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INTEGRATING QUALITY INTO EARNED VALUE MANAGEMENT

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Abstract: The Earned Value Management (EVM) is the most commonly used system in construction projects all over the world to integrate both time and cost controls of a project. However, numerous researchers have identified gaps and limitations to using this method. The most agreed-upon limitation in using the EVM, is that it does not incorporate the quality aspect of a project, although it is one of the main drivers of success in any project. As a result, this study was conducted as a contribution to efforts in this field with the aim of identifying a proper way to integrate quality, time and cost using the EVM. A framework was developed to assess the quality of a project by the means of proposed equations and formulae that hopefully will aid project managers and responsible parties in a project in having a broader vision of the project's performance in terms of time, cost and quality. Furthermore, a case study from an actual construction project was analysed to verify and validate the framework, and the results were in favour of using the framework rather than the conventional EVM calculations.

1 Introduction

Earned value management (EVM) is a project management and control technique that offers the project manager a tool to timely evaluate the general health of a project along the life of the project by integrating the project scope with the schedule and cost (PMI, 2008). It was initially introduced in the early 60's as a financial analysis speciality, but later became a fundamental component of project and cost management (DSMC, 1997).

EVM was initially adopted by the U.S. Department of Defense (DoD) to standardize its processes for the evaluation of project performance. Since then, the EVM has gained more reputation and acceptance and has shifted into a best-practice tool, which project managers in all sectors and industries could use (Fleming and Koppelman, 2010).

The use of EVM expanded beyond the U.S. Department of Defense as the National Aeronautics and Space Administration, United States Department of Energy and other technology-related agencies adopted it. Many industrialized nations also began to utilize EVM in their own procurement programs.

An overview of EVM was included in the Project Management Institute's first PMBOK Guide in 1987 and was expanded in subsequent editions. In the most recent edition of the PMBOK guide, EVM is listed among the general tools and techniques for processes to control project costs (PMI, 2013).

The construction industry was an early commercial adopter of EVM. Closer integration of EVM with the practice of project management accelerated in the 1990s. In 1999, the Performance Management Association merged with the Project Management Institute (PMI) to become PMI's first college, the College of Performance Management. The United States Office of Management and Budget began to mandate the use of EVM across all government agencies, and, for the first time, for certain internally managed projects.

Valle and Soares (2006) listed the key benefits of EVM as follows: (1) integrated cost, progress and time management; (2) better view of the project in terms of scope and procurement; (3) early warning to issues and problems and foreseeability of project divergence trends; (4) decreased time to notice and understand problems and find solutions; (5) support for negotiations and the decision making process; and (6) the encouragement of people to implement the project control process.

On the other hand, some limitations associated with EVM have been identified in literature and various improvements have been implemented to overcome the identified shortcomings in the earned value practice.

Regarding the precision of the EV method; Cost Variance (CV), Cost Performance Index (CPI), Schedule Variance (SV), and Schedule Performance Index (SPI) are in the center of attention. In theory, the zero value for SV means that the activity is completed or is performed according to the initial plan of the project, making it impossible to distinguish between completed or ongoing activities. Also, schedule performance at the end or completion of the project is equal to one, whether the project is behind or ahead of schedule. These performance index values also evaluate the end date and the final budget of a project considering a very slight variation after certain percentage of progress in a project without considering the effect of delay (Lennon and Francis, 2010). Moreover, EVM metrics do not illustrate the time remaining to finish the project or the exact time when the desirable EV is requested, as they are based on currency units. According to Coiffi (2006), PV is an S-curve because of the parallel activities in the life cycle of a project while in practice it is considered to be linear.

Vanhoucke and Vandevoorde (2007) mentioned that faster progress in non-critical activities and small delays in critical activities may lead to inaccurate result of various forecasting methods and a false SPI value. They also indicated that higher degree of critically in project activities leads to higher accuracy in forecasting, in comparison with parallel activities. On the other hand, SV and SPI are also incapable of distinguishing between critical and non-critical activities. For instance, SV and SPI might show that the project is completed based on critical activities, while non-critical activities are behind the schedule. Concurrently, this issue has negative impact on forecasting the status of project at completion too (Forecast project Duration= (Planned original Duration/SPI)). Moselhi (2011) developed a model which is based on the Critical C-BCWS and C-BCWP and their Adjustment Factors (AF). It was recommended “to use only critical activities in generating project baseline and subsequently in generating Schedule variances and indices in order to forecast project duration” (Moselhi, 2011).

Another method named, Periodic Delays Process (PDP) was developed by Lennon and Francis (2010) to calculate the SPI and SV in terms of duration that are based on critical activities. The proposed method, consider the impact of delays on the total duration of project and calculate the SPI base on the project duration plus accumulated delays. The proposed method consisted of 6 steps to calculate the SPI at the actual monitoring date that is equal to (SPIi= 1- (The portion of attributable delay over / actual duration) at monitoring period of i). The actual duration based on Lennon and Francis model is measured using PERT to estimate the most likely probable duration, and then reviewing each ongoing activity by considering the most likely, pessimistic and optimistic duration for that activity. Next, they identified all ongoing critical activities in each point of monitoring time (i) and checked for (Total Float=0, Actual Start date less than Monitoring date and Revised Finish date bigger than Monitoring date). The proportion of delay at each actual monitoring time (Rx) for each ongoing critical activity is also calculated by subtracting the maximum delay attributable to monitoring date (i) from maximum delay attributable to monitoring date (i-1) (Lennon and Francis, 2010).

Walt Lipke developed a method named the Earned Schedule in 2003 to solve the previously mentioned problems related to SV and SPI. This method uses time instead of cost to measure schedule performance, as it was believed that SPI metrics might serve managers with unreliable time forecast at the end of the project (Lipke, 2003). Later on, Jacob and Kane (2004) mentioned that SPI and SPIt should be used on the activity level in order to be more reliable (lowest hierarchy of Work Breakdown Structure (WBS)) not on the control account level or any higher level of WBS. However, Vanhouche (2011) believed that if a project contains many critical activities, using a higher level of hierarchy in measurement of project performance is acceptable (Chen and Zhang, 2012). “Earned Sschedule (ES) can be calculated by crossing a horizontal line from the current cumulative Earned Value (EV) to the Planned Value (PV) curve, the intersection of this line with the PV curve is the ES. Thus, ES is the point in time when the current earned value was to be accomplished and the point at which the project PV is supposed to be equal to the current EV" (Ghorbani, 2017).

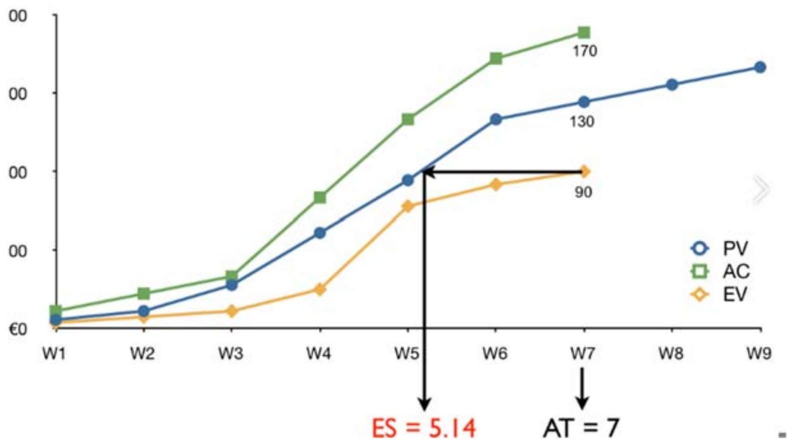

Figure 1 ES Method Illustration (Ghorbani, 2017)

Moreover, according to the Department of Defense of United State (DOD), EVM indexes are stable after 20% progress in the project. However, CPI can experience instability and variation as a result of the different activities performances, which leads to inaccurate estimation of EAC=(BAC/CPI). Where EAC is the Estimate at Completion, BAC is the Budget at Completion and CPI is the Cost Performance Index. In other words, EVM considers the variation of each cost account to be independent while the CPI of each independent activity is dependent on other activities when the output of first activity can become the input of next activity. Therefore, the workflow of activities is not stable and due to instability of CPI, BAC is also no longer valid. "Christensen (1996) mentioned that the cumulative CPI-based cost estimate at completion is closer to estimate of contractors and managers and the most accurate estimation gain from the average EAC based on the cumulative CR" (Chen and Zhang, 2012). The equation below illustrates the average of stability in CPI, which challenges the state of DOD (According to Souza and Rocha (2015), in average the CPI becomes stable after 66 percent progress in projects). "This equation integrate EVM with CPI historical data of processes including gathering CPI historical data of each process with traditional measures of the EVM technique, calculated separately to each process" (Souza and Rocha, 2015).

$$CPI_{Exp} = \frac{EV_{AcumProject} + \sum_{1}^{N}(BAC_{PN} - EV_{AcumPN}) + \sum_{1}^{N} BAC_{PN}}{AC_{AcumProject} + \sum_{1}^{N}(AC_{Expected\,PN} - AC_{AcumPN}) + \sum_{1}^{N}(AC_{Expected\,PN})},$$

Where:

EVAcumProject and ACAcumProject: are the traditional EVAcum and ACAcum of the project, BAC= sum of PV activities of the process, EVAcum and ACAcum are the sum of each EV and AC of each executed activity and ACExpected is the ACcum expected of each process after execution= (BACpn/Historic CPI of PN).

Despite the numerous efforts exerted on researches implemented to improve the schedule and cost aspects of the EVM, some other important factors like quality are disregarded although they are crucial factors affecting the earned value process. Quality along with time and cost are the main three success drivers of any project as the desired target of any construction project is to perform the specified work in the shortest time of construction possible, the lowest cost possible and the highest quality possible. Also, various studies have shown that quality errors are considered a frequently occurring phenomenon in construction sites that lead to costly expenditure to rectify these problems. According to Crosby, the cost of poor quality can be valued at 15-40% of business cost (Crosby, 1979). Also, in a study by Boukamp and Akinci, it was found that 6-15% of the construction cost is wasted due to rework of defective components detected in the construction process which can either be due to human factors like unskilled workers or insufficient supervision of construction work, or due to material or design failures (Boukamp and Akinci, 2007). Moreover, various studies including the study by Solomon and Young (2007) discussed how performance and quality requirements should be integrated to the EVM as these are crucial indicators for the overall success of the project. Nassar et al. (2005) also confirmed the previous study and supported the development of an integrated framework adding various metrics for project evaluation claiming that the schedule and cost should not be considered the only indicators for project's performance.

These observations suggest that an integrated management control technique is required to monitor and control the project progress in the three aforementioned aspects: time, cost and quality. And since the Earned Value Method is globally considered as one of the best integration methods of cost and time of a project, the idea of integrating a quality performance indicator to the EVM came to light to provide a broader view of the overall project performance.

2 Framework Design

2.1 Cost of Quality Definition

There are various approaches to defining Cost of Quality mentioned in literature. The concept of cost of quality was first introduced by Juran (1951) as the "Cost of Poor Quality" which refers to the costs associated with providing poor quality product or service or the amount of money a company loses as a result of having its products or services not done right in the first place. According to Crosby (1979), cost of quality is the "Price of Non-Conformance", while Abdelsalam and Gad (2009) defined it as "Cost of Conformance and Non-Conformance", where conformance cost include the monetary value of education, trainings, testing, inspections, validations and audits. While non-conformance cost include elements like material wastage, rework required and warranty repairs. Feigenbaum (1991) introduced a methodology to calculate cost of quality that is based on a concept he named the "P-A-F" which includes prevention costs, appraisal costs, and failure costs. Nassar (2009) defined the cost of quality that truly impacts a projects performance as the cost of rework required for a certain work item. And Waje and Patil (2015) added to the definition of Nassar that the quality cost includes all the causes of internal failures from rework, scrap or delays.

2.2 Factors' Definitions

The factors proposed as part of the framework presented in this paper is discussed in this section along with their definitions.

CPQ: Cost of Poor Quality – The concept adopted in this paper is the one proposed by Waje and Patil (2015), which states that the main factors to be included in the CPQ are the internal and external failure caused in a construction project as these have the most impact on the project's performance.

CPQ%: Cost of Poor Quality Percentage – The percentage of the CPQ in comparison with the actual cost spent on the work items

SPIq: The effect of poor quality on the Schedule Performance Index of the project.

CPIq: The effect of poor quality on the Cost Performance Index of the project.

QPI: Quality Performance Index – An average score given to the work item based on the corresponding CPQ%. This is adopted from the concept proposed by Nassar (2009) based on the normalization of the CPQ% to get the score given to each work item.

Table 1: QPI Scores based on Normalization of CPQ% (Nassar, 2009)

Condition	Rating	CPQ%	QPI

A	Outstanding Performance	CPQ% <= 0.5	QPI > 1.15
B	Exceeds Target	0.5 < CPQ% <= 1.0	1.15 >= QPI > 1.05
C	Within Target	1.0 < CPQ% <= 2.0	1.05 >= QPI > 0.95
D	Below Target	2.0 < CPQ% <= 4.0	0.95 >= QPI > 0.85
E	Poor Performance	CPQ% > 4.0	QPI <= 0.85

2.3 Proposed Equations

To quantify the previously mentioned factors, a set of equations is proposed as part of this study to be used in the quality integration into EVM.

CPQ = Total Cost of Poor Quality in a Work Item / Project

CPQ% = $\frac{\text{CPQ}}{\text{Total Cost of Work Item / Project}}$

SPIq = CPQ / BCWP

CPIq = CPQ / ACWP

3 Framework Implementation

For the purpose of illustration of the proposed framework, a case study project that was previously studied by Hall and Tomkins (2000) to identify the various errors or defect items included in the cost of quality calculation was chosen for utilization in this paper. The case study is further analyzed in this paper in terms of applying the methodology and calculations of the conventional EVM and the proposed EVMq concept.

3.1 Project Description

The project studied and analyzed in this paper was planned to be a £2.3 million building project undertaken on a design and build basis. The project was an office development of a low technical complexity. The project schedule was greatly emphasized in this project, as the client required the completion of all project works by Christmas period, which meant a total construction period of 38 weeks. However, the lack of schedule flexibility added up to the costs of the project till it reached £2.7 million.

In this paper, the rework and failures in activities are studied to apply the proposed concept of integrating quality into the conventional EVM.

3.2 Conventional EVM Calculations

The conventional EVM calculations and formulae were used on the selected project, and the SV, CV, SPI and CPI were obtained.

Table 2: Monetary Values of Work Planned and Performed and Actual Expenditures in Selected Project

Work Item	BCWS	BCWP	Failures	Additional Costs	ACWP
Preliminaries	332,513	332,513	9,182	73,473	415,168
Demolition	65,121	65,121	403	5451	70,975
Groundworks and Substructure	282,764	282,764	73,764	47,745	404,273

Work Item	BCWS	BCWP	Failures	Additional Costs	ACWP
Frame	215,825	215,825	5,902	19,128	240,855
External Envelope	365,072	365,072	16,280	38,577	419,929
Internal Construction Activities	153,902	153,902	3,601	20,042	177,545
Mechanical and Electrical Installation	207,884	207,884	4,314	17,403	229,601
Roof	134,857	134,857	3,024	18,008	155,889
Finishes	129,094	129,094	11,884	15,311	156,289
External Works	426,542	426,542	6,786	38,163	471,491
Total	2,313,574	2,313,574	135,140	293,301	2,742,015

By applying the EVM calculations to the values in the table above, it was concluded that:

SV = BCWP - BCWS = 0

CV = BCWP - ACWP = £ (428,441)

SPI = BCWP / BCWS = 1

CPI = BCWP / ACWP = 0.84

The SV and SPI showed that the project was completed on time. In this case, it is known for us that this is true because the deadline of Christmas was met, however, in other cases, the SV and SPI can give a false indicator if the project is already completed, it will still show that it was completed on time even if this was not the case. This is one of the main limitations of the EVM.

Regarding the cost performance of the project, it was shown that the performance was less than expected or required and that the project experienced a budget overrun of £428,441.

3.3 Proposed "EVMq" Calculations

We applied the proposed equations on the same project data to analyze the effect of poor quality performance on the project's schedule and cost performance as well as quantify the total project performance with respect to quality.

CPQ = £ 135,140

CPQ% = $\frac{\text{CPQ}}{\text{Total Cost of Work Item / Project}}$ = 4.93%

Since the CPQ% – which represents the ratio between the cost of poor quality including rework and failures in the project and the total project cost – is 4.93%, then the corresponding value for QPI = 0.8 which indicates a "Poor Performance" in regards to quality of work done on project.

SPIq = CPQ / BCWP = 5.84%

This value means that the poor quality affected 5.84% of the schedule performance of the project. If the quality cost was eliminated, the schedule performance is expected to have been better by this value.

CPIq = CPQ / ACWP = 4.93%

This value means that the poor quality affected 4.93% of the cost performance of the project. If the quality cost was eliminated, the cost performance is expected to have been better by this value.

3.4 Overall View of the Project

The following figure was created with the aim of visualizing an overview of the whole project performance in regards to the three main key players in the project: time, cost and quality. The actual values of SPI, CPI and QPI are compared with the baseline values which are assumed to be 1 for the three values if the project is to perform perfectly according to the specified schedule, budget and quality requirements.

According to the figure, it can be viewed that the project performed according to the specified schedule, but the cost performance and quality performance were less than expected or required.

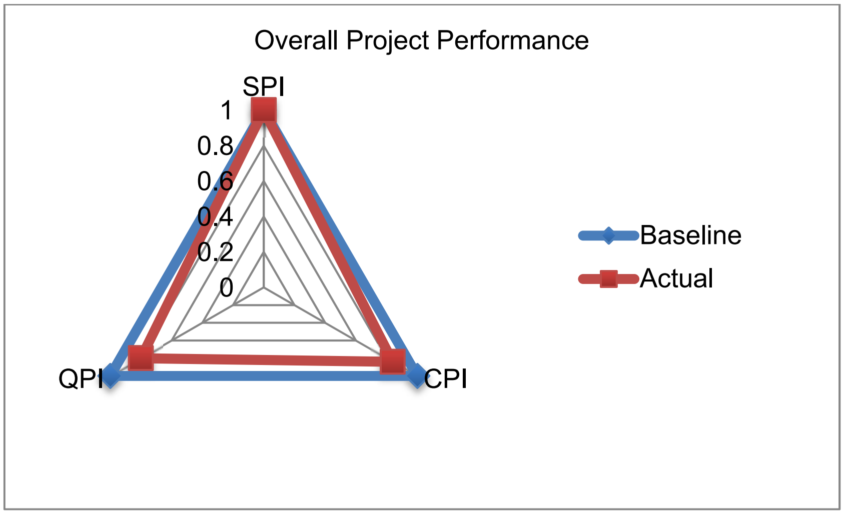

Figure 2: Overall Project Performance

4 Conclusion and Recommendations

Earned value management (EVM) is a method for evaluating projects' performance and progress through integrating the project schedule, and cost. EVM has been widely utilized in various industrial sectors and numerous studies have been conducted on EVM and its application in the industry. In this paper, an extensive literature review was made on the EVM, its applications and functionality. The limitations of the EVM cited in literature were also discussed along with finding solutions proposed by previous researchers to these limitations. The limitations identified were mainly related to schedule and cost performance evaluation issues. One of the key limitations identified in literature was the lack of integration between the EVM and quality performance evaluation in a project, so a framework of quality integration into the EVM method is proposed in this paper that is based on previous researches and findings in the literature of the field. This framework mainly quantifies the cost of poor quality in a project –consisting of internal and external failures- and compares it to the total cost of the work item or project and gives the quality a score based on this percentage. After that, using some proposed equations, the percentage of the schedule affected by poor quality is estimated, as well as the percentage of the cost affected by poor quality. This mainly serves as an overall overview or indicator for the upper management on how well the project is performing or have performed in terms of the three success drivers of the project: time, cost and quality. This is expected to help the management generate a more realistic lessons learned document as well as be able to identify the competitiveness of the labour for better planning of future projects. To further illustrate, elaborate and explain the proposed framework, a case study from a real construction project was studied and both the conventional EVM calculations and the proposed quality-integrated EVM calculations were applied on it to show the difference between both and realize the contribution the proposed framework offers with respect to the overall project performance evaluation.

To further investigate the applicability and reliability of the proposed model, the application of the proposed quality-integrated EVM framework to an ongoing project is recommended to evaluate its applicability in un-completed projects rather than completed projects like the one presented in this paper as well as its application into other disciplines and industries other than construction. It is also encouraged for further researches to utilize the proposed framework from the beginning of a real project and monitor the difference it makes on the performance of the labour in a project after quantifying their poor quality work and the corresponding decisions of the management in the project or in the following projects.

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