A 4D-EVM PARADIGM TO ADVANCE CONSTRUCTION PROJECT CONTROL

Nguyen Anh Duc
Ha Noi University of Civil Engineering

ARTICLE INFO		ABSTRACT
Received:	10/02/2025	Classical earned value management estimates cost and schedule but overlooks key dimensions of project success: risk and quality. This paper introduces 4 Dimension-Earned Value Management, a framework that explicitly incorporates these often-neglected factors by discounting earned value when tasks exhibit substandard quality or elevated risk. Using an actual construction project subdivided into three distinct work packages - Structural, Finishing, and MEP - each under its own subcontractor, the study demonstrates how 4D-earned value management highlights the unique performance profile of each package. Results obtained by a Monte Carlo simulation show that this method provides earlier detection of potential overruns and more accurate predictions when rework looms. Stakeholder feedback underscores the practical value of the framework. In particular, the project manager and the quantity surveyors of the primary contractor commend its ability to prevent inflated earned value in the presence of poor workmanship. Subcontractors report that explicit quality metrics spur early remediation of defects, while the owners appreciate the transparency in forecasting final outcomes. By unifying cost, schedule, risk, and quality, 4D-earned value management aligns performance measurement with the multidimensional realities of project execution and fosters more proactive, informed decision-making against uncertainties.
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NGHIÊN CỨU MÔ HÌNH 4D-EVM ĐỂ NÂNG CAO NĂNG LỰC KIỂM SOÁT DỰ ÁN XÂY DỰNG

Nguyễn Anh Đức
Trường Đại học Xây dựng Hà Nội

THÔNG TIN BÀI BÁO		TÓM TẮT
Ngày nhận bài:	10/02/2025	Quản lý giá trị thu được là công cụ kiểm soát dự án có hiệu quả trong việc theo dõi chi phí và tiến độ nhưng lại bỏ qua hai khía cạnh quan trọng của dự án: rủi ro và chất lượng. Nghiên cứu này đề xuất "Quản lý giá trị thu được 4 chiều", một công cụ mới, tích hợp hai yếu tố thường bị bỏ sót này bằng cách điều chỉnh giảm giá trị thu được khi các hạng mục công việc có chất lượng dưới tiêu chuẩn hoặc mức độ rủi ro gia tăng. Áp dụng cho một dự án xây dựng thực tế được chia thành ba gói thầu riêng biệt—kết cấu, hoàn thiện và cơ-điện-nước)—mỗi gói do một nhà thầu phụ đảm nhận, nghiên cứu này cho thấy Quản lý giá trị thu được 4 chiều làm nổi bật đặc điểm hiệu suất riêng của từng gói. Kết quả mô phỏng Monte Carlo cho thấy các dự báo từ phương pháp này giúp phát hiện sớm nguy cơ vượt ngân sách hoặc chậm tiến độ và đưa ra dự đoán chính xác hơn khi xảy ra yêu cầu làm lại công việc. Phản hồi từ các bên liên quan đến quá trình kiểm soát dự án nhấn mạnh giá trị thực tiễn của công cụ này. Trong đó, chỉ huy trưởng của nhà thầu chính và các kỹ sư khối lượng đánh giá cao khả năng ngăn chặn việc đánh giá quá cao giá trị thu được trong điều kiện chất lượng thi công kém. Các nhà thầu phụ cho biết việc đưa ra chỉ số chất lượng rõ ràng thúc đẩy khắc phục lỗi sớm. Chủ đầu tư đánh giá cao tính minh bạch trong việc dự báo kết quả cuối cùng của dự án. Bằng cách thống nhất bốn yếu tố—chi phí, tiến độ, rủi ro và chất lượng—Quản lý giá trị thu được 4 chiều điều chỉnh quá trình đo lường hiệu suất phù hợp hơn với thực tế đa chiều của việc triển khai dự án, đồng thời khuyến khích phong cách quản lý chủ động để đối phó sớm với các yếu tố bất định.
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[*] Corresponding author. *Email: ducna@huce.edu.vn*

1. Introduction

Earned Value Management (EVM) is a common project control tool that evaluates scope, schedule, and cost parameters to find performance deviations [1]. Project managers can use Planned Value (PV), Earned Value (EV), and Actual Cost (AC) to analyze adherence to cost and schedule baselines [2]. Despite its utility, conventional EVM focuses largely on cost and schedule, leaving other essential dimensions—such as risk and quality—only indirectly captured once they appear in cost or schedule deviations [3] - [6].

Projects are susceptible to several uncertainties. Risk might occur from unforeseen site conditions, labor variations, regulatory adjustments, or technical challenges, leading to cost overruns and schedule delays [7] - [9]. But quality issues can lead to expensive revisions and poor outputs, even if budget and schedule requirements seem reached [10], [11]. The seeming Earned Value can be deceiving when quality failures need subsequent repairs, as "completed" tasks must be reviewed [12], [13].

To fix these issues, this study proposes a "4 Dimension-Earned Value Management" (4D-EVM) method that adds risk and quality to cost and time. The motivation is twofold: 1. High-risk or high-quality projects need advance notice of prospective effects; 2. Managers get a better view of project health than EVM alone can provide. In this research, the author uses 4D-EVM for a real-world–inspired construction scenario subdivided into three primary work packages—structural construction, finishing works, and MEP installation. A principal contractor's project manager oversees each work package, which is classified as a separate project with its own subcontractor. The author shows how Earned Value risk and quality modifications assist predict final cost and duration by modeling each package's performance. Stakeholders, such as the owner, project management consultants, and quality assurance (QA) engineers of each subcontractor, also assessed the 4D-EVM outputs, providing useful insights on the method's pros and downsides.

The paper is structured as follows. Section 2 outlines the methodology, beginning with a brief literature review on EVM, risk, and quality integration, stressing the need for a better framework, then the theoretical foundations and computational methods for 4D-EVM are developed. Section 3 shows the simulation findings for the three task packages, the evaluation of stakeholder viewpoints, and the broader implications for project management, before the paper's conclusion.

2. Methodology

2.1. The need for a more dimensional EVM

EVM is used in many industries to manage project performance by unifying scope, cost, and schedule tracking into standardized measures like Cost Performance Index (CPI) and Schedule Performance Index (SPI) [1]. While multiple studies demonstrate that EVM use increases project visibility and early warning capabilities [14], conventional EVM inevitably focuses on how much budget has been spent relative to how much work has been performed within a certain time frame [14]. The "triple constraint" focus might leave intangible or postponed issues, including developing dangers or poor quality, untouched until cost or schedule slips.

Risk management is a key knowledge topic in major frameworks like PMBOK, which promotes identifying, assessing, and controlling uncertainties [2], [15]. Quantitative risk methods, such Monte Carlo simulations and Bayesian networks, offer scenario-based forecasting of prospective cost or schedule outcomes [16], [17]. Standard EVM excludes "risk exposure" in Earned Value estimates. It is usually a distinct analysis or contingency component [6], [14]. This fragmented approach can delay real-time notice of compounded risk events. Quality management frameworks like ISO and Total Quality Management (TQM) emphasis fault prevention and compliance with standards [18]. However, the link between quality metrics and Earned Value is still weak in traditional practice. Numerous studies have advocated for the inclusion of rework-related costs or partial credit for incomplete work [19]. However, these

approaches exhibit a lack of uniformity. In the absence of a quality dimension, EVM may indicate near-complete task fulfillment while failing to meet performance standards, thereby obscuring actual progress.

Recent studies indicate a connection between EVM and risk registers, rework models, or advanced cost–schedule–quality trade-off analyses [6], [14], [16], [20], [21]. Khesal et al. [22] created new EVM control indices (CCoI, SCoI, QCoI) that use a cost-of-quality model and Monte Carlo risk buffers to improve project result predictions. However, this strategy still uses multiple indices instead of unifying risk and quality into Earned Value. This is the reason behind the 4D-EVM approach—explicitly quantifying how risk and quality modify realized progress. For instance, sub-standarded jobs, which signal a need for rework, may get only part of their projected value.

The literature confirms that (1) traditional EVM is important but inadequate, (2) risk management is vital but often not integrated, and (3) quality is a key project feature but not necessarily linked to Earned Value. The 4D-EVM research route tackles these concerns by including risk and quality as dynamic modifiers of Earned Value (EV) throughout the project lifecycle, giving a more complete management mechanism.

2.2. 4D-EVM Theoretical and Algorithmic Development

2.2.1. Revisiting Classical EVM

EVM tracks project progress using three core measures [14]:
- Planned Value (PV): Budgeted cost for the work scheduled up to a status date.
- Earned Value (EV): The budgeted cost of actual work completed up to that date.
- Actual Cost (AC): The cost incurred for work performed.

From these, practitioners can calculate performance indices, such as Cost Variance $-$ CV $=$ EV $-$ AC, Schedule Variance $-$ SV $=$ EV $-$ PV, Cost Performance Index $-$ CPI $= \frac{EV}{AC}$, and Schedule Performance Index $-$ SPI $= \frac{EV}{PV}$. To estimate total project completion costs, $EAC = AC + \frac{(BAC-EV)}{CPI}$, where BAC is the Budget at Completion.

While these metrics facilitate early detection of cost or schedule deviations, they do not explicitly incorporate risk or quality impacts—factors that can derail a project's real progress or inflate future cost and duration.

2.2.2. Incorporating Risk and Quality into EVM

To formalize the addition of risk and quality in Earned Value calculations, the author introduces two stochastic functions, $R(t)$ and $Q(t)$, that represent the overall (project-level) states of risk and quality at any status date *t*. In practice, these can be derived from individual tasks' local risk and quality factors, or they can be aggregated metrics that reflect the project's current status. Specifically:

- Quality Factor, $Q_i(t)$:

For each task *i*, the author defines $Q_i(t) \in [0,1]$ as the fraction of the quality specification met by time *t*. If a task is fully complete and meets or exceeds quality requirements, $Q_i(t) = 1$. If it is incomplete or shows deficiencies, $Q_i(t) < 1$.

$$EV_q(t) = \sum_{i=1}^{N} [PercentComplete_i(t) \times Q_i(t) \times PV_i(total)] \qquad (1)$$

Where, $PercentComplete_i(t)$ is the fraction of scope completed for task *i* by time *t*, and $PV_i(total)$ is the total planned value of task *i*. If any task is completed below standard, that shortfall directly reduces the recognized Earned Value for that task.

Rework Probability Interpretation: A lower $Q_i(t)$ implies a higher chance of future rework, which classical EVM would not explicitly capture. By discounting EV at the time of reporting,

practitioners acknowledge these potential costs earlier, rather than waiting until rework expenses or schedule slips become visible.

- Risk Factor, $R_i(t)$:

Similarly, $R_i(t)$ is defined for each task i, reflecting the level of uncertainty or exposure. For instance:

$R_i(t) = 1$ can represent the *baseline* risk scenario.

$R_i(t) > 1$ indicates higher-than-baseline risk (e.g., procurement delays, site conditions).

$R_i(t) < 1$ indicates reduced or mitigated risk.

To combine individual task-level risks into a single project-level factor R_t, the author takes a weighted average (e.g., weighting each task by its share of total planned value):

$$R(t) = \frac{\sum_{i=1}^{N}[R_i(t) \times PV_i(total)]}{\sum_{i=1}^{N} PV_i(total)} \tag{2}$$

Then there is a definition of a risk-adjustment function, $f_R(\cdot)$, which *discounts* the effective Earned Value:

$$EV_r(t) = EV(t) \times f_R(R(t)) \tag{3}$$

A simple example:

$$f_R(R) = \frac{1}{1 + \alpha(R - 1)} \tag{4}$$

Where $\alpha > 0$ is a sensitivity parameter. If $R > 1$, indicating elevated risk, the factor $f_R(R)$ becomes less than 1, reducing the recognized Earned Value. Conversely, if $R < 1$, it may slightly boost EV, assuming that lower risk improves the reliability of the *earned* work.

- Combined 4D Earned Value, $EV_{4D}(t)$:

To handle both risk and quality in a unified expression, the author merges their effects. One practical approach is:

$$EV_{4D}(t) = [EV_q(t)] \times f_R(R(t)) \tag{5}$$

That is, the author first "quality-adjusts" the nominal EV to reflect partial or imperfect completions, then "risk-adjusts" the result to account for potential volatility or future losses. A more explicit breakdown is:

$$EV_{4D}(t) = \sum_{i=1}^{N}[PercentComplete_i(t) \times Q_i(t) \times PV_i(total)] \times f_R(R(t)) \tag{6}$$

- 4D Performance Indices and Forecasts

Once $EV_{4D}(t)$ is defined, the author can analogously define the project's cost and schedule performance indices in four-dimensional terms:

$$CPI_{4D}(t) = \frac{EV_{4D}(t)}{AC(t)}; \ SPI_{4D}(t) = \frac{EV_{4D}(t)}{PV(t)} \tag{7}$$

Correspondingly, the Estimate at Completion in 4D-EVM would be:

$$EAC_{4D}(t) = AC(t) + \frac{[BAC - EV_{4D}(t)]}{CPI_{4D}(t)} \tag{8}$$

Where BAC is the total Budget at Completion. Notably, under higher risk or poorer quality conditions, $EV_{4D}(t)$ is lower, leading to a higher forecasted EAC_{4D}, thus flagging potential overruns sooner.

- Example: Rework Probability and EV Discount

If one wishes to incorporate a rework probability more explicitly, let ρ_i be the probability that task i will require rework due to insufficient quality. Then we can augment $Q_i(t)$ with a penalty term, or reduce the earned portion by $\rho_i \times PV_i$. For instance:

$$EV_q(t) = \sum_{i=1}^{N}[PercentComplete_i(t) \times (1 - \rho_i) \times PV_i(total)] \tag{9}$$

where $\rho_i = 1 - Q_i(t)$ if $Q_i(t)$ is treated as a direct measure of conformance to specification. Integrating these probabilities into the risk function $R(t)$ or applying it separately is up to the project's modeling detail.

By embedding these formulas into the Earned Value framework, the project team can monitor not just how much work is claimed complete, but also how reliably it was completed (quality) and how exposed it is to future disruptions (risk). This 4D-EVM ensures that a task or milestone is not given full "credit" until it meets the required quality level and mitigates the associated risks, thus offering a more realistic measure of project progress.

2.2.3. Algorithmic Procedure

Based on above theoretical foundation, Algorithm 1 outlines a pseudo-code procedure integrating risk and quality into a typical EVM workflow:

Begin Algorithm 1

- *Initialize Project Data*: Define tasks with planned values, durations, risk baselines, and target quality.

- *Calculate Classical EVM Metrics*: For tasks completed so far, compute EV, AC, CPI, SPI.

- *Update Risk*: If CPI or SPI lags behind 1, increase risk factors for remaining tasks.

- *4D-EVM Forecast*: Calculate EV_{4D} by adjusting for risk and quality; forecast cost and schedule to completion (EAC_{4D}, etc.).

- *Simulate Actuals*: Randomize actual cost/duration based on risk, degrade quality where appropriate, then compare to forecasts.

- *Compute Errors*: Track final differences (e.g., Cost MAPE, Duration MAPE) and observe how risk/quality shortfalls drive rework or schedule impact.

End of Algorithm 1

3. Results and Discussion

In order to illustrate 4D-EVM in a realistic setting, the study uses an actual but simplified construction case study divided into three major work packages: Structural, Finishing, and Mechanical, Electrical, & Plumbing (MEP). Each of these packages is managed by its own subcontractor under a single primary contractor's supervision. The reasoning is that these three domains inherently involve unique problems, risk assessments, and quality standards. The Structural package (20 tasks with PV in the range of 20,000-80,000 cost units and duration in 5-15 days) entails extensive materials and labor-intensive operations that must adhere to stringent engineering requirements. Whereas, the Finishing package (30 tasks, PV in 1,000-5,000 cost units, duration in 1-5 days)—typically occurring near project completion—encounters increased volatility due to the late discovery of concealed faults. The MEP portion (25 tasks, PV in 5,000-20,000 cost units, duration in 3-8 days) requires specialized trades and just-in-time procurement, exposing it to logistical risks. Figure 1 shows the difference in scope in both cost and duration aspects across packages. It is noteworthy that the costs of the project are scaled (and measured in currency units) to protect the owner's right according to a confidential agreement.

Some basic descriptive statistics reveal that the Structural package, with the highest planned budget, also exhibits relatively high overall quality standards (average final quality near 0.90–0.94) and risk factors in the range of 0.05-0.2. The Finishing package, though smaller in budget, shows the greatest variability in both schedule and quality (often 0.70–0.80). Its individual risk factors ranges from 0.1-0.25. The MEP package, positioned between these two in terms of scope and expense, often upholds relatively high quality levels (about 0.83–0.87) and encounters risks mainly due to specialized labor limitations (risk factors ranging from 0.05-0.15). By concurrently assessing these three packages, the study may underscore the flexibility and granularity of 4D-EVM, along with its capacity to elucidate disparities in risk exposure and quality deficiencies across various workstreams.
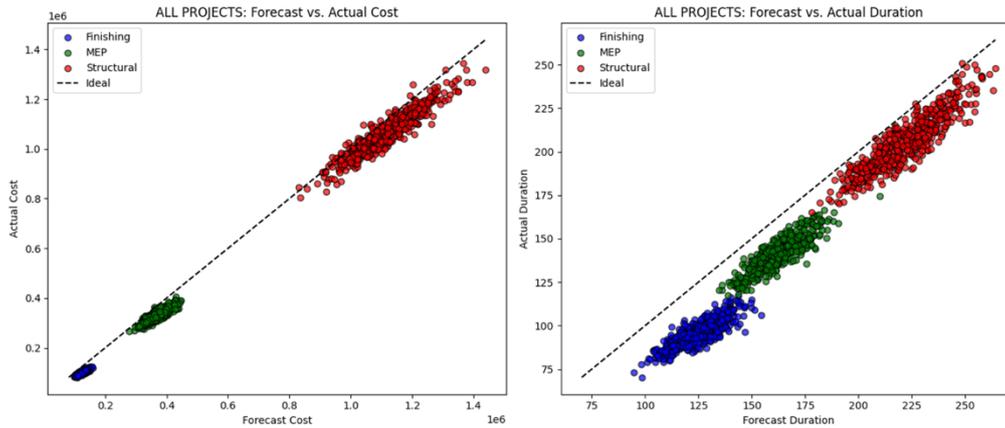
Figure 1. *Three packages' scopes comparison*

3.1. Forecast and actual performance

- **Finishing Package**

Figure 2 depicts results of the cost and duration forecast using 4D-EVM. The ForecastCost for Finishing tasks commonly exceeded the ActualCost, yielding a *negative* CostError (i.e., ForecastCost − ActualCost), often in the range of −20,000 to −30,000 units. The ForecastDuration also tended to overshoot the ActualDuration (negative DurationError).
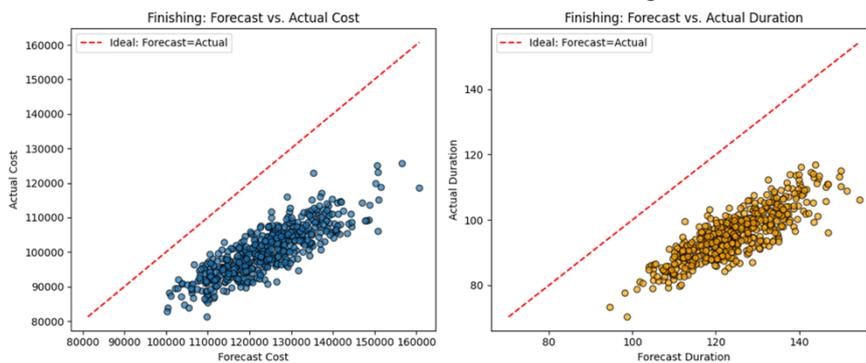
Figure 2. *Finishing package's cost and duration forecast vs. actual*

The Finishing package exhibited notable cost and schedule uncertainty, consistent with the final-phase volatility that is common in real projects where finishing work may encounter hidden defects or late-stage design modifications.

- **MEP Package**
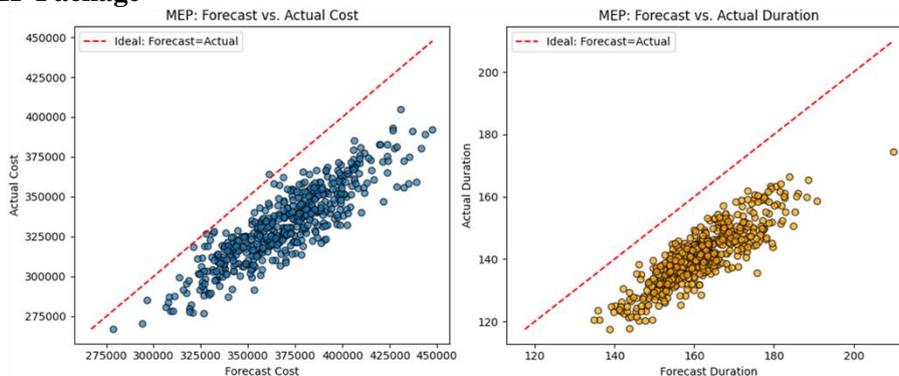
Figure 3. *MEP package's cost and duration forecast vs. actual*

Similarly, Figure 3 shows the results of the cost and duration forecast using 4D-EVM of the MEP package. MEP tasks showed fewer extreme swings than Finishing in many runs. While CostError could still become sizeable (e.g., −50,000 or −60,000 in some runs), the relative percentage error (Cost MAPE) frequently remained in the single- to mid-double-digit range (e.g., 5%–20%). Duration errors likewise display variability, but often less severe than in the Finishing package. Some runs still reached Duration MAPE around 15%–20%, particularly when risk factors caused procurement or specialized labor delays.

- **Structural Package**

Figure 4 presents the forecast of the Structural package.
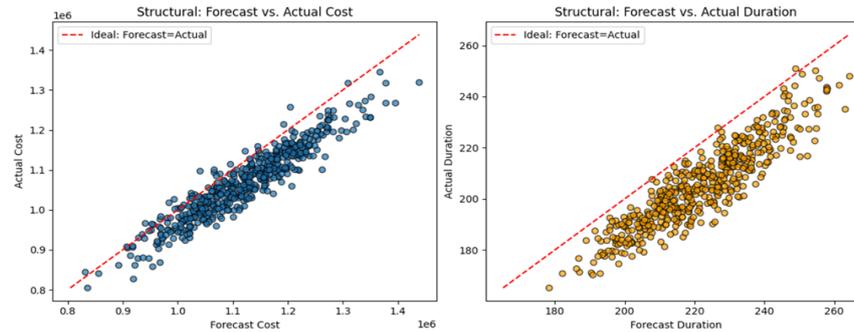
Figure 4. *Structural package's cost and duration forecast vs. actual*

Structural work typically has a higher overall Planned Value (PV), and so the absolute cost errors sometimes reach tens of thousands—or even over 100,000. However, in relative terms (Cost MAPE), many runs stay in the lower single-digit to mid-teen percentages. Some runs still have sizable forecast overshoots (e.g., −80,000 to −100,000), translating to around 5%–10% error. Despite occasional large negative DurationErrors, the relative schedule accuracy often lands within 5%–12%. In some runs, the actual duration is lower than forecast by over 20 days, pushing the Duration MAPE toward 10%–15%. The Structural tasks often exhibit forecasts that align more closely with actual outcomes, primarily due to their critical nature in the overall project. With minimal tolerance for structural rework and stringent safety requirements, the subcontractor must maintain rigorous quality standards and precise planning, thereby reducing the likelihood of significant deviations from the baseline.

Across the three packages, these figures consistently indicate that Finishing tasks have the greatest relative volatility, and MEP tasks have moderate swings but are still prone to risk impacts, and Structural tasks—though large in absolute values—often shows relatively lower *percentage* errors, with consistently high quality scores.

3.2. Error Distributions

Figure 6 and Figure 6 show the Mean Absolute Percentage Error (MAPE) in cost and duration of the three packages. MAPE is a metric that expresses the difference between forecasted values and actual results as a percentage of the actual values; it is commonly used in cost or schedule forecasting to gauge how closely predictions align with real project outcomes [23].

The boxplots of Cost MAPE and Duration MAPE reveal that Finishing exhibits a relatively wide interquartile range (IQR) for both cost and duration errors, indicating the highest median MAPE among the three. Whereas MEP maintains a generally narrower distribution, pointing to somewhat more reliable forecasting against final actual outcomes, though there are still outlier runs where cost or duration errors exceed 20%. Meanwhile, Structural package typically shows a median Cost MAPE within single digits. However, a few cases display significant forecast overshoots or undershoots, likely attributable to advanced or hidden structural complexities, and these emerge as outliers in the boxplots. The difference among MAPE of the three packages can be seen clearly in Figure 7.
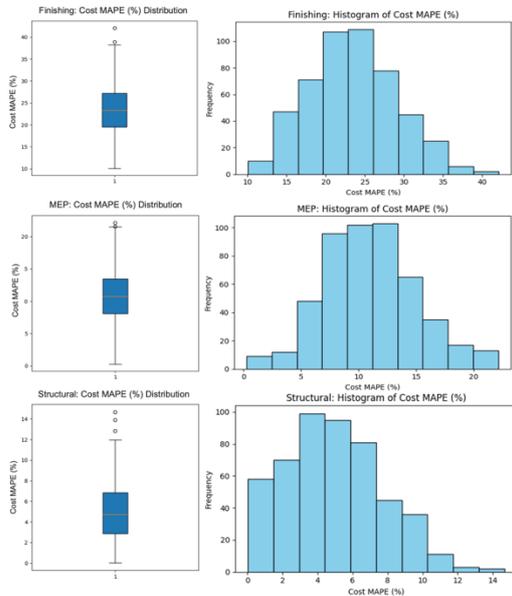
Figure 5. *Cost MAPE across packages*
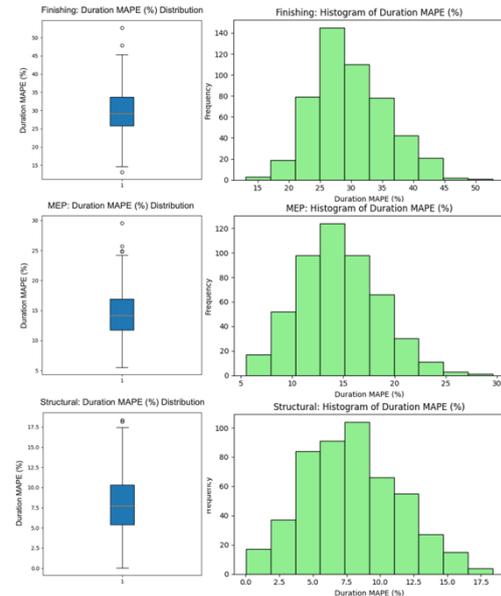
Figure 6. *Duration MAPE across packages*
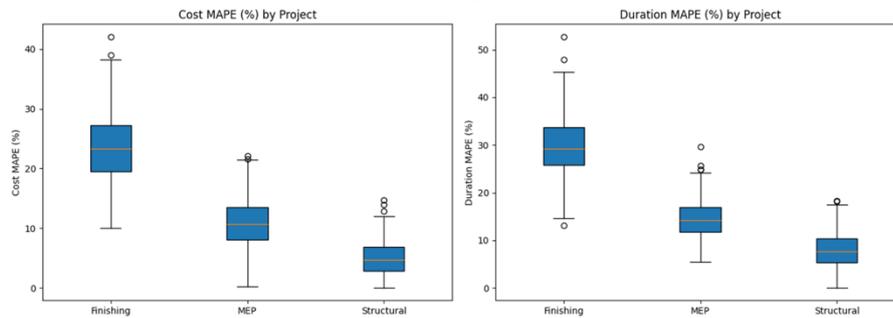
Figure 7. *Cost and duration MAPE across packages comparison*

Histograms of MAPE likewise show a noticeable skew toward moderate-to-high errors in Finishing, pointing to the greater unpredictability of late-stage activities where rework or final touches often introduce extra variance. In contrast, MEP displays a more balanced (though still variable) curve, suggesting that while certain specialized or procurement-related risks exist, overall deviations remain clustered in a narrower band. Structural exhibits a slightly more centered distribution, reflecting relatively stable performance. However, there is a recognizable tail of outlier runs. These outliers underscore the impact of unexpected structural complexities—such as design changes or unforeseen site conditions—that can lead to sudden cost or schedule adjustments. Collectively, these patterns highlight the importance of tailoring risk management efforts across different work packages and underscore the value of integrating risk and quality considerations into Earned Value calculations.

3.3. Quality Impact Analysis

In Figure 8, Final Average Quality is plotted against Cost/Duration MAPE to reveal some important observations about the impact of quality in the analysis.

Finishing has the most variety (0.70–0.80) in FinalAvgQuality across the three packages, MEP has a modest range (0.83–0.87), and Structural has consistently excellent scores (typically over 0.90). Structural activities, which have stringent criteria, have the most accurate projections, followed by MEP and Finishing. Finishing packages with a quality threshold below 0.75 generally had cost or schedule MAPE spikes, whereas those near or above 0.78 fared better. In MEP, some runs had

excellent quality but required more rework or time extensions, despite higher quality usually correlating with modest performance issues. Structural tasks, which rarely fell below 0.90 in quality, had a reduced link between final quality scores and MAPE, perhaps because major flaws are fixed early or avoided by required specs. In all three packages, poor quality affects the "earned" part of project value, which might signal budget overruns or schedule delays if rework is needed.
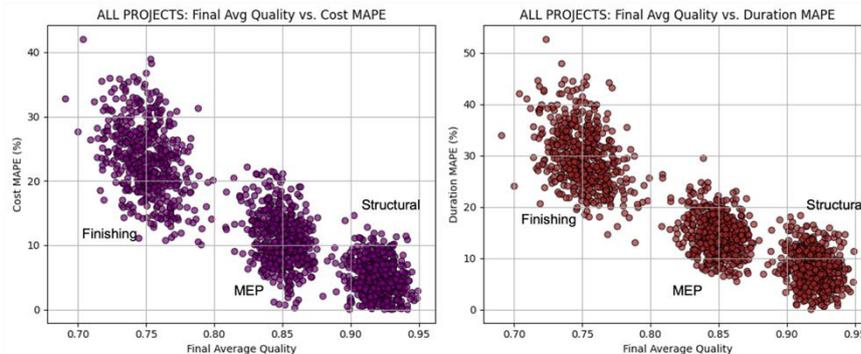
Figure 8. *The impact of quality factor on the analysis*

3.4. Stakeholders' discussions and project control implications

The 4D-EVM analysis of Finishing, MEP, and Structural packages underscored crucial lessons for all stakeholders. The primary contractor's project manager praised early warnings for cost and schedule overruns arising from substandard quality or escalating risk, noting that discount factors in $EV_{4D}(t)$ prevented artificially inflated Earned Value and sharpened resource allocation. Subcontractors reacted differently but generally confirmed 4D-EVM's utility. Specifically, the Finishing subcontractor saw repeated quality dips significantly reduce Earned Value, ultimately boosting accountability. The MEP subcontractor observed moderate discounting yet appreciated the built-in risk-escalation for delayed equipment deliveries. While the Structural team noted that even minor percentage changes in large budgets created substantial absolute variances, making explicit risk adjustments highly beneficial. Meanwhile, the Quantity Surveyor (QS) relied on more realistic cost forecasts to anticipate overruns and redirect contingencies, and QA engineers appreciated the direct link between poor workmanship and reduced Earned Value.

Owners valued the integrated perspective on cost, schedule, risk, and quality, while project management professionals highlighted that conventional EVM may underestimate the consequences of poor quality. They valued the flexibility of the 4D-EVM for incorporating advanced rework models or correlated risk factors. Collectively, these observations confirm 4D-EVM's strength in surfacing finishing defects, MEP supply issues, and structural uncertainties early, offering a unified metric that discourages unresolved risks. Lessons learned include greater discipline in defect resolution for Finishing and heightened QS confidence in EAC. Although 4D-EVM forecasts can be conservative, most stakeholders see this buffer as preferable to last-minute overruns or schedule slips. With systematic data collection and stakeholder engagement, 4D-EVM shifts project reporting from a retrospective exercise to a forward-looking, risk-focused control mechanism.

4. Conclusion

This study introduces and elaborates a 4D-EVM paradigm that incorporates risk and quality into Earned Value Management, providing a more accurate assessment of project status compared to traditional EVM alone. This method quantitatively adjusts Earned Value based on quality deficiencies and outstanding risks, revealing early signs of possible rework and increasing costs or delays. The simulation-based case study—subdivided into Structural, Finishing, and MEP work packages—demonstrated how 4D-EVM highlights the unique performance profile of

each package, reflecting real-world differences in volatility, quality standards, and subcontractor management styles.

Feedback from stakeholders substantiated the value of 4D-EVM. The project manager of the primary contractor appreciated the prompt visibility into suboptimal quality and risk-laden activities, improving coordination and resource allocation. Subcontractors perceived the system as motivating, as high-risk or substandard work directly affected their EV, hence incentivizing the prompt resolution of concerns. Quantity Surveyors and QA engineers commended the improved openness, observing that jobs marked as completed but containing flaws are now classified as incomplete in project metrics—alerting teams prior to downstream rework that could escalate overall costs. Finally, the owner and project management consultants recognized 4D-EVM's potential to unify decision-making across all project participants, thanks to its multifaceted performance measures that transcend mere cost and schedule viewpoints.

While some prior works [22] share the author's goal of integrating risk and quality with EVM, this 4D-EVM approach goes further by directly discounting Earned Value whenever tasks exhibit high risk or substandard quality, thus embedding all four dimensions in the same core metrics. This cohesive viewpoint provides a more timely and transparent alert system, enhancing the managerial decision-making process. Subsequent research may expand 4D-EVM to encompass sophisticated data analytics or real-time monitoring technologies, enhancing the ability of project teams to integrally manage cost, schedule, quality, and risk. Ultimately, by including risk and quality into Earned Value monitoring, 4D-EVM addresses a critical deficiency in project control, guaranteeing that the metrics employed for daily choices are more closely aligned with the true determinants of project success.

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