Responsible Design and Delivery of the Constructed Project
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# ON THE LIMITATIONS OF THE EARNED VALUE MANAGEMENT TECHNIQUE TO ANTICIPATE PROJECT DELAYS

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A significant proportion of projects across the construction industry fail to meet their planned completion dates, being this a recurrent topic in the project management literature. Multiples causes of project delays have been proposed, however, hardly any attention has been paid to the fact that the most celebrated project monitoring and control technique – the Earned Value Management (EVM) – may not be as fit for purpose as it seems. It is proposed that because EVM ignores activity duration variability it always results in optimistic completion dates which may be very difficult to meet in the real projects. This research offers a fresh and long overdue critique of EVM in its most common implementation (assuming deterministic activity durations and costs), while highlighting its shortcomings. Particularly, Monte Carlo simulations are implemented to exemplify how the merge event bias phenomenon is inadvertently impacting the schedule in both time and cost dimensions. A fictitious case study is used to demonstrate the connection between these shortcomings and what is then conceived as a delay in project completion.

*Keywords*: Project management, Monitoring, Scheduling, Merge event bias, Stochastic network analysis.

## 1 INTRODUCTION

Earned Value Management (EVM) is, probably, one of the most prominent monitoring techniques for tracking project progress and also one that has received extensive research attention (Vanhoucke 2009, Vanhoucke 2011, Vanhoucke 2012).

EVM, in its classical form and using the most recent metrics denominations consists of the Planned Value (PV), the Actual Cost (AC) and the Earned Value (EV). There is a fourth metric named 'Earned schedule (ES)' (Lipke 2003) which measures in time units what EV measures in money units. These four metrics allow the calculation of a series of time and cost variances, performance indicators and forecasting indicators which (theoretically) represent how the project is doing in either or both time and cost dimensions.

The main advantage of this technique is its relative simplicity and that it only requires the kind of information (activity percentages of completion and actual costs mostly) that is actually gathered for other purposes during the project execution. The biggest disadvantage, which has apparently remained out-of-sight for most practitioners and researchers alike is that EVM is a technique that measures 'amount of work performed', NOT time deviations.

Put it in simple words, EVM measures the differences between EV and PV (for time deviations) or between EV and AC (for cost deviations). If EV is greater that either PV or AC, the project is doing well in time or cost, respectively. But EV increases as more activities are finished, irrespective of whether the order of execution was the most appropriate.

The reasonable question then is: are the activities being finished so far the ones that will lead to achieving the project duration we planned originally? EVM cannot tell. Indeed, if we deviate significantly from the project schedule, complementary indices like the p-factor (Lipke 2004), which measure schedule adherence, inform us about the risk of rework but they still fail to anticipate what (negative) time deviations can be expected.

EVM is therefore, a technique that works perfectly in the cost dimension (Ballesteros-Pérez et al. 2015, Ballesteros-Pérez et al. 2016), as all activities contribute to the total project cost according to their respective budgets. But that is not the case for time deviations. Activities need to happen in specific order to achieve a particular duration.

In this paper, a case study showing the execution of a project with paths in parallel will be exemplified. Detailed calculations of all (even the latest) EVM metrics will evidence how, despite this project is experiencing delays, the metrics cannot inform the project manager until it is too late (the situation cannot be remediated). Discussions will show how further research in EVM is still required to come up with alternative metrics that take care of situations where an imbalanced project progress among paths is occurring and at least one path is falling behind.

## 2 CASE STUDY

Let us present an example highlighting relevant shortcomings of the EVM technique. Figure 1 represents a fictitious project (schedule) consisting of three paths with four activities each. For the sake of simplicity it will be assumed that each activity has the same cost (100 monetary units) and the same duration (modeled by the cast of a six-sided die). This example could have also been illustrated with just one activity in each path, but for the sake of not using decimal places when casting dice, four activities have been considered per path.

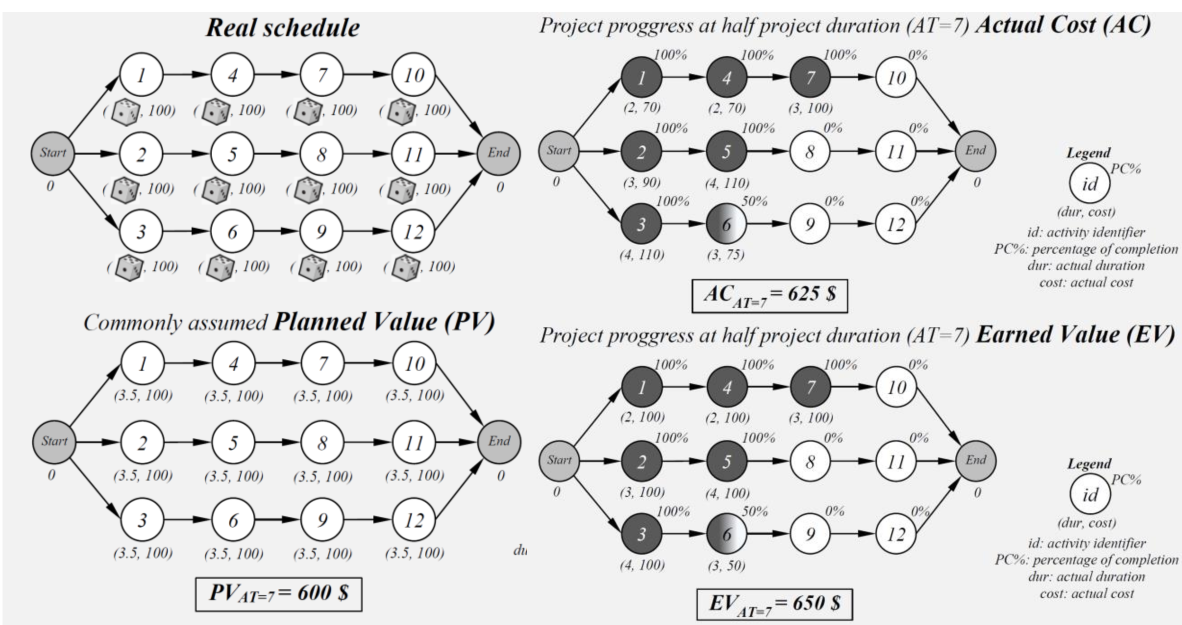


Figure 1. Activity on Node (AoN) networks and EVM calculations for the fictitious project.

Figure 1 represents at the top left the 'real model' of this schedule: each activity is variable concerning its duration, but not in the cost dimension. The bottom left network represents the abstraction (simplification) normally assumed by most Project Managers (PMs) when deciding which is the most representative (mistakenly believed to be the average) scenario. This is the Planned Value (PV) network, which could also have been represented, and indeed it usually is in real settings, by means of a Gantt chart. According to all specified data, this PV diagram tells that the project should last 14 days and cost 1,200 monetary units. The top right and bottom right networks represent the Actual Cost (AC) and the Earned Value (EV) with the progress at half of (what is believed to be) the project duration (Actual Time, AT, equal 7 days or other time unit).

By having a look at the percentages of completion (top right from each activity node) the path located in the center has advanced exactly according to the plan: two activities out of four (activities 2 and 5) have been completed at AT=7. The path at the top has progressed beyond what was planned: three activities out of four (activities 1, 4 and 7) have finished, only activity ten is left. Conversely, the path at the bottom has underperformed and only one and a half activities (100% of activity 3 and 50% of activity 6) are finished as of AT=7.

At this moment it was expected (planned) that the project would have had an EV of 600 monetary units, as the PV anticipated that 6 activities should have been finished at AT=7. However, whichever six activities is not something that the EV metric differentiates. Let us observe in Figure 2 the evolution of the PV, AC and EV metrics since this project started.

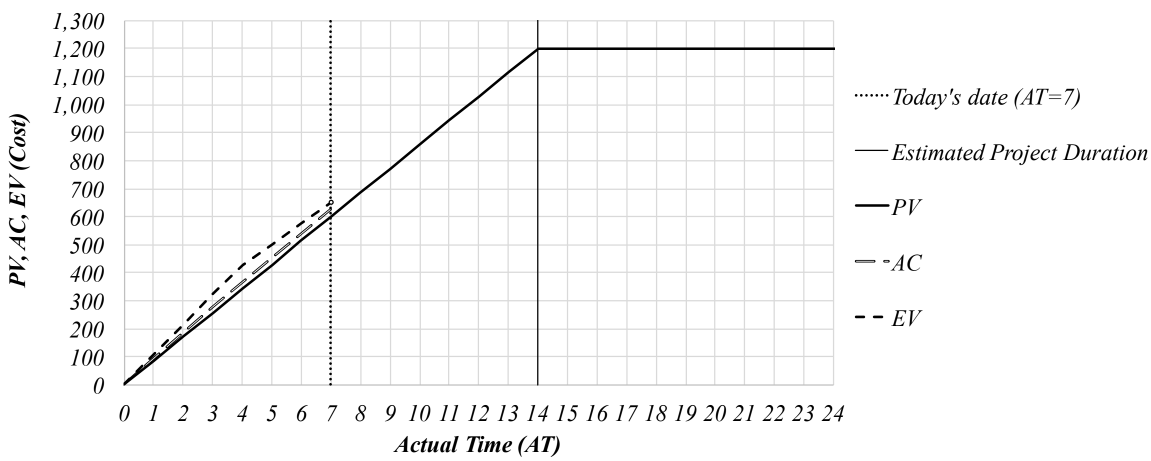


Figure 2. EVM metrics representation for the fictitious project at AT=7.

Undeniably, the EV curve remains on top of the AC and the PV curves. This project, in theory, is doing great: it is ahead of schedule and it cheaper (details of all calculations can be found in the Appendix). But the 'real' situation is not that favorable. If the project duration is estimated by Monte Carlo (MC) simulations as in Figure 3 at two moments: just before the project started (AT=0) and now (AT=7), both say that, on average, this project is not going to last 14 days, but much longer (around 17 and 16.5 days, respectively). What has happened then?

First, the PV network could not account for the effect of the merge event bias (Ballesteros-Pérez 2017a). The merge event bias is the phenomenon by which when two or more parallel activities with variable (uncertain) durations converge into a single one cause (on average) an extra local delay before the single successor can start. This delay is the consequence of computing the maxima of multiple duration probability distributions, unlike the average, which is the common operation when activities are in series (Ballesteros-Pérez 2017b). Therefore, from the very beginning this project was not going to last 14 days on average, but 17. At AT=7, the project progress has actually outperformed the expectations (the probabilistic duration curve is actually slightly located to the left compared to the curve at AT=0), but, when there are several paths, we just need one to underperform (fall behind) in order to cause a project delay (not meet the initial completion date). From the statistical point of view, irrespective of how many activities each parallel path has, it is likely that, as the number of parallel paths increases, there will be at least one which will not progress as planned.

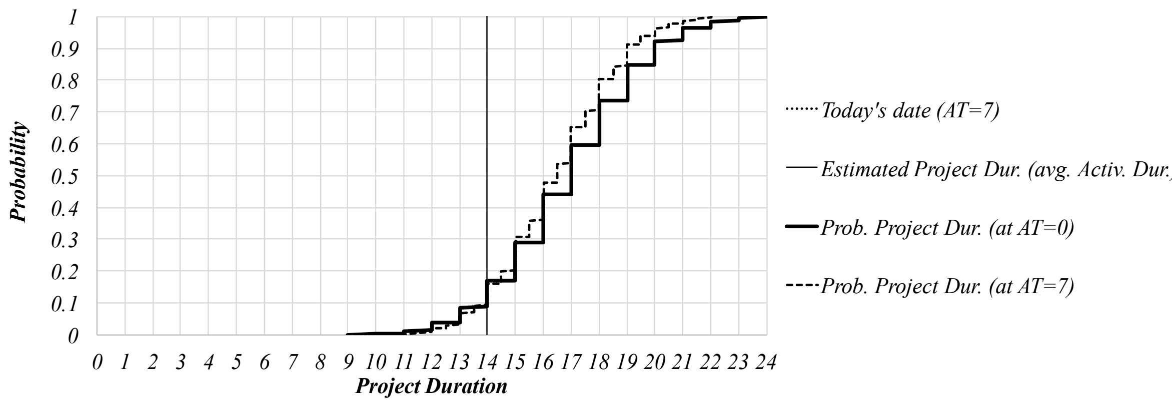


Figure 3. Project duration estimation for the fictitious project at AT=0 and AT=7.

Initially, this does not seem to be a problem: during the first stages of any project execution, there are plenty of activities to carry out. Actually, during the initial stages of a project, most paths are opening. This is mathematically obvious: for any series of paths to converge, first, those paths should have been opened (branched out from other activities). But later, the project progresses and the paths start to converge and, as the merge event bias effect prescribes, delays keep cumulating at each converging node, and finally translated to the overall project duration. That is why many projects do not seem to experience a delay initially (during the stages in which paths opening are the majority against paths converging), and then, all of a sudden the PM starts losing track of them gradually and they end irremediably late. At that advanced stage, hardly anything can be done by the PM when the project is already late as, normally, resources are not that transferable and/or activities cannot be crashed beyond certain limits (Ballesteros-Pérez 2017b). Therefore, no signs of alert came from the EVM technique on time.

## 3 DISCUSSION

A smart way of addressing this situation might have been then, to simulate multiple times the possible planned expenditure by MC simulations for example, that is, the potential PV or EV curve, as they represent the same here. Then take the average of all those curves so that we can have a representative 'average' PV curve against which the future EV curve can be fairly compared (the AC curve does not have any bias, therefore ignored from now on). These curves have been named 'Average EV simulations' and 'Median EV simulations' in Figure 4, but, they could have also been named 'Average PV simulations' and 'Median PV simulations'.

The results are quite surprising in two ways. First, near the end, both the average and the median EV curves remain below the commonly assumed (average, and straight in this case) PV line because of the merge event bias. The most representative curve is actually the median, as that is the curve that reaches the PV of 1,200 monetary units at day 17 (when half of the project simulations have finished the project). The average EV curve will not reach the cost of 1,200 until all the simulations have finished the project, that is, with just one project simulation unfinished, the average will not reach 1,200. This means that the average EV curve is not a good alternative for the PV as theoretically the average will always be an asymptote of the BAC.

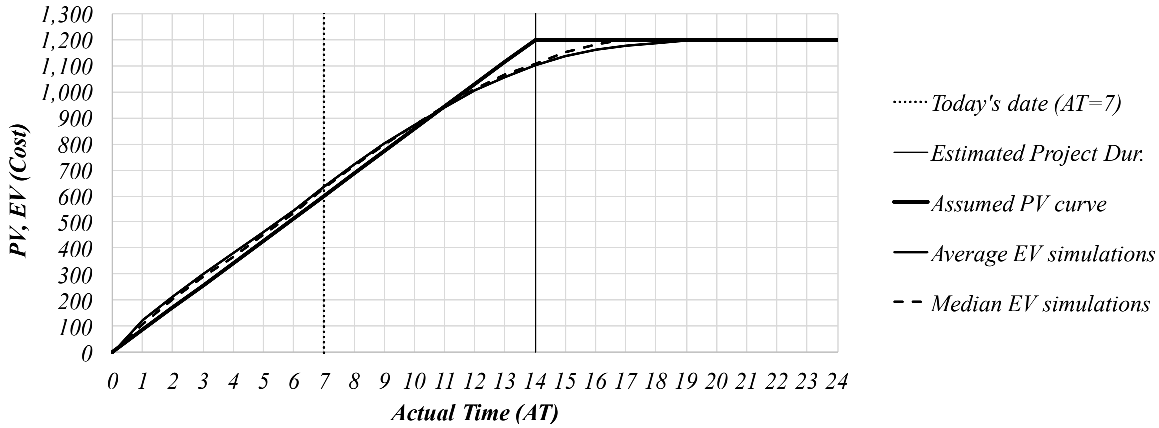


Figure 4. ‘Commonly assumed’ PV versus the ‘actual’ average and median EV.

Second, both the average and the median EV curves, are initially ‘above’ the ‘assumed PV curve’. This means that, at initial stages, the EVM technique is going to make the scheduler think that the, despite the progress might be just ‘average’, it is doing better than expected (planned) by comparing to the wrong ‘commonly assumed’ PV line. Only later (at AT=11 in this project) both curves will move ‘below’ the ‘commonly assumed’ PV curve and the project will be late. This happens whenever there are more than two parallel paths (virtually in any real project).

Therefore, the EVM technique is, at least as it is conceived nowadays, dangerously misleading concerning its time dimension: it will frequently make the project manager believe that everything might be going well initially, but later, probabilistically speaking, the project will still have high chances experiencing delays when it is too late to correct. What is worse, this flaw cannot be corrected by just simply adopting a ‘median EV simulation’-like curve instead of the straight PV curve as in Figure 4. This is because, as it was stated initially, the EVM only measures ‘amount of work’ without differentiating whether the activities performed so far have been the ones that will keep the optimum (shorter) sequence of project execution (duration).

## 4 CONCLUSIONS

The major limitations of the EVM technique have been highlighted. This technique is used by many Project Managers around the world and it is one of the most referenced project monitoring and control tool by core Project Management guides (e.g. PMBoK, IPMA competence Baseline, APMBoK). However, without exception, by neglecting activity duration variability and the merge event bias, project duration monitoring tasks with this technique are significantly optimistic in presence of multiple parallel paths. Furthermore, even in cases with no activity duration variability, EVM could still provide misleading interpretations about the project progress. This as EVM measures ‘amount of work performed’ without considering if that work has been performed in the right order of execution.

The influence of this unaccounted duration variability is different for each industry, though. The manufacturing industry, in general, tend to work indoors (lower climate influence), with semi-repetitive products (higher opportunity of learning from the past), with relatively stable project teams and clients. This might limit the activity duration variability and, hence, cause a lower impact of the optimistic biases described here. On the other side of the spectrum, the construction industry needs to deliver projects with more variable conditions (works are carried out mostly outdoors, projects are generally unique, constant changes in project team is the norm, different project locations, etc). It may not be that surprising then, that construction projects have traditionally been one of the sectors suffering more from missing the original completion dates.

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## Appendix. EVM calculations

Summary of EVM metrics calculations at AT=7 with PV=600, AC=625 and EV=650:

$SV = EV - PV = 50 > 0$ $SPI = EV / PV = 1.08 > 1$ → Project ahead of schedule (Wrong!)

$CV = EV - AC = 25 > 0$ $CPI = EV / AC = 1.04 > 1$ → Project with cost underrun (Correct)

Metric calculations with Earned Schedule at AT=7 with ES=7.58:

$SV(t) = ES - AT = 0.58 > 0$ $SPI(t) = ES / AT = 1.08 > 1$ →Project ahead of schedule (Wrong!)

Calculations with p-factor at AT=7 with p=0.93, $EV(e)_{min}=EV \cdot p=604.5$ and $ES_{EV(e)}=7.05$:

$SV = EV(e)_{min} - PV = 4.5 > 0$ $SPI = EV(e)_{min} / PV = 1.01 > 1$ → Ahead of schedule (Wrong!)

$SV(t) = ES_{EV(e)} - AT = 0.05 > 0$ $SPI(t) = ES_{EV(e)} / AT = 1.01 > 1$ → Ahead of schedule (Wrong!)

Calculations of all the Time Forecasting indicators (EAC(t) either with PV, ED or ES would also give optimistic Project Durations (<14) since all the variances and performance indicators are above 0 and 1, respectively.

Calculations of all the Cost Forecasting indicators (EAC) will be accurate only if the Performance Factor (PF) used is the CPI, otherwise (PF=SPI, SPI(t), SCI or SCI(t)) it will be not.

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