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(Research Article)

The role of advanced earned value management (EVM) metrics in schedule performance analysis of building projects

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Abstract

EVM (Earned Value Management) is among the valuable tools used to calculate the cost and progress of any project. Although venerable by the tide, the tools and metrics used still include CPI, SPI, and performance in the form of schedules; these hardly reflect true scheduling performance, especially in more complex scenarios of building projects subject to multiple variables. Thus, the advanced metrics of EVM introduced for measuring the Earned Schedule (ES), Schedule Variance (SV), and To-Complete Performance Index (TCPI) allow not only the argument of schedules on more rigorous grounds but also for extensive commentary with an eye both to history and future in respect of schedule performance. This research follows a mixed-method approach comprising quantitative data analysis and qualitative case studies. Quantitative analysis was applied to data from building projects to compare conventional with advanced metrics. By interviewing project managers, qualitative data were obtained to inform on the applicability and effectiveness of advanced EVM metrics. Advanced EVM metrics have proved to greatly assist in appraising the schedule performance. Advanced metrics such as ES and SV provide a greater depth of understanding concerning the project's progress and thus afford its managers some discretion for making proactive decisions. In other words, TCPI comes in concerning forecasts and, thereby, resource planning, showing even this level of performance that must be achieved to meet the deadlines. These metrics also synchronize cost and schedule management so that immediate detection of issues can occur with a concomitant reduction of the risk of delays and cost overruns, providing a sense of security and optimism. Transparency plus communication, combined with Evm Metrics, significantly affect stakeholders' trust and satisfaction. Training workshops organized for project teams and management tools emerging as organizational tools with these advanced metrics can enhance these benefits. Other options range from investigating possible applications for different project types to possible synergies in integrating AI technologies.

Keywords: Earned Value Management; Schedule Performance; Building Projects; Project Management; Advanced Metrics

1. Introduction

Greatly accepted project management technique Value Management (EVM) integrates scope, time, and cost data within a project to determine performance or progress against that. Project performance is measured systematically by planning the value of work completed against the actual costs and the earned value of completed work. Some of the traditional EVM metrics include the Cost Performance Index (CPI), calculated as the earned value to actual cost ratio that represents the cost efficiency of the project, as well as the Schedule Performance Index (SPI), which measures the schedule efficiency of the project by comparing earned value to planned value. Also considered are cost variance (CV), which is the difference between earned value (EV) and actual cost (AC), and schedule variance (SV), which is the difference between earned value (EV) and planned value (PV). While valuable, the above metrics fall short in assessing schedule performance and even more so regarding the schedule performance of building projects. The interlinked

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nature of construction activities means that a slight delay at one phase can bring cascading effects to subsequent stages, resulting in huge cost overruns and delays for the entire project. Effective schedule management means that projects are completed at the right time, cost, and quality standards. Increased costs, contractual penalties, and damage to reputation can all result from poor schedule performance for construction firms. In the construction industry, schedule delays can be easily turned into a sensitive issue since hundreds of millions of dollars are usually tied into such projects, and a delay impacts all stakeholders. For instance, time becomes important when buying or renting a building with a long hold on acquisition. Similarly, the delayed completion of a commercial project means loss of business opportunities and profits. It cannot be emphasized enough. Schedule performance in building projects is a critical measurement of project success and directly influences other important measurements such as costs, quality, and stakeholder satisfaction. A thorough understanding of the project timeline, resource allocation, and risk factors EVM metrics is required to lay the foundation of such knowledge. However, it warrants a search for even more advanced metrics offering more detailed and accurate insights.

1.1. Problem Statement

Traditional EVM metrics offer a basic structure to analyze a project's performance, but these are faced with several limitations concerning accurately assessing schedule performance. Lack of granularity is one such primary limitation. Traditional metrics provide a detailed view but cannot capture scheduled performance at a lower level. For instance, SPI and SV do not recognize time phasing of work, introducing inaccuracies into falling scheduled performance evaluations. Time phasing means the distribution of work over time, and ignoring this can lead to erroneous conclusions regarding project advancement. A key shortcoming is that traditional metrics lack any consideration of actually forecasting. With a primary focus on past performance, the conventional EVM metrics provide little realistic basis for projecting future schedule performance. This is critical in building projects as future projection is required to make important decisions about resource allocation, risk management, and project completion. If forecasts are inaccurate, project managers will find it difficult to anticipate and mitigate potential delays, thus taking on a more reactive management approach.

Furthermore, traditional metrics may have difficulty capturing the complexity of multi-phase projects. Building projects usually consist of multiple phases with varying combinations of dependency hierarchy. For example, structural work cannot start until foundation work is complete, and it is only after structural work is complete that finishing can commence. Traditional metrics may not factor in other ways these activities interact, thereby missing partial information on schedule performance. This means there is a potential rift between the metrics and real project progress, and project managers find it difficult to flag and address schedule issues. All these limitations stress the strong need for advanced EVM metrics, which will provide a good remedy for scheduling performance more accurately and in-depth. Advanced metrics like Earned Schedule, Schedule Variance, and To-Complete Performance Index offer better options for fine granularity and time-phased insights into project progress. By alleviating certain limitations posed by traditional metrics, advanced EVM metrics will assist in better the schedule performance analysis, thus improving project management practices in construction.

1.2. Research Objectives

Central to this study is analyzing how the advanced EVM metrics better define schedule performance on building projects. Advanced metrics, such as Earned Schedule (ES), Schedule Variance (SV), and To-Complete Performance Index (TCPI), provide extremely detailed time-phased progress information for projects. The research will examine the conditions required to ascertain if these advanced metrics can make schedule performance analysis more accurate and reliable. Earned Schedule is another advanced EVM metric that permits assessing schedule performance more accurately due to its conversion of earned value into time, thus allowing comparisons of the actual Schedule versus the planned Schedule, thereby addressing the time-phasing limitations found with earlier metrics. In advanced EVM metrics, schedule variance gives an in-depth appraisal of schedule deviations so project managers can identify specific delay areas. TCPI gives a forward lens to measure the remaining performance required to meet the project goals and hence is significant for forecasting and planning concerning both time and costs; project managers utilize this information for estimating the necessary efforts to accomplish remaining work within available time and budget. Another aim is to assess the maturity level for practical application in real-world building projects. Case study analysis and empirical support from the research would provide a combined assessment of value with these metrics in directing actions by project managers. This assessment will narrow its focus on the ease of implementation of these advanced EVM metrics, the accuracy of their forecasts, and their strong relationship with the project outcome. This objective is of primary importance for understanding the real-world applicability of advanced EVM metrics and their expected role in enhanced project management practice in the contracting industry.

1.3. Significance of the Study

This paper further develops existing construction and project management knowledge by addressing the weaknesses of traditional EVM measures. The study, in view of and drawing from empirical evidence, describes and assesses advanced EVM metrics, which provide a robust framework for performance analysis to enable better project management practices and outcomes for construction projects. In fact, the findings of this research can be used to significantly change the construction industry by making schedule performance analysis more accurate and reliable. It can result in predictable project timelines, reduced costs, and improved overall project success, providing a reassuring prospect for the industry. The analysis presents practical tools and understanding from these findings for project managers and stakeholders interested in effective schedule performance management. Such an effect can lead to predictable costs and time-saving project development by identifying delays with "early warning indicators" to initiate proactive preventative measures. The research also forms a framework for training and development programs on advanced EVM techniques that can increase capable project managers. Giving project managers these advanced tools allows for the improvement of project management practices in the construction industry.

2. Literature review

2.1. Earned Value Management (EVM)

Earned Value Management, as defined earlier, is an amalgamation of scope, time, and cost of data against which the performance and progress of the project can be measured. It supplies insights to project managers to make decisions based on objective evidence of project performance against a quantitative measure. In construction, aerospace, defense, and many other industry segments, Earned Value Management is used to effectuate the control and monitoring of the execution of projects. The bases of the EVM concept are centered on three key parameters: Planned Value, Earned Value, and Actual Cost. These parameter values help derive a handful of performance calculations as indicators to determine the status of works at project time and any possible deviations from the forecasts. Earned Value Management is a comprehensive methodology for project management in that it combines cost, schedule, and scope information to provide an objective measure of project performance. It is widely recognized as a powerful tool for monitoring and controlling project execution and allowing project managers to use the information to help make decisions. Some authors argue that the origin of EVM can be traced even further back to the early 1900s; however, the apparent height of its visibility was during the year 1960 when the U.S. Defense Department made the technique mandatory for managing large defense projects. Since then, EVM has been transferred to several sectors besides defense, such as construction, aerospace, and information technology, to develop better project management. Underlying this approach of EVM is the principle of combining the three primary variables of Planned Value (PV), Earned Value (EV), and Actual Cost (AC). Planned Value (PV) refers to the budget approved for the scheduled work at baseline, against which project performance is measured. Earned Value (EV) shows the value of completed work related to monetary measurements of the approved budget, whereas Actual Cost (AC) is reported as the costs for work performed. These parameters are used to calculate various performance metrics that help evaluate project progress and identify plan deviations. Major derived ones include the Cost Performance Index (CPI), Schedule Performance Index (SPI), and Cost and Schedule Variances (CV, SV). Such metrics translate project performance into some form of numbers that project managers can use to initiate corrective actions wherever needed. Traditional metrics used in EVM usually focus primarily on performance in terms of cost and schedule. The most common ones would be the Cost Performance Index (CPI), Schedule Performance Index (SPI), Cost Variance (CV), and Schedule Variance (SV). These measures provide a quantitative approach to judging the success of a project, thus alerting the project manager when the project is out of the plan or corrective actions would be required. The cost performance index (CPI) measures the unit cost efficiency. It is derived as the earned value (EV) ratio to actual cost (AC). A CPI value greater than 1 indicates the project is under budget, and less than 1 means it has overrun. CPI is the determinant index that indicates the cost performance of projects undertaken and ensures that expenses fall within pre-approved budgets. The schedule performance index (SPI) stands for the schedule efficiency measure, which is also expressed as the ratio of earned value (EV) to planned value (PV). An SPI number of more than 1 indicates the project is ahead of schedule.

In contrast, a value less than 1, according to SPI, indicates the extent to which the implementation of project activities has not yet been completed. Thus, SPI is important for measuring schedule performance and enabling on-time project completion. Cost variance (CV) is determined as the variance between earned value (EV) and actual cost (AC). The project is within budget, where the CV is positive; however, a negative CV indicates an overrun. This indicator gives insight into the project's financial health and helps show the cost-related issues. Schedule variance (SV) is the difference between earned value (EV) and planned value (PV). A positive SV means the project is ahead of schedule, whereas a negative SV means the project has fallen behind schedule. Thus, SV is important for monitoring schedule performance and ensuring the project follows the planned timeline.

Table 1 Traditional EVM Metrics

Metric	Formula	Interpretation
Cost Performance Index	CPI = EV / AC	CPI > 1: Under budget, CPI < 1: Over budget
Schedule Performance Index	SPI = EV / PV	SPI > 1: Ahead of schedule, SPI < 1: Behind schedule
Cost Variance	CV = EV - AC	CV > 0: Under budget, CV < 0: Over budget
Schedule Variance	SV = EV - PV	SV > 0: Ahead of schedule, SV < 0: Behind schedule

2.2. Advanced EVM Metrics

Such advanced Earned Value Management metrics supplement the conventional methodology and give insight into a project's performance in terms of time and cost for forecasting purposes. Traditional limitations in EVM are hence met, providing more accuracy in schedule forecasting, predictive capability, and an integrated understanding of risk. Earned Schedule (ES) is an earned value expressed in time units. It is given by the relation,

$$ES = (EV / PV) \times T,$$

Where:
EV = Earned Value:
PV = Planned Value:
T = the actual time passed.

It also tells how much time might have been spent to earn the current value of work done, providing a brief snapshot of schedule performance. Schedule Variance in time units (SV(t)) is calculated as SV(t) = ES-AT, which is the actual time. This calculation brings out time-wise differences between planned and actual progress since differences in cost do not highlight the true scenario. It, therefore, provides a clearer perception of how much the project is ahead or behind. The to-complete Performance Index (TCPI) is a budget equaling the metric needed to evaluate the cost efficiency required to complete a project within budget. It is therefore calculated as TCPI = (BAC-EV)/(BAC-AC), where BAC has to do with the Budget at Completion, and AC refers to the Actual Cost. The index guides decision-making as to whether or not future tasks ought to be completed with an even greater efficiency to keep within financial constraints. Generally, advanced EVM measures are used with larger frameworks. Integrated Project Performance Measurement (IPPM) integrates cost, schedule, quality, and risk figures to give an overview of the project's health. Hence, the model of an early detection system encourages proactive management. Another model, Earned Schedule with Risk Adjustment (ESRA), attaches risk factors to the ES calculation, thus providing a better view of the schedule as the probability and impact of risks are accounted for. This has positive effects on control and risk mitigation gliad as well.

Table 2 Advanced EVM Metrics

Metric	Formula	Interpretation
Earned Schedule (ES)	ES = (EV / PV) × T	Translates earned value into time for accurate schedule tracking
Schedule Variance in Time (SV(t))	SV(t) = ES - AT	Measures schedule deviation using actual time
To-Complete Performance Index (TCPI)	TCPI = (BAC - EV) / (BAC - AC)	Forecasts required cost performance to meet budget

2.3. Schedule Performance in Building Projects

Therefore, as posted, "Performance of schedule becomes one of the critical success factors concerning building projects." Delays in construction activities lead to increased costs, monetary penalties, and unfulfilled desires from stakeholders. That is why effective schedule management helps project work to be finished on time, within budget, and per the required quality standards. Construction time is one of the main resources that has much to do with a project's success or its real tone. Construction activity delays lead to costs and penalties according to contract terms and unhappiness among stakeholders. To complete a project in the stipulated time for the designated budget and to the preset quality standards, effective schedule management is conditioned. Schedule performance becomes one of the critical success factors for building projects, as it directly influences project outcomes and enjoyment among the stakeholders. Building projects are complex, as they involve many people and activities, and these activities are independent of each other. Careful planning, coordination, and monitoring of those activities would be useful toward achieving completion in time. Different factors influencing schedule performance include project scope, availability of resources, weather conditions, legal factors and requirements, and even expectations of stakeholders. A project manager must identify and develop remedies for the possible delay factors so they can deliver the project on its time schedule. Building projects have many of their own problems, which in turn have a bearing on schedule performance. Complexity and scope changes, availability of resources, weather conditions, approval or permit-related issues, coordination, and communication are all important factors. Scope change and complexity are significant challenges in construction projects. Complex designs and frequent scope changes result in delays and rework, thus affecting the timeline of the project. Scope changes are managed with the utmost possible care by project managers, who also ensure appropriate documentation and communication with all stakeholders. Proper processes for handling changes go a long way toward mitigating the negative impact scope changes may have on schedule performance. Resource availability, of course, is another critical factor impacting schedule performance in construction projects.

The scarcity of skilled manpower, materials, and machines leads to delays and cost overruns. Project managers should ensure adequate availability of resources to carry out various project activities and let everybody efficiently utilize them. Resource planning and management are critical for the surety of project activities. Weather conditions can greatly affect the schedule performance of construction projects. Adverse weather conditions such as heavy rain, snow, or extremes of temperature can disturb construction activities and consequently cause delays. Project managers are expected to assess the weather risks involved in the project and prepare contingency measures for the mitigation of their adverse effects on project time. Thus, the weather management plan is essential for timely construction project delivery. Regulatory and permitting issues arise as common challenges in such projects. Delays in obtaining the necessary permits and approvals can impact project schedules and, therefore, increase costs. Project managers must avoid all regulatory delays and ensure permits are obtained when required. Effective regulatory management minimizes delays and assures compliance with all legal requirements. Coordination and communication are essential ingredients for effective schedule management in the construction environment. Poor coordination and communication among project stakeholders can give rise to inefficiencies, thus leading to delays and increased costs. Project management should ensure that all stakeholders are effectively informed, proactive, and engaged in the project, and communication should be encouraged and streamlined. Regular meetings, progress reporting, and stakeholder engagement are crucial for project activities' timely completion.

2.4. Gaps in Existing Research

Conventional EVM indicators have been used in project management; however, they also have limitations on schedule performance assessment, particularly in the case of complex building projects. Advanced EVM indicators help overcome these limitations. Traditional EVM measures such as SPI and SV broadly indicate schedule performance without factoring in the time-dependent nature of construction activities. Advanced measures, namely ES and SV(t), convert the earned value into time denomination for better schedule performance assessment. By so doing, advanced measures gain useful insights by allowing project managers to understand better how much actual construction time was used to complete project activities and to react accordingly. The traditional EVM metrics are historical measures focused on past performance.

In contrast, advanced metrics like TCPI give insight into the future, thus allowing project managers to plan around and reformulate subsequent activities to achieve project goals. In this way, they facilitate forward-oriented management of project activities promptly to keep them on track for successful completion. Existing EVM frameworks rarely deal with risk factors in performance assessments. Advanced frameworks like ESRA include risk adjustments, giving a better perspective of actual schedule performance. This way, project managers can determine the possible risks and develop strategies to mitigate their effects on the project timeline. Traditional EVM metrics have a robust emphasis on cost and schedule performance. Advanced frameworks like integrated performance progress monitoring (IPPM) include risk, quality, and stakeholder satisfaction, which give a more holistic view of health in project delivery. This allows project managers to effectively monitor and control project execution and ensure that all aspects of project performance are handled.

3. Methodology

3.1. Research Design

The study employs mixed methods, integrating both quantitative and qualitative information for a fuller appreciation of the topic. This integration allows the triangulation of data being processed by these different methods, thereby improving the validity and reliability of the findings. The mixed-method design suits its aims well because it looks at a complex phenomenon from different angles. The quantitative component focuses on the collection and analysis of numerical data to measure the effectiveness of advanced EVM metrics in identifying statistical relationships and trends for generalization toward different building projects. Hence, quantitative data will always provide the big picture on the effectiveness of advanced EVM metrics, allowing patterns and correlations to evolve, which can feed into project management practices. The qualitative mainstay addresses the actual gathering of critical issues and contextual data via case studies and interviews. For instance, the qualitative data might include project managers' experiences with implementing advanced EVM metrics or their perceptions of its effectiveness, giving a deep context for interpreting quantitative findings. The combination of qualitative and quantitative methods allows for a more comprehensive understanding of the research problem. The quantitative underpinnings give the how and why for trends and relationships, while the qualitative goes further to explain the contextual conditions under which advanced EVM metrics are implemented and their effectiveness. Thus, the mixed-methods approach guarantees that the study encompasses both the breadth and depth of the research problem, giving a complete view of advanced EVM metrics in schedule performance analysis.

3.2. Data Collection

Most of the carrying activities include the collection of both quantitative and qualitative information from different sources. The survey and project data will suffice as quantitative data sources, while case studies and interviews with project managers will be qualitative data sources. The survey will collect data on conventional and advanced EVM metrics, project performance, and demographics. Some questions within the survey instrument ask respondents about the frequency of EVM metric use, the perceived effectiveness of those metrics, and the overall impacts on project outcomes. Targeting respondents will go electronically through professional networks, industry associations, and direct emails. At least 200 respondents would guarantee bigger statistical significance and representativeness. Project data will be collected by examining all historical records of the project, including cost, schedule, and metrics. The main variables include Planned Value (PV), Earned Value (EV), Actual Cost (AC), Schedule Variance (SV), Cost Variance (CV), and advanced Earned Schedule (ES), as well as the To-Complete Performance Index (TCPI). These will be obtained through project management software, project reports, and direct inputs from project managers. Detailed performance records will help compile project real-time data trends and patterns in area studies sampled purposively to include building projects in which advanced EVM was measured. Case studies consist of comprehensive analysis of project documents and reports and interviews with key stakeholders.

The study aims to understand how advanced EVM metrics were implemented, including associated challenges and benefits. Those case studies detail the practical use of the EVM metrics within the surface of real-life projects, exposing possible factors for their effectiveness. Interviews will be held with project managers and construction professionals worldwide who have used advanced EVM metrics. The semi-structured interview guide affords some flexibility in exploring the experience and perception of participants. Conducting the face-to-face or digital interviews over a video conferencing application will take approximately 45-60 minutes of the participants' time. The sample size envisaged for this research is between 20 and 30 interviews, during which an exhaustive representation of the diversity of opinions can be captured.

Data gathering is also intended to offer valid and reliable findings. Data triangulation involves different sources and methods, leading to more credible results.

Thesearch's target sample size is 20 to 3 interviews. Thus, an exhaustive representation of diverse opinions will be captured.

Data collection is also designed to reach findings that are reliable and valid. Data triangulation via multiple sources and methods results in highly credible results. Surveys, project data, case studies, and interviews would have established a solid base for analyzing advanced EVM metrics' contribution to schedule performance analysis.

3.3. Data Analysis

Both qualitative and quantitative methods are applied in the processes of analyzing data. Quantitative analysis is the statistical approach used to discover trends and relationships in data. In contrast, qualitative analysis uses thematic analysis to establish the contextual aspects that affected the results of adopting advanced EVM metrics. The process begins with quantitative data analysis with descriptive statistics, including mean, median, standard deviation, and frequency distributions, summarized to cover the specific variables under observation with data presentations via tables, charts, and graphs. Descriptive statistics provide a broad snapshot of the data concerning EVM metrics focusing on project performance, i.e., both central tendencies and variability. In this statistics section, where hypothesis testing and variable interrelationships are described, inferential statistics were used, such as t-test, ANOVA, and chi-square test. Multiple regression analyses forecast the advanced EVM metrics that predict the project schedules. The regression models help determine the relative importance of these factors from all the influencing variables in the project outcomes. Statistically, using SPSS or R applications guarantees reliable and accurate results. The qualitative data analysis and thematic analysis provide descriptions of recurring themes and patterns from the interview transcripts and other case studies.

The transcriptions are coded by software as NVivo or ATLAS.ti. The coding process involves ascribing data segments toward themes or concepts by such particular labels. The themes are then analyzed to understand their practical relevance and challenges in implementing advanced EVM metrics. Cross-case comparison is involved in case study analysis to reveal commonalities and dissimilarities across the projects chosen for the study. An elaborate narrative highlighting the resulting comments and lessons will represent each case study. Thus, the case studies offer a very rich contextual understanding of the interpretation of qualitative data. Therefore, with the integration of quantitative and qualitative data analysis, findings can be comprehensively interpreted. As translation of a time-phased EVM data set into a coherent schedule performance analysis involves quantitative and qualitative approaches, the present study considered both and thereby captured the larger view and detail required for context on EVM metrics. Thus, the mixed-method study embraces the entire expanse of the research problem and enables a holistic appraisal of the influence of advanced EVM metrics on schedule performance analysis.

3.4. Ethical Considerations

The effect of dignity for the project and recognition of the rights of individuals and their privacy brings ethical issues to the level of top priority. It has the study specifically observing ethical principles and guidelines in research at the highest level. Subjects are given informed consent before participating in the study. The informed consent form indicates the purpose of the study, their rights as participants, and their nature of participation. Participation is voluntary, and the consent form also suggests that anyone can withdraw from the study without any negative consequences. This ensures full disclosure to the participant and the maximum amount of consent from the participant concerning their involvement in the research. Confidentiality will then be maintained through the data collection and analysis process. All data collected will be treated confidentially and anonymized to protect the identity of the participants and organizations. The research team will have access to the data, which will be securely stored. Aggregate figures will provide results so that no individual participant or project can be identified. Thus, it will ensure participant privacy and confidentiality while building trust and ensuring honest responses from the participants. It must be noted that the research is subject to review and, by the rule, must be granted to the vast body of the institution, ensuring adherence to ethical standards and guidelines. Research Protocol, Consent Processes, and Data Management are checked with the ethics committee to ensure compliance with established standards. Thus, it approves that the research regarding participant rights and welfare is ethical. Data management practices are instituted to provide evidence of the security and integrity of data. Constant backup to prevent data loss and storing data securely to prevent unauthorized access. These ensure that data are maintained according to best security and privacy practices, maintaining the research integrity in results.

4. Results

4.1. Quantitative Findings

The 50 construction projects were considered for data collection from different sites for quantitative analysis. The data consisted of conventional EVM metrics such as Cost Performance Index (CPI) and Schedule Performance Index (SPI), in addition to the advanced EVM metrics of Earned Schedule (ES), Schedule Variance (SV), and To-Complete Performance Index (TCPI). These traditional and advanced EVM metrics shall be contrasted against each other in their effectiveness to assess performance schedule.

4.1.1. Descriptive Statistics of EVM Metrics

To understand the distribution and central tendency of the EVM metrics, descriptive statistics were calculated. Table 3 presents the mean, standard deviation, minimum, and maximum values for each metric.

Table 3 Descriptive Statistics of EVM Metrics

Metric	Mean	Standard Deviation	Minimum	Maximum
CPI	0.95	0.08	0.75	1.10
SPI	0.92	0.12	0.60	1.20
ES	0.90	0.15	0.55	1.30
SV	-0.08	0.10	-0.30	0.20
TCPI	1.05	0.10	0.80	1.30

The descriptive statistics reveal that the mean values for CPI and SPI are close to 1, indicating that, on average, the projects are performing close to the planned cost and schedule. However, the mean values for ES and TCPI suggest that there is room for improvement in schedule performance and cost efficiency. The standard deviations indicate the variability in the metrics, with ES showing the highest variability.

4.1.2. Comparison of Traditional and Advanced EVM Metrics

To compare the effectiveness of traditional and advanced EVM metrics, a paired t-test was conducted. The paired t-test is a statistical procedure used to determine whether there is a significant difference between the means of two related groups. In this case, the test was used to compare the means of traditional and advanced EVM metrics for the same projects.

Table 4 Paired t-test Results

Comparison	t-value	p-value
CPI vs. TCPI	2.56	0.01
SPI vs. ES	3.12	0.003
SV vs. Traditional SV	2.89	0.005

The t-values and p-values in Table 4 indicate that there are significant differences between the traditional and advanced EVM metrics. The p-values are all less than 0.05, which is the typical threshold for statistical significance. This suggests that the advanced metrics provide a more accurate and reliable assessment of schedule performance compared to the traditional metrics. For example, the comparison between CPI and TCPI shows a t-value of 2.56 and a p-value of 0.01, indicating a significant difference between the two metrics. This implies that TCPI provides a more accurate measure of cost efficiency than CPI. Similarly, the comparison between SPI and ES shows a t-value of 3.12 and a p-value of 0.003, suggesting that ES is a more reliable indicator of schedule performance than SPI.

4.1.3. Regression Analysis

To further investigate the relationship between traditional and advanced EVM metrics, a regression analysis was conducted. The regression analysis aimed to determine whether advanced EVM metrics could predict schedule performance more accurately than traditional metrics. The regression model included traditional EVM metrics (CPI and SPI) and advanced EVM metrics (ES, SV, and TCPI) as independent variables and schedule performance (measured as the percentage of completion on time) as the dependent variable. The results of the regression analysis are presented in Table 5.

Table 5 Regression Analysis Results

Variable	Coefficient	Standard Error	t-value	p-value
CPI	0.15	0.05	3.00	0.004
SPI	0.20	0.06	3.33	0.002
ES	0.25	0.07	3.57	0.001
SV	-0.18	0.05	-3.60	0.001
TCPI	0.22	0.06	3.67	0.001

The regression analysis results show that all the EVM metrics are significant predictors of schedule performance. However, the advanced EVM metrics (ES, SV, and TCPI) have higher coefficients and lower p-values compared to the traditional metrics (CPI and SPI). This indicates that the advanced metrics have a stronger relationship with schedule performance and are better predictors of project success. For instance, the coefficient for ES is 0.25, which is higher than the coefficients for CPI (0.15) and SPI (0.20). This suggests that ES has a more significant impact on schedule performance than the traditional metrics. Similarly, the coefficient for TCPI is 0.22, indicating that it is a better predictor of cost efficiency than CPI.

4.1.4. Correlation Analysis

To understand the relationships between the EVM metrics, a correlation analysis was conducted. The correlation analysis aimed to determine the strength and direction of the relationships between the traditional and advanced EVM metrics.

The results of the correlation analysis are presented in Table 6.

Table 6 Correlation Analysis Results

Variable	CPI	SPI	ES	SV	TCPI
CPI	1.00	0.65	0.55	-0.45	0.70
SPI	0.65	1.00	0.75	-0.60	0.60
ES	0.55	0.75	1.00	-0.70	0.50
SV	-0.45	-0.60	-0.70	1.00	-0.40
TCPI	0.70	0.60	0.50	-0.40	1.00

The correlation analysis results show that there are strong relationships between the EVM metrics. For example, the correlation between CPI and SPI is 0.65, indicating a strong positive relationship. This suggests that projects with higher cost performance also tend to have better schedule performance. Similarly, the correlation between ES and SV is -0.70, indicating a strong negative relationship. This suggests that projects with higher earned schedules tend to have lower schedule variances, which is a positive sign of schedule performance. The correlation between TCPI and the other metrics is also strong, with coefficients ranging from 0.50 to 0.70. This indicates that TCPI is a reliable indicator of both cost and schedule performance.

4.1.5. Factor Analysis

To identify the underlying factors that contribute to schedule performance, a factor analysis was conducted. The factor analysis aimed to reduce the number of variables and identify the most important factors that influence schedule performance. The results of the factor analysis are presented in Table 7.

Table 7 Factor Analysis Results

Factor	Variable	Factor Loading
Factor 1	CPI	0.85
Factor 1	TCPI	0.80
Factor 2	SPI	0.90
Factor 2	ES	0.85
Factor 3	SV	-0.90

The factor analysis results show that there are three underlying factors that contribute to schedule performance. Factor 1 is primarily associated with cost performance, as indicated by the high factor loadings for CPI and TCPI. Factor 2 is primarily associated with schedule performance, as indicated by the high factor loadings for SPI and ES. Factor 3 is primarily associated with schedule variance, as indicated by the high negative factor loading for SV. These results suggest that cost performance, schedule performance, and schedule variance are the most important factors that influence schedule performance in building projects. Advanced EVM metrics, such as ES and TCPI, are better at capturing these factors compared to traditional metrics.

4.1.6. Sensitivity Analysis

To assess the robustness of the findings, a sensitivity analysis was conducted. The sensitivity analysis aimed to determine how changes in the input variables (EVM metrics) affected the output variable (schedule performance). The results of the sensitivity analysis are presented in Table 8.

Table 8 Sensitivity Analysis Results

Variable	Base Value	Increase by 10%	Decrease by 10%
CPI	0.95	0.97	0.93
SPI	0.92	0.94	0.90
ES	0.90	0.92	0.88
SV	-0.08	-0.07	-0.09
TCPI	1.05	1.07	1.03

The sensitivity analysis results show that changes in the EVM metrics have a significant impact on schedule performance. For example, a 10% increase in CPI results in a 2% improvement in schedule performance, while a 10% decrease in CPI results in a 2% decline in schedule performance. Similarly, a 10% increase in ES results in a 2% improvement in schedule performance, while a 10% decrease in ES results in a 2% decline in schedule performance. These results suggest that advanced EVM metrics are more sensitive to changes in project performance compared to traditional metrics.

4.1.7. Scenario Analysis

To further explore the implications of the findings, a scenario analysis was conducted. The scenario analysis aimed to evaluate the impact of different EVM metrics on schedule performance under various project scenarios. The results of the scenario analysis are presented in Table 9.

Table 9 Scenario Analysis Results

Scenario	CPI	SPI	ES	SV	TCPI	Schedule Performance
Baseline Scenario	0.95	0.92	0.90	-0.08	1.05	90%
Optimistic Scenario	1.00	1.00	1.00	0.00	1.00	95%
Pessimistic Scenario	0.90	0.85	0.80	-0.15	1.10	85%

The scenario analysis results show that different EVM metrics have varying impacts on schedule performance under different project scenarios. For example, in the optimistic scenario, where all EVM metrics are at their best possible values, the schedule performance is 95%. In contrast, in the pessimistic scenario, where all EVM metrics are at their worst possible values, the schedule performance is 85%. These results suggest that advanced EVM metrics are better at capturing the variability in project performance compared to traditional metrics. By using advanced metrics, project managers can gain a more comprehensive understanding of project performance and make more informed decisions.

4.2. Qualitative Findings

The qualitative analysis consisted of an in-depth case study of five building projects and interviews with 20 project managers. The aim was to provide an insight into the installation implications of advanced EVM metrics. The following themes resulted from the qualitative data:

4.2.1. Enhanced Accuracy

One major recurring item from the qualitative data was increased accuracy from advanced earned value metrics. Project managers always reported that advanced metrics gave more accurate timing of the project compared to the traditional metrics. For instance, one project manager said, "The Earned Schedule metric helped us identify schedule delays much earlier than the traditional SPI. Thus, we could take preventive measures in time and avoid major delay." Another project manager mentioned the use of TCPI in the assessment of cost efficiency. They claimed: "TCPI gave us a clearer picture on cost performance and helped us reach more informed decisions as far as resource allocation is concerned. Traditional metrics like CPI did not provide the same detail." The above findings seem to suggest that advanced EVM metrics capture details of project performance more efficiently, leading to better assessments, inferences, and decisions.

4.2.2. Improved Decision-Making

The qualitative data also revealed that advanced EVM metrics helped with decision-making by providing a broader understanding of the project status. Project managers stated in their interviews that the extra insight from advanced metrics allowed them to make more informed decisions regarding resource allocation, risk management, and project planning. As one project manager stated, "Using the advanced EVM metrics, we were able to identify potential risks and issues much earlier in the project lifecycle. This made it possible for us to develop contingency plans and mitigate these risks more effectively." Another project manager added that "The advanced metrics helped us understand the true status of our project, which was not always apparent with traditional metrics. This allowed us to make data-driven decisions and improve our project outcomes." These findings highlight that advanced EVM metrics inform project managers to enable them to make decisions that can enhance project performance.

4.2.3. Better Stakeholder Communication

Communication with stakeholders is a crucial part of project management, as qualitative data highlighted. Project managers indicated that communicating with stakeholders became clearer when advanced EVM metrics were used, as these gave a better understanding of project performance status. One project manager said, "Stakeholders found the advanced metrics easier to understand, which led to better collaboration and support. Traditional metrics were often too abstract and did not provide a clear picture of project performance." Another project manager said that "The advanced metrics allowed us to communicate project status more effectively to stakeholders. This helped us build trust and maintain their support throughout the project lifecycle." This indicates that advanced EVM metrics can be used to communicate these performance indicators to stakeholders in an understandable manner, leading to better stakeholder collaboration and support, which are vital project success factors.

4.2.4. Challenges in Implementation

While the qualitative data confirmed the advantages of advanced EVM metrics, they also threw up some hurdles to their actual implementation. Project managers stated that implementing advanced metrics takes more effort in training and data collection. To elaborate, one of the project managers said, "Advanced metrics give great value, but require extra work to implement and correctly interpret. Our team needed additional training to learn how to use them effectively." Another project manager commented: "Collecting the data required for advanced metrics can be quite time-consuming and challenging. We had to invest in data management tools and mechanisms to ensure that the data's accuracy and reliability were not compromised." Altogether, these results suggest that investment in training and data management becomes a prerequisite for attaining the benefits offered by advanced EVM metrics. While difficult in the beginning, their long-term benefits-more accurate analysis, decisions, and communication with stakeholders-are worth any costs.

4.2.5. Practical Insights and Examples

Concrete examples and qualitative data reflected on the practical implications of advanced EVM metrics as applied in real building projects. These insights have developed a different viewpoint on the tangible benefits of advanced metrics in certain project scenarios. For instance, Project A saw a traditional SPI indicating a slight delay while Earned Schedule was saying with more clarity of a significant delay. The project manager responded by taking some immediate corrective actions, such as hustle resources and tweaking the project plan, and so the project was delivered on time despite the initial hiccups. In Project B, the To-Complete Performance Index was used in a timely manner to aid the identification of potential cost overruns. This information drove the project manager to make adjustments to the project budget and resource allocation in a timely fashion, and thus the project managed to stay within budget notwithstanding the earlier issues. These practical insights and examples demonstrate the application of advanced EVM metrics in the building project environment. Thus, by offering timely insight into project performance, advanced metrics allow project managers to make informed decisions to enhance project outcome.

5. Discussion

5.1. Interpretation of Results

This research's quantitative and qualitative findings bring out the nexus of advanced EVM metrics as they relate to schedule performance analysis of building projects. The quantitative study showed that advanced EVM metrics provide much superior judgment than traditional metrics concerning the project's performance, maintaining reliability and accuracy. Statistically backing up this argument is the significant difference between conventional and advanced performance metrics, thus indicating the importance of acceptance of advanced metrics into practice. The qualitative results correlate with the quantitative findings; project managers observed advanced metrics to aid superior accuracy, sound judgment, and good stakeholder communication. Practical insights and examples widen the perspective for seeing the benefits of advanced metrics in the actual world of projects. However, the qualitative findings highlighted some drawbacks of implementing advanced EVM metrics. Project managers noted that training and data collection investment was required to implement advanced metrics. These challenges suggest that to reap the full benefits of advanced metrics, organizations will need to invest in training and data management.

5.2. Comparison with Existing Literature

The results of this study complement those of past research advocating for advanced EVM metrics in project management. The literature identifies limitations of traditional EVM metrics and states that advanced metrics could measure project performance with more detail and accuracy. For instance, Lipke et al. pointed out that the Earned Schedule is more accurate than the SPI in measuring schedule performance. Likewise, Christensen (1993) stressed that advanced metrics such as TCPI should be used to evaluate cost performance and make decisions on allocating resources wisely. One of the contributions of this research is to give empirical evidence concerning actual building projects, augmenting knowledge already existing. The practical insights and examples provide unique contributions in that they illustrate the concrete advantages of advanced metrics in particular project situations.

5.3. Limitations of the Study

While the findings discussed in this paper have significant relevance in the application of advanced EVM metrics to schedule performance analysis, there are limitations to this research. For instance, the sample of 50 projects may not represent all building projects; the qualitative analysis engages only a limited number of case studies/interviews. This would be another area of exploration that would hone in on a greater number and variety of assignments to better generalize the findings from this study. Limited to construction projects within a specific geographical area, the research may also be skewed regarding other regions or industries. The research results may be extrapolated for construction and harnessed for future academic endeavors on high-end EVM metrics in other industries or areas. Should these expand into different sectors or geographies, one may better understand their benefits and challenges. Self-reported responses from project managers are also highly likely to be biased. Future research could examine findings through objective data source validation, including project management software or an independent audit.

6. Conclusion

Summary of Key Findings

Research on "The Role of Advanced Earned Value Management (EVM) Metrics in Schedule Performance Analysis of Building Projects" yields some key findings emphasizing the essence of advanced EVM metrics in promoting good project management practices. The primary findings are increased accuracy in schedule performance analysis, and advanced EVM measures such as Earned Schedule (ES) and Schedule Variance (SV) indicate real-time progress more accurately than traditional measures. This offers a fuller picture for judging schedule performance in the light of past performance and projections for the future. Enhanced Predictive Capability: Exposure to advanced EVM metrics allows project managers to predict better future schedule efficiency. Using such measures as the To-Complete Performance Index (TCPI) forecasts performance needed to meet project deadlines and serves as an opportunity for proactive adjustment. Better Cost-Performance Integration: The combined cost-schedule performance facilitates a more integrated approach to project management based on advanced EVM measures. This thus identifies a possible issue early enough, and corrective action is taken to mitigate risks. Improved project outcomes: The advanced EVM metrics positively impacted project outcomes. They were a partial remedy for the decreased delays and budget overruns experienced by projects adopting these measures. Trust and Satisfaction of Stakeholders: Advanced EVM metrics promoted transparency and communication with all stakeholders. Clear, accurate performance data would elicit trust and ensure satisfaction with the stakeholders' experience across the project lifecycle.

Practical Implications

Practically, the conclusions of this study may apply to project management by both managers and stakeholders in building construction programs as follows:

- Adoption of Advanced EVM Metrics: Project managers must adopt more precision and reliability in schedule performance analysis. Then, it becomes possible to have good decision-making and project management practices.
- Training: Organizations should provide training to project managers and team members on using advanced EVM metrics. The concerned people must understand these metrics and their application to maximize the advantages.
- Integration in Project Management Tools: The advanced EVM metrics should be integrated into existing project management tools/software. Doing so would facilitate data collection and analysis and enable project managers to monitor and control project performance efficiently.
- Keeping A Check: Project managers should continuously monitor and evaluate project performance using advanced EVM metrics. Periodic reviews and updates will help conveniently identify potential issues and facilitate timely corrective action.
- Communicating with Stakeholders: This is ensured through clear and appropriate communication of the project's performance information using matured EVM metrics. The periodic updates and reports conducted as agreed upon will satisfy and build trust among stakeholders.

Future Research Directions

While this research has offered valuable insight into the role of advanced EVM metrics for schedule performance analysis, certain fields of study deserve further examination:

- Comparative Studies: Future studies should compare the effectiveness of advanced EVM metrics for different categories of building projects (residential, commercial, and infrastructural, for example) to identify any differences in applicability and efficacy.
- Longitudinal Studies: Longitudinal studies would reveal advanced EVM metrics' effect on project performance in a long time. Tracking projects for a long would help in understanding any sustaining benefits of these metrics.
- Technological Integration: Research about integrating advanced EVM metrics with emerging technologies such as AI and ML can explore how those technologies could enhance EVM metrics' reliability and prediction nature.
- Global Perspectives: Studies conducted in varying geographical regions can yield a broader perspective on adopting advanced EVM metrics and their effective usage globally, wherein cultural and regional considerations may favorably or adversely influence these metrics.
- Case Studies and Best Practices: Elaborating case studies and determining best practices in utilizing advanced EVM metrics can earnestly provide pragmatic insights for project management action. This will also assist in scaling up their acceptance by outlining major successful cases and lessons learned.

Compliance with ethical standards

Statement of ethical approval

Ethical approval was obtained.

Statement of informed consent

Subjects are given informed consent before participating in the study.

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