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Earned Value-Based Performance Monitoring of Facility Construction Projects

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1. Introduction

The primary purpose of managing a facility construction project is to complete it on time and within the budget while conforming established requirements and specifications (Pewdum *et al*., 2009). To achieve that objective, substantial effort on managing the construction process must be provided and could not be done without an effective performance monitoring system. Performance measurement is a basic requirement for tracking cost, time, and quality of a facility construction project (Yang et al., 2010). No matter how perfect the construction project plan is, if no regular and timely reviews are performed during the project execution, neither the project progress nor the effectiveness of the plan can be evaluated (Cleland, 2007). Project monitoring allows to determine what has happened and to foresee what may happen in the future if previous performance behaviour is expected to continue and if there are no changes in the management of the project. These are primary objectives set towards the monitoring system.

Generally, there are three performance drivers that any project team tries to keep on track: cost, time and scope of work (Cleland, 2007). Managing these three metrics within expected intervals allows keeping the desirable level of quality of a construction project. Performance monitoring allows a project team to track these project triple constraints in a timely manner. Monitoring is a recurring action to compare actual versus planned performance, to determine cost and time estimates at completion, and, if necessary, to take preventive and corrective actions based on such estimates (De Marco, 2011). Important components for establishing an effective monitoring system are a detailed work breakdown structure at the planning phase, appropriate relevant performance monitoring metrics, and an accurate performance forecasting system. Any late corrections to the planned baseline, such as changing work scope and revising the schedule, are often ineffective and can cause cost overrun and considerable delay. Thus, the later the corrective action, the less the ability of influencing the

project cost and time.

Most concerns arise with regard to the choice of a valid performance monitoring methodology. In fact, most facility construction projects are tracked using only planned cost and actual cost measures (Fleming and Koppelman, 2003). Accordingly, this approach does not count for the value of work accomplished thus ignoring a third dimension: the earned value of work (Fleming and Koppelman, 2003). What is missing from most of these analyses is an understanding of how much work has been earned during the project execution and its integration with cost and time (Al-Jobouri, 2003). A method of thoroughly quantifying the technical performance of the project and integrating it with cost and time is Earned Value Management (EVM). EVM is a powerful quantitative technique for objectively monitoring the physical project progress. It enables measuring actual work performance and associated cost and time versus an agreed plan (PMI, 2005). Thus, timely and targeted feedback signals project managers about problems early and make corrections that can keep a project on time and on budget. Any project with considerable cost overrun and schedule delay typically gets in trouble at its beginning, and unfortunately, project managers does not realize this problem until late in the project when their ability to recover the project to achieve its planned objectives diminishes (Alvarado *et al.*, 2004). However, project managers should perform the objective cost and time estimates based on anticipated progress reporting, which is of great importance to project success. According to the Project Management Institute (PMI) (2005), EVM has proven itself to be one of the most effective performance measurement and feedback tools for managing projects and enabling managers to close the loop in the plan-do-check-act project management cycle. One of its distinctive features is an easy integration of a project's cost, schedule and scope metrics into a single performance measurement system. Today, an increasing level of globalization and cross-industry collaboration in the project management environment requires a great need for current EVM application in many sectors. Earned Value (EV) practice has been greatly experienced mostly in defence, energy, product

and software development projects. However, little practice has been achieved in applying the EVM technique in the construction industry and related projects. The construction industry is still lagging behind other industries and has difficulties in adequately adapting the approach that can help project managers to undertake more objective and effective control actions with integrated information related to future performance predictions and uncertainty (Narbaev and De Marco, 2011). In the literature, the understanding of the reasons of such poor diffusion of EVM usage in the context of the European construction industry is still an open and quite new subject and there is a lack of papers to encourage field utilization by construction professionals and practitioners.

The purpose of this paper is to help overcoming the literature lack and to contribute to the dissemination of the EVM methodology within the European construction industry and to demonstrate its applicability and viability through a case study application in a facility renovation project in Italy. This attempt shows that the proposed performance monitoring technique is adaptable from other industries to medium sized construction projects in Europe.

This paper is organized as follows. The next section is a brief review of EVM background together with some basic concepts of the methodology. Then, EVM application in the European construction industry is presented. Later, a case study of an Italian construction project is provided to demonstrate the applicability and viability of the proposed methodology. Finally, we discuss the main results of the study and draw practical conclusions together with limitations and future research directions.

2. Earned value management background

2.1. Evolution of Earned Value Management

EVM originated late in the 1960s as a financial management tool to control defense acquisition projects. Project control specifications were defined by the US Department of Defense (DoD) to correct projects' deviations through cost and schedule accounting and

reporting. These criteria were then finalized into the American National Standards Institute/Electronic Industries Alliance Standard 748, Earned Value Management Systems (ANSI/EIA-748) (Abba, 2001). During the 1980s the methodology emerged as a project management tool and was available also to other industries across the US. In 1999, the PMI established its first College of Performance Management, today the premier professional organisation for EVM research and project planning and control, and included the methodology in its *standards* (PMI, 2008). Consequently, the technique got across other countries and many industries.

The uniqueness of the method is that it provides accurate cost performance and progress measurement data for project monitoring and control. Scientific studies by Christensen (1993; 1998; 1999; 2002) and his associates prove that an accurate cost performance index (CPI) recorded at the 15 to 20 percent completion point are reliable enough for predicting the final cost within a range of no more than 10 percent. And the significance of this method is that it shows an "early warning" signal at the 20 percent completion point. However, despite significant adoption in energy and oil construction projects, the methodology is still not universally accepted by all construction practitioners. Some of difficulties faced by EV practitioners in implementing the tool are a need for a detailed plan and schedule before the project starts, reliable and honestly reporting of measurement, and hardness on measuring physical actual progress of construction activities. Specific drawbacks of the technique inherent with construction projects are discussed later in the paper.

Despite such claims that EVM is too difficult to use and primarily applies to large projects, today the methodology is becoming challenging and recognized as a valuable and effective performance monitoring practice in various types of projects, and of any size and risk. Thus, the crucial principle is a proper choice of EVM form with an appropriate selection of its criteria tailored to the needs of project control and monitoring. In 1995 the defense departments of Australia, Canada, and the US joined and created the International

Performance Management Council to facilitate mutual development in the EVM field (Bower, 2007). Today, Australia and Canada have already adopted this technique by establishing the US-similar EV criteria and industry standards both in defense and private sectors. Also, Japan joined the EVM community through its Ministry of Construction (Abba, 2001; Song, 2010). Among European countries, the U.K. and Sweden experience the largest reported application of EVM techniques.

2.2. Earned value analysis fundamentals

The key practice of EVM includes two steps: first, establishing a Performance Measurement Baseline (PMB) and, second, measuring and analyzing a project's performance against the PMB. Steps to effectively build a PMB includes decomposition of work scope to a manageable level, assigning responsibilities, developing a time-phased budget for each work task, and maintaining PMB integrity throughout the project. Performance measurement and analysis comprises recording resource usage during the project execution, objectively measuring the actual physical work progress, analyzing and forecasting cost/schedule performance, reporting performance problems, and taking corrective actions (PMI, 2011).

EVM relies on three key variables which represent fundamentals of its analysis: Budgeted Cost of Work Scheduled (BCWS), Budgeted Cost of Work Performed (BCWP), which is also referred to as Earned Value (EV), and Actual Cost of Work Performed (ACWP). The fourth data point is the Budget at Completion (BAC): it represents the total BCWS for the project. The four data points are used for deriving variances of actual versus budgeted performance and associated indices, and for forecasting a project's cost and time at completion. The PMB is the standard against which the project actual cost (ACWP) and progress (BCWP) is compared from start to finish.

The difference between a PMB and the actual status is measured by using two variances revised continuously throughout the project life. The variances give precise monetary values of positive

or negative status. Cost Variance (CV) is a measure of the budgetary conformance of actual cost of work performed: CV = BCWP – ACWP; while Schedule Variance (SV) is the difference between BCWP and BCWS. Positive values of these variances indicate under budget and ahead of schedule respectively while negative – over budget and behind schedule respectively.

Indices, instead, do not give a precise monetary value of a project actual status, but are used as indicators of actual performance. They are merely ratio expressions of CV and SV such as the Cost Performance Index (CPI = BCWP/ACWP) indicating how efficiently a project team is using its resources, and the Schedule Performance Index (SPI = BCWP/BCWS) indicating how efficiently the team is using its time. In the above formulae, 1.00 indicates that performance is on target; more than 1.00 indicates excellent, and less than 1.00 indicates inefficient performance. Overall, both the variances and indices are measures of past behaviour and, if no corrective actions are undertaken, are used to predict the project final cost and time (CII, 2004).

2.3. Forecasting cost and time at completion

Predicting the expected final project cost – Cost Estimate at Completion (CEAC) – and the time to finish the project – Time Estimate at Completion (TEAC) – is essential to project on-target completion. Fundamental and crucial metrics introduced earlier in the study are used to predict CEAC and TEAC by extrapolating actual project progress to the end of the project. The PMI (2011) provides two commonly used formulae to determine CEAC and TEAC which are coherent to the planned budget (BAC) and duration (D). To consider project past behaviour and actual performance the original values are corrected by the corresponding performance indices, as given in Equations 1 and 2.

$$CEAC = ACWP + (BAC-BCWP)/CPI = BAC/CPI \quad (1)$$

$$TEAC = (BAC/SPI)/(BAC/D) = D/SPI \quad (2)$$

Though universally accepted as a benchmark for cost and time estimates at completion these two fundamental formulae have been largely reviewed and criticized with regard to CPI accuracy and SV and SPI reliability respectively.

The CPI accuracy problem has been studied by applying methodological statistical testing and its findings can be generalized as follows: first, the final CV will be worse than the CV at the 20 percent completion point; second, the CPI does not change by more than 0.10 from its value at 20 percent completion point, and in most cases it only worsens; and lastly, CEAC estimated using this CPI is a reasonable lower bound to the final cost (Christensen, 1993; 1999). These findings resulted in Equation 3.

$$CEAC = BAC/(CPI_{@20\%} \pm 0.10) \quad (3)$$

The problem with schedule relates not only to TEAC itself, but also to its determinants: SV and SPI. In general, EVM method has one mental hurdle: defining these schedule indicators not in units of time but in units of currency, e.g. euro. EVM is not directly connected to schedule; as far as these schedule indicators are in units of currency there is no way to evaluate the project progress thus leading to false conclusions with regard to schedule performance assessment. This lack of EVM can be seen, for instance, when there are some activities that may be accomplished out of sequence. Some activities which have less value but critical can be behind schedule while more costly tasks are completed ahead of schedule (Lipke, 2005; Russell, 2008). Thus both measures are entirely associated with cost performance only and no time constraint is taken into account as it relates to the execution of a project in a chronological sequence (Howes, 2000).

The other inherent defect to schedule assessment is that as far as a project progresses to its end the SV tends to 0 and the SPI to 1 even if the project behind schedule meaning the project is on time without delay even if there is a delay. At some point to a project completion both SV and SPI lose their management value: in most projects regardless nature and structure this is after a project 2/3 complete. Obviously, these indicators are only useful as

early as when a project is from 15-20 percent complete until 60-70 percent.

Thus, to overcome these two weaknesses an extension to the EVM theory, named Earned Schedule (ES) was created by Lipke (2003); today the methodology is regarded as an emerging practice in the field of EVM. The ES method is based on two new variables: Actual Time (AT) and Earned Schedule (ES). Here, ES is determined by comparing BCWP to BCWS, and the value of ES is determined by projecting BCWP at a certain point in time (AT) to BCWS curve which represents ES: a point in time when the current BCWP should actually have been achieved. This point can be before or after AT depending on whether a project is ahead or behind schedule. Then, the technique renames the two traditional SV and SPI into SV($) and SPI($) that is clearly in units of currency and introduces the two time-based metrics: the Schedule Variance expressed in units of time (SV(t)) that is the difference between ES and AT, and the Schedule Performance Index (SPI(t)) as the ratio of ES to AT. The uniqueness of the ES concept is that both SV(t) and SPI(t) behave suitably reasonable throughout the project life. Respectively, ES and TEAC(t) are defined as per Equations 4 and 5.

$$ES = C + (BCWP(\$) - BCWS(t))/(BCWS(t+1) - BCWS(t)) \quad (4)$$

where: C is the number of whole time increments of the PMB for which BCWP $\geq$ BCWS.

$$TEAC(t) = (BAC/SPI(t))/(BAC/D) = D/SPI(t) \quad (5)$$

The main EVM and ES metrics introduced above are represented in Figure 1 exposing a standard condition of a construction project: over budget and behind schedule. Here, CV reveals that unfavourable condition is defined because ACWP to date (AT) far exceeds BCWP, and SV($) shows that less work has been accomplished than planned in terms on units of currency while SV(t) expressed in units of time.

Figure 1. Earned Value and Earned Schedule metrics.

Hence, a specific purpose of this paper is to demonstrate how these techniques can be used to predict cost and time estimates at completion in construction projects with a special focus on

a case-study application in an industrial facility renovation project. This should serve as a contribution to the dissemination of the usefulness and applicability of EVM and ES in the context of the European construction industry.

3. Standards and application of EVM in the European construction industry

3.1. Specific concerns for EVM application in construction projects

Even though EVM may be widely appreciated as an established, proven and valuable project management technique, it has not been experiencing wide implementation by project managers and fast diffusion in the construction industry (Bower, 2007). This challenge can be explained as affected to some extents by several aspects mainly inherent with the nature of facility construction projects, cost and benefits of EVM usage, problems of selection of the EVM model, and requirements that should be met for successful implementation.

A comparison with defence projects might help in the task of understanding why EVM and ES are not diffused in construction. The nature of a project can be viewed in its size and length, contract type and delivery methods, a network structure, work scope changes and reworks. Government-funded DoD projects are large sized (averaged to several billion dollars) with several years to execute. Consequently, risks associated with all possible consequences such as possible scope changes and reworks, more parallel activities, manpower utilization issue in development of the project are considered in delivering the project. For such projects that are of state security importance, the objective is to accomplish the project on time and less attention is drawn to cost overruns. Therefore, the government shoulders the risks to successfully execute a defense project (Workman, 2006). Obviously, all these considerations make it possible to achieving the project execution through cost-reimbursable contracts only.

A very different approach applies to facility construction projects, which have much lower budgets and durations, are characterized by traditional late rework and late scope changes, more serial activities, substantial material weight in budget. All these issues create different risk

sharing options to both contractors and owners. Late rework, scope changes, and re-baselining make cost accrual late into the project execution. Thus, the cumulative cost curve line, which accounts for more material and subcontractors' costs and, therefore, less manpower in then product/software development projects, is characterized for its early low pace and late high speed.

Also, the traditional construction contract payment scheme is a lump-sum fixed price or unit price and not an open-book cost-reimbursable form of payment, such as transparent incentivising cost plus fee schemes, which are better systems for EV application (Bryde and Joby, 2007).

Another concern for EVM application in facility construction projects is the cost and complication of EVM application. According to Christensen's (1998) analysis, with regard to the DoD projects, on six studies related to cost of EVM implementation over 1970's through 1990's this cost ranges from 0.1 to 5.0 percent of total project cost. The EVM analysis and reporting are regarded as too detailed, repetitive, and voluminous undermining project performance by diverting project manager's time and attention. But delivering defense projects through cost-reimbursable contracts was not hardened with these obstacles where its benefits far exceed the costs. No study was reported with regard to quantitative analysis of cost issue of EVM in construction projects, but an increasing number of EVM adopters in the construction industry demonstrate that the technique is more beneficial than its costs. Moreover, increasing complexity in construction projects and associated risks require from parties involved more objective and transparent performance monitoring and forecasting approach than subjective reporting, which EVM perfectly outperforms. The main cornerstone here is an optimal selection of EVM criteria and establishing a form of EVM model tailored to the needs of a construction company. The proper selection can be made from different widely used EVM practice standards: (PMI, 2011), ANSI/IEA-748 (the US National Defense Industrial Association), DoD's C/SCSC (the US DoD), and similar EVM guides for the U.K.,

Australia, and Canada (Song, 2010).

Fleming and Koppelman (2002) state that the construction industry uses parts of EVM as any other industry, but in the industry the practitioners rarely use the term “Earned Value” and do not realize that they are in fact applying a simple form of EV. Construction managers first establish baseline plans and when their project starts they monitor the project performance against the established baseline; this is exactly the same as EVM method does. The starting point is to get three main variables of EVM and to transfer these measures into the EVM language. Already agreed project baseline curve represents nothing else but BCWS – BAC of the project, ACWP comes from invoices, and physical progress helps to find EV (BCWP) simply multiplying BCWS to actual percent complete of the WBS items. This does not mean that the method can easily be applied; traditionally, a sound project accounting and a network schedule management are needed as prerequisites to successfully implement EVM and achieve benefits.

3.2. EVM trends in the European construction industry

The reasons for the low level of acceptance of EVM in the European construction industry are a quite new open issue. In addition to the various industry-specific and project-inherent cited motivations, and the need to better understand the benefits of EMV (Fleming and Koppelman, 2004), we also highlight three factors associated with the cultural and academic environment (of primary concern to the authors and most of the readers of this journal) that might have an influence on usage diffusion. First, despite a vast methodological literature, few studies have been targeted to investigate the EVM practice in Europe so that there is a shortage of recorded applications in European construction projects and the availability of reported best practices and case studies in both scholarly and trade literature is limited (Buyse and Vandenbussche, 2010; Marshall, 2008).

Second, there is a reduced availability of research or interest groups specifically focused on

spreading the EV management methodology and proving its benefits. Some most qualified worldwide associations, such as the PMI, the International Project Management Association, and the Association for Project Management have been starting specific programs towards this direction. For instance, the PMI European chapters advocate the methodology together with the PMI College of Performance Management and we can see an emerging tight collaboration between those US based organisations and European counterparts.

Third, except the U.K. and some northern Europe countries (e.g.: Sweden), EVM suffers from the lack of established European standards enforced by governments or practice guides adopted by national trade associations in most European countries.

4. Case study and data analysis

In the next sections it is shown how EV and ES methods discussed above can be used to analyse a project performance and progress indicators, and forecast cost and time estimates at completion on the case study of a project to renovate an industrial facility in Turin, Italy

4.1. Case study and basic requirements for EV performance monitoring organisation

The demonstration project is selected because it experienced a Project Manager with necessary capabilities and maturity in EVM, an owner and general contractor with high commitment in implementing EVM, and direct involvement of the authors as consultant to the engineering company.

The selected case is a project to renovate a section of an industrial facility, with the construction volume of a 50,000 square-meter portion of a former manufacturing plant layout with two aside service lane buildings. The facility has modular steel structures that represent typical repetitive steel framing. The turn-key work involves all construction and architectural activities, including all plumbing, electrical and HVAC systems. The project with BAC of 21.4 million euro is to start on July 1, 2007 and finish on January 5, 2008 with a scheduled duration of 189 calendar days. The contract is awarded to a general contractor based on a

traditional design-bid-build delivery system and a fixed price lump-sum payment scheme is selected with monthly progress reported payments. The engineering company produces the basic and detailed engineering design and acts as a construction manager thus performing project control and monitoring.

The scope of work consists of more than 1,200 activities and to monitor the cost reporting and scheduling the project is delivered by developing a 4-level work breakdown structure. To avoid problems with overwhelming number of work items and to appropriately decompose the WBS an effective work progress measurement system should be achieved (CII, 2004). Thus, the construction activities are developed based on the specificity and scope of the work item. The on/off measurement approach is chosen to compute the finished work element and it is registered as 100 percent if the item is substantially completed.

In summary, the following three basic requirements are established in order to implement an effective EVM system as discussed so far in the paper: firstly, a scope of work is decomposed so as to get to a progress measurable level of detail; secondly, appropriate simple progress measurement technique is chosen (the “on/off” approach); and, thirdly, the weighted summation of individual bottom elements up to the top level of the WBS is defined to compute the whole project progress.

4.2. The project EV analysis and estimates at completion

Based on the established monthly performance monitoring reports, the project management team calculates the three main EV variables, cost and time variances and indices along with cost and time estimates at completion.

Calculations related to cost using the EV analysis are summarized in Table 1. Both cost and time estimates are performed when the project is 20percent complete which is end of September 2007 review period. According to Christensen (1993; 1999), the CPI stabilises when the construction project is 20 percent complete and worsens as far as the project tends

to its finish. By the end of the project the CPI tends to unity as adjustments are typically undertaken for improving the remaining construction activities.

Table 1. Earned Value variables and cost estimation.

At this time interval CEAC is also calculated and serves as a benchmark for future cost estimates. In fact, when the BAC is 20.76 percent complete and the ACWP is worth 21.32 percent of the original budget, a 2.02 percent cost overrun is determined to project completion, as per Equation 1. Note that the CEAC is only reliable when the project is 20 percent complete when the CPI stabilizes. By using Equation 3 the CEAC ranges from 93.13 to 114.15 percent of the BAC. These values are considered as the lower and upper bound cost estimates.

Likewise, at the end of September, the EV, ES analysis and time estimates are computed using Equations 2, 4, and 5. The TEAC using SPI($) is not reliable because of the index defect to calculate late project estimates. ES value are calculated using Equation 4 and confusions may arise with regard of determining its values in first and last reporting periods: in first reporting period the value of C from Equation 4 equals zero and in the last reporting period the value of ES is equal to planned duration that is 6.16 months (189 calendar days). To overcome the SPI($) bias the ES concept is used and the TEAC in September is a reliable estimate: 214-days forecast versus 212-days actual duration measured at the end of the project (Table 2).

Table 2. Earned Schedule variables and time estimation.

Overall, Table 3 illustrates the EV analysis in comparison with the ES computations. This case demonstrates that cost and time estimates can reliably be forecasted as early as when a project is 20 percent complete.

Table 3. Comparison between EV and ES estimates and final actual cost and duration.

The case study also proves that time estimates based on ES concepts gives a better indication of the total duration of the project at completion because it allows overcoming the SPI bias.

5. Conclusions

This work explores the EVM theory and practice and has to be considered as a contribution to the dissemination of EVM application in the European construction industry.

To this end, first the study recalls the evolution of EVM and describes the utility and advantages of its main analysis and forecasting concepts.

Then, the challenges of an effective EVM implementation and difficulties in applying it to facility construction projects are presented together with differences from projects in other industries Also, the level of adoption of the methodology from the European construction industry is discussed.

Finally, the viability and applicability of the EVM method is presented via a demonstration field application. In particular, a case study shows a simple application of EVM to an industrial construction project and proves that forecasting can be predicted as early as when a project is 20 percent complete.

This paper and the ensuing simulation suggests the following characteristics and advantages should be legitimated among construction professionals to sustain adoption and diffusion of the EVM practice, namely its applicability to facility construction projects of any size and complexity; adaptability from other industries with a more mature level of implementation; ability to predict performance and to integrate cost, schedule and scope in a single methodology.

Further research is encouraged to assist the dissemination process through studies within single European countries, reporting of extended field applications, and establishment of shared standards.

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