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An extension of the EVM analysis for project monitoring: The Cost Control Index and the Schedule Control Index

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Abstract

In this paper we propose two new metrics that combine Earned Value Management (EVM) and Project Risk Management for project controlling and monitoring. We compare EVM cost and schedule variances with the deviation the project should have under the risk analysis expected conditions.

These two indexes allow project managers to analyse whether the project over-runs are within expected variability or there are structural and systemic changes over the project life cycle. The new monitoring indexes we present are the Cost Control Index and the Schedule Control Index.

Keywords: Project management; Risk management; Earned Value Management

1. Introduction

Earned Valued Management (EVM) is a management technique for project performance monitoring. Recently, Morin (2009) has described the origins of this methodology, whose costs and benefits were described in Christensen (1998).[1] A detailed explanation of EVM basis can be found in Anbari (2003), Fleming and Koppelman (2005) and PMI (2005). More recently, Lipke et al. (2009) have reviewed the main concepts.

EVM integrates scope, cost and schedule control under the same framework and it provides performance variances and indexes which allow managers to detect over-costs and delays. Furthermore, under this methodology, new real data generated during project run time is used to describe trends for the future project total cost and finishing date (based on past performance).

In this paper, we extend EVM to integrate project variability and risk analysis into the earned value framework. Uncertainty and variability are common facts to all the activities in real projects. By means of quantitative risk analysis, we get the probability function and distribution of both project duration and cost, so that, for instance, we can get levels of maximum over-runs within a particular confidence level. In other words, we get a measure of the "planned" or "expected" variability of the project, assuming the probabilistic nature of activity costs and durations.

However some structural or systemic changes during project life cycle can alter the initial expected variability and lead the project outside confidence limits. Moreover some managerial decisions could change some initial conditions. Project managers should not wait until the end of the project to know whether over-runs are within the probabilistic expected levels or not. At every time during project life cycle we need to be confident whether over-runs are within expected variability.

In the EVM framework, variances and performance indexes inform project managers whether the project has over-cost or delays, but they do not inform whether the over-runs are within the bounds of the project expected variability.

In this paper, we adopt the concept of *risk baseline* in the sense described by Cagno et al. (2008): the risk baseline represents the residual risk (uncertainty) to fulfil the remaining activities of the project. We use the risk baseline to evaluate new

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[1] Dr. Christensen maintains a large repository of bibliographic references on EVM that is periodically updated: http://www.suu.edu/faculty/ChristensenD/EV-bib.html.

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performance indexes which integrate the triple scope/schedule/cost with project risk. These new measures facilitate project managers the early adoption of corrective actions.

This paper is organised as follows. First we summarise the main features of EVM and its relationship with risk analysis. Next section provides an explanation of our methodological proposal to integrate EVM and residual risk (the project uncertainty in terms of its parameters variability). Finally, we show the application of these measures to a simple and theoretical case study which gives the reader the opportunity to replicate the results. We close this work with the main conclusions of our research.

2. Earned Value Management: Some extensions

EVM has been used with little changes since it was introduced in the 60s by the U.S. Department of Defense. EVM is based on three measures: planned value (PV) or budgeted cost of work scheduled; actual cost (AC) of work actually performed; and earned value (EV), or planned cost of the work actually completed.

There are some definitions already described in the literature we briefly summarise:

- Cost variance (CV = EV − AC)
- Schedule variance (SV = EV − PV)
- Cost performance index (CPI = EV / AC)
- Schedule performance index (SPI = EV / PV)
- BAC (budget at completion) is the budgeted cost of the project
- SAC (schedule at completion) is the initially planned duration of the project.

Whenever CV < 0 and CPI < 1, the project has over-costs (otherwise, if CV > 0 and CPI > 1 the project is under budget). If SV < 0 and SPI < 1, the project is delayed (otherwise, if SV > 0 and SPI > 1 the project is ahead of schedule). When CV = 0 (CPI = 1) and/or SV = 0 (SPI = 1) the project is respectively on cost and/or timely.

By means of monitoring the evolution of these indexes over the project life cycle, managers can detect deviations from plan, so that they can take early corrective actions.

In Fig. 1 we show the evolution of cumulative values of AC, EV and PV over time. As most of the project effort is usually performed in the middle of its life cycle, commonly, the curves are S-shaped. PV line is the project *cost baseline*, that is, the expected accumulated cost if the project is performed as planned.

EVM not only informs us about the performance of the project, but gives us new estimates about project cost and finishing date which depend on the assumptions concerning the future evolution of the project.

When the project is close to its end, all the planned activities will be nearly finished, so the budgeted cost of scheduled work will equal to the planned cost of performed work. EV will tend to PV, and as a consequence, SV will converge to zero and SPI will tend to 1, even if the project has serious delays from planned schedule. It means that SV and SPI cannot give relevant information at the late stages of the project.

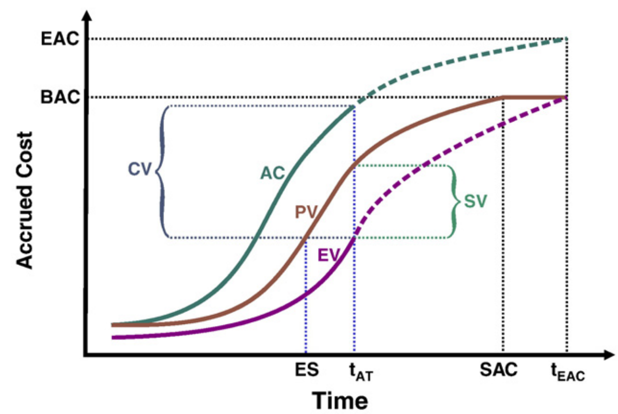

Fig. 1. Earned value and earned schedule figures.

To overcome this limitation Lipke (2003, 2004) propose the use of Earned Schedule (ES). ES is the date when the current earned value should have been achieved. To compute ES (see Fig. 1) at time (t_{AT}), we first calculate the earned value. We use this value on the PV line (cost baseline) to compute the date when EV equals PV. This date is the Earned Schedule (ES).

Some researchers have proposed extensions to the basic procedures, mainly related to forecasting improvement: Zwikael et al. (2000) evaluate five forecasting methods; Vandevoorde and Vanhoucke (2006, 2007) summarise some of the cost and schedule forecasting methods and study their accuracy in real and simulated projects; Christensen and Templin (2002) or Lipke et al. (2009) have studied statistical confidence limits to improve estimates at completion and Byung-cheol and Reinschmidt (2009) have proposed a new probabilistic forecasting method based on Bayesian inference and the Beta Distribution which integrates original estimates with observations of new actual performance.

Other researchers have extended the earned value management report to provide a final cost estimation. Christensen (1994) proposed new indexes to assess the accuracy of the estimated final cost (Estimation At Completion, EAC). Christensen and Templin (2002) justify the usability of two EAC evaluation methods by means of statistical evidence from a sample of defense acquisition contracts.

Our proposal is in a new direction: integrating risk management within the EVM framework.

3. Integrating EVM and risk management: The risk baseline and buffers

EVM does not take into account project risk analysis and variability. There are several methodologies to deal with project risks in terms of uncertainty.[2]

PERT (US Navy, 1958a,b) methodology allowed a first approach to deal with project risk (duration variability): the expected project duration and its variance are computed as the sum of durations and variances of the activities belonging to the critical path (being the activities statistically independent).

[2] See Cagno et al. (2007) for a detailed analysis and classification of risks.

However, this simple approach could give us misleading estimation of durations and costs, because in practice critical path changes over time on real duration of activities.

Monte Carlo simulation is a powerful methodology to deal with project uncertainty. After estimating probability distributions of costs and activity durations, the project is simulated for different values of activity costs and durations. It provides the probability distribution of project total cost and schedule. By means of Monte Carlo simulation, we can answer questions like, "what is the probability for the project to finish in less than, i.e., 18 months?"

Depending on activity durations and the real evolution of the project, the critical path could be different in different runs of the project. *Criticality* is the probability of an activity to belong to the critical path. Special effort should be made in order to reduce the duration of activities with high criticality numbers, as we will be decreasing the project total duration (in a probabilistic sense). Williams (1992, 1993, 2002) proposes to complement criticality with a measure of *cruciality*, that is, the correlation between the duration of an activity and the duration of the total project. Delays in very crucial activities will induce delays in the total project schedule. Williams suggests managers to make efforts to reduce the risk of activities exhibiting higher levels of cruciality.

We propose to integrate project uncertainty in terms of its parameters variability within the EVM framework to improve project control. First, we need to introduce the concept of Project Risk Baseline; then we propose new performance indexes for monitoring how far the project is executed from this baseline.

Project managers compute measures of project risk (variances, impact, probabilities, etc.) before the project start-up. But, once the project is running, it is also convenient to re-compute the remaining risk. For instance, at any time during project execution, we can use again Monte Carlo simulation to compute the statistical properties of cost and duration of the pending project. Alternatively, project team could re-estimate probabilities and impact of major remaining cost and duration, so that new measures of project risk could be obtained.

If the project execution takes place as *planned*, the project risk should decrease over time, as completed activities have zero risk (in terms of their variability). We define the Project Risk Baseline (RB) as the evolution of the value of project remaining risk over time: the remaining variability of project cost/duration during the project life cycle.

Project risk at time *t* is computed as the risk of a project made up of the remaining unfinished activities, taking into account that project performance has been as planned until time *t*. It is useful to define both a Cost Risk Baseline and a Schedule Risk Baseline. During project runtime, over-costs and delays could take place. But if everything remains as planned, delays and over-costs values should lay between the planned variability derived from the defined risk baselines.

However, unexpected and unplanned situations take place during project life cycle, affecting not only actual performance, but also project risk itself. Williams (2002) shows that a high percentage of delays is a consequence of systemic phenomena during specific stages of the project, and he alerts that, in some cases, special actions taken in order to reduce delays and over-costs have an additional negative effect, bringing out more delays and over-costs (Williams, 2005). For instance the work to be performed by a subcontractor might be postponed over time because precedent activities are delayed. If he/she has other commitments in the new date, he/she will postpone its work further introducing an unexpected gap in the sequence of activities (positive feedbacks).

For these reasons, it should be useful to detect whether current delays or over-costs are within the range of expected variability (project under control) or, on the other side, systemic and undiscovered phenomena are taking place moving the project out of control.

Cost and schedule performance indexes and variances tell us whether the project is delayed and/or has over-cost. But these measures do not alert about structural changes within the project beyond the "expected variability", that is, structural changes which contribute to put the project out of control. Therefore, we propose new measures and indexes comparing the cost and schedule variances with a "maximum control deviation per unit of time".

We define two buffers: the Cost Project Buffer (CPB_f), and the Schedule Project Buffer (SPB_f). Both are computed taking into account the statistical properties of the probability distributions of project cost and schedule. The CPB_f is the difference between the maximum cost at a confidence level (ccl%)—the probability of the project cost to be lower than this maximum cost is ccl%—and the cost mean value. In the same way, SPB_f is the difference between the maximum duration at a confidence level (scl%) and the duration mean value. The project manager decides the ccl% and the scl% he/she requires to the project (for instance, in relationship with the contingency allowances).

Then, we will split these cost and schedule buffers (CPB_f and SPB_f) among all time intervals. Therefore we could estimate how much cost and schedule would deviate per unit of time from planned values. To split those buffers, we use weights (wc and ws) that are proportional to the expected risk reduction in every interval, that is, the difference between two adjacent points along the risk baseline:

$$wc_t = CRB_{t-1} - CRB_t \tag{1}$$

$$ws_t = SRB_{t-1} - SRB_t$$

where CRB_t and SRB_t are the cost and schedule risk baselines at time *t*. Consequently,

$$\sum_{t=1}^{T} wc_t = \sum_{t=1}^{T} CRB_{t-1} - \sum_{t=1}^{T} CRB_t = CRB_0 - CRB_T = \sigma_{pc}^2$$

$$\sum_{t=1}^{T} ws_t = \sum_{t=1}^{T} SRB_{t-1} - \sum_{t=1}^{T} SRB_t = SRB_0 - SRB_T = \sigma_{ps}^2$$

where σ_{pc}^2 and σ_{ps}^2 are respectively the total project cost and schedule variances. Realize that the risk baselines at $t=T$ are 0 (the project has finished) whereas at $t=0$ equals the total project variability.

	precedent relations	min	max	mean	planned cost	real duration	real cost
a1	-	1	3	2	700	3	720
a2	a1	2	6	4	1.900	4	2.000
a3	a1	3	7	5	1.500	6	1.620
a4	a2,a3	1	3	2	700	2	750
			Project	9	4.800	11	5.090

Fig. 2. Project AON diagram, planned and real duration and costs.

Then, the maximum cost and schedule buffers during the interval $(t-1, t)$ will be:

$$CBf_t = wc_t * CPBf / \sigma^2_{pc} \quad (2)$$

$$SBf_t = ws_t * SPBf / \sigma^2_{ps}.$$

And the cumulative cost and schedule buffers are:

$$ACBf_t = CBf_t + ACBf_{t-1}$$

$$ASBf_t = SBf_t + ASBf_{t-1}.$$

These cumulative values should be compared with the Earned Value variances, as the variances show us the extra costs and delays over planned values. We define the Schedule Control Index (SCoI) as:

$$SCoI_t = ASBf_t + SV(t) = ASBf_t + ES - AT \quad (3)$$

where SV(t) is the earned schedule variance. We should realize that whenever the project is delayed, the schedule variance will be negative, so in practice, Eq. (3) compares the cumulative buffer with the delay in the actual time (AT). If the cumulative delay ($-$SV(t)) is higher than the cumulative buffer then SCoI would be negative. This means that the schedule deviations are higher than "normal", alerting us about structural and systemic changes in the project.

Analogically, we can define a Cost Control Index, comparing the cost buffers with cost variances, but in this case the analysis requires additional elements. Cost variance is the difference between the actual cost of work done and the planned value of work done. To analyse the work done, we should compare the cost variance with the cumulative cost buffer (ACB_f) not in actual time but in the time of earned schedule (t=ES). So we define Cost Control Index (CCoI) as:

$$CCoI_t = ACBf_{(t=ES)} + CV_t = ACBf_{(t=ES)} + EV - AC. \quad (4)$$

And again, a negative CCoI alerts about extra-changes over the normal and planned variability.

When the project is performing better than expected (SV(t) and/or CV are positive), these indexes will be positive too. Therefore, no corrective actions should be taken.

4. Putting the new metrics to work

A simple example[3] will help us to illustrate the new indexes explained above. In Fig. 2 we show the activity on node diagram of a simple project. We suppose that activity durations are uniformly distributed within a minimum and a maximum duration. In Fig. 2, we also show planned duration (mean) and the planned cost of all the activities. Total planned cost is 4800.00 monetary units (m.u.) whereas planned duration is 9 weeks. However, once the project has been executed, the crude reality shows us that the project was developed in 11 weeks, with a total cost of 5090.00 m.u.

4.1. EVM analysis

We suppose that costs are uniformly distributed among time; this means that, for instance, if the duration of activity *a2* is 4 weeks and its planned cost is 1900 m.u., then the planned cost to be spent for each week is 1900/4=475 m.u. We use the same reasoning to compute actual costs and earned value. In Fig. 3, we show EVM figures.

Cost variance (CV) is always negative and Cost Performance Index (CPI) is below 1; indeed both indexes are lower as the project advances. This means that there are always over-costs, but we do not know whether the over-costs are under normal probabilistic levels or some structural changes are taking place. Schedule variance (SV) is also negative and Schedule Performance Index (SPI) is also below 1. As explained in precedent sections, their values tend to 0 and 1 respectively as the project is close to the end. However, Earned Schedule Variance SV(t) is more realistic, as it is always below 0, and it decreases until reaching the real two weeks of delay.

4.2. Risk analysis and EVM working together

We have performed Monte Carlo analysis using the software CrystalBall version 7.2 by Decisioneering. After 100,000 simulations,[4] we get the results shown in Fig. 4.

[3] We choose a simple case study to illustrate the applicability of these metrics. It allows interested reader to replicate the exercise.

[4] The computational cost is quite low in this case (less than five seconds) and there is no sense to optimize the number of simulations.

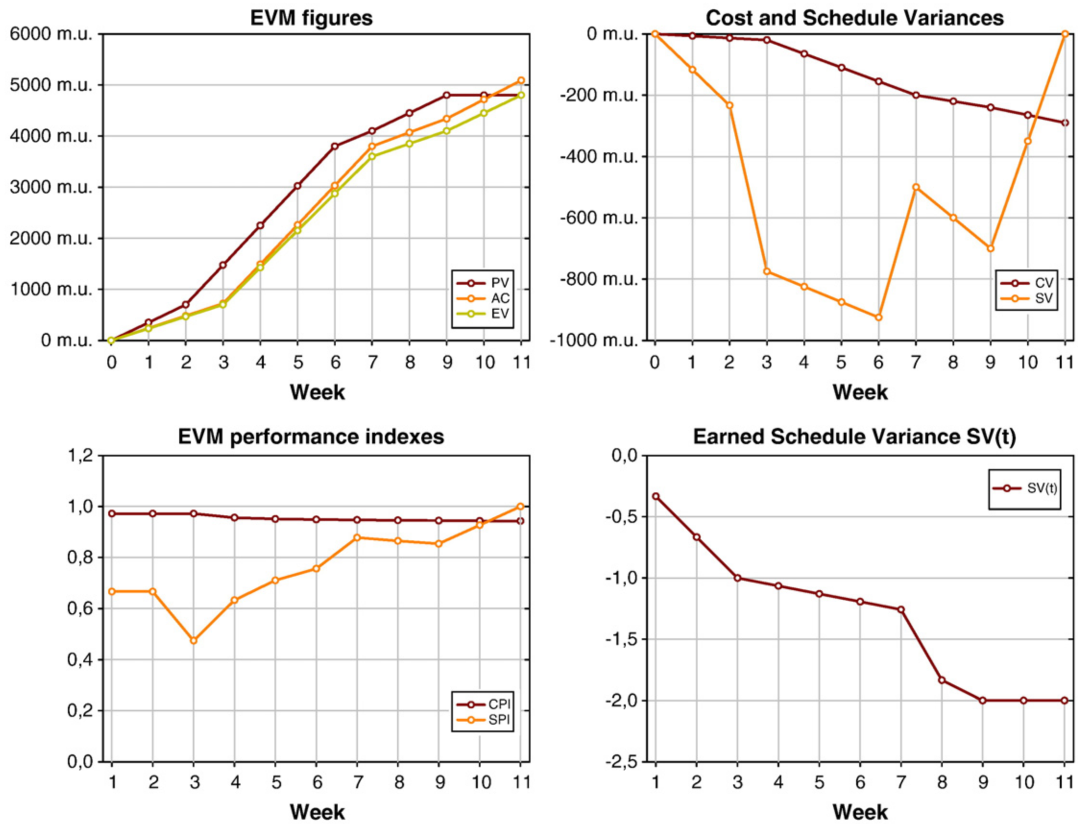

Fig. 3. Earned value analysis.

We show both the project cost and schedule distributions. If we fit ccl% and scl% both at 90% the percentiles are 10.94 weeks and 5371.26 m.u., whereas the mean values are 9.29 weeks and 4801.20 m.u. respectively.

The resulting buffers are:

- Cost Project Buffer at ccl% = 90%: $CPB_f = 5371.26 - 4801.20 = 570.06$

	duration	cost
90 % prob	10.94	5371.26
expected	9.00	4800.00
prob (mean)	40.63	50.00
mean	9.29	4801.20
variance	1.65	180,349.01
buffer	1.65	570.06

	criticity	cruciality	
		Contrution To Variance	Rank Correlation
a1	1.00	0.22	0.44
a2	0.28	0.06	0.24
a3	0.72	0.50	0.66
a4	1.00	0.22	0.44

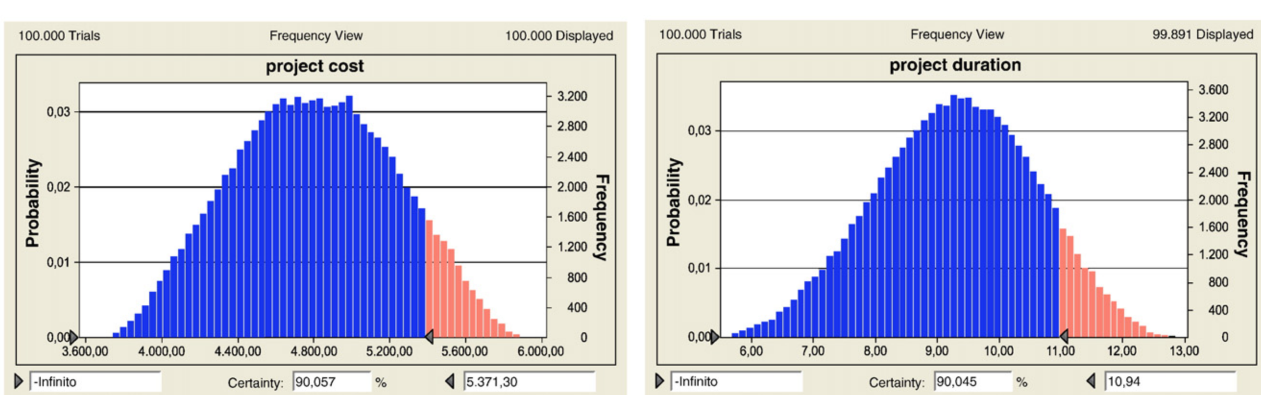

Fig. 4. Monte Carlo simulation.

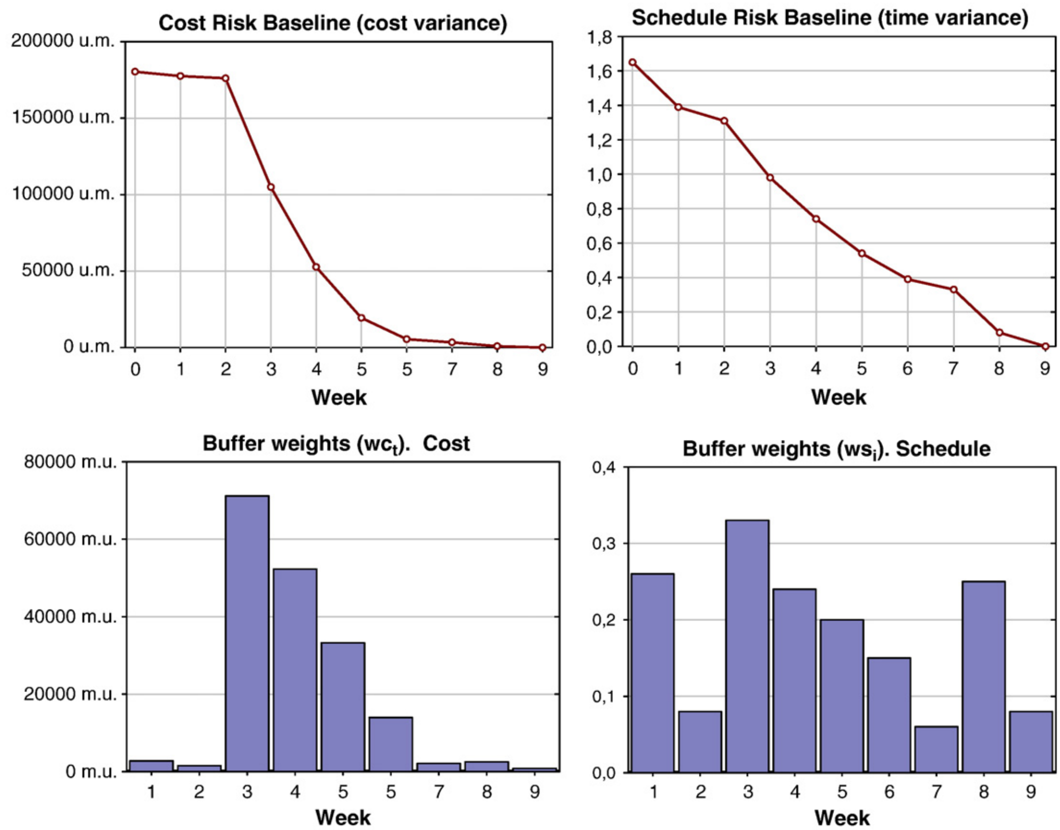

Fig. 5. Risk baseline and buffer weights.

- Schedule Project Buffer at scl%=90%: $SPB_f = 10.94 - 9.29 = 1.65$

The analysis of the activities of the project offers the following summary. Activity *a3* is the most crucial and its risk is of particular relevance for the project. Of course, *a1* and *a4* are always critical. Beyond that, *a3* is specially critical and crucial, so we should make efforts to reduce its duration and risk.

In Fig. 5 we show the Cost Risk Baseline (CRB) and Schedule Risk Baseline (SRB). Of course, both curves are decreasing but their slopes give us information about how the project is reducing risk over time. In Fig. 5 we also show the weights wc and ws.

Fig. 6 represents the Cost and Schedule Control Indexes. It gives us relevant information about what is happening internally within the project. SCoI is negative most of the time. This means that the actual delays are higher than the expected delays. Maybe the initial project estimations were wrong, or maybe some extraordinary events or systemic effects have changed the internal structure of the project. The negative value of SCoI indicates that corrective actions should be taken. Otherwise the project would be finished two weeks delayed (beyond the 1.65 weeks of 90% of probability).

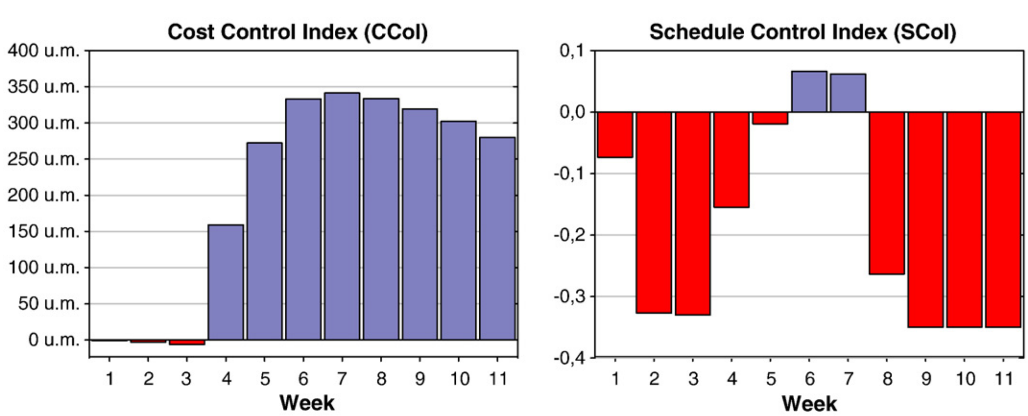

Fig. 6. Cost and schedule control indexes.

On the other side, although cost variances and performance indexes are below 0 and 1 respectively, we see in Fig. 6, that CCoI values are higher than zero after week 3. This means that although there are over-costs in the project, these values lay within the expected project variability. For this reason, project over-costs do not exceed the tolerance level of the 90% percentile.

5. Conclusions

We have introduced two new metrics for integrating EVM and Project Risk Management methodologies: Cost Control Index (CCoI) and Schedule Control Index (SCoI). Both indexes compare EVM measures with the maximum values that the project should exhibit if the project was running under the risk analysis hypothesis.

Both CCoI and SCoI alert project managers about systemic and structural changes affecting the project risk, cost and schedule for a determined confidence level of cost and schedule (ccl% and scl%). When CCoI(t) and/or SCoI(t) are negative, appropriate early decisions should be taken (the project delay and/or over-cost are greater than expected).

Like EVM, the new indexes operate at the project cumulative data. We propose here new indicators that require neither much additional computing work nor additional data. If both cost accounting and risk analysis are performed, the new indexes give us rich information without additional effort. As long as we understand, any extension of the EVM methodology should keep it as simple as it was initially designed, so that project professionals could adopt it.

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