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Analysis of Project Performance of a Real Case Study and Assessment of Earned Value and Earned Schedule Techniques for the Prediction of Project Completion Date

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Abstract
The management of a project, especially in the construction industry, is without doubt a subject of high interest, demanding and complex and in the same time challenging and exciting. In the line process of planning-supervision-control, the last element enables the manager to determine the deviation range of actual practice from the original planning. Developing a construction schedule for a complex viaduct using the software MS Project 2007, and tracking the progress with real dates and durations, the results of Earned Value (EV) and Earned Schedule (ES) techniques are assessed regarding the duration forecasting accuracy schedule performance of a late finish project. The schedule includes complex interrelations, logistics in relation to the effective management of construction equipment and unforeseen events during the construction process. Three different scenarios are examined, from the construction of the whole bridge to a single structural element in order to assess the effectiveness of the methods, their sensitivity to re-baselining, and the contribution of critical tasks to the end result.

Keywords
Construction Management, Earned Value, Earned Schedule, Microsoft Project, Egnatia Odos AE

1. Introduction

In project management, it is vital to have adequate means of obtaining information about the progress of a project against a baseline and the anticipated outcome of the project. The information are required to (1) assure managers that the project is progressing within acceptable budget, schedule and quality expectations; (2) support decisions to approve the movement of the project through its stages, and (3) confirm subjective assessments that benefits will be realised. A project has traditionally been viewed as successful if it was completed on time, within budget and with the specified quality. More recent views of project management consider a project successful if it came in within its original schedule and its expected cost, but also if it still works after the implementation as suggested by Mahaney and Lederer (2008) with a particular relevance to construction projects. EV systems, being a standard method of measuring project performance, have been setup to deal with the complex task of controlling and adjusting the baseline project schedule during execution, taking into account project scope, timed delivery, and total project budget. Vanhoucke and Vanvoorde (2006) state that although EV systems have been proven to provide reliable estimates for the follow-up of cost performance within certain project assumptions, it often fails to predict the total duration of the project. Although there are barriers to having an estimating formula for predicting final project duration from EVM data, it remains a desired capability. Project managers (PM) need the ability to generate reasonable estimates of the duration. Furthermore, they need to be able to estimate a revised completion date at every reporting period without having to exhaustingly evaluate the tasks remaining each time. That is, to manage cost and schedule equally well, PMs need comparable analysis capability for both (Lipke and Henderson, 2006). Earned Value Method (EVM) has not been as successful in assessing schedule performance. After a project is about two-thirds complete, EVM schedule performance metrics become unreliable, as EV invariably converges on PV. Another question frequently asked is how the project managers handle the effects of re-baselining in making their forecasts. Lipke (2008) states that in the research it was discovered that there is a little discussion of the topic, in even the best EVM reference books.

Lipke in 2003 proposed the concept of 'Earned Schedule" (ES) to address these issues. Rather than just looking at schedule performance using the value of work, earned schedule also looks at when the work was to be completed. ES aims to measure schedule performance using a time-based measure from which time based measures of Schedule Variance (SV(t)) and Schedule Performance Index (SPI (t)) metrics are derived. The ES concept is claimed to be analogous to EV and can be used to calculate measures intended to be analogous to EVMs cost based counterparts. Small scale research mainly focused on IT or high technology projects has occurred throughout the evolution of ES. Although lack of testing is a drawback, the risk associated with ES usage is minimal. Henderson (2003) suggests that one compelling point supporting ES is that, regardless of the circumstances of the application (who, project type, company, country), the findings from all sources are consistent. The ES method, in every application, outperforms other EVM-based methods for representing schedule performance.

The purpose of the paper is to examine the capability of the methods to represent the schedule performance effectively in a late construction project with inherent complexities and unforeseen events. It is also to test the capabilities of the methods to adequately forecast the final duration. The analysis includes three parts. First, we compare the classic earned value performance indicators SV and SPI with the newly developed ES performance indicators SV(t) and SPI(t) and their forecasting accuracy, during the assessment of the overall viaduct construction schedule. Next, we present the comparable findings when a re-baselining takes place at an early stage of the project. Finally, we illustrate the use of each method on lower-WBS level where the majority of activities are part of the critical path of the project. The methodological approach is outlined in detail and results are presented in tables and graphs. The conclusion is that the ES concept has validity. The ES based schedule metrics more accurately portray a project's schedule performance compared to the EVM equivalents.

2. Project monitoring tools, EVM vs. ES

Earned Value Management (EVM) uniquely connects cost, schedule, and requirements thereby allowing for the creation of numerical project performance indicators and enable to managers to express the cost and technical performance of their project in an integrated and understandable way to employees, superiors and customers. EVM has three measures: Planned Value (PV), Actual Cost (AC), and

Earned Value (EV). The planned values of the tasks comprising the project are summed for the periodic times (e.g., weekly or monthly) chosen to status project performance. The time-phased representation of the planned value is the Performance Management Baseline (PMB). AC and EV are accrued and are likewise associated with the reporting periods. For each measure, the time-phased graphs are characteristically seen to be "S-curves". From the three measures, project performance indicators are formed. The schedule indicators are: SV = EV - PV, and SPI = EV / PV, where SV is the schedule variance and SPI is the schedule performance index. The fact that PV equals BAC at the planned completion point and does not change when a project runs late causes the schedule indicators to falsely portray actual performance. In fact, it is commonly observed that the schedule indicators begin this behavior when the project is approximately 65% complete (Lipke, 2008). The irregular behavior of the schedule indicators causes problems for project managers. At some point it becomes obvious when the SV and SPI indicators have lost their management value. From this time of uncertainty until project completion, the manager cannot rely on the schedule indicators portion of EVM. For all of the accomplishments of EVM in expressing and analyzing cost performance, it has not been as successful for schedule performance. The EVM schedule indicators are, contrary to expectation, reported in units of cost rather than time. Beyond this problem, there is the much more serious issue: the EVM schedule indicators fail for projects executing beyond the planned completion date.

The technique to resolve the problem of the EVM schedule indicators is Earned Schedule (ES). The ES idea is simple: identify the time at which the amount of earned value (EV) accrued should have been earned (Lipke, 2003). By determining this time, time-based indicators can be formed to provide schedule variance and performance efficiency management information. Projecting the cumulative EV onto the PV curve (i.e., the PMB), determines where PV equals the EV accrued. This intersection point identifies the time that amount of EV should have been earned in accordance with the schedule. The vertical line from the point on the PMB to the time axis determines the "earned" portion of the schedule. The duration from the beginning of the project to the intersection of the time axis is the amount of Earned Schedule (ES). With ES determined, time based indicators can be formed. It is now possible to compare where the project is time-wise with where it should be in accordance with the PMB. Actual time (AT) is the duration at which the EV accrued is recorded. The time-based indicators are easily formulated from the two measures, ES and AT. Schedule Variance becomes SV(t) = ES - AT, and Schedule Performance Index is SPI(t) = ES / AT. The computed value of ES describes where the project should be in its schedule performance.

3. The project

Egnatia Odos, part of the Trans-European Road Network and one of the 14 priority projects of the EU, is a modern 680km highway, stretching from one side of Greece to the other. Being one of the few Greek highways to be designed and built to full up-to-date national and modern international specifications has been described as Europe's most difficult and modern motorway. The case study used in this paper is related to the construction of complex viaduct is part of the significant structural content of a 37km section 720m€ from Panagia to Grevena in the western part of the motorway, crossing a mountainous area with complex geology and severe environmental constraints.

4. The case study of a bridge construction and the monitoring of the construction schedule

This bridge carries the road over the deep valley of a river (Figure 1). At the southern end of the valley the carriageway splits into two separate viaducts, the lengths of which are different due to the prevailing topography. The structure consists of twin segmental box girder viaducts, with integral piers varying in height from 29m to 70m. The ground conditions are variable with visible fractures in the rock slope formations. The overall length is 636.20m and 531.10m for the eastbound and westbound structures respectively. The isolated site, with its steep 70m-deep valley, required a bridge solution driven more by construction method than anything else, which is why a balanced cantilever bridge was chosen. Similarly, the position of the river Venetikos in relation to the steep valley slope resulted in spans up to 120m.

Fig 1: View of the viaduct

4.1 Time Schedule Details

In a bridge of such size and complexity, overall time is mainly determined from the construction equipment (machinery, cranes, and formworks) which is available on the construction site and obviously not all activities start simultaneously. Thus in addition to the scheduling of works for the construction of foundations and pier walls, critical activities for the completion of the bridge are the available number of formwork for the construction of pierhead and cantilevers, and effective use and transfer from pier to pier. A WBS established to make such a complex project more manageable and is formed in such a way to help breakedown the project into manageable chunks that can be effectively estimated and supervised. The analysis followed the determination of deliverables with a four level breakdown structure. Resources include the detailed quantites of all the items of the bridge construction (concrete, reinforcing steel, prestresssing steel, earthworks, accessories) in accordance with the design provisions and tender documents. The overall cost of the bridge is estimated at 19.6 m€. The start date of the construction was the 27th of May 2005, with a planned duration of 129wks. The schedule is characterized by slow early progress, followed by a significant acceleration following completion of about 10% of works. The actual duration was 145.2 wks.

4.2 Particular aspects of construction

There are several factors affected the schedule performance. Some of them were unforeseen events others required re-work of several activities. However most or all of them are common in the construction projects. Variations in the initially assumed geotechnical conditions, under-skilled personnel in demanding activities, late supply and management of equipment, bad concreting and a fire incident are the main aspects influenced the schedule performance.

4.3 Analysis and results

For the analysis of the overall bridge construction schedule, nine control periods were determined taking into account the percentage completion of works and main events along the timeline of the project. In Table 1, the control dates are presented along with the corresponding items.

Control period	1	2	3	4	5	6	7	8	9
Wk. No.	10	19	37	45	76	89	106	123	141
Compl.%	1	3	7	11	34	44	66	84	96

Table 1: Data related to the control periods of the schedule

Based on the activities progress and completion dates, the curves of Earned Value (EV) and Planned Value (PV) against cost are prepared at each control period, followed by the accumulation of all the results representing the overall schedule performance as illustrated in Fig 2.

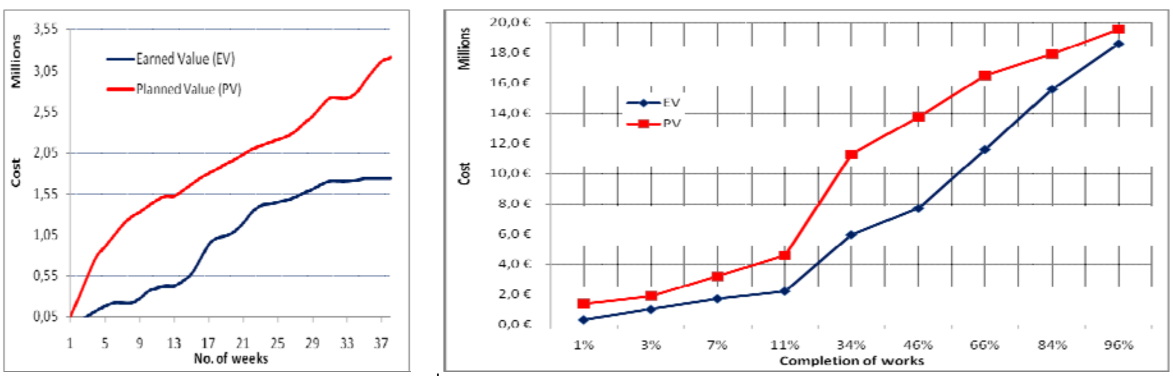

Fig 2: PV, EV curves for the 3rd control period and the overall schedule

Following the principles and techniques of the methodologies presented in the precedence paragraphs, the main duration metrics and indices are calculated with both methods. EV metrics are obtained directly from MS-Project where ES values are processed manually. Fig 3(a), portrays the forecasting performance of the two methods, along with the actual duration (in black) and the Critical Path(CP) analysis (in red) for comparison. It is apparent that Earned Schedule converges faster towards the actual duration but without any remarkable results. It is also clear that CP forecast, continuously underestimates the actual duration. The schedule performance is illustrated in Fig 3(b), where SPI for both methods is plotted against the percentage of work performed. It is clear, from a value of as low as 0.2, that there is a late start and slow progress at the beginning up to approximately 1/3 of the work completed, which clearly indicates a problematic project. The tendency of the SPI(c) to reach a value of 1.0 is clearly noted even though the project is late and exceeded the original contractual deadline, and that occurs at about 66% completion, that is when 2/3 of the project is effectively complete.

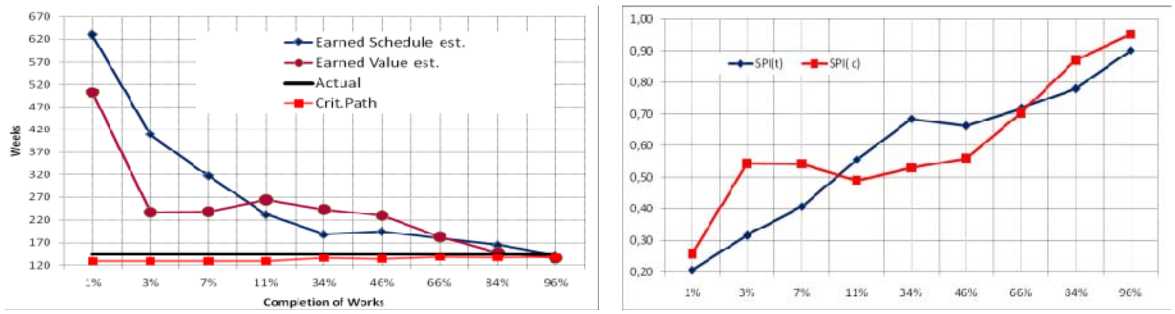

Fig 3 : (a)Comparison of forecasting accuracy and (b)Schedule Performance Index

A second analysis includes the assessment of the two methods during re-baselining. During this process a revised baseline is set, which purposely involves the BCWS of the 3rd control period since it corresponds to approximately 10% of work completion. A recalculation of EV and ES metrics is carried out in order to assess the forecasting result, having recovered the project form a late start. In Fig 4, the revised baseline (in red) is plotted against the original PV (in brown) and the EV curve (in green).

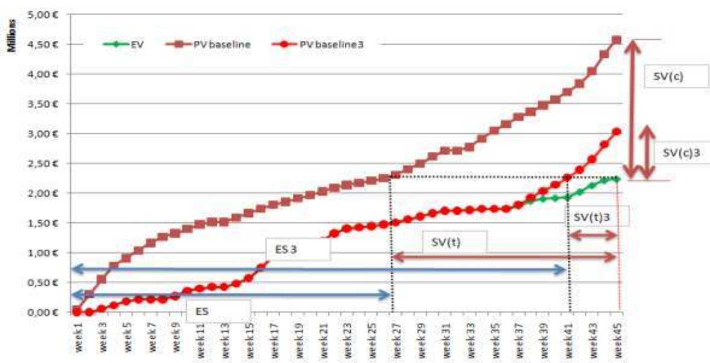

Fig 4 : Re-Baselining and ES,EV metrics

The values from the analysis and the revised indices are shown in Table 2. It is remarkable how the schedule performance index is improved, with values of 0.7 and 0.9 for EV and ES analyses respectively comparing with original corresponding values of 0.49 and 0.56. What is to be noted is that the forecasting made with ES is 144.7wks is remarkably close to the actual duration of 145.2wks, whereas EV suggests a value of 189wks.

EV & ES Metrics	Original Baseline	New Baseline
BCWP, EV(€)	2.239.983,37	2.239.983,37
BCWS, PV(€)	4.582.255,75	3.034.095,15
SV(c) (€)	- 2.342.272,38	- 794.111,78
SPI(c)	0,489	0,7
ES	25,01	40,11
SV(t), (wks)	-19,99	-4,89
SPI(t)	0,56	0,89
Forecasting with ES	232,08	**144,72**
Forecasting with EV	263,80	184,29
Actual	**145,2**	**145,2**

Table 2 : Data of ES and EV extracted from re-baselining

A third analysis included the schedule performance of a single structural element which includes the foundation and column of the pier, the pier table and the cantilevers. The pier selected, has all its activities along the critical path of the project. The control periods are now coinciding with the full completion of a structural section or activity. The schedule consists of 64 activities with a small and controllable duration. The planned duration was 48.2 weeks. Thirteen control periods were set from the start date to 100% completion of the cantilevers. Fig 5, illustrates the schedule performance and the project duration forecasting. It is stated that the planned work should have been completed at 62% completion. It is very clear from the first diagram that SPI(c) tends to increase at 2/3 completion in order to receive eventually the value of 1.0, thus not accurately representing the schedule performance. On the contrary SPI(t) follows a smoother trend, with a better representation of the performance reaching a value of 0.8. Very good convergence is shown by ES after the 43rd week which corresponds to the 50% completion at a SPI(t) value of around 0.6. On the contrary convergence using EV is reached after the 80% completion of works. Almost accurate is the CP but that is explained from the fact that all activities are in critical path therefore the software provides almost the exact duration throughout the schedule.

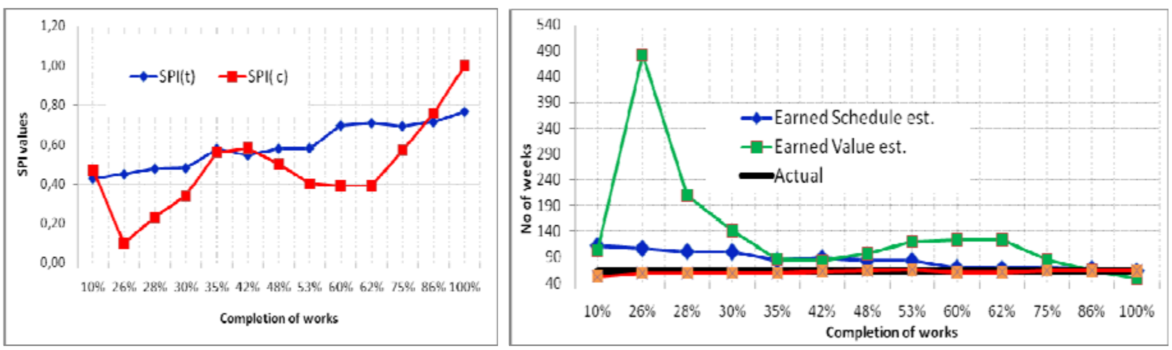

Fig. 5 : Schedule performance and forecasting accuracy

5. Summary and conclusions

Highway construction projects are quite uncertain in nature and often are late, exceeding original budget. Although responsibilities of parties and causes of such events are interesting to explore further in a contractual framework, for a client who needs to prioritize work and effectively manage European funding within strict deadlines, the ability to forecast the end date of a project and have progress indicators early in the course of construction and at least before the 2/3 of the duration, is of vital importance. Testing the performance of the techniques on an actual construction project was a challenge as it allows easy comparisons of the forecasting ability and performance indicators analytically obtained, with real values. In this paper, we presented an application of the EV and ES methodologies, as specific-duration methods, using EV metrics and evaluate them on real-life construction project data extracted from a complex viaduct in Egnatia Odos highway, using MS-Project. The three analyses carried out reveal the superiority of the ES method showing reliable results during the whole project duration, confirming conclusions previously published in literature related to the weakness of the EV method to produce reliable duration forecasting even at 50% project completion. The ES method seems to provide valid and reliable results along the project's lifespan. The value of the paper to practicing professionals can be summarized in the following items:

1. It demonstrates the application of the two methods on a late construction project with variations and unforeseen events, having the actual data of the schedule as planned, the actual progress and the actual finish date.
2. The methods are tested with three scenarios including a re-baselining of the schedule and a group of activities along the critical path, giving a very good insight of how the methods are performing in each case in terms of forecasting the duration and progress indicators and compared with the real case.
3. It helps the reader and potential user of a tracking method, to get an appreciation of the use of the techniques for particular cases and how the indices resulting from the methods should be read, their reliability during the 2/3 duration of the project and how these can be assessed and combined to obtain a good idea of how the schedule is performing leading to an optimum decision to recover from a possible disaster.

As a conclusion, the use of EVM or the ES method depending on the need and knowledge of the project manager might lead to similar results for project monitoring in the early and occasionally in middle stages. However this statement can be misleading if a re-baselining is applied at early project stages, and that needs to be handled very carefully. In general, the EV metrics shall be set-up as early warning signals to detect potential problems in an easy and efficient way. Our forecasting results and the assessment of schedule performance on the three cases demonstrate that reliable early warning signals are obvious. We refer to Cooper (2003) stating that the use of EVM 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. Therefore further investigation is necessary to this research topic and more data is necessary for assessment and comparison when a complex project also subject to a vast amount of rework cycles.

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