II International Conference on Industrial Engineering and Industrial Management
XII Congreso de Ingeniería de Organización
September 3-5, 2008, Burgos, Spain

Integrating Risk in Project Monitoring. New Performance Indexes for Earned Value Measurement

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Abstract

We propose new metrics to integrate Earned Value Management (EVM) and Project Risk Management methodologies in project control and monitoring. We compare EVM cost and schedule variances with the deviation the project should have under the risk analysis expected conditions.

Therefore, we are able to distinguish whether the project over-runs are within expected variability or there are structural and systemic changes over the project life cycle. To this aim, we propose new monitoring indexes, as 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 common method used in project management to monitor project performance. EVM integrates scope, cost and schedule under the same framework. The method itself is quite simple and easy to implement and it provides project performance indexes, allowing managers to detect overruns. Finally, the new real data generated during run time is integrated within the indexes in order to produce new forecasts about project cost and finishing date. However, as it was explained in Pajares and Lopez (2007), the methodology has some important limitations: it does not take into account managerial flexibility and internal learning processes, forecasts are sensitive to the project net structure, and the role of project risk is missed.

In this paper, we are concerned with the role of risk, and we propose new performance indexes integrating scope, schedule and cost with project risk: it does not make sense to take extreme corrective actions in order to reduce delays or over-costs, if, at the same time, the feasibility of the project is dramatically endangered. It is necessary to develop control systems integrating risk and uncertainty with the conventional measures of cost and schedule variances, so that project managers could know whether over-runs are bounded inside the acceptable level of risk of the projects.

This paper is organised as follows: first we will briefly summarise the main features of EVM and its limitations. In section 3, we analyse the role of risk analysis and in section 4 we suggest how to integrate both methodologies. We show our proposal with an example in section 5, and we finish with the main conclusions of our research.

2. Earned Value Management and Earned Schedule

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. Then, several performance indexes are defined: Cost variance (CV=EV-AC); schedule variance (SV=EV-PV); cost performance index (CPI=EV/AC) and schedule performance index (SPI=EV/PV).

Some numbers might be useful. Let us suppose a project to create 100 handicraft sculptures, with a total budget of 1000 € and delivery time of 10 days. If we suppose linearity, at day 3, we should have manufactured 30 items, with a total cost of 300 € (PV). But real world is rude: let suppose we see that we have spent 350 € (AC) and we have manufactured only 20 items. We could say that project over-cost is 50 €, but it will be a naïve view, as we have only manufactured 20 items, and we had planned to expend only 200 € (EV) for manufacturing them ("the value earned for the project" is only 200 €). So, actual over spending is 150 € (CV, cost variance of –150 €) and we have a delay of 100 € (SV, schedule variance of –100 €) (equivalent to one day, 10 items). The lower the variances (more negative values), the higher the over-costs and the delays.

In order to compare projects with different sizes, we can use performance indexes: CPI=200/350=0.5714; and SPI=200/300=0.6666. Performance indexes below 1 alert us about project over-runs.

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 figure 1, we show the evolution of accrued values of AC, EV and PV over time. PV line is the project *cost baseline*, that is, the expected accumulated cost that we will see if the project is performed as planned. BAC (budget at completion) is the budgeted cost of the project, and SAC (schedule at completion) is the initially planned duration of the project.

EVM not only informs us about the performance of the project, but give us new forecasts about project cost and finishing date. Forecasts depend on the assumptions concerning the future evolution of the projects:

- Assumption 1: past problems have been identified and solved. Therefore, we can suppose that the rest of the project will run as planned. In the example of the handicraft sculptures, may be that the first day of work, our senior sculptor became hill, and the not-supervised junior sculptors were working slowly and were spending more material than expected. However, the senior sculptor has just phoned us to confirm that tomorrow (day 4), he/she will come to work. So we can suppose that the remaining 80 items will we done in 8 days and with a cost of 800 €. So the new forecast for cost will be 350+800=1150 €, with a finishing date of 3+8=11 days. We have to remark that 1150=1000-(-150), that is, the new forecast (EAC, estimate at completion) is EAC=BAC-CV. In the same way, the TEAC (time estimate at completion) is equal to SAC-SV/TV, where TV=100€/day, that is, the ratio between cost and time (TV=BAC/SAC=1000/10=100).

- Assumption 2: we have to accept that we have not planned properly, and the past performance is a good estimation of future performance. So we have to accept that we need to spend 350 € and 3 days to manufacture 20 items. This means that, in order to manufacture the remaining 80 items, we will need 350*80/20=1400 € and 3*80/20=12 days. So, the new forecasts for cost and schedule will be EAC=350+1400=1750 € and TEAC=3+12=15 days. We should realise again that EAC=BAC/CPI=1000/0.5714=1750 and TEAC=SAC/SPI=10/0.6666=15

- Assumption 3: Neither assumptions 1 either 2 are plausible, so we need to compute new forecasts for remaining work *ad hoc*.

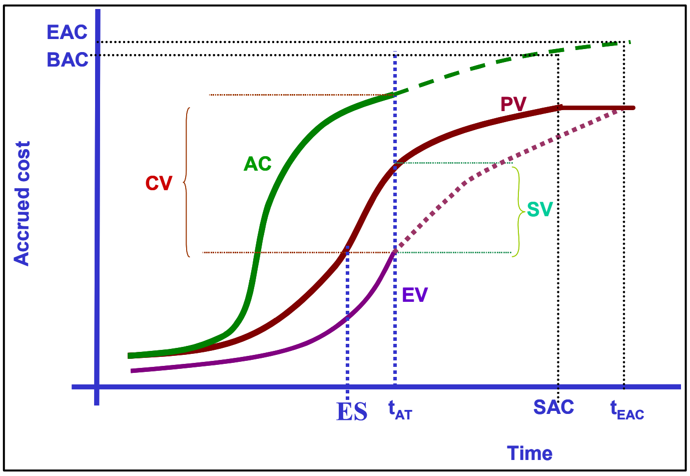


Figure 1. Earned value and earned schedule figures.

When the project is close to its end, all the planned activities will be nearly finished, so the budgeted cost of work planned will equal to the budgeted cost of work done, and 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. This means that SV and SPI do not work properly during the late stages of the project.

In order to overcome this limitation, the initial Earned Value Methodology was extended, and the Earned Schedule (ES) was proposed. ES is the date when the actual earned value should have been achieved. In order to compute ES (see figure 1) during actual time (t_{AT}), we have to compute earned value, and we have to move to the PV line (cost baseline) to compute the date when EV equals PV. This date is the Earned Schedule (ES). In the handcrafts example, at day 3 the earned value is 200 € (equivalent to 20 items), and we had planned to have spent 200 € at day 2, so ES=2.

3. The role of risk in project management and control

Project risk management is crucial for project success. However, EVM does not take into account project risk. Therefore, in some cases, we could take decisions in order to improve EVM performance indexes, without realising that indeed, we are increasing future project risks. It makes no sense to improve cost and schedule performance indexes, if we are endangering seriously the viability of the project. We propose to integrate risk analyses in project control. EVM focuses on the history of the project, whereas risk management procedures look forward. An integrated methodology could help us to control the future performance of the project taking into account lessons learned from the past.

Different approaches have been proposed to deal with project risk. First, project teams have to identify major risks, their probabilities to take place and their impact on scope, time and costs. The PERT methodology allows a first approach to deal with project risks: 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). However, this simple approach could give us misleading estimation of durations and costs, because in practice, critical path changes over time, depending of real duration of activities.

Monte Carlo simulation is a powerful methodology to deal with project risk. After estimating probability distributions of costs and activity durations, the project is run (by means of simulation) thousands of times, with different combination of values of activity costs and durations, so that the probability distribution of project total cost and schedule can be estimated. By means of Monte Carlo simulation, we can answer questions like, what is the probability for the project to finish in less than 18 months?

Depending on actual 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 and 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.

4. Integrating EVM and Risk Management. Risk Baseline and Buffers

We propose to integrate EVM and project risk management methodologies in order to improve project control. First, we define 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 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 costs and durations of the remaining project. Alternatively, project team could re-estimate probabilities and impact of major remaining cost and durations, 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 (perfect information). We define Project Risk Baseline (RB) as evolution of the value of project remaining risk over time. 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. Of course, we can define a

Cost Risk Baseline and a Schedule Risk Baseline. During project runtime, over-costs and delays will take place, but if everything remains as planned, delays and over-cost values should lay between the planned variability derived from the risk baseline.

However, unexpected and unplanned situations take place during project life cycle, affecting not only actual performance, but also project risk itself. Imagine that, because of some delays, the work performed by a subcontractor should be moved to another dates, but the subcontractor has other commitments with other firms and, probably, he/she will have to postpone our work. Moreover, Williams (2002) shows that a high percentage of delays are leaded by systemic phenomena (positive feedbacks) during specific stages of the project, and he alerts that, in some cases, special actions taken in order to reduce delays and over-cost have an additional negative effect, bringing out more delays and over-costs (Williams, 2005).

For these reasons, it should be useful to detect whether current delays or over-costs are within the range of normal 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 “normal 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.

To this aim, first we compute a cost project buffer (CPBf) and a schedule project buffer (SPBf). Both buffers are computed taking into account the statistical properties of the probability distributions of project cost and schedule (for instance, 90 % percentile). Then, we will split these cost buffers among all time intervals, so that we could estimate how much cost and schedule could deviate from planned values. In order to split the buffers, we use weights (wc and ws) proportional to the expected risk reduction in every interval. That is:

$$\begin{aligned} wc_t &= CRB_t - CRB_{t-1} \\ ws_t &= SRB_t - SRB_{t-1} \end{aligned} \qquad [1]$$

where CRB_t and SRB_t are the cost and schedule risk baselines. It is evident that $\sum_{t=1}^{T} wc_t = \sigma_{pc}^2$ and $\sum_{t=1}^{T} ws_t = \sigma_{ps}^2$, where the squared sigmas are the total project cost and schedule variances respectively.

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

$$\begin{aligned} CBf_t &= wc_t * CPBf / \sigma_{pc}^2 \\ SBf_t &= ws_t * SPBf / \sigma_{ps}^2 \end{aligned} \qquad [2]$$

And the accrued cost and schedule buffers are:

$$\begin{aligned} ACBf_t &= CBf_t + CBf_{t-1} \\ ASBf_t &= SBf_t + SBf_{t-1} \end{aligned}$$

These accrued 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:

$$SCoI = ASBf_t + SV(t) = ASBf_t + ES - AT \quad [3]$$

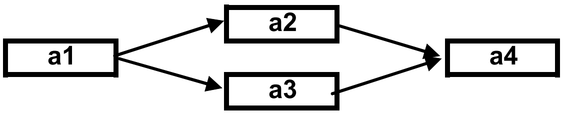
Where SV(t) is the earned schedule variance. We should realise that whenever the project is delayed, the schedule variance will be negative, so in practice, equation [3] compares the accrued buffer with the delay in the actual time (AT). If the accrued delay (-SV(t)) is higher than the accrued buffer, then SCoI will be negative, and 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, we should take a little bit of care. Cost variance is the difference between the actual cost of work done and the planned value of work done in actual time. We should compare work done with work done, so we should compare cost variance with the accrued cost buffer (ACBf) not in actual time, but in the time of earned schedule (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.

5. Putting the new metrics to work

A simple example will help us to illustrate the new indexes explained above. In figure 2, we show the activity on node diagram of a simple project. We suppose activity durations are uniformly distributed within a minimum and a maximum duration. In figure 2, se also show planned duration (mean) and the planned cost of all the activities. Total planned cost is 4800 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 days, with a total cost of 5090 mu.



	prec relations	min	max	mean	planned cost	real duration	real cost
a1		1	3	2	700	3	720
a2	a1	2	6	4	1900	4	2000
a3	a1	3	7	5	1500	6	1620
a4	a2,a3	1	3	2	700	2	750
			Project	9	4800	11	5090

Figure 2. Project AON diagram, duration and costs. Planned and real.

5.1 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 2000, then the planned cost to be spent for each week is 2000/4=500 m.u. We use the same reasoning to compute actual costs and earned value. In figure 3, we show EVM figures.

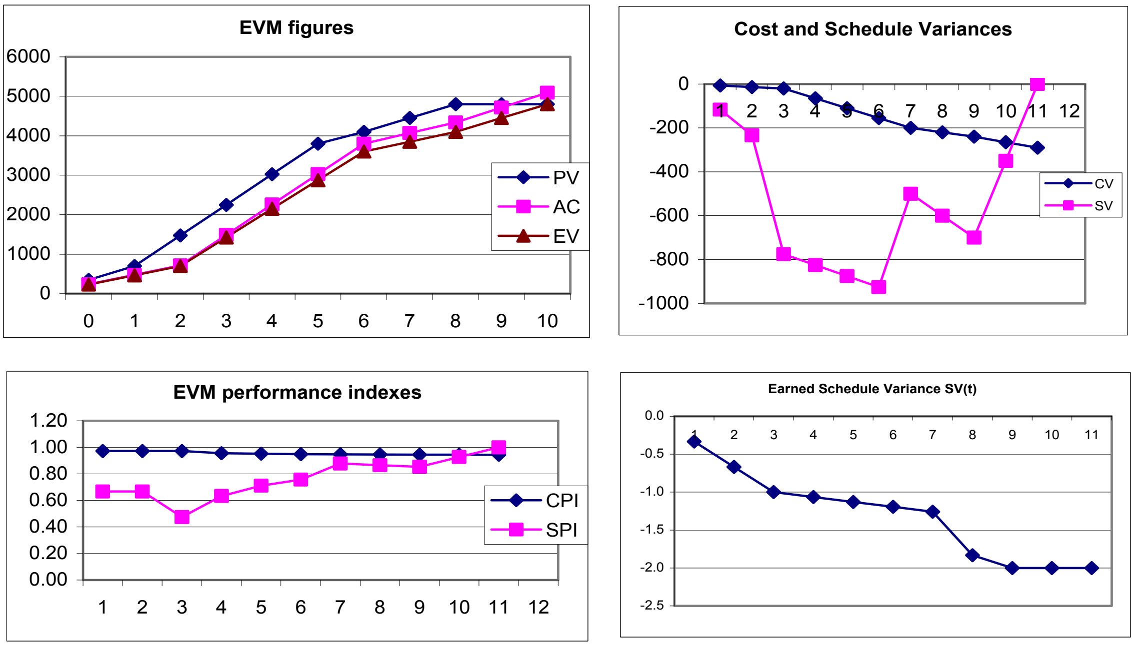


Figure 3. Earned Value Analysis

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 know not whether the over-cost 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 their end. However, Earned Schedule Variance (SV(t)) is more realistic, as is always below 0, and it decreases until reaching the real 2 weeks of delay.

5.2 Risk Analysis and EVM working together

We have performed Monte Carlo analysis using the software CrystalBall version 7.2 by DECISIONEENING (www.crystalball.com). After 100000 simulations, we get the results shown in figure 4. We can see the shapes of project cost and schedule distributions. The 90 % percentiles are 10.94 weeks and 5371 m.u., whereas the mean values are 9.29 weeks and 4801 m.u. respectively. Therefore, we will use the difference between the 90% percentile and the mean values as Cost Project Buffer (CPBf=570.06) and Schedule Project Buffer (SPBf=1.65) respectively. Activity a3 is the most crucial, so we should have special care about its risk. 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 figure 5, we show the Cost Risk Baseline (CRB) and Schedule Risk Baseline (SRB). Of course, both lines are decreasing, but their slopes give us information about how the project is reducing risk over time. In figure 5, we also show the weights wc and ws, that is, the time first differences in risk baseline curves.

	duration	cost
90 % prob	10.94	5371.26
expected	9	4800
prob (mean)	40.63	50
mean	9.29	4801.2
variance	1.65	180349
buffer	1.65	570.06

		cruciality	
	criticity	Contr. To Variance	RankCorrelation
a1	1	0.22	0.44
a2	0.28	0.06	0.24
a3	0.72	0.50	0.66
a4	1	0.22	0.44

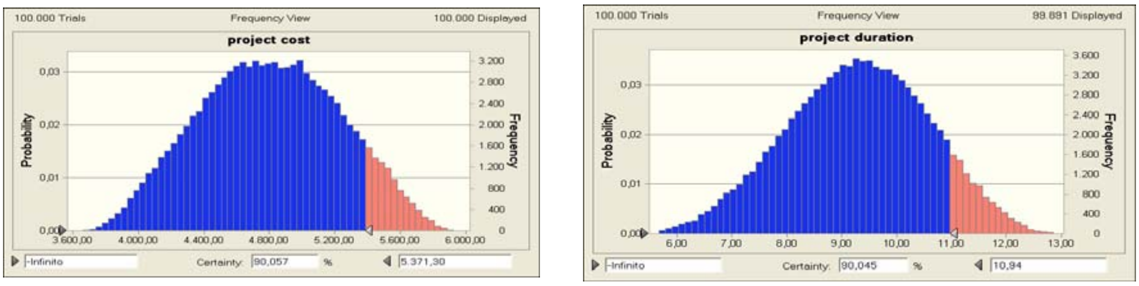


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Figure 4. Monte Carlo Simulation.

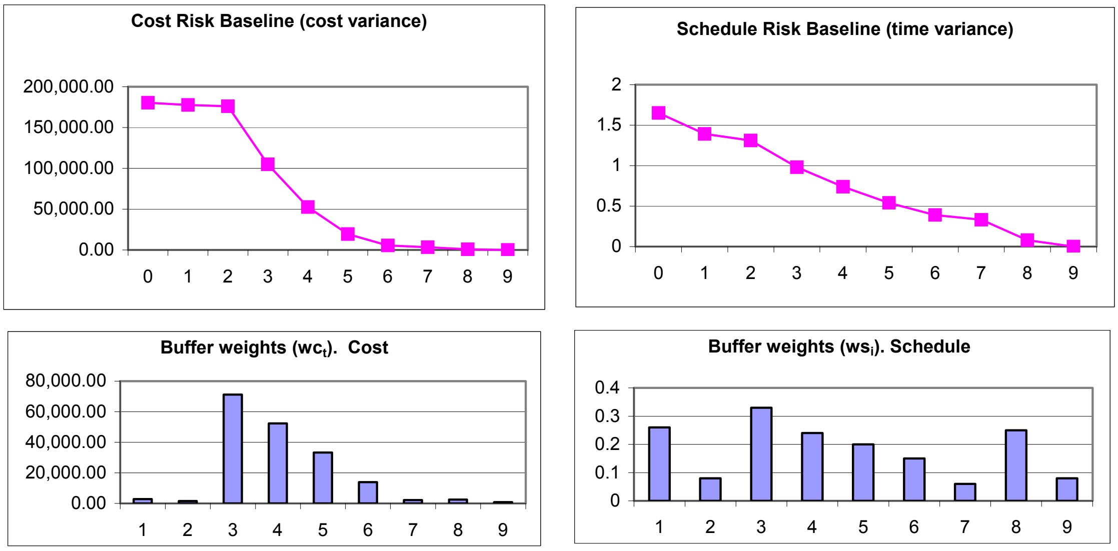

Figure 5. Risk Baseline and Buffer weights.

In figure 6, we show Cost and Schedule Control Indexes. They give us important information about what is happening internally within the project. SCoI is negative most of the time. This means that the real delays are higher than the expected delays. May be that the initial project estimations were wrong, or may be that some systemic effects are changing the internal structure of the project. However, project managers did not realised this fact, and for this reason, the project finishes 2 week delayed, beyond the 1.65 weeks of 90 % of probability. The persistent negative values of SCoI should have alerted project managers to inquiry about structural changes in the project.

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

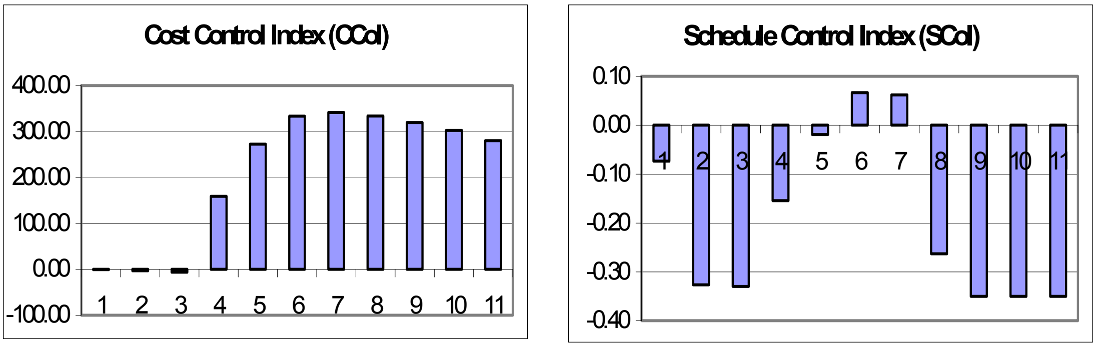

Figure 6. Cost and Schedule Control Indexes.

6. Conclusions

We have introduced two new metrics for integrating EMV and Project Risk Management methodologies: Cost Control Index (CCoI) and Schedule Control Index (SCoI). Both indexes compares EVM measures with the maximum values that the project should exhibit if the project is running under the risk analysis hypothesis. Both CCoI and SCoI alert project management about systemic and structural changes affecting the project risk, cost and schedule.

Like EVM, the new indexes operate at the project aggregate level; like EVM, the measures we propose here do not require much additional computing work, nor additional data. If both cost accounting and risk analysis is performed, the new indexes give us rich information without additional effort.

Of course, we are in the first steps of our research, and the new indexes have to be validated with real projects and need to be extended in their scope.

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