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# Factors Affecting Implementation of Earned Value Management (EVM) in Construction Projects

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## Abstract

Earned Value Management (EVM) has emerged as an effective project monitoring and control method while the construction industry has lagged other industries, such as defense and aerospace, in adopting it. This research explored the barriers to effective EVM implementation for construction projects by investigating the factors affecting EVM adoption and utilization. The effort included a literature review and personal communications to obtain initial industry input to devise and distribute a survey questionnaire. Out of a total of 354 valid returns, 203 were familiar with (aware of) EVM while the remaining 151 respondents were not. Further, 77 respondents out of the group familiar with EVM indicated that they had not implemented EVM in their projects. Two categorical dependent variables and several categorical independent variables formulated from the survey data were statistically analyzed using cross tabulation and logistic regression. It was found that the first dependent variable (Is EVM implemented) was influenced by management commitment level, project budget range, availability of resources, extent of work breakdown structure (WBS) being aligned with schedule, difficulty of estimating earned value (EV), detail level of WBS, and accuracy of planned value (PV). The cost of EVM implementation was found to be the least important hindrance to its adoption. It was further concluded that the second dependent variable (how effectively is EVM implemented) was influenced by the extent execution follows schedule baseline, accuracy of PV, availability of resources, management commitment level, difficulty of estimating EV, extent WBS is aligned with schedule, and type of contract. The findings of the study were discussed and validated by a focus group of construction industry experts to close out this research effort. Interest in and support by senior management was identified as the most influential factor for EVM adoption and effective implementation.

**Keywords**

EVM, Project Management, Project Monitoring and Controlling, Construction Industry, EVM Implementation Barriers, Managerial Implications

# 1. Introduction

## 1.1. Background and Fundamentals

Performance systems used to gauge the success of a project involve monitoring of cost and schedule. However, it may be difficult to perform effective project controls without considering the relationship between these two parameters. It is usually clear when a project is over or under budget if the actual and planned costs do not match, while no information is revealed on how much work has been accomplished vis a vis. the expenses incurred in this process. Further, while the planned versus actual cost comparison could indicate overspending, the cause of this situation would not be understood without referring to time-based information. This could be attributed to not adhering to the project budget while work was completed as scheduled, although the work might have cost more than what was estimated. Alternatively, the estimated cost could be accurate, but because of not adhering to the schedule, the amount of work executed could be less than what was planned.

In view of such obscurities, an improved method is required to objectively measure and quantify project performance, and Earned Value Management (EVM) accomplishes this goal. By combining both the time and cost-related information and integrating them into one metric, it provides the capability to determine if a project will have a late or early completion, as well as finding out if any over or under spending has occurred. This method also reveals the expenses associated with the work that should have been executed per the plan. EVM mainly addresses three questions relevant to a project [1]: a) What is the product (*i.e.* scope)? b) How much does it cost to deliver the project (cost)? and c) When will the product be delivered (schedule)?

EVM analysis uses three basic variables, namely, Planned Value (PV), Earned Value (EV), and Actual Cost (AC). **Planned Value** is the authorized budget assigned to the work to be performed. It represents the portion of the project budget planned to be spent at any given point in time. PV is plotted versus time to give a cumulative time-phased budget from project start to completion. The cumulative PV curve is used as a performance measurement baseline (PMB) of the project. **Earned Value** is the measure of work performed up to a point in time expressed in terms of the planned budget assigned to the work. EV for an item of work is obtained by multiplying the planned budget for that work by its percent progress up to the completed proportion. It shows how much the work performed should have cost according to the initially planned budget. **Actual Cost** is the total cost incurred in accomplishing the work performed for an activity or Work Breakdown Structure (WBS) component. It indicates how much was spent on the work done and the total cost incurred in accomplishing the work measured by EV.

### 1.2. EVM as a Monitoring and Controlling Tool

Controlling a project is about ensuring that the work execution is done per the plan and exercised by comparing the project work status to where the project is supposed to be according to the plan at a given point in time. It also includes subsequent action to correct any deviations from the plan [2]. Project control involves constantly measuring project progress, evaluation of plans, and taking corrective actions when required. Continuous attention to schedule and cost management processes often results in successful project completion on-time and within budget [3] [4].

Performance assessment of a project from the cost perspective is conducted by comparing the AC to the EV of an activity or component in the project WBS. Schedule-wise performance evaluation, on the other hand, is accomplished by comparing the PV to the EV. These performance measurements are based on variances and performance indices calculated for desired detail levels of the WBS. Synchronization of the status dates for AC, PV and EV is essential.

"Variance" and "performance indices" are two EVM metrics used to monitor and control project progress relative to time and cost. Cost variance (CV) is used to show if work accomplished up to status date costs greater or less than what was planned. It is a measure of the cost performance. Similarly, schedule variance (SV) indicates whether the amount of work completed to date is more (or less) than planned work. SV measures the schedule performance and shows if a project is falling behind its baseline schedule. It will ultimately be equal to zero when the project is completed, as all of the planned work will have been executed at the time of completion.

For both CV and SV, a positive value indicates favorable progress while a negative value signifies unfavorable progress. A positive CV value shows the project is under budget, while a negative CV denotes an over budget status.

It is difficult to compare the performance of a given project against other similar projects using CV and SV values because project sizes and budgets vary widely. The variance, however, can be converted to efficiency indicators (performance indices) to reflect the cost and schedule performance of any project as well as comparing against other similar projects [5]. The cost performance index (CPI) and schedule performance index (SPI) respectively assess the budget and schedule status of a project. The mathematical formulas and graphical representation of CV, SV, CPI, and SPI are given in **Figure 1** [6].

In practical terms, a CPI value greater than 1.0 indicates a project cost underrun, and when the value is less than 1.0 it means an overrun. In contrast, SPI, compares work performed to work planned. An SPI greater than 1.0 (or less than 1.0) indicates more work (or less work) was completed than was planned. However, it is important to note that when SPI is greater than 1.0, implying "more work was completed than planned", this does not necessarily mean the project is ahead of schedule. This happens when more work than planned is completed by performing activities that are outside of the critical path [7] [8].

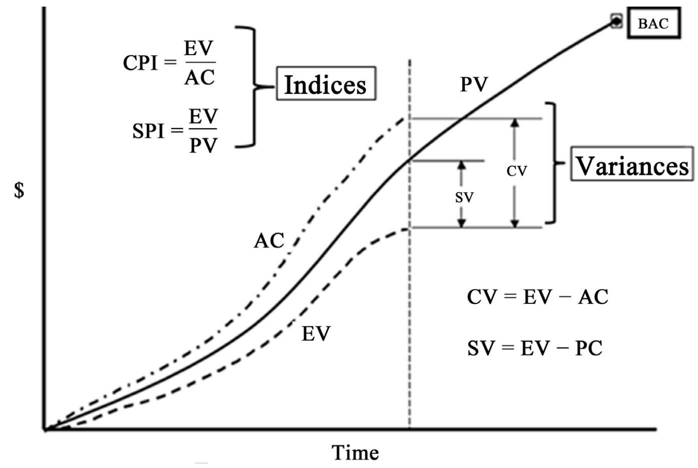


**Figure 1.** Earned value management metrics.

### 1.3. Problem Statement

EVM methodology has been widely used in military contracts, space industry, energy, and software engineering fields, and its application has been expanding [9]. A detailed report [10] covers the current EVM practices at NASA including the challenges and the lessons learned. Alongside this trend, it has been suggested that while project complexity, globalization. and competition are increasing, the adoption and implementation of EVM by construction firms and practitioners have not advanced to their full potential [11] [12]. This could be partly explained by the fact that many large construction projects involve highly complex and dynamic processes. Furthermore, there is belief that construction has historically been slower than many other industries in embracing innovations and new technologies.

A method integrating cost and schedule would be beneficial to construction engineers and managers in establishing the true and current status of a project. However, EVM use still remains relatively uncommon in construction projects despite its advantages. In addition, questions have been raised on its effectiveness and reliability in construction projects. Kim *et al.* [9] reported that although EVM practitioners mostly agreed with its principles, there were obstacles to applying and fully utilizing this tool. Some of the challenges identified were high cost, complicated formulations, and significant paperwork requirements. An additional barrier mentioned in the literature was the lack of motivation by top management to support EVM adoption and utilization [13].

In view of these considerations, a systematic study of the various factors that affect the implementation of EVM in construction projects was deemed to be warranted. It was expected that the findings of the study would not only help identify the significant factors, but would also lead to offering helpful suggestions to EVM practitioners to improve their decision making on its use as a project management tool. Accordingly, the following research objectives were established:

- Identify the factors that influence the implementation and effectiveness of EVM, and detect the most important (significant) factors;
- Quantify and characterize the relationship/interrelation between the various factors (independent variables) and the implementation and effectiveness of EVM (dependent variables) through the development of regression models;
- Devise strategies to mitigate the negative influences of relevant factors (barriers) on effective EVM implementation;
- Formulate recommendations and suggestions to improve the framework to increase the effectiveness of EVM implementation in the construction industry.

## 2. Literature Review

Most of the initial work and application of the EVM principle was done by the department of defense [13]-[15]. Early research surveying EVM applications covered the fundamentals of cost and schedule calculations, performance indices and variations, and prediction methods for cost and time of completion with examples [16]. Some deficiencies and limitations of EVM on the schedule aspects were later noted leading to the development of a new method to conceptually extend the EVM in to address these shortcomings [17]. In an attempt to remediate the limitations of the schedule metrics Lipke [6] observed that SPI and SV would always converge to 1 and 0 respectively at the end of the project regardless of whether the project was completed early, on time or late. To address this limitation, the author proposed an Earned Schedule (ES) value defined as the time where the EV accomplished should have been realized on the PV curve. It was recognized that by using ES, the schedule performance measures could be expressed in units of time rather than money like original EVM, thereby improving the relevance and interpretation of the schedule metrics. The importance of the ES method was validated and confirmed by Henderson [17] applying its concept to real projects, half of which were completed early, and the other half completed late. ES was shown to adequately portray projects that were finished late.

Relatively few research papers are available that are focused on exploring the implementation of the EVM method in the construction industry, limiting its benefit to the project management practitioners. In addition, the past studies did not consider the perspectives of the actual practitioners in terms of the nature and extent of the problems that they encounter with EVM implementation.

A few researchers have nevertheless explored EVM awareness and application in construction projects. An investigation by Keng and Shahdan [18] discovered that awareness of EVM among construction practitioners along with the extent of EVM use was quite low. The researchers observed that the level of awareness of

EVM was very limited and only some parts of the EVM concepts were being implemented. Similarly, in evaluating the application of EVM in construction projects Morad and El-Sayegh [19] found out that although some construction firms were employing EVM for project control, a considerable majority was not implementing it at all. The study also unearthed the fact that strong commitment from top management played a key role in the successful application of EVM. The association between EVM implementation and the interest and commitment of the higher management to allocate adequate resources was also explored by other researchers [20] [21].

Buyse *et al.* [22] suggested that EVM effectiveness could depend on project attributes such as project cost, type of contract, length of project, and project schedule. Similar observations were also made by other investigators [23] [24]. Other project characteristics reported as potentially influencing the implementation of EVM included accuracy of the PV [25]-[27], detail level of project WBS [28], and adherence of project execution to original schedule [29]. Another study [30] found that determining real physical progress of construction activities, and obtaining reliable input data were some of the most common difficulties encountered with EVM. Although these studies have made important contributions to the understanding of various factors influencing EVM adoption and implementation, the information shared is fragmented, and a holistic approach such as the one presented in this paper has not been attempted.

## 3. Data Collection and Research Methodology

This research employed both ordinal and categorical variables to address the research objectives. Data was collected from project management professionals working in the construction industry using a survey questionnaire. Interviews and discussions were initially held with project managers, consultants, and contractors to underpin this effort. In addition, communications with project managers and EVM practitioners were continued throughout this research to get reliable sources of data and information. Following data collection and analysis, a focus group consisting of experienced construction project managers was formed to gain further insights into our findings while acquiring industry perspectives.

### 3.1. Research Variables and Survey Data

The potential research variables were primarily identified by examining EVM-related information in the literature, followed by iterative group discussions by the authors with the addition of industry experts to develop a fishbone diagram, which is shown in **Figure 2**. This diagram was subsequently transformed into a set of questions for developing a survey instrument to collect data.

A total of 631 survey questionnaires were sent to design and construction professionals by e-mail using a list drawn from the authors personal networks, supplemented by names suggested by the mentioned industry experts. Social media platforms such as LinkedIn©, and professional groups like PMI-GLC (Great Lakes

Chapter) were also utilized to solicit additional participation and extend our reach. Overall, 366 survey responses were received, of which 354 responses were fully completed and 12 were incomplete (*i.e.* missing data). Out of these 354 valid returns, 203 respondents were familiar with (aware of) EVM. Further, out of the 203 respondents who were familiar with EVM, 126 indicated that they implemented EVM in their projects; the remaining 77 had not implemented EVM at all. For ease of presentation the survey data were classified into four groups as illustrated in Figure 3, which were as follows:

- **Group A (Aggregate Group)** represented all respondents (354 of them) who completed the survey regardless of their familiarity with EVM.
- **Group B**, consisting of 203 respondents, represented those people who said "Yes" to the question on familiarity with EVM.
- **Group C**, containing 126 participants, represented respondents who were familiar with EVM and answered "Yes" to the question of if they implemented EVM.
- **Group D**, comprising of 77 people, represented those respondents who were familiar with EVM but answered "No" to the question on if they implemented EVM.

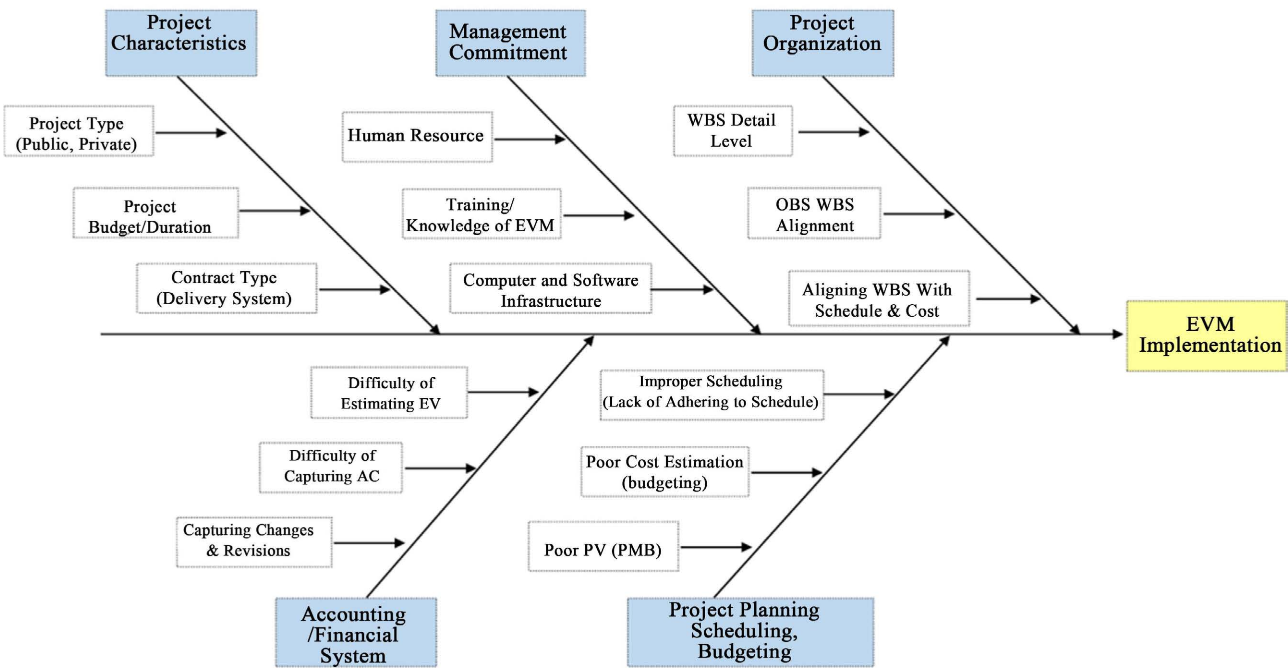


**Figure 2.** Fishbone diagram showing factors influencing application of EVM.

The individual respondent demographics showed that returns included professionals with industry experience levels of more than 15 years (29%), between 10 and 15 (20%) years, between 5 and 10 years (23%), and less than 5 years (28%). The survey recipients were predominantly comprised of project engineers/architects, project managers, schedulers, cost estimators and owner and senior management representatives.

### 3.2. Data Analysis

The survey data were divided into two groups: dependent variables (DV) and independent variables (IV). As shown in **Figure 4**, the first DV (Is EVM Implemented) is nominal and dichotomous requiring a yes or no response, while the second DV (How Effective is EVM Implemented) is an ordinal variable represented by five levels of EVM implementation effectiveness, namely very low, low, medium, high, and very high. level of effectiveness. Note that most of the IVs listed in the figure are ordinal. A Likert scale was used to convert the ordinal data into quantitative data to perform statistical analysis and regression modeling.

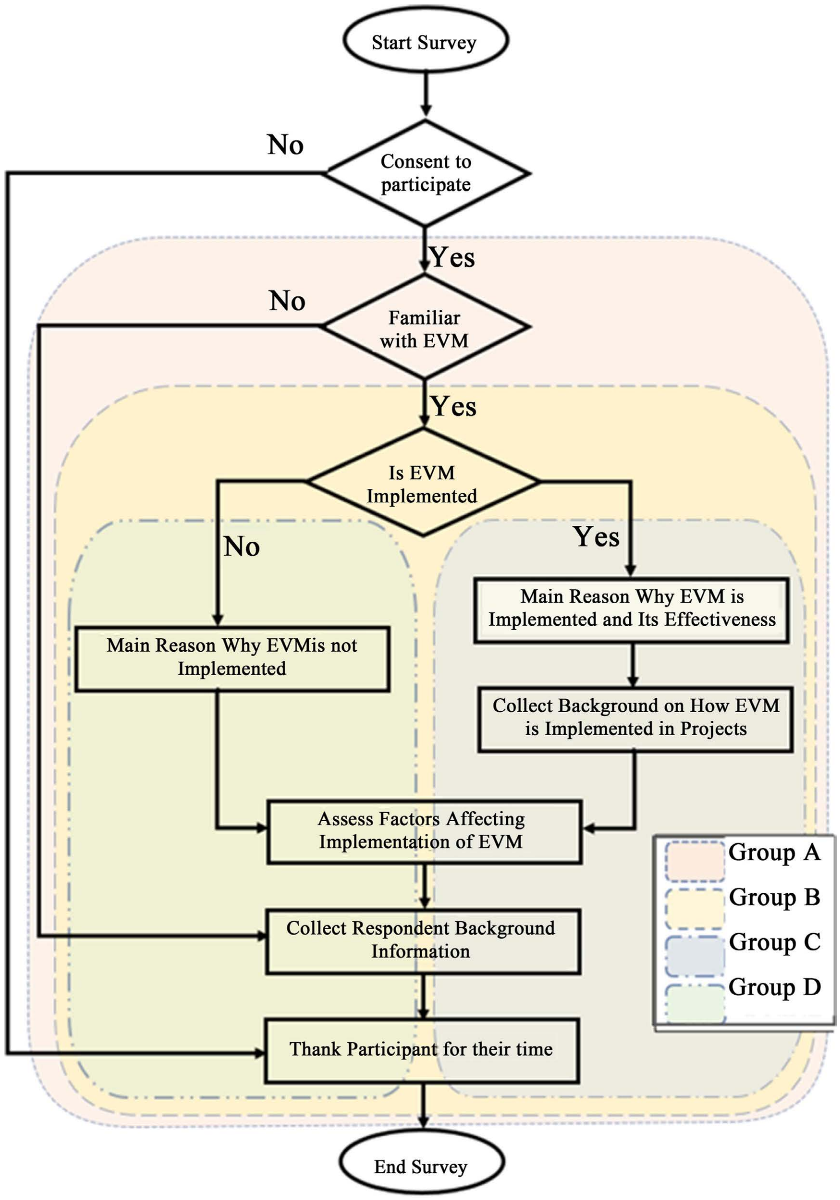


**Figure 3.** Survey question flow chart and clustering of respondents into four groups.

Descriptive frequency analysis was first used to organize and convert the raw data into a more manageable and easier-to-understand format. This enabled the extraction of useful information embedded in the survey responses. Another tool employed to present the data was Pareto analysis [31], which is a statistical technique that helps identify a smaller number of factors that produce a significant overall effect. This helps prioritize the problems/factors so that attention is initially focused on those having the greatest effect.

Next, to investigate how the IVs listed in **Figure 4** were associated with the DV's, cross-tabulation and logistic regression analyses were performed.

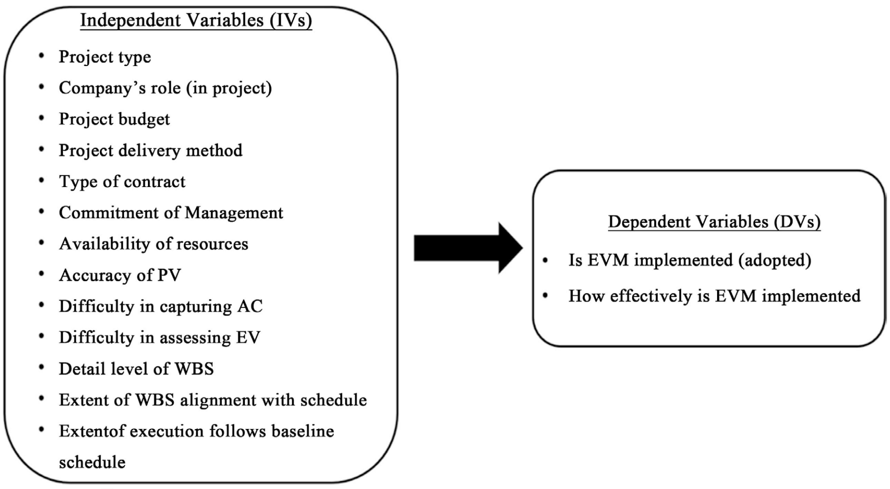


**Figure 4.** Research variables (Classified as dependent and independent variables).

### 3.2.1. Cross Tabulation

Cross-tabulation is a two (or more) dimensional table that records the number of observations with the specific characteristics described in the cells of the table. It is a useful tool to analyze the relationship between the variables using the Pearson chi-square, $\chi^2$, which compares the observed frequency in each cell with those that would be expected if there were no relationship between the two variables. A chi-square of zero means the two variables are independent and not associated, while a nonzero value indicates some association between the variables. Note that statistical significance and association are two different things; it is possible for two variables to be associated but still be independent [32].

The Pearson chi-squared test examines the hypothesis that the variables are independent (*i.e.* the results are the products of a merely random chance). The null hypothesis $H_o$ expresses the absence of any association and describes the case when the variables are independent. The alternative hypothesis $H_1$, represents the presence of a significant association between the variables. The test displays the calculated test statistics and an associated $p$-value, which is used to determine whether the deviation of the observed from the expected result is due to chance. If the $p$-value falls below a critical value such as 0.05, which corresponds to the 95% confidence level, the null hypothesis $H_o$ is rejected at that significance level suggesting the presence of a significant association or dependency between the variables.

The phi (Φ) or Cramer's V values are used to determine the relative strength of the relationship between the variables. The values of Phi and Cramer's V range from 0 (no association) to 1 (perfect association). Phi (Φ) is used when both variables have only two categories, while Cramer's V can be used for any size, including those with more than two categories in either variable. In this study, Cramer's V was used following the recommendation by Healey [33] and other researchers [34] [35]. The Cramer's V values computed in this research were judged to represent a weak relationship if they were between 0 and 0.1; a moderate relationship between 0.11 and 0.3; and a strong relationship between 0.31 and 1.

### 3.2.2. Logistic Regression

Logistic regression is a statistical modeling approach used to examine the probability of outcomes as a function of influencing factors. It helps define the relationship between a DV and a set of IVs by finding the best-fitting model. Although this type of modeling is often employed in social sciences research, it has also been used by several construction management researchers [35]-[38]. Logistic regression can be used to model situations in which the DV is both categorical and dichotomous, while the IVs can be continuous or categorical. This modeling technique was adopted in this research to investigate the effects of the IVs (influencing factors) to forecast the two DV's (if EVM is implemented or how effective EVM's implementation is).

Mathematically, a logistic function is formulated from the odds of the probability of occurrence of an event to its non-occurrence probability. The probability of the occurrence of an event $Y$ is given by:

$$P\left(Y=1 \middle| X_{1\cdots k}\right)=1/\left(1+\mathrm{e}^{-\hat{Y}}\right)=1\Big/\left(1+\mathrm{e}^{-\left(\hat{\beta}_0+\hat{\beta}_1X_1+\hat{\beta}_2X_2+\cdots+\hat{\beta}_kX_k\right)}\right) \quad (1)$$

where $\hat{\beta}_0,\hat{\beta}_1,\hat{\beta}_2,\cdots,\hat{\beta}_k$ are the regression coefficients corresponding to the $k$ IVs; $e$ is the base of the natural logarithm. The statistical significance of the $\beta$ coefficient is the criteria used in the selection of the IVs and is evaluated using the Wald test [32] [33] for each coefficient. In addition, the Hosmer and Lemeshow test [39] is used to assess the goodness of fit of the developed logistic regression model. For this study, the test indicates a poor fit if the chi-square significance ($p$) value is less than 0.05. The $p$-value needs to be greater than 0.05 for the regression model to be validated, which means that it adequately fits the data.

**1) Odds Ratio**

An odds ratio is a measure of association between a factor and an outcome. It represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. It can also be defined as the change of the odds of being in one category of outcomes (DV) when the value of a predictor (IV) increases by one unit. For a given $\beta$ coefficient, the odds ratio is Exp($\beta$) or $\mathrm{e}^{\beta}$. A change of one unit for the IV multiplies the odds by $e^{\beta}$ [32].

An odds ratio greater than 1 reflects the increase in odds of an outcome (DV) with a one-unit increase in the predictor (IV); an odds less than 1 indicates the decrease in odds of the outcome by a one-unit change. For example, an odds ratio of 2.13 means the odds of the outcome is 2.13 times as likely with a one-unit increase in the IV. That means the odds are increased by 113%. An odds ratio of 0.85, on the other hand, indicates that the odds of the outcome is decreased by 15%.

**2) Model Development**

Logistic regression models must be validated to quantify their performance and avoid inaccurate prediction of the outcomes for DV. Generally, validation can be done in two ways: external validation and internal validation. External validation entails applying the developed model and comparing its performance with the one using a related but slightly different dataset. Internal validation, adopted in this study, is conducted by splitting the original dataset.

A common split is 80/20 in which 80% of the data is used for developing the model and the remaining 20% for cross validation. After performing regression analysis on the larger subsample, predicted scores are computed for the smaller subsample using the regression coefficients. Finally, the predicted scores are compared with actual scores for the smaller sample to assess the validity of the developed model. The scores compared are binary, e.g., yes-no, high-low and so on.

### 3.3. Focus Group

The focus group is a technique that leverages communications and interactions between knowledgeable individuals to elaborate and shed light on obtained results. Such bodies explicitly use group interaction, exchange knowledge and experience, and comment on each other's point of view [40]. The use of focus groups does not only create an environment to discuss the preliminary findings of the researchers, but it also allows them to obtain the collective assessments of these findings from the industry perspective. In this research, this approach was an extremely useful tool; it allowed the study to draw upon attitudes, beliefs, experiences, and reactions of industry professionals in a way that would otherwise not be feasible with other methods.

## 4. Results and Discussion

### 4.1. Cross Tabulation

#### 4.1.1. "Is EVM Implemented" vs Influencing Factors

Results of the significant associations between the first DV (Is EVM Implemented) and the influencing factors are displayed in **Table 1**. All associations between the factors shown in the table are found to be significant at a 95% confidence level as indicated by the chi-square $p$-value. The strength values shown by Cramer's V range between 0.56 (strong relationship) for the Management Commitment Level and 0.22 (moderate relationship) for the Accuracy of PV.

According to the criteria given in **Section 3.2.1**, the relationship of the first DV (Is EVM Implemented) with Management Commitment Level, Project Budget Range, and Availability of Resources is strong, while the relationship with Extent WBS is Aligned with Schedule, Difficulty of Estimating EV, Detail Level of WBS, and Accuracy of PV is moderate. The following subsections expound on these findings.

**1) Management Commitment Level**

Crosstab analysis results between the first DV and Management Commitment Level show that EVM implementation has an association with a high level of management commitment. Understandably, if the senior management is committed to providing software, training and other resources to support of EVM application, this would likely result in the adoption and implementation of EVM, as was mentioned earlier [22]. It is known that agencies like NASA have provided courses and training on EVM application and have even availed a handbook containing guidelines to support project management processes, laying the foundation for EVM implementation [11] [20].

**Table 1.** Crosstab analysis: "Is EVM Implemented" vs. the influencing factors.

| | Management Commitment Level | Project Budget Range | Availability of Resources | Extent WBS is Aligned with Schedule | Difficulty of Estimating EV | Detail Level of WBS | Accuracy of PV |
|---|---|---|---|---|---|---|---|
| $\chi^2$-value | 63.69 | 30.69 | 25.06 | 18.33 | 13.11 | 11.57 | 9.50 |
| Significance ($p$-value) | <0.001 | <0.001 | <0.001 | <0.001 | 0.01 | 0.02 | 0.05 |
| Cramer's V | 0.56 | 0.39 | 0.35 | 0.30 | 0.25 | 0.24 | 0.22 |

**2) Project Budget Range**

It is shown in the table that there is an association between the first DV and Project Budget Range, signifying that projects with a larger budget are more likely to implement EVM. Major projects usually have sufficient funds set aside for implementing EVM, and some government agencies require the use of EVM depending on the budget amount of the project. For the Department of Defense (DOD) the minimum project budget which sets off EVM use is $20 million [15].

**3) Availability of Resources**

Presence of an association between the first DV and Availability of Resources suggests that companies/agencies that can afford to have the required human and infrastructure resources (qualified people and technology support to run EVM) usually end up implementing EVM. It has been reported that getting the right people at the beginning for EVM implementation plays a key role on successful project completion [21].

**4) Extent WBS is Aligned with Schedule**

The significant association between the first DV and Extent WBS is Aligned with Schedule makes it clear that projects where schedule is better aligned with

WBS are more likely to implement EVM. Our analysis revealed that 76.5% of the projects with a high degree of alignment between the WBS and schedule have employed EVM, as opposed to 23.5% which have not. Projects which have better alignment between the WBS and the baseline schedule normally have a more streamlined work execution due to logical sequencing of activities. This creates a clear pathway for the work to proceed smoothly, achieving a better overall cost and schedule performance.

**5) Difficulty of Estimating EV**

Crosstab analysis between the first DV and Difficulty of Estimating EV indicated that respondents who selected low difficulty in estimating EV in our survey (44%) were more likely to implement EVM in their projects compared to those who felt that the difficulty level would be high (10%). In reality, EV can be estimated from the authorized budget PV, if the work completion percentage is known. EV estimates that are close to the existing/actual progress status will yield more accurate EVM metrics.

**6) Detail Level of WBS**

Creation of a WBS is an effort to hierarchically decompose deliverables into smaller components called work packages executed in successive levels. Each level is a breakdown of the previous level, and each successive level gives more detail than the previous level. **Table 1** confirms the association between the first DV and Detail Level of WBS, pointing towards the notion that having a high level of detail in a project WBS will impose EVM implementation to a higher degree than a low level of detail. It is therefore logical to think that a decomposition of the deliverables to higher levels of detail would facilitate better management of the work packages, and EVM implementation would effectively support this outcome. A study [28] reporting poor performance on an EVM application at low detail levels of WBS reinforces this relationship.

**7) Accuracy of PV**

The relationship between the first DV and the Accuracy of PV shows that high Accuracy of PV associates with the implementation of EVM in contrast to low or very low PV accuracy. An accurate estimation of project cost, or PV, at planning stage often results in a less discrepancy between PV and AC of an activity during execution, leading to more accurate results. This, in return, will foster and encourage EVM implementation, because the accuracies of EV and PV are interdependent [25].

#### 4.1.2. "How Effectively Is EVM Implemented" vs Influencing Factors

Cross-tabulation results between the second DV (How Effectively is EVM Implemented) and the influencing factors are listed in **Table 2**, which is structured similarly to **Table 1**. Like those previously discussed, all associations presented in this table are statistically significant at a 95% or above confidence level ($p$-value selected as 0.05), The strength of associations between the DV and the IVs is again assessed by Cramer's V, which varies from 0.26 (lowest) to 0.47 (highest) corresponding to moderate and strong relationships respectively. Further details follow.

**1) Accuracy of PV**

As can be observed in Table 2 there is a significant association between the second DV (How Effectively is EVM Implemented) and accuracy of PV meaning that when the PV accuracy is high, EVM implementation effectiveness is also high. Having an accurate PV as a project baseline for measuring project performance and hence assessing the effectiveness of EVM implementation has been emphasized by Fleming and Koppelman [26].

**Table 2.** Crosstab analysis: "How Effectively is EVM Implemented" vs. the influencing factors.

| | Accuracy of PV | Extent Execution Follows Schedule Baseline | Availability of Resources | Management Commitment Level | Difficulty of Estimating EV | Extent WBS is Aligned with Schedule | Type of Contract |
|---|---|---|---|---|---|---|---|
| $\chi^2$-value | 69.58 | 109.57 | 57.55 | 50.36 | 41.47 | 38.11 | 33.31 |
| Significance ($p$-value) | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.01 |
| Cramer's V | 0.37 | 0.47 | 0.34 | 0.32 | 0.29 | 0.28 | 0.26 |

**2) Extent Execution Follows Schedule Baseline**

According to the results shown in Table 2, when execution often follows schedule baseline, the level of EVM implementation effectiveness becomes high. Executing project tasks more in line with the schedule baseline creates an organized and streamlined work flow that minimizes the probability of making mistakes and frequent rework activity. This will produce more accurate EVM metrics and a higher effectiveness of EVM implementation by reducing variances from the baseline plan.

**3) Availability of Resources**

The significant association between the second DV and availability of resources displayed in Table 2 appears consistent with the fact that 50% of our survey respondents indicated a high effectiveness level of EVM implementation in their projects while also underlining the need for a high level of resource availability. A similar observation was also reported by Vanhouchke [21].

**4) Management Commitment Level**

The significant association observed in Table 2 between the second DV and Management Commitment Level can also be tied to the fact that about 60% of the survey respondents thought medium to high commitment of management corresponds to medium to high level of EVM implementation effectiveness. In contrast, the respondents opined that when the management commitment is low or very low, the level of EVM implementation effectiveness is also mostly low or very low. This is an important factor in management decisions on the allocation of adequate resources for necessary tools and know-how for employees can effectively use EVM. It should be noted that attaining high levels of EVM effectiveness through management commitment to training and team development activities has been emphasized in the literature [19] [20].

**5) Difficulty of Estimating EV**

There is a high degree of association between the Second DV and Difficulty of Estimating EV according to the results included in **Table 2**. Based on responses received from about 48% of our survey participants, it was established that a low level of EV estimation difficulty would correlate with a high level of EVM implementation effectiveness. Accurately estimating the progress level with little difficulty, coupled with having an accurate PV value, results in an accurate EV. Also, since all EVM equations include EV in their formulation, the resulting EVM metrics are going to be more accurate, enhancing the effectiveness of EVM implementation.

**6) Extent WBS is Aligned with Schedule**

**Table 2** also reveals that a significant association exists between the second DV and Extent WBS is Aligned with Schedule. According to 40% of the survey respondents, a high level of alignment of WBS with schedule produces a high level of EVM implementation effectiveness. In the opinion of a much smaller fraction of the respondents (9%), the converse was true, meaning a low level of effectiveness will come about from a high level of WBS schedule alignment. Based on these statistics, it can be stated that projects whose WBS is more aligned with schedule baseline will have a more efficient work execution pattern with fewer rework cases, which results in a clear pathway for the work to proceed as planned. This would lead to better schedule and cost performance and will likely represent the actual status of the project.

**7) Type of Contract**

The significant association between the second DV and the type of contract underscores the fact that projects with a fixed price contract produce a higher effectiveness in EVM implementation. Unlike the cost plus or the other contract types, fixed price contracts have a higher risk to the contractor [11] thus requiring a much closer oversight of schedule and cost controls, which results in more effective EVM implementation. The most common contract type favored by the respondents was the fixed price, which is consistent with the findings of Fleming and Koppelman [23], who echoed the preponderance of this type of contract use in the construction industry.

### 4.2. Logistic Regression Models

Logistic regression analysis was performed for both the first DV (Is EVM Implemented) and the second DV (How Effective is EVM Implemented) to identify the most important factors to construct a model for each, establishing the relationship between the DV and the IVs. Similar to the previously discussed approach, the data was randomly divided into two subsets; 80% of the dataset was used to develop the model and the remaining 20% to validate the model. The IVs that exhibited statistically significant association with the DVs from the cross-tabulation analysis covered in **Section 4.1.** were selected for the logistic regression analysis.

#### 4.2.1. Is EVM Implemented Model

The logistic regression was employed to model, assess and quantify the statistically significant factors that affect the first DV. This analysis resulted in the selection of three significant factors: Management Commitment Level (Q14), Difficulty of Estimating EV (Q18), and Extent WBS is Aligned with Schedule (Q20), where Q's denote the corresponding numbers in the survey questions. Table 3 summarizes the logistic regression results for the first dependent variable (Is EVM Implemented) with estimates of the $\beta$-coefficients for the IVs, also called predictor variables.

**Table 3.** Model variables for "Is EVM Implemented".

| | | | | | | 95% C.I. for Exp($\beta$) | |
|---|---|---|---|---|---|---|---|
| Variables | Coefficient $\beta$ | Standard Error | Wald | Sig. | Exp($\beta$) | Lower | Upper |
| Q14 | 1.612 | 0.401 | 16.160 | <0.001 | 5.013 | 2.284 | 11.001 |
| Q18 | −1.310 | 0.518 | 6.393 | 0.011 | 0.270 | 0.098 | 0.745 |
| Q20 | 0.862 | 0.377 | 5.223 | 0.022 | 2.369 | 1.131 | 4.963 |
| Constant | −0.491 | 0.309 | 2.524 | 0.112 | 0.612 | | |

C.I. is Confidence Interval.

The $\beta$ values in the table describe the magnitude and direction of the relationship between the first DV and each influencing factor (predictor variable) identified by the model. The magnitude of the $\beta$-coefficients is indicative of the degree each predictor affects the outcome. The first and third predictors have a positive $\beta$-coefficient indicating a positive relationship, while the second predictor in the middle has negative $\beta$-values showing a negative (inverse) relationship. The regression constant is also negative.

The Hosmer and Lemeshow goodness-of-fit test for the logistic regression model yielded a $p$-value of .570, which is greater than .05, indicating that the data obtained from analysis fits the model satisfactorily. Discussions of individual predictor factors follow below.

**Q14-Management Commitment Level:**

The positive $\beta$-coefficient of 1.612 in Table 3 indicates that a high management commitment level results in a higher probability of EVM being implemented. The Exp($\beta$) value (odds ratio) of 5.013 in the table quantifies this information revealing that when the management commitment level is high, it is 5.013 times more likely for EVM to be implemented. In addition, this odds ratio implies a 401.3% increase in the likelihood of implementing EVM.

An increase in management commitment to the project could occur in many ways. It may be manifested as sending people into training, allocating an adequate budget for the EVM infrastructure, such as record keeping, or investing in computer technology, hardware and software. Such commitment would translate into a higher probability of implementing EVM.

**Q18-Difficulty of Estimating EV:**

The negative $\beta$-coefficient of 1.310 in **Table 3** indicates that if the difficulty of estimating EV is high, the probability of implementing EVM decreases. If the EV of the executed work packages cannot bed accurately estimated, EVM analysis will not produce reliable results, which would discourage companies from implementing EVM. The odds ratio of 0.270 is below one, showing that if the difficulty level of estimating EV is high, the odds of implementing EVM is 0.270 times lower than when the difficulty is low. In other words, a high level of difficulty in estimating EV leads to a 73.0% decrease in the odds of implementing EVM in projects.

**Q20-Extent of WBS Alignment with Schedule:**

The positive $\beta$-coefficient of 0.862 in **Table 3** suggests that the high alignment of WBS with schedule will leads to an increased probability of implementing EVM. The corresponding odds ratio of 2.369 reveals that if a project has a high alignment of WBS with schedule, the odds of implementing EVM becomes 2.369 times higher than if the extent of alignment is low. Alternatively, the presence of a high level of alignment of WBS with schedule results in an increase of 136.9% in the odds of EVM being implemented. Simply put, when the WBS is highly aligned with schedule the likelihood of implementing EVM goes up. It is logical to expect that when the two are aligned, it becomes easier to track the cost and the progress of the project, thus making the calculation of EVM easier and its interpretation more realistic.

**Constant:**

The constant term represents all other factors that are not captured by the model. The negative constant (−0.491) indicates that those uncaptured factors have a cumulative effect of lowering the probability of implementing EVM. This means there are other known and unknown factors in addition to the mentioned three, which will reduce the probability of EVM implementation. In mathematical terms, the model can be expressed as:

$$P\left(Y=1\right)=1\Big/\left(1+\mathrm{e}^{-\left(0.491+\left(1.612\right)\left(Q14\right)+\left(-1.310\right)\left(Q18\right)+\left(0.862\right)\left(Q20\right)\right)}\right) \quad (2)$$

where $Y$ is the DV and $P(Y=1)$ represents EVM is implemented; Q14, Q18 and Q20 are the IVs.

To validate the model, Equation (2) was applied to the 41 random cases (20% of the dataset) set aside for this purpose. The 41 cases consisted of 24 cases where EVM was implemented and 17 where it was not implemented. The model was used to estimate whether EVM was implemented in these 41 cases. Then the estimates were compared to the values in observed cases. **Table 4** is the classification table for the model estimates, and out of a total observed 24 cases (sum of 6 and 18) in which EVM is implemented, the model correctly predicts that EVM is implemented in 18 cases (75.0%). On the other hand, out of the 17 cases (sum of 11 and 6) that do not implement EVM, 11 cases (64.7%) are accurately predicted. The overall classification accuracy of the validation dataset is 70.7% which is more than the prediction produced by the naive model (64.3%). Based on these figures, it can be concluded that the developed model predicts more accurately than the naive model as to whether EVM is going to be implemented in a given project.

**Table 4.** Classification table for the validation dataset of the first DV.

| Observed | | Predicted by the model | | |
|---|---|---|---|---|
| | | Is EVM Implemented | | Percentage Correct |
| | | No | Yes | |
| Is EVM Implemented | No | 11 | 6 | 64.7 |
| | Yes | 6 | 18 | 75.0 |
| Overall Percentage | | | | 70.7 |

### 4.2.2. How Effectively Is EVM Implemented Model

Logistic regression analysis was also conducted with the second DV (effectiveness of EVM implementation). This time, the data from the Group C (see **Section 3.1.**) of the survey respondents was analyzed. The 126 cases in hand were spilt into two parts on a 80 - 20 basis like before. So, 100 cases were used to construct the model and the remaining 26 cases for model validation. **Table 5** displays the result of the logistic regression analysis showing the variables with the highest degree of prediction power for the second DV along with their associated parameters. The independent variables are: Accuracy of PV (Q16), Management Commitment Level (Q14), Extent Execution Follows Schedule Baseline (Q21), and Type of Contract (Unit Price-UP) (Q13_UP).

**Table 5.** Logistic regression model for "How Effective is EVM Implemented".

| | | | | | | 95% C.I. for Exp($\beta$) | |
|---|---|---|---|---|---|---|---|
| Variables | Coefficient β | Standard Error | Wald | Sig. | Exp($\beta$) | Lower | Upper |
| Q16 | 1.139 | 0.529 | 5.636 | 0.031 | 3.123 | 1.180 | 8.810 |
| Q14 | 1.410 | 0.464 | 9.645 | 0.002 | 4.225 | 1.702 | 10.490 |
| Q21 | 0.869 | 0.451 | 3.713 | 0.050 | 2.385 | 0.958 | 5.772 |
| Q13_UP | 1.017 | 0.511 | 3.961 | 0.047 | 2.765 | 1.016 | 7.527 |
| Constant | −0.392 | 0.434 | 0.816 | 0.366 | 0.676 | | |

C.I. is Confidence Interval.

The model's Hosmer and Lemeshow test $p$-value was found to be 0.612, which is greater than 0.05, indicating that the developed model is statistically significant. All of the variables (factors) have positive regression coefficients, and the odds ratio of each factor is greater than 1, signifying the positive association between the influencing factors and the DV (effectiveness of EVM implementation). The model parameters and how each predictor affects the DV are discussed in the following subsections.

**Q16-Accuracy of PV:**

The positive $\beta$-coefficient listed in **Table 5** indicates that as the accuracy of PV increases, the probability of effective EVM implementation also increases. If the PV of the work packages, also called Schedule of Values, is estimated with a high degree of accuracy during the project planning phase, EVM metrics can also be estimated accurately. This means that a more accurate and representative PV value will increase the likelihood of effective EVM implementation. The importance of PV accuracy in improving the effectiveness and the predictive power of EVM has been recounted by Chen *et al.* [27]. In addition, performance indicators are dependent on PV, and indicator accuracy usually depends on the accuracy of PV [25].

**Q21-Extent Execution Follows Schedule Baseline:**

The extent of execution following the schedule baseline represents how well the work execution adheres to project plan. As indicated by the positive $\beta$-coefficient shown in **Table 5**, effectiveness of EVM implementation will increase when work performed follows the schedule baseline. When there is an inconsistency between a planned work item and an actually performed work item at a given status point, a comparison between the PV and AC will not be meaningful because the work items are not the same. Furthermore, when there is a marked deviation from the project plan during execution, a significant amount of rework is often required [29]. Rework in a project complicates the EVM analysis and reduces its reliability, ultimately undermining its effectiveness as a project performance measurement and forecasting tool.

**Q14-Management Commitment Level:**

The positive $\beta$-value in **Table 5** signifies that a high management commitment will result in a high level of EVM implementation effectiveness. When top management grasps the benefits of EVM, it would be easier for them to adopt EVM not only as a tool for improving company project management processes, but also as an opportunity to use it for successful bidding for future projects. EVM additionally provides a secondary benefit for capturing valuable data and information that would help continuously improve relevant processes and systems, thereby driving quality improvements in the organization.

**Q13_UP-Type of Contract (Unit Price):**

The logistic regression analysis performed in this study identified only the unit price type of contract as a statistically significant factor. This is justifiable because in most cases fixed price contracts are less motivating for EVM implementation than others. Once the contract is awarded, the cost of the project is of less concern as it is already set [24]. When the contract is fixed price (lumpsum), project managers are less inclined to use EVM, which is supported by the model exhibited in **Table 5**.

**Constant:**

The constant term in the model, as explained before, represents all other factors that are not captured by the model, and the negative value suggests that those uncaptured factors lower the probability of having an effective EVM implementation.

Using the $\beta$ coefficients found in Table 5, the developed model can be expressed as

$$P(Y=1)=1\Big/\left(1+\mathrm{e}^{-\left(-0.392+(1.139)(Q16)+(1.410)(Q14)+(0.869)(Q21)+(1.017)(Q13_{UP})\right)}\right) \quad (3)$$

where $Y$ is the second DV and $P(Y=1)$ represents the case of EVM implementation effectiveness is high; Q16, Q14, Q21, and Q13_UP are the independent variables.

To validate the result, the model given by Equation (3) was applied to the validation dataset of 26 responses, which consists of 16 cases where EVM implementation effectiveness is high and 10 where EVM implementation effectiveness is low. Comparing the results of the predicted cases by the model equation with the observed cases, the model was able to predict 60% (6 out of 10) of the low effectiveness cases and 62.5% (10 out of 16) of the high effectiveness cases yielding an overall classification of 61.5% as shown in Table 6. As before, this overall classification is greater than the classification given by the naïve model.

**Table 6.** Classification table for the validation dataset of the second DV.

| Observed | | Predicted by the model | | |
|---|---|---|---|---|
| | | How Effective is EVM Implemented | | Percentage Correct |
| | | Low | High | |
| How Effective is EVM Implemented | Low | 6 | 4 | 60.0 |
| | High | 6 | 10 | 62.5 |
| Overall Percentage | | | | 61.5 |

## 4.3. Views on and Experiences with EVM

Survey respondents were solicited for their views and experiences regarding EVM, which are summarized below.

### 4.3.1. Factors Hindering EVM Implementation

All respondents familiar with EVM (Group B, which includes C and D) were asked to identify those factors they considered to be obstacles to implementing EVM in the construction industry. Their responses are graphically illustrated in Figure 5. It is observed from this figure that nearly one in four respondents identified "general lack of EVM knowledge" as the primary barrier to EVM implementation in projects. This mirrors the findings of Sunarti *et al.* [41] who reported a lack of EVM knowledge, expertise, and experience by the user as the major challenge in implementing EVM. Insufficient understanding of EVM was also identified as an impediment to its implementation [9], paralleling the result of our survey findings. About 90% of the survey respondents, who are familiar with EVM, indicated that when EVM use is not required by the company, EVM becomes a low priority. Another hindrance acknowledged by the respondents was the tedious data collection and reporting procedure involved in the process. This is generally tied to collection of the AC data in a timely manner, which often leads to making an assumption on its value. The cost of EVM implementation was reported as the least important reason that hinders its adoption, finding previously shared by Fleming and Koppelman [5].

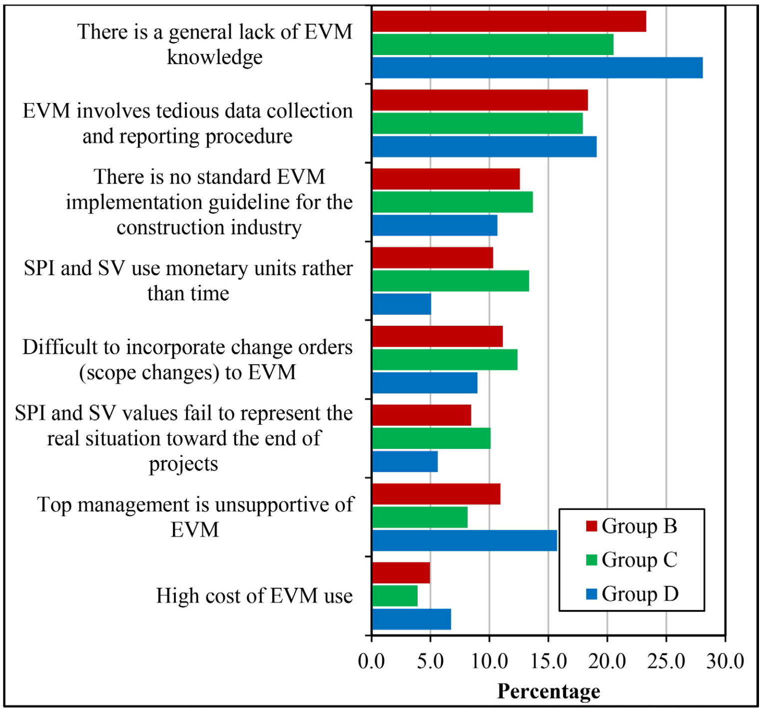


**Figure 5.** Factors hindering the implementation of EVM in construction projects.

A Pareto analysis was conducted on the various factors impeding the implementation of EVM in the construction industry; the results are plotted in **Figure 6** as pertaining to Group C (respondents who know EVM and implement it). This analysis, which is aimed at identifying the significant few, revealed that almost 50% of the hindrance could be attributed to two factors, "general lack of EVM knowledge" and "tedious data collection and reporting procedure". Further, if "lack of standard EVM implementation guidelines for the construction industry" is included as a third factor, it can be stated that focusing on three most dominant factors shown in the figure, the construction industry could address 60% of deterrents to the utilization of EVM.

#### 4.3.2. Ways EVM Implementation Challenges Were Overcome

Respondents who implemented EVM in their projects (Group C) were also asked how they overcame the challenges that they had faced (see **Section 4.3.1**); the responses are displayed in **Figure 7**. Almost 30% of the respondents thought that the mentioned challenges could be overcome by improving communications among project participants, which was closely followed by the allocation of adequate resources and training to the project personnel. Having robust communications among project participants has been recognized as a success factor for EVM implementation by other researchers as well [11]. Furthermore, the importance of having adequate resources is consistent with the findings reported by Zhan *et al.* [13].

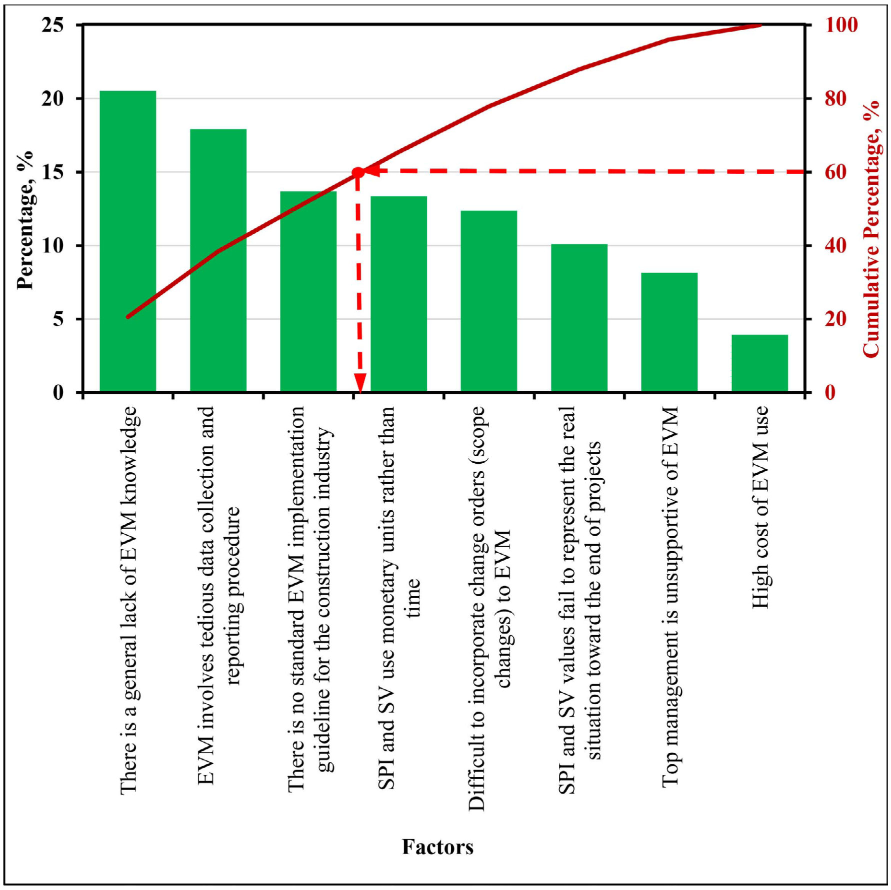


**Figure 6.** Pareto analysis of the various factors hindering the implementation of EVM.

### 4.3.3. General Views and Observations Regarding EVM

The last question of the survey was an open-ended inquiry primarily directed to the respondents who are aware of EVM (Group B). This question was not only meant to capture personal insights from the respondents but also to detect any important issues that the survey instrument might have failed to address.

Diverse responses were received from the participants. A few representative responses are included here. Some respondents indicated that they use EVM for cost performance only and use CPM (critical path method) to control the schedule. Long time to collect cost data was reported as being a disincentive to use EVM, and for fast-paced projects, collecting all the required cost data is often a "next to impossible" task. Some respondents also mentioned that they use company specific tools, as opposed to EVM, to control their costs. Many stressed the fact that owners/stakeholders did not require the use of EVM, and their top management was not supportive and did not provide the required resources. A few indicated that they implemented EVM on their projects when required by locally and federally funded developments. Finally, some emphasized that the difficulty of incorporating change orders requiring project re-baselining in EVM calculations and the challenges with receiving relevant information (especially cost) in time discouraged them from implementing EVM.

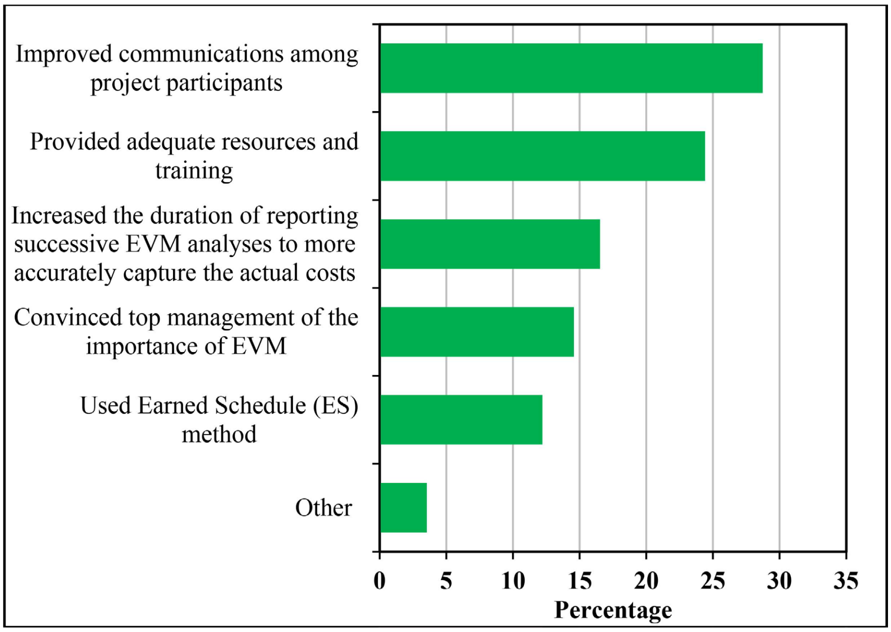


**Figure 7.** Ways Group C respondents overcame challenges to implementing EVM.

## 4.4. Focus Group

A synopsis of the study and its findings was distributed to the focus group participants for their review. The focus group was made up of experts from the construction industry representing owners, contractors, engineering firms, and construction management agents. They were selected based on their knowledge of and direct involvement with EVM in the construction industry to bring the industry perspective and validate the survey findings. The participants were then assembled to discuss each of the major findings of this research, while the authors captured the main points raised. The group offered their perspectives, insights, and recommendations regarding the various factors and their effects on the dependent variables. While there was general agreement with a great majority of the study findings, there were also some differing perspectives. The synthesis of the meeting discussions is summarized through the following bullets:

- Participants, in large part, concurred with the findings of the study finding them in general alignment with their experience in the industry. However, they took exception to the survey result on the influence of actual cost (AC) on EVM implementation being difficult to capture, while emphasizing the challenge of capturing AC in a timely manner that affects the accuracy of EVM reports. This happens because AC data is often not available by the status date, as it does not arrive early enough to be incorporated in the EVM analysis. Thus, it is the delay factor that obscures the accuracy of AC determination, and not necessarily the inability to capture the needed cost data for performing calculations.

- It was additionally suggested that breaking down and allocating the AC values to account for project progress using the contractors' invoices, which cover the individual work items or activities in the WBS, can also introduce delays leading to inaccuracies in EVM reporting.
- Project complexity was mentioned as another factor affecting EVM implementation. Normally, the assumption is that the higher the project budget, the higher the level of complexity. However, it was stated that this may not always be the case. Consequently, both the budget and complexity of projects should be considered as possible factors influencing EVM implementation.
- Several participants mentioned that contractors conduct EVM analysis for their own purposes, meaning they do not usually publicly share/report their analyses to maintain their competitive edge, without divulging their vulnerabilities and risks. Instead, they take the valuable information from EVM analyses, which allows them to take advantage of EVM as a learning tool to improve their processes and systems and use the information as the need arises; e.g., in bidding future projects.
- The group recommended the use of simpler tools such as MS Excel instead of Primavera or MS Project to conduct EVM. This is because MS Excel is not only less costly to acquire and maintain but also people are more likely to have the knowledge and skills to use it more efficiently compared to working with the more advanced and costly software. For instance, possible cost-savings can be realized from using Excel. The simplicity of Excel should, however, has to be balanced against its limitations in handling large and complex projects, especially with respect to scheduling aspects.
- From the focus group discussions, it appeared that many in the construction industry would adopt and implement EVM if mandated by the owner or the company's upper management. Incorporating EVM as a contractual requirement that needs to be met by the contractor is a recommendation that participants identified as a factor that would drive EVM implementation. This suggestion was notably favored by group members representing the contractor community and is supported by the survey findings. It was additionally emphasized by the group, however, that for smaller contracting companies if the owner requests EVM, the associated expense has to be included as a line item in the budget.
- An observation shared by a group member was the lack of effective integration of the scheduling system and the accounting system in projects and organizations. Coordinating the accounting/financial system with the scheduling sys-

tem in the field can ease information flow and reduce extra work in getting the relevant information to conduct EVM. This assertion could be further investigated in future research efforts.

- The commitment of top management in implementing EVM was reiterated by the participants. Getting such commitment would depend on proper knowledge and understanding of EVM, and its purpose and benefits by the top management. Awareness of and experience with EVM could increase the belief that the benefits of EVM outweigh the extra costs associated with its use. Besides affording the ability to track and forecast project progress, EVM can provide a secondary advantage of capturing valuable data and information to continuously improve relevant processes and systems thereby driving quality improvements in the organization and its projects.
- Participants affirmed the survey finding on the importance of resource availability, which would include financial resources, as well as technical know-how (human resources), equipment, hardware, software required to implement EVM.
- Group members also agreed with the survey finding regarding the importance of having a standard guideline and a toolkit to implement EVM in the construction industry. These guidelines would create a common platform and terminology for the parties to adopt and implement to report EVM information in construction projects. It appears that a future effort in pursuing this matter is also warranted.

## 5. Summary and Conclusions

In the past few decades, EVM has proven its importance in many industries, but it has not made significant inroads into the construction industry. This research investigated the various factors influencing EVM adoption and effective implementation in construction projects. A qualitative approach was employed. When survey respondents were asked why they implemented EVM in their projects, one out of five respondents indicated the client's or owner's request to be the motivating factor, while a very small percentage (4%) expressed other reasons. On the other hand, when respondents who did not implement EVM in their projects were asked the reason why, an overwhelming majority (over 90%) indicated lack of any requirement for EVM implementation in their organization.

Two DVs were selected for researching influencing factors: "Is EVM Implemented" and "How Effectively is EVM Implemented". The study found the first DV to be affected by management commitment level, project budget range, availability of resources, extent WBS is aligned with schedule, difficulty of estimating EV, detail level of WBS, and accuracy of PV in decreasing order of influence. The factors influencing the second DV were found to be accuracy of PV, extent execution follows schedule baseline, availability of resources, management commitment level, difficulty of estimating EV, extent WBS is aligned with schedule, and type of contract, in a decreasing order. Using logistic regression analysis, the mentioned factors influencing the DVs based on cross-tabulation analyses were further reduced in number and their relationships were expressed using quantitative parameters, such as $\beta$-coefficients and odds ratio.

The survey findings were validated internally, and by using a focus group of industry experts. The participants discussed and generally agreed with the findings of the research. They also calibrated and expanded the findings by providing valuable information from their own experiences. One such case, missed by the survey responses, was the difficulty of capturing AC in a timely manner and how it negatively affected the implementation and effectiveness of EVM. Several other refinements were also suggested by the participants of the focus group, such as making EVM reporting monthly, including EVM as a contractual requirement, and so on.

EVM can help provide project managers greater confidence in making evidence-based objective inferences about their project, enabling better project control and oversight. This would ultimately lead to the completion of the project within time and budget. Pareto analysis adopted for this research indicated that if the construction industry could focus on a relatively small number of dominant deterrents, namely "general lack of EVM knowledge", "tedious nature of data collection", "reporting procedures involved in EVM", and "lack of standards for EVM implementation guidelines", a large fraction of the problems faced in implementing EVM could be properly addressed. An important revelation of this study was the fact that the cost of adoption and implementation of EVM was not a significant factor at all.

In light of the findings of this research, preparing a standard EVM implementation handbook or guideline similar to the one developed by NASA [41] or by the DOD [15] is recommended. This document should be specifically tailored to the construction industry. Such a handbook needs to include clear definitions of requirements and responsibilities for the implementation process, so it can serve as a guideline for EVM implementation. The handbook would essentially provide a consolidated reference document on EVM guidance for the effective implementation, and utilization of EVM for construction projects. Specifying a threshold project budget above which EVM should be implemented would expand implementation of EVM.

Furthermore, incorporating EVM into project contracts (e.g. making EVM a project control requirement, defining EVM metrics and reporting requirements, and setting performance expectations such as penalties or bonuses) and setting performance-based incentives tied to EVM metrics would greatly increase implementation of EVM in the construction industry and its acceptance by construction professionals.

## 6. Managerial Implications

Finally, a recurring theme that came up in the literature review and was reinforced by this research is the importance of senior management decisions relative to EVM adoption and implementation. It is clear that EVM offers managers a robust tool for improving project control and decision-making in the construction industry. To leverage its full potential, managers should integrate EVM into their standard practices, making it a part of organizational culture rather than a compliance measure. By adopting a standard EVM guideline tailored to their specific needs and making EVM a contractual requirement, managers can ensure consistent application. Furthermore, managers can use EVM metrics for continuous improvement, identifying areas for process enhancement and achieving better project outcomes.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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