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An Exploratory Study of EVMS Environment Factors and their Impact on Cost Performance for Construction and Environmental Projects

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Abstract: A high-performing Earned Value Management System (EVMS) can influence project success and help stakeholders meet project objectives. Although EVMS processes are well-supported by technical guidelines and standards, project managers often face challenges related to the project culture, team, resources, and business practices that make up the project environment within which an EVMS is being used. A comprehensive literature review revealed a lack of a data-driven and consistent assessment frameworks that can gauge the environment surrounding EVMS implementation. This paper will discuss the EVMS environment of construction and environmental projects, and examine its impact on cost performance. The authors used a multi-method approach to identify 27 environment factors that make up the EVMS environment, assessing them on 18 construction and environmental projects worth over $2 billion of total cost. Research methods employed include: (1) a literature review of more than 300 references; (2) a survey of 294 respondents; and (3) remote research charrettes with more than 60 participating expert practitioners. Culture (one of the identified environment categories) was found to be relatively more important in terms of its impact on the EVMS environment, followed by people, practices, and resources. These exploratory results show statistically significant differences in cost performance between completed projects with either a good or poor environment, for the sample projects. Key environment factors are outlined, and guidance is provided to practitioners around how to set up an effective EVMS environment in a construction or environmental project to inform decision-making and support achieving the project cost objectives successfully.

Key words: Earned Value Management System, project environment, project performance

1. INTRODUCTION

For over 50 years, the concept of Earned Value Management (EVM), that uses the information produced from EVM System (EVMS), has evolved, and been widely used by industry organizations to manage their projects or programs in diverse industries. EVMS is a systematic approach that integrates project cost, schedule, and scope for effective planning, performance, and management control [1]. However, project managers and decision makers struggle in effectively measuring the progress of projects, accurately forecasting their performance, coordinating the various EVMS sub-processes with each other, and making timely project decisions [2]. Though the reliability of EVMS is largely dependent on compliance with well-established technical standards and guidelines. However, it is important to recognize the success criteria or factors that are also important for a high-performing EVMS beyond the technical system requirements; these factors, in this scope of study, are related to the project culture, team, resources, and business practices that make-up the environment within which an EVMS is used in an integrated project management setting [1]. This integration between the role of the technical standards and the social behavior of the team members is what makes the socio-technical aspect of EVMS [3].

Due to these identified needs and interests, the U.S. Department of Energy formed a research team to assess the EVMS maturity (i.e., technical component), and the EVMS environment (i.e., social component, which is the scope of this paper). As such, this paper focuses on identifying a list of environment factors, and studies their impact on project cost performance. The paper provides background information on the research and a brief literature review, describes the objectives and methodology, presents the EVMS environment factors, discusses results in relevance to cost performance, along with guidance to EVMS practitioners and key stakeholders.

2. BACKGROUND AND LITERATURE REVIEW

2.1. Definitions

The definitions of terms used in this paper are based on a literature review and refined by a research team of 27 industry experts representing 16 owners and 11 contractors from governmental and non-governmental organizations. *EVMS environment* is defined as the "conditions (i.e., people, culture, practices, and resources) that enable or limit the ability to manage the project and program using the EVMS, serving as a basis for timely and effective decision-making." [3]. Consequently, an *EVMS environment factor* is "one of the circumstances, facts, or elements that contributes to the result or outcome of an EVMS" [3]. Moreover, an *EVMS environment category* is a class or division of factors regarded as having shared characteristics, arranged in a topological fashion. In summary, the boundary conditions of the study's EVMS environment are within a scope of a project or a program where project leaders and personnel understand the efficacy of EVMS or project controls. They are engaged in using EVMS to support integrated project management and achieve favorable project outcomes; the leaders represent the contractor organization or the customer organization who use processes, procedures, and key resources that directly impact the outcomes of the project around a certain project culture. The next section discusses the environment factors based on the literature.

2.2. EVMS Environment Factors

The recent literature review by Aramali et al. [3] identified 27 publications, from 2000 until early 2021, addressing examples of environment factors that affect EVMS. These include effective team alignment, leadership support and organizational buy-in, culture, and communication [4-7]. Industry and government practitioners have published a number of articles identifying EVMS environment factors by tracking lessons learned from past experiences [3]. Many have identified the top challenges in achieving a reliable EVMS with some factors related to EVMS environment

[1]. However, there has not been a unified effort to develop a systematic approach that ensures identifying and addressing environment during the life of the project with the intent of improving the EVMS environment. Based on this literature gap and the high practitioner interest in understanding the EVMS environment, a method to assess EVMS environment factors was developed and is discussed in succeeding sections.

3. OBJECTIVES AND METHODOLOGY

The objectives of this study are to (1) identify important EVMS environment factors; (2) rate these EVMS environment factors; and (2) study their impact on project cost performance for real projects in the construction and environmental sectors.

To achieve the objectives of this study, a multi-method approach was followed, including (1) a literature review of more than 300 references, (2) a survey with 294 responses, (3) a number of collaborative research team meetings, (4) four virtual workshops with 47 expert industry practitioners, (5) four industry virtual performance workshops to collect completed project data, and (6) data analysis. All the workshops were planned to take place in person in 2020-2021 (during the COVID-19 pandemic period); subsequently the authors changed the approach and hosted virtual workshops to complete the study successfully. This was possible through following the remote research charrettes method discussed by Gibson et al. [8]. Virtual data collection actually led to more diverse participation and rich data set [8].

The literature review highlighted the gaps on the EVMS environment and helped the authors compose a list of environment factors [2,3]. The authors administered and analyzed a large industry survey to identify the critical factors that impact the EVMS environment in the state of practice [1]. In-person and virtual research team meetings (after Covid restrictions) were conducted with the 27 industry experts to help understand, define, and critique the factors. These steps helped the authors finalize the EVMS environment factors. To further improve the definitions and receive weighting of these factors in terms of the importance on the overall EVMS environment, the authors conducted four virtual workshops where the 47 EVM and project control industry practitioners, averaging 19 years of industry experience, provided the weighting of the different EVMS environment factors and categories [8]. Once the definitions and the weights were complete, the authors hosted four performance remote workshops where 16 unique participants evaluated the 27 environment factors on 18 completed construction and environmental projects. These data were used to analyze the EVMS environment's impact on project performance in terms of cost growth. Finally, guidance to practitioners was provided in how to set-up an effective EVMS environment in construction and environmental projects.

4. EVMS ENVIRONMENT

This section focuses on the EVMS environment factors. A list of 33 environment factors critical to EVMS environment in four categories (Culture, People, Practices, Resources) were initially formed based on the literature, industry survey, and research team meetings.

Through a series of multiple meetings over a period of eight months, the research team agreed on the final details of the environment factors, the assessment structure and a five-point Likert scale to evaluate each factor, ranging from *Not Acceptable* to *Needs Improvement*, *Meets Some*, *Meets Most* and finally *High Performing*. The list of the factors was arranged under one of four categories and each has a sentence describing the factor, along with several sentences giving information about how each factor affects the environment. The authors hosted four virtual workshops to receive feedback on this draft, with participants developing relative weights of the factors based on level of importance. Considering an anchor project as a point of reference, each participant was asked to rank the factors based on their relative importance within each EVMS environment category. Participants were also asked to allocate 100 points across the four categories one versus the other based on level of importance. A more-detailed account of this process, along with details of the development described below, is explained in a research report by the authors [9].

The first two workshops used the list of 33 factors resulting in the first draft of weights and 368 comments. The research team addressed these comments, refined the details, and used the new draft in later workshops. By looking at the normalized weights of the 33 factors, the results showed that 6 environment factors received less than 15% relative weights compared to others. Therefore, the authors, along with input from the research team, merged these relatively less important factors into the existing factors. The new list of 27 edited environment factors was utilized in two additional virtual workshops. Then, the final collected data was used to calculate the final weights of the *High Performing* rating level in the EVMS Environment, normalized from 0 to 1,000 points. For this purpose, the ranks of the environment factors received by the 47 workshop participants were first converted to importance scores. For example, factors ranked first received a score of 5 and so forth. Accordingly, mean scores per factor were calculated. Similarly, mean scores per each environment category were calculated, from the scores received by participants. Then, the scores were screened by boxplots, and thereby outliers and extremes were removed to ensure the data is not skewed. Accordingly, four outlier responses were removed, and the remaining 43 participant responses were used to generate final scores. Next, the weighted averages per factor across all categories were calculated by multiplying the average of the weights for each environment category by relative weight of each factor. They were further normalized over a scale from 0 to 1,000. Finally, the scores for the different rating levels per factor (from *Needs Improvement* to *Meets Most*) were calculated by linear interpolation, with *Not Acceptable* assigned a 0 score. The selection of each rating level leads to a factor score. The scores are published online [9]. For example, if factor 1a was ranked as *High Performing*, it received the associated highest score of 78 (out of 1,000).

In total, 675 comments on the environment factors were also addressed, further clarifying and refining the list of factors. Tables 1 and 2 show abbreviated factor names of the resulting list of 27 environment factors. The factors are arranged in the order of highest relative importance to project success to lowest relative importance, per category based on the results of the workshops. Table 3 shows an example of one of the 27 factors giving a better indication of what the participants used to evaluate their projects.

Table 1. EVMS first and second environment categories and factors

1. Culture (7 factors)	**2. People (6 factors)**
1a. Contractor organization is supportive and committed	2a. Contractor team is experienced and qualified
1b. Culture fosters trust, honesty, transparency, communication, and shared values	2b. Customer team is experienced in understanding and using EVM
1c. Customer organization is supportive and committed	2c. Leadership is defined, effective, and accountable
1d. Timely and transparent decisions	2d. Project/program stakeholder interests are appropriately represented
1e. Leadership effectively manages and controls change	
1f. Effective teamwork exists	2e. Professional education is appropriate
1g. Alignment and cohesion exist among key team members	2f. Team members are co-located and/or accessible

Table 2. EVMS third and fourth environment categories and factors

3. Practices (8 factors)	4. Resources (6 factors)
3a. Project promotes and follows standard practices	4a. Adequate technology/software and tools are integrated and used
3b. EVMS requirements definition is in place, and agreement exists	4b. Sufficient funding is committed for implementing and executing the EVMS.
3c. Roles and responsibilities are defined, and well-understood	4c. Team is adequate in size and composition
3d. Communication is open and effective	4d. Sufficient calendar time and work-hours are committed and available
3e. Effective oversight is in place and used	4e. Data are readily available
3f. Contractual terms and conditions are known and have been addressed	4f. Project utilizes an appropriate periodic cycle
3g. Subject Matter Expert (SME) input is adequate	
3h. Coordination exists between key disciplines	

Table 3. Example environment factor

Full factor name	Description
4e. Data are readily available to populate EVMS tools supporting analyses for decision-making.	Data are readily available and accessible in a consistent and timely manner according to the business rhythm. It should be shared effectively and efficiently, and support analyses to properly manage the project/program. These data are current, accurate, complete, repeatable, auditable, and contextualized to aid understanding which leads to effective, timely, and informed decision-making at all levels. Data also meet applicable EVM reporting requirements, such as file type, format, and so on.

Results from the survey and team discussions revealed that culture is the top category. This aligns with a recent study that showed that culture is a significant mediator between efficient leadership and project team performance [10].

Four facilitated remote workshops were conducted to help EVMS practitioners in rating the environment factors on their projects. Briefly, the method consisted of evaluating a completed project retroactively at 20 percent project completion. This project lifecycle point was confirmed by the research team and the literature review, to be the most suitable benchmarking point for comparison among the studied projects [11]. The authors administered a Qualtrics survey where each participant was able to rate the 27 factors individually to the best of their knowledge as applied on their projects. The scores were summed up to a total EVMS environment score of the project between 0 and 1,000. The authors received performance information and background information from 18 completed construction and environmental projects and analyzed the data accordingly as reported in the next sections.

5. IMPACT OF EVMS ENVIRONMENT ON COST PERFORMANCE

The next subsections provide the details of the collected data and report a cost analysis of the completed projects considering EVMS environment.

5.1. Environment Scores

In total, data from 18 completed construction and environmental projects were collected, totaling approximately $2 billion in final project costs with an average of 43 months in final project duration. The construction sample projects include construction of buildings, underground facilities, and substations. The environmental sample projects include nuclear and hazardous waste cleanup projects. The plot of Figure 1 shows the environment assessment scores of the 18 projects, representing an environment score for each project.

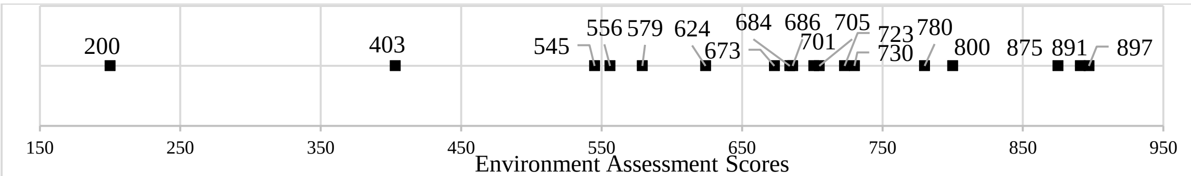

Figure 1. Environment assessment scores (0-1,000) of completed projects (N=18)

Microsoft Excel™ and SPSS™ tools were utilized to analyze this data. The cost growth of the projects was calculated comparing the final project cost to the initial performance measurement baseline set at 20 percent project completion. One project out of the 18 did not have cost information (score = 556) available, therefore the authors excluded it from the analysis. Table 4 represents the descriptive statistics of the analyzed dataset for the remaining 17 projects.

Table 4. Descriptive statistics of completed projects (N=17)

	Avg.	Median	Std. Dev.	Min	Max
Total Project or Program Cost (in $M)	129.62	83.85	135.24	4.80	497.56
EVMS Environment Score (out of 1,000)	676	701	176	200	897
Cost Growth (in %)	+15.30	+5.66	31.50	-13.81	+105.70

5.2. Cost Growth

For this exploratory study, the impact of the EVMS environment scores on construction and environmental project cost growth is investigated based on completion estimate at twenty percent project complete. The projects were divided into two subsets based on the environment score median (701), which represents a preliminary cut-off evaluation point that the authors used to designate projects in this sample with "good" environment scores (those above the medium) versus those with "poor" environment scores. Eight projects had environment score less than 701, and nine projects had environment score greater than or equal to 701. The use of the median to group the projects was considered due to the small sample size, however the authors' future research includes an in-depth analysis of a cut-off score when a larger sample is analyzed [11]. Table 5 shows the details of these two subsets.

Table 5. Environment assessment score and project cost growth (N=17)

	EVMS Environment Score < 701				**EVMS Environment Score >= 701**			
	N	Avg.	Median	Std. Dev.	N	Avg.	Median	Std. Dev.
Score (out of 1,000)	8	549	601	169.88	9	789	780	80.86
Cost Growth (%)		+30.05	+12.50	40.21		+2.20	+5.66	12.64

The comparison of the two subsets shows a cost growth difference of an approximate 28% in average between the projects that have poor environment scores versus those that have good scores; the projects with better EVMS environment score have lower cost growth. Next, the two subsets were tested for normality. The results showed a normal distribution of cost growth data corresponding to projects with good environment scores (calculated p-value = 0.48 > 0.05) and poor environment scores (calculated p-value = 0.08 > 0.05) [12]. Therefore, the authors applied independent sample t-test to statistically compare the mean cost growth difference between the two subsets [12]. The results showed a statistically significant difference in cost growth between projects with a good EVMS environment versus a poor environment, at a significance level of 0.1 (p-value = 0.096 < 0.1). This indicates that for this sample, the construction and environmental projects could potentially achieve cost savings when improving their EVMS environment. Stated another way, for this sample, project leaders and teams who measured their EVMS environment at or around the 20 percent completion stage of their project would have had the potential for improvement by addressing the poorly rated factors in their projects.

6. GUIDANCE TO PRACTITIONERS

There are perhaps clues to why some projects performed better than others in terms of EVMS environment in the sample. To identify these clues, the authors examined the factors that were both highly and poorly rated in the sample. The results showed that, for this sample, the top two poorly-rated factors are attributed to issues related to the customer. First, the customer organization did not show support and commitment to the implementation and use of EVMS (factor 1c). Second, the customer team did not have sufficient experience in understanding and using the EVM results to inform decision-making (factor 2b). This matched with a past finding where 272 industry practitioners identified that issues related to customer support, and past knowledge and experience can have the highest impact on the use of EVMS [1]. Conversely, the results showed that the top two most highly-rated factors in the sample corresponded to culture and resources categories. The top factor in projects with good environment was effective teamwork with team members working synergistically toward common project goals (factor 1f). This is supported by a finding based on a data collected from 275 employees, that a collaborative culture facilitates project teamwork [10]. These projects also utilized an appropriate periodic cycle to execute the EVMS effectively (factor 4f). This is consistent with the EVM implementation standards, which call for the establishment of a periodic business rhythm to report and efficiently implement EVM [13].

This exploratory study has shown that environment does have an impact on cost performance for this sample. Using the list of the 27 environment factors during the project lifecycle is a strategy to identify potential “stumbling block" issues similar to these highlighted above, or other issues manifesting themselves as project progresses. The authors’ ongoing effort include collecting additional data from both completed and in-progress projects.

7. CONCLUSION

This paper identified 27 environment factors that frame the EVMS environment needed for effective integrated project management. These 27 EVMS environment factors were based on an extensive literature review, industry survey, research team meetings with 27 industry experts, and also through workshops where 47 participants provided valuable feedback. The factors were retroactively rated in 18 completed projects, worth over $2 billion in final project costs. The authors studied the impact of EVMS environment on final project cost performance versus the baseline at twenty percent project completion for this sample. This exploratory analysis shows that for this sample, the completed projects with good EVMS environment (i.e., those at or above the median of the sample) statistically ($p < 0.10$) outperformed those with poor environment by 28% in terms of cost growth compared to performance measurement baseline set at 20 percent project completion.

A major contribution of this work to the body of knowledge is the identifying top issues in construction and environmental projects that could lead to better cost performance; based on the analysis, the top issues were related to customer support and commitment to the use of EVMS, customer knowledge and experience in using EVMS, project teamwork, and the establishment of a periodic business cycle in using EVM results. Addressing these issues and using the list of the 27 environment factors to identify emerging issues are strategies stakeholders can apply during the life of the project for an effective project control. Future work includes analyzing data with a larger sample size of projects corresponding to other industry sectors and studying the impact of EVMS environment on other project performance metrics.

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