Responsible Design and Delivery of the Constructed Project
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RESEARCH TRENDS IN EVM LIMITATIONS AND PROPOSED IMPROVEMENTS

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The earned value method (EVM) is a recognized management technique that is used for monitoring, evaluating, and controlling the progress of projects. The method's employability challenges have consistently been addressed in the literature along with proposed enhancements that aim at improving its application. The overall objective of this paper is to synthesize those limitations reported to be encumbering EVM employability and to examine the main enhancements proposed for the EVM traditional set of metrics. To this effect, this paper initially validates the importance of project controls, as the top factor cited as being critical to the success of projects. Secondly, it presents a classification of the shortcomings reported to be impeding EVM employability, along with their corresponding improvement studies. As such, the paper looks at the temporal distribution of these limitation and improvement research studies, while shedding light on the trend of such interconnected research efforts over the last three decades. As such, the paper presents a synthesis of the improvements found to be affecting the representation, usage and measurements of the EVM set of metrics, with the aim of gaining perceptiveness on how the reported EVM shortcomings may probably be overcome. The findings revealed that the highest frequency of reported improvements (138 in total) was found to be pertaining to the method's set of key parameters.

Keywords: Project controls, Critical success factors, Shortcomings, Enhancements, Metrics.

1 INTRODUCTION

The construction industry is huge, unpredictable, and needs remarkable capital expenditures. However, client satisfaction during project execution is threatened due to cost overrun and/or schedule slippage (Kaliba *et al.* 2009). To this end, successful projects have all common characteristics; they have a well-defined scope of work, achievable schedule, and a realistic budget. Although these characteristics are the core of a successful project, project monitoring and controls is a main critical success factor for construction projects. As such, Naderpoor and Mofid (2011) defined earned value method (EVM) as a recognized project monitoring and controls method that integrates cost, schedule and scope into a unique measurement system.

Although EVM is gaining exceptional significance within the construction industry, many obstacles have hindered its wide employability as a main project monitoring and controls method. To this effect, researchers suggested improvements to EVM, including the introduction of fuzzy indices to compute the percent complete of executed works (Moslemi-Naeni and Salehipour 2011); stochastic S-curves to account for uncertain work environments (Acebes *et al.* 2015);

computerized applications for automating the controls process (Turkan *et al.* 2013); and artificial intelligence to forecast time and cost at-completion figures before the start of the project (Chao and Chien 2009).

2 PROJECT CONTROL AS A CRITICAL SUCCESS FACTOR

The first track of review of existing literature performed by this research tackled the work related to project critical success factors published in the last three decades, precisely intended to pinpoint the significance of effective controls as a main critical success factor (CSF). The adopted studies were searched for using the "Google Scholar", "Science Direct", and "ASCE" databases search engines, using the semantics and keywords-based methods. Consequently, the search led to adopting a total number of 65 relevant studies, allowing the adoption of general headings describing the main factors contributing to success of projects. Figure 1 shows the fifteen adopted headings that were found to have citation frequencies of more than ten in the reviewed studies, shown in a decreasing order of occurrence frequency. As shown in Figure 1, "effective project monitoring and controls methods" is the heading receiving the highest citation frequency of 62, thus emphasizing the significant importance of applying suitable controls processes for achieving project success.

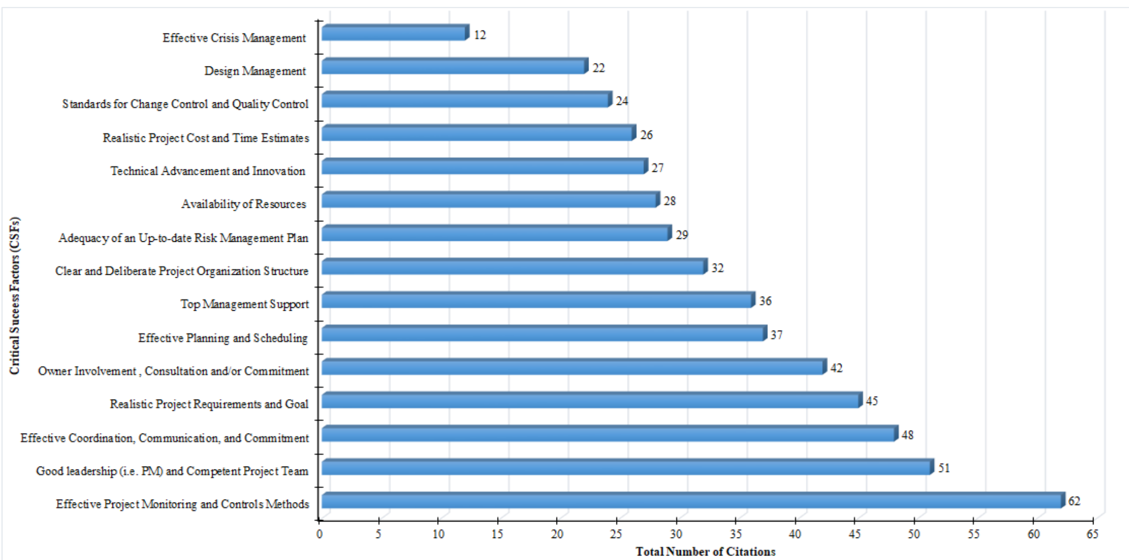

Figure 1. CSFs encountered in the reviewed literature.

3 TEMPORAL DISTRIBUTION OF EVM STUDIES

An in-depth review of the current literature related to project controls and EVM in the last three decades allowed the adoption of two sets of 56 and 230 shortlisted research studies, dealing with EVM shortcomings and proposed improvements, respectively. To this effect, the adopted EVM publications focus on (a) the main difficulties deemed to have prevented the method's applicability and (b) the proposed improvements, with the purpose of attaining a wider future employability. The filtered studies were categorized based on their years of publication, the affected EVM metrics, and the main tracks said to be related to EVM enhancements. Figure 2 shows the frequencies reported in connection with EVM limitations and improvement studies, distributed according to their years of publication. It is important to note here that the shown frequencies represent the findings of the search to date; in other words, those findings represent partial results of the on-going research. The depicted distribution clearly shows that a considerable volume of research work related to EVM limitations has been performed in the beginning of the 21st century. However, it can be safely inferred that the last three years (i.e., 2015-2017) included a substantial number of publications (33 percent) reporting on the main enhancements to the EVM methodology. This shift in the research work trend can be seen as an indication of the potential significance of encountered improvements studies in addressing EVM limitations.

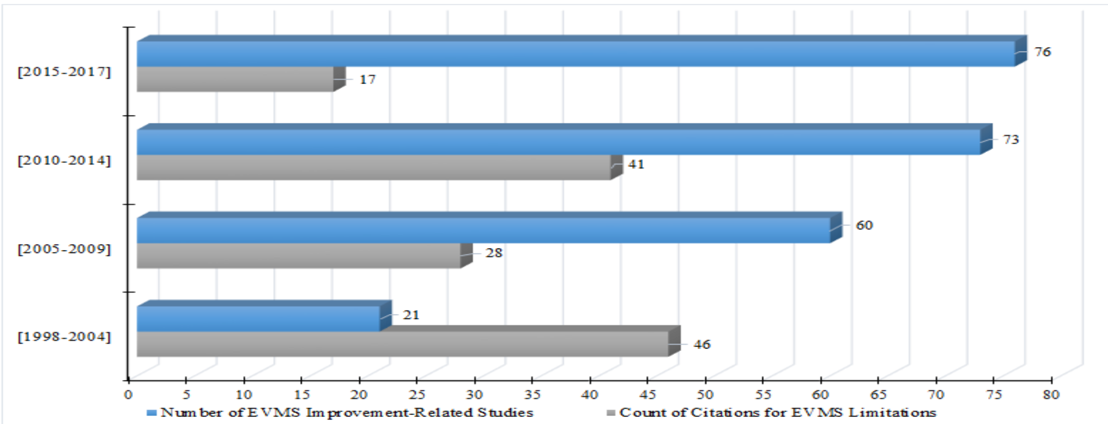

Figure 2. Temporal distribution of research studies.

4 ENCOUNTERED EVM LIMITATIONS

The 56 adopted research studies made reference to various shortcomings said to be limiting the employability of the EVM methodology. An in-depth review of all encountered shortcomings allowed their classification into general headings describing the main obstacles reported to be hindering the applicability of this tool. As such, twelve headings were generated for describing the EVM limitations, as shown in Figure 3. It can be noted that the top two frequencies, 19 and 17, of reported limitations are found to be associated with the accuracy of forecasting metrics and the quality of inputs, respectively.

5 IMPROVEMENT STUDIES

Principally, the application of EVM entails a static reference point, represented by the project baseline schedule and the budget-at-completion, coupled with the process of frequently monitoring and controlling the project performance during execution. Monitoring performance related to time and cost is done by (a) comparing the three pillars of EVM: planned value (PV), actual costs (AC) and earned value (EV), (b) generating cost and schedule variances and performance indexes, and (c) forecasting the expected project at-completion duration and cost.

As such, Figure 4 shows the breakdown of the filtered studies according to the three sets of EVM' metrics, including: key parameters, performance measures, and forecasting parameters. It is found that about 15 percent (36) of the improvement studies do not deal with a specific set of EVM' metrics, and these are classified in the "general category", as shown in Figure 4. Examples include those improvements proposed for tackling human- and process-related EVM shortcomings, such as the introduction of (a) an educational game to support and teach EVM concepts (von Wangenheim *et al.* 2012), (b) web-based database management systems to ease the application of EVM for project controls by generating project status reports (Cheung *et al.* 2004, Li *et al.* 2006), and (c) models to improve the acceptance and performance of EVM (Kim *et al.* 2003).

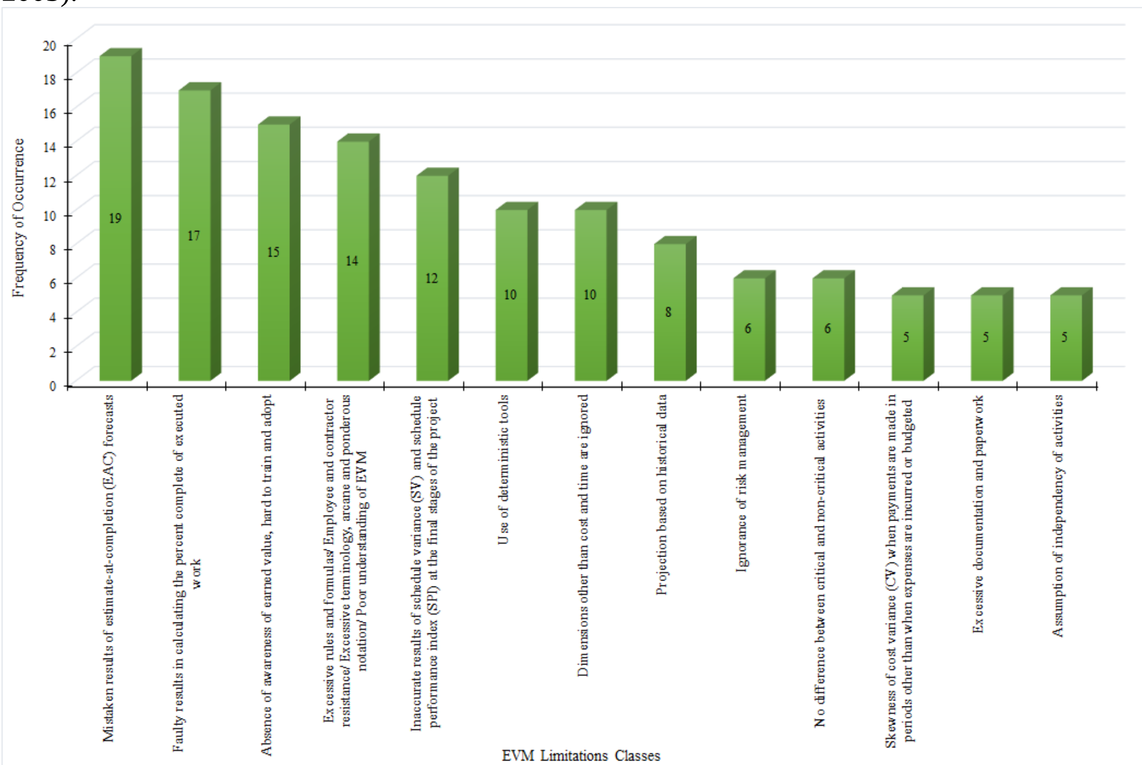

Figure 3. Frequency of reported EVM limitations classes.

Furthermore, it can be inferred that the studies dealing with EVM key parameters contributed to about 60 percent (138) of the reported enhancement studies. To this effect, six out of the 138 studies are mainly concerned with the generation of empirical S-curves in order to provide early estimates for decision-making support; examples of enhancement-related studies included the introduction of the use of neural networks and polynomial functions (Chao and Chien 2009), regression analysis models (Blyth and Kaka 2006) and analytic parametrization (Cioffi 2005). Similarly, six out of the 138 studies were related to the introduction of novel approaches for the generation of construction S-curve used for project controls, by introducing fuzzy S-curves (Ponz-Tienda *et al.* 2012), progress-based S-curves (Barraza *et al.* 2004), and optimal S-curves (Lo 2007). A number of studies (seven) were concerned with the EV/AC prediction before and during project execution, as proactive actions to advance favorable performance outcomes (Chen 2014, Chen *et al.* 2016). Moreover, 111 out of the 138 studies were dealing with the automation of data collection and progress tracking in construction sites for effective calculation of the EV of executed works, aided by information management technologies, such as those by El-Omari and Moselhi (2011), Han *et al.* (2017), and Zhu *et al.* (2017). Likewise, eight studies targeted the calculation of the EV figure by proposing modifications such as the effective EV (Lipke 2004), the quality EV (Dodson *et al.* 2015), and the customer EV (Kim *et al.* 2015), or introducing fuzzy indices to compute the EV in a more vigorous and reliable way (Moslemi-Naeni *et al.* 2011).

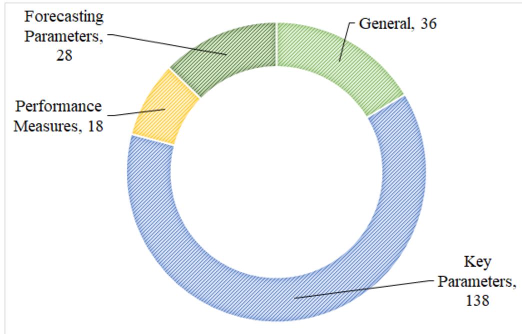

Figure 4. Number of shared improvement studies per affected EVM metrics.

To this effect, improvement studies (18 ones) related to the traditional EVM performance measures (i.e. schedule and cost indicators) have been suggested, examples of which are concerned with improvements introducing: (a) the concept of the "earned schedule" (Lipke 2003) with the purpose of shifting the focus of EVM from cost to time controls; (b) the introduction of the "weight EV" (Zhong and Wang 2011) and "the schedule forecasting indicator" (Czemplik 2014) to differentiate between critical and noncritical activities while performing EVM calculations; and (c) the formulation of a model for probabilistic evaluation of the cost performance stability of individual projects using project-specific information (Kim 2015). Lastly, in relation to the method of forecasting estimate-at-completion figures, 28 studies presented several extensions, including artificial intelligence (Cheng and Roy 2011), fuzzy logic (Moslemi-Naeni *et al.* 2011), and visualization of the performance of a project (Chou *et al.* 2010).

6 CONCLUSIONS AND FUTURE WORK

The research work reported in this paper is concerned with improvement studies aimed at addressing the EVM limitations and widening its applicability as a main project monitoring and controls tool. Thirteen general headings were eventually adopted to describe the deduced EVM limitations, with those related to the quality of inputs (faulty results in calculating the percent complete of executed work) and outputs (mistaken results of estimate-at-completion forecasts) receiving the highest occurrence frequencies of 17 and 19, respectively. To this effect, the paper investigated the distribution of the reported enhancements in the 230 reviewed studies, showing their breakdown over the main EVM sets of metrics: "key parameters", "performance indicators", and "forecasting parameters". The on-going research work by the authors involves a thorough analysis of the reported enhancements, with the aim of developing novel integrated sets of metrics for this control's tool.

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