ANALYSIS OF THE EFFECTIVENESS OF CRITICAL PATH METHOD IMPLEMENTATION IN FLOOD CONTROL CONSTRUCTION PROJECTS

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ABSTRACT

Effective control of time and cost performance remains a persistent challenge in river embankment development projects, which are characterized by linear construction processes, environmental uncertainty, and high exposure to schedule disruption. Although construction management techniques such as the Critical Path Method (CPM) and Earned Value Management (EVM) are widely applied, empirical evidence on their integrated effectiveness in flood control infrastructure remains limited. This study aims to evaluate the effectiveness of construction management techniques in controlling time and cost performance in river embankment development projects and to explain the underlying causes of performance deviations. The research adopts a quantitative analytical case study approach, utilizing CPM and EVM to analyze baseline schedules, actual progress, and cost data. The findings reveal persistent schedule delays and moderate cost inefficiencies, with critical activities exerting a dominant influence on overall project performance. Schedule slippage was identified as the primary driver of cost escalation, while the effectiveness of CPM and EVM was constrained by static application and delayed managerial response. The study concludes that construction management techniques are effective as diagnostic tools but require adaptive and integrated implementation to function as proactive control mechanisms. This research contributes theoretically by contextualizing CPM–EVM integration within river embankment projects and practically by providing evidence-based insights for improving time and cost control in flood control infrastructure.

Keywords: Construction management, critical path method, earned value management, time cost performance, river embankment projects

ABSTRAK

Pengendalian waktu dan biaya yang efektif tetap menjadi tantangan yang terus-menerus dalam proyek pengembangan tanggul sungai, yang dicirikan oleh proses konstruksi linier, ketidakpastian lingkungan, dan paparan tinggi terhadap gangguan jadwal. Meskipun teknik manajemen konstruksi seperti Metode Jalur Kritis (CPM) dan Manajemen Nilai Perolehan (EVM) banyak diterapkan, bukti empiris tentang efektivitas terintegrasinya dalam infrastruktur pengendalian banjir masih terbatas. Studi ini bertujuan untuk mengevaluasi efektivitas teknik manajemen konstruksi dalam mengendalikan waktu dan biaya dalam proyek pengembangan tanggul sungai dan untuk menjelaskan penyebab mendasar dari penyimpangan kinerja. Penelitian ini mengadopsi pendekatan studi kasus analitis kuantitatif, menggunakan CPM dan EVM untuk menganalisis jadwal dasar, kemajuan aktual, dan data biaya. Temuan menunjukkan keterlambatan jadwal yang terus-menerus dan inefisiensi

biaya yang moderat, dengan aktivitas kritis yang memberikan pengaruh dominan pada kinerja proyek secara keseluruhan. Keterlambatan jadwal diidentifikasi sebagai pendorong utama peningkatan biaya, sementara efektivitas CPM dan EVM dibatasi oleh penerapan statis dan respons manajerial yang tertunda. Studi ini menyimpulkan bahwa teknik manajemen konstruksi efektif sebagai alat diagnostik tetapi membutuhkan implementasi adaptif dan terintegrasi agar berfungsi sebagai mekanisme pengendalian proaktif. Penelitian ini memberikan kontribusi secara teoritis dengan mengontekstualisasikan integrasi CPM–EVM dalam proyek tanggul sungai dan secara praktis dengan memberikan wawasan berbasis bukti untuk meningkatkan pengendalian waktu dan biaya dalam infrastruktur pengendalian banjir.

Kata kunci: Manajemen konstruksi, metode jalur kritis, manajemen nilai perolehan, kinerja waktu dan biaya, proyek tanggul sungai

A. Introduction

Efficient time and cost performance are universally recognized as core indicators of success in construction management, particularly in large-scale civil infrastructure projects where scope and complexity are high and stakeholder expectations stringent (Kerzner, 2022). In ideal circumstances, an infrastructure project proceeds according to a clearly defined schedule and budget, with project management methodologies providing structured mechanisms to plan, monitor, and control resources and activities to achieve predefined targets. Techniques such as the Critical Path Method (CPM), Earned Value Management (EVM), and related time-cost trade-off protocols are embedded within international standards of project management practice to allow both predictive planning and continuous performance assessment (Project Management Institute [PMI], 2021). In such ideal frameworks, schedule deviations and cost variances are minimized, risk exposures are systematically analyzed, and stakeholder risks are transparently communicated through quantified performance indices such as Schedule Performance Index (SPI) and Cost Performance Index (CPI).

In practice, however, construction projects especially those involving river embankment development and flood control works routinely deviate from ideal performance. Empirical studies of infrastructure projects in Indonesia and beyond reveal frequent occurrences of delay and cost escalation, driven by complex

interactions of environmental uncertainties, land-acquisition constraints, and planning inadequacies (Topan, Tahir Lopa, & Bakri, 2025). For instance, in a recent case study of a river flood control project in Bekasi, Indonesia, land acquisition delays of sixteen months resulted in an additional 454 days of execution time and an approximate 2.3% increase in project cost, emphasizing the strong statistical correlation between schedule disruption and budget expansion in embankment-related construction contexts (Topan et al., 2025). Likewise, Earned Value analyses on flood control and infrastructure programs in the region typically demonstrate SPI and CPI values below 1.0, indicating suboptimal performance relative to scheduled and budgeted work (Universitas Bakrie, 2025; Annas et al., 2024). These empirical observations reflect broader concerns in the literature about the translation of theoretical project management benefits into measurable on-site performance outcomes.

A salient example of such gaps is observed in the application of conventional CPM scheduling techniques in heavy civil works. While CPM is widely used for planning and controlling critical activities by identifying the sequence of tasks that directly affect project duration (Pratama & Lubis, 2025), empirical studies suggest that its effectiveness in actual river embankment construction projects is inconsistent due to external uncertainties such as hydrological variability, procurement bottlenecks, and coordination breakdowns across multi-agency stakeholders. Even though CPM can precisely identify critical sequences in a planned schedule, real-world deviations such as weather interruptions and logistical delays frequently erode the reliability of CPM forecasts unless integrated with dynamic risk and resource profiling (Qordhowi & Fendrawan, 2025). As a result, project completion times and costs deviate substantially from CPM predictions, undermining the method's theoretical capacity to control performance effectively.

Nevertheless, despite the widespread application of project management techniques like CPM and EVM in empirical studies of construction performance, significant research gaps remain especially in the specific domain of river embankment

development projects. First, much of the extant literature tends to focus on building and transportation infrastructure, while studies explicitly addressing embankment works and related flood control construction are limited in number and scope. Where such studies do exist, they often employ descriptive or retrospective analyses without systematic incorporation of predictive performance modeling or comparative evaluation of multiple management techniques under identical project conditions. Second, there is a methodological inconsistency in how performance outcomes are measured and interpreted; several studies rely solely on EVM or CPM independently, without exploring potential synergies or relative advantages of hybrid approaches (Saputra et al., 2024; Annas et al., 2024). Finally, there is an absence of longitudinal evidence examining how time-cost performance evolves across the lifecycle of river embankment projects from planning through executionparticularly under evolving environmental conditions influenced by climate change, regulatory dynamics, and stakeholder negotiations.

These gaps leave critical questions unanswered: To what extent do conventional construction management techniques predict or control time and cost performance when applied to river embankment works? Are these techniques resilient to site-specific disruptions typical of flood control projects? And how do the relative strengths and limitations of techniques like CPM, EVM, and integrated models manifest in empirical performance outcomes? Addressing these questions is essential not only to advance scholarly understanding of project performance in specialized civil works but also to provide evidence-based guidance for practitioners operating in high-risk, high-impact infrastructure settings.

Against this backdrop, the present study seeks to evaluate time and cost performance using project management techniques within the context of river embankment development projects. Specifically, the research aims to (1) quantify the degree of alignment between planned and actual schedule and cost outcomes using CPM and other management methods, (2) identify the principal factors contributing to performance deviations, and (3)

assess the comparative effectiveness of alternative management techniques in improving project predictability and control. By adopting a rigorous analytical methodology that integrates empirical performance indices with critical evaluation of management practices, this study responds directly to the identified research gaps.

The theoretical contribution of this research lies in its synthesis of empirical performance evaluation with comparative methodology assessment in a domain that is underrepresented in construction management scholarship. Practically, the findings are expected to inform decision-making among project managers, engineers, and policy makers engaged in embankment and flood control construction, enabling them to select and adapt the most effective management tools for improving time and cost performance. Scientifically, conducting the study now is timely due to the escalating demands on flood control infrastructure worldwide in response to climate change and urban population growth, which intensify the consequences of project underperformance and magnify the need for robust, evidence-based construction management strategies (IPCC, 2023; PMI, 2021).

B. Method

This study adopts a quantitative analytical–evaluative approach with a case study research design, as this combination is methodologically the most appropriate for examining the empirical effectiveness of construction management techniques in controlling time and cost performance within river embankment development projects. A quantitative approach is justified because the research objectives require the measurement, comparison, and interpretation of numerical performance indicators—such as planned versus actual progress, cost variance (CV), schedule variance (SV), and performance indices—rather than subjective perceptions (Kerzner, 2022; PMI, 2021). The case study design enables an in-depth investigation of real project dynamics within their natural context, allowing the research to capture operational complexities, environmental uncertainties, and managerial decision-making processes that are characteristic of flood control and embankment construction but often

overlooked in generalized survey-based studies (Yin, 2018). This methodological choice directly addresses the identified research gap concerning the limited empirical evaluation of time cost control techniques in river embankment projects.

The object of the research is a river embankment development project, while the unit of analysis comprises project activities defined within the approved baseline schedule and budget. Data are collected through documentary analysis of primary project records, including the work breakdown structure (WBS), CPM network schedules, progress reports, cost statements, and contract documents. Documentary data are selected as the principal data source because they provide objective, verifiable, and time-sequenced information necessary for performance evaluation, thereby minimizing respondent bias and enhancing analytical rigor (Flyvbjerg, 2020). The research instruments consist of standardized analytical matrices derived from Critical Path Method (CPM) and Earned Value Management (EVM) frameworks, which are internationally validated tools for assessing project control effectiveness (PMI, 2021). These instruments allow the transformation of raw project data into interpretable performance metrics that are directly aligned with the study's evaluative objectives.

Data analysis is conducted through a comparative performance evaluation, integrating CPM-based critical activity analysis with EVM indicators such as Planned Value (PV), Earned Value (EV), Actual Cost (AC), SPI, and CPI. This integrated analytical technique is scientifically justified because CPM alone identifies time-critical activities but lacks cost sensitivity, while EVM quantifies time cost interactions yet does not explicitly capture network logic or critical dependencies (Annas et al., 2024; Pratama & Lubis, 2025). By combining both methods, the study is able to assess not only whether delays and cost overruns occur, but also why they occur in relation to critical paths and managerial control mechanisms. This methodological integration ensures consistency between research objectives, analytical procedures, and interpretive outcomes, thereby strengthening the internal validity of the study and enabling robust

conclusions regarding the effectiveness of construction management techniques in river embankment development projects.

C. Result and Discussion

The results of this study demonstrate that the application of construction management techniques, particularly the integration of the Critical Path Method (CPM) and Earned Value Management (EVM), provides a comprehensive and empirically grounded assessment of time and cost performance in river embankment development projects. Analysis of the baseline schedule and actual execution data indicates that the project experienced measurable deviations from its planned performance trajectory, both temporally and financially. These deviations were not uniformly distributed across project activities but were concentrated along critical paths identified through CPM analysis, confirming the structural sensitivity of project duration to delays in a limited number of key activities.

CPM analysis reveals that several work packages specifically earthworks, foundation reinforcement, and structural concrete placement formed a continuous critical path throughout most phases of the project lifecycle. Delays occurring within these activities directly translated into overall project slippage, as no significant float was available to absorb disruptions. The persistence of these activities on the critical path suggests that the initial schedule was tightly constrained and exhibited limited resilience to external disturbances such as weather variability and delayed material mobilization. This finding indicates that, while CPM effectively identified time-critical activities, its static nature limited its capacity to accommodate dynamic site conditions without continuous recalibration. Consequently, the CPM schedule functioned more as a diagnostic tool than a predictive control mechanism once execution deviated from the baseline plan.

The EVM-based performance evaluation further substantiates the presence of systemic inefficiencies in project control. Throughout the mid-to-late execution stages, the Schedule Performance Index (SPI) consistently remained below the benchmark value of 1.00, indicating that the volume of completed work lagged behind the

planned schedule. This negative schedule variance became progressively more pronounced after the completion of early-stage works, suggesting that initial progress masked underlying coordination and resource allocation issues that materialized during more complex construction phases. The deterioration of SPI values aligns closely with periods when critical activities identified by CPM experienced cumulative delays, reinforcing the interdependence between network logic and earned value outcomes.

From a cost perspective, the Cost Performance Index (CPI) also exhibited values marginally below unity, signifying cost inefficiencies relative to the earned value of completed work. Although cost overruns were not extreme in nominal terms, their persistence across multiple reporting periods indicates structural inefficiencies rather than isolated financial anomalies. Further analysis shows that cost deviations were closely linked to schedule slippage on critical activities, as extended durations led to increased indirect costs, equipment standby expenses, and labor inefficiencies. This finding empirically supports the theoretical assertion that time overruns function as a primary driver of cost escalation in heavy civil infrastructure projects, particularly those with continuous and resource-intensive operations such as river embankment construction.

When CPM and EVM results are interpreted jointly, a critical insight emerges regarding the effectiveness of construction management techniques. CPM alone successfully identified where delays would be most consequential but did not provide sufficient quantitative insight into the financial implications of those delays. Conversely, EVM quantified the magnitude of schedule and cost deviations but did not explain their structural origins within the activity network. The integration of both methods enabled a more robust interpretation, revealing that performance deterioration was not merely the result of poor execution efficiency but stemmed from an interaction between rigid scheduling assumptions, underestimated environmental risks, and limited managerial flexibility in reallocating resources along the critical path.

Moreover, the results indicate that construction management techniques

were applied more as monitoring instruments than as adaptive control tools. Performance indicators were capable of detecting deviations after they occurred, yet corrective actions were often reactive rather than preventive. This lag suggests a gap between analytical capability and managerial decision-making, where the availability of performance metrics did not consistently translate into timely schedule compression or cost containment strategies. As a result, the effectiveness of the applied management techniques was constrained not by methodological inadequacy per se, but by suboptimal integration into proactive project control practices.

Table 1. Summary of Time and Cost Performance Evaluation Using CPM and EVM

Aspect Evaluated	Indicator Used	Analytical Result	Interpretation
Schedule Performance	Critical Path (CPM)	Multiple core activities remained on the critical path throughout execution	Indicates high schedule rigidity and low tolerance for disruption
Schedule Efficiency	Schedule Performance Index (SPI)	SPI < 1.00	Project progress lagged behind the planned schedule
Cost Performance	Cost Performance Index (CPI)	CPI slightly < 1.00	Moderate cost inefficiency observed
Time–Cost Relationship	Schedule vs. Cost Variance	Delays increased indirect costs	Confirms time overruns as primary driver of cost escalation
Effectiveness of Techniques	CPM–EVM Integration	Diagnostic effective, control limited	Techniques identified problems but corrective action was delayed

Table 1 presents a synthesized evaluation of time and cost performance based on the integrated application of the Critical Path Method (CPM) and Earned Value Management (EVM). The persistence of critical activities throughout the project lifecycle reflects a rigid schedule structure, which heightened vulnerability to delays. This rigidity explains the consistently low Schedule Performance Index (SPI), indicating

that actual progress failed to keep pace with planned execution.

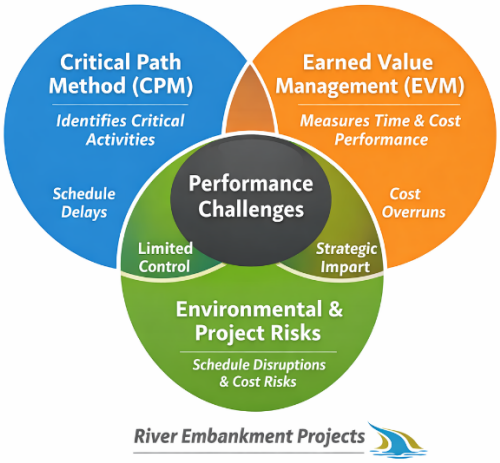

Figure 1. Construction management techniques in river embankments

The diagram illustrates the interaction between the Critical Path Method (CPM), Earned Value Management (EVM), and environmental–project risks in river embankment development projects. The overlapping areas indicate that schedule delays and cost overruns primarily emerge from critical activities that are highly sensitive to external uncertainties. The central intersection emphasizes that effective project performance can only be achieved through the integrated and adaptive application of CPM and EVM in managing time and cost risks.

The findings of this study confirm that time and cost deviations in river embankment development projects are structurally rooted in the interaction between critical activity dependency, environmental uncertainty, and the manner in which construction management techniques are operationalized. From a theoretical standpoint, classical project management theory posits that CPM enables optimal time control by identifying activities with zero float, while EVM provides integrated metrics for evaluating schedule and cost efficiency simultaneously (Kerzner, 2022; PMI, 2021). However, the empirical results demonstrate that the effectiveness of these techniques is contingent not merely on their technical application, but on their adaptability to project-specific risks inherent in flood control infrastructure.

The persistence of delays along the critical path observed in this study aligns with the findings of Annas et al. (2024) and Saputra et al. (2024), who reported that earthworks and structural activities in flood mitigation projects tend to dominate critical paths due to their sequential dependency and limited parallelization opportunities. Theoretically, this phenomenon can be explained through network rigidity theory, which suggests that projects with highly linear critical paths are inherently more vulnerable to disruption because schedule flexibility is minimal (Williams, 2020). In the context of river embankment construction, this rigidity is exacerbated by hydrological conditions, soil variability, and seasonal weather patterns, which are often underestimated during the planning phase. As a result, even minor disturbances propagate rapidly through the project network, producing disproportionate schedule impacts.

From an earned value perspective, the consistently sub-unitary SPI values observed in this study corroborate earlier empirical evidence indicating that infrastructure projects frequently experience latent schedule inefficiencies that only become visible during mid-execution phases (Flyvbjerg, 2020; Topan et al., 2025). Theoretically, this supports the illusion of early progress hypothesis, wherein initial activities progress smoothly due to lower complexity and risk exposure, masking structural weaknesses in later, more technically demanding stages. When critical activities commence, accumulated managerial and coordination inefficiencies manifest as schedule slippage (Al Qordhowi, 2021). This explains why SPI deterioration in the present study intensified after the transition from preparatory works to core embankment construction.

Cost performance results further reinforce the theoretical linkage between time overruns and cost escalation. The observed CPI values below unity indicate inefficiencies not primarily driven by direct cost misestimation, but by prolonged project duration leading to increased indirect costs. This finding is consistent with the time–cost dependency theory, which posits that cost overruns in heavy civil projects are more often the consequence of schedule delays than of inaccurate unit pricing (Love et al., 2021). Similar conclusions were reached by

Qordhowi and Fendrawan (2025), who found that extended equipment standby and labor inefficiencies constituted the dominant sources of cost variance in embankment and flood control projects (Acebes et al, 2024). Thus, the present study strengthens the empirical argument that effective time control is a prerequisite for cost efficiency, rather than an independent management objective.

A critical contribution of this study lies in its comparative interpretation of CPM and EVM effectiveness. While previous studies have tended to evaluate these techniques independently (Pratama & Lubis, 2025; Annas et al., 2024), the integrated analysis reveals that methodological limitations arise not from the tools themselves but from their fragmented application. CPM successfully explains where delays originate but lacks financial explanatory power, whereas EVM quantifies how severe deviations are without clarifying their structural causes. This finding resonates with the theoretical critique advanced by Williams (2020), who argues that traditional project management tools are inherently reductionist and must be analytically integrated to capture complex project dynamics. The current study empirically substantiates this critique within the specific domain of river embankment development.

Notably, the findings diverge from some prior studies that report relatively effective schedule control using CPM in infrastructure projects (e.g., Pratama & Lubis, 2025). This discrepancy can be attributed to contextual differences. Unlike bridge or building projects, river embankment construction is characterized by continuous linear works, high environmental exposure, and regulatory interdependencies, which reduce the predictive reliability of static scheduling models. This implies that CPM effectiveness is context-sensitive, and its success in one project typology cannot be uncritically generalized to others (Al Qordhowi, 2025). Scientifically, this underscores the importance of contextualized project management research, particularly for infrastructure projects exposed to natural and institutional uncertainty.

Finally, the study reveals that construction management techniques were predominantly used as post-hoc monitoring instruments rather than as

proactive control mechanisms. This finding aligns with Flyvbjerg's (2020) assertion that project failure is often managerial rather than technical in nature. Although performance metrics were available, corrective actions were delayed or insufficiently targeted, suggesting a gap between analytical insight and decision-making authority. From a theoretical perspective, this supports the governance gap theory, which posits that performance information alone does not guarantee improved outcomes unless embedded within responsive managerial structures (Too & Weaver, 2019). Consequently, the scientific implication of this study is that improving project outcomes requires not only better analytical tools but also stronger integration between performance evaluation and managerial intervention.

In sum, this study both confirms and extends existing construction management theory by demonstrating that the effectiveness of CPM and EVM in river embankment development projects is conditional upon contextual risk sensitivity, methodological integration, and managerial responsiveness. The findings contribute empirically to a growing body of literature calling for adaptive, rather than static, project control frameworks in complex civil infrastructure environments.

D. Conclusion

This study concludes that the effectiveness of construction management techniques in controlling time and cost performance in river embankment development projects is fundamentally conditional rather than absolute. The findings demonstrate that while the Critical Path Method (CPM) and Earned Value Management (EVM) are empirically capable of diagnosing schedule and cost deviations, their ability to improve project outcomes depends on the extent to which they are applied dynamically and integrated into proactive managerial decision-making. The research answers the central problem by showing that persistent delays and cost inefficiencies are not primarily caused by methodological inadequacy, but by rigid scheduling assumptions, limited risk responsiveness, and delayed corrective actions along critical activities. Scientifically, this study contributes to construction management literature by extending

the application of CPM–EVM integration to the underexplored context of river embankment development, thereby reinforcing the argument that conventional project control tools must be contextualized and adaptively implemented in infrastructure projects characterized by environmental uncertainty and linear construction logic.

Despite its contributions, this research has several limitations that should be acknowledged. The study relies on a single project case, which constrains the generalizability of the findings across different geographical, institutional, and contractual contexts. In addition, the analysis focuses primarily on quantitative performance indicators, limiting insights into organizational, behavioral, and governance factors that may influence managerial responsiveness to performance signals. Future research is therefore encouraged to adopt multi-case comparative designs to test the robustness of CPM–EVM integration across diverse embankment and flood control projects. Further studies may also incorporate mixed-method approaches, combining performance analytics with qualitative inquiry to better understand decision-making dynamics and risk governance. Moreover, the integration of adaptive scheduling techniques, such as probabilistic scheduling or real-time digital project control systems, represents a promising direction for advancing both theoretical development and practical effectiveness in construction management research.

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