	
	RPI	0.95	Rate Performance Index	ACBC/AC
	BCPI	0.8771	CPI in terms of original currency value	EV/ACBC
*	BCPI'	0.9649	CPI modified for scope in original currency value	EV'/ACBC
*	BAPI	1.14	Activity Performance Index adjusted for curr. change	API/RPI

*Fundamental values from equation (5) **Fundamental values from equation (4)
+Fundamental values from equation (3) S Standard EVA

Summary and Conclusions

Equation (1) expresses the classic dependence of timeliness upon efficiency and the level of intensity of work expended. Equation (2) further expands the latter into components relating respectively to the effects of attendance during the task and start delays. Equation (3) isolates the dependence from the effects of the last. Equation (4) further isolates the impacts of mis-estimates of scope upon the Earned Value variables while Equation (5) further strips away the effects of changes in the value of the currency.

This paper therefore extends the diagnostic power of the EVA methods by defining parameters which successively cleanse the analysis of effects that can distort its true interpretation. The fundamental values that remain, i.e. SPI, BCPI', BAPI, and PPI now provide purer indications of the underlying time-efficiency, cost efficiency, level of intensity and punctuality respectively of the task being analysed.

References

[1] ‘Practice Standard for Earned Value Management’, PMI (2005)