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Integrating RII, VSM, and EVM to Optimize Construction Performance of a Physiotherapy Facility in a Remote Mining Area

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Abstract

Background: Construction projects in remote mining areas face schedule disruptions caused by complex approval procedures, logistical constraints, and changing project requirements. An integrated assessment is needed to identify the underlying causes of delays, their operational impacts, and their consequences for project performance.
Objective: This study aims to integrate the Relative Importance Index (RII), Value Stream Mapping (VSM), and Earned Value Management (EVM) to assess construction performance in a physiotherapy facility renovation project.
Methods: A single-case study was conducted using questionnaires completed by 30 respondents, interviews with 10 key informants, observations of 19 activities, project progress reports covering 34 weeks, and project documentation. RII was used to prioritize delay factors, VSM to identify operational waste, and EVM to evaluate schedule performance.
Results: The dominant delay factors were approval delays (RII = 0.947), logistical constraints (RII = 0.920), and scope changes (RII = 0.900). VSM identified 217 activity-days of cycle time and 292 activity-days of waiting time, yielding a total of 509 activity-days and a value-added ratio of 36.94%. The proposed future-state scenario indicated a potential reduction of 128 activity-days, although this estimate requires empirical verification. EVM yielded Schedule Performance Index (SPI) values of 0.773, 0.847, and 0.970 in Weeks 14, 27, and 34, respectively.
Conclusion: Integrating RII, VSM, and EVM provides a traceable framework for prioritizing delay factors, identifying process bottlenecks, and assessing schedule deviations. The proposed improvements require post-implementation validation before their effectiveness can be confirmed.

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INTRODUCTION

Engineering, procurement, and construction (EPC) projects undertaken within active industrial facilities constitute temporary production systems that connect the release of engineering documents, approvals, procurement, logistics, work-area readiness, construction, inspection, and handover. In a physiotherapy facility renovation project located in a remote area, approval delays, delivery uncertainty, scope changes, and instability in work sequencing may reinforce one another. Although change orders, material-related issues, coordination problems, and productivity constraints have been widely recognized as causes of project delays, the magnitude of their impacts remains dependent on the project context (Assaf & Al-Hejji, 2006). Globally, schedule delays remain endemic in construction (Kadry et al., 2017; Purushothaman et al., 2026). A comprehensive synthesis of delay studies cataloged more than one hundred recurring causes, predominantly related to design and approval, materials and procurement, and

coordination, across diverse regions and project types (Durdyev & Hosseini, 2019). Therefore, lists of factors or schedule indices analyzed in isolation do not adequately explain how disruptions arise or where corrective actions should be implemented.

Value Stream Mapping (VSM) distinguishes value-adding from non-value-adding activities and makes process waiting and flow interruptions visible (Hines & Rich, 1997). Previous studies have demonstrated the benefits of VSM in diagnosing flow problems and designing flow improvements (Anggraini et al., 2022). However, much of this evidence derives from manufacturing or urban construction settings characterized by comparatively stable logistics and shorter approval chains. The behavior of value streams in remote EPC environments, where long-haul supply chains and multi-party approvals are dominant, has rarely been examined, limiting the direct transferability of reported improvement percentages. Moreover, implementation outcomes depend on the project context, data quality, and organizational capabilities. Consequently, reduction percentages reported in other studies cannot be directly adopted as targets for the project examined in this study (Morato & Ferreira, 2024).

EVM complements VSM by measuring deviations from the performance measurement baseline using planned value (PV), earned value (EV), actual cost (AC), the schedule performance index (SPI), the cost performance index (CPI), schedule variance (SV), and cost variance (CV) (PMI, 2019). EVM quantifies the magnitude of project deviations but does not identify the underlying process mechanisms that cause them. Its results are also sensitive to baseline changes and data quality (Lipke et al., 2009). Meanwhile, RII can prioritize factors based on stakeholder assessments but cannot identify the locations of waste or quantify its consequences for project performance. These complementary limitations provide the conceptual basis for integrating the three methods rather than merely applying them within a single study.

To the best of the authors' knowledge, previous studies have predominantly applied RII, VSM, and EVM independently or in pairs. This study positions the three methods within a multilevel performance assessment framework: RII identifies the factors that warrant priority attention; VSM identifies where and how the associated disruptions manifest as cycle time (CT), waiting time (WT), and non-value-adding (NVA) activities; and EVM quantifies their consequences for budget-weighted project progress. The relationships among the three methods are sequential and traceable: factors prioritized through RII are linked to VSM bottlenecks, the bottlenecks are translated into Kaizen Bursts, and the effects of the proposed interventions are subsequently assessed through changes in flow indicators and SPI/SV. If the project indicators do not improve, the factor priorities and the value stream map must be reviewed. Accordingly, this study contributes a cross-level diagnosis–action–verification framework with a feedback mechanism for remote EPC projects.

Based on this research gap, the objectives of this study are to (1) identify the dominant delay factors using RII; (2) explain the relationships between these factors and value-adding (VA), non-value-adding but necessary (NVAN), non-value-adding (NVA), waiting time (WT), and bottlenecks across 19 activities; (3) translate the identified bottlenecks into Kaizen Bursts and develop a transparent future-state scenario; and (4) examine the consistency between the flow diagnosis and the schedule exposure measured through EVM without interpreting SV as an actual financial loss. The expected benefits are twofold. Theoretically, the framework advances project performance assessment by connecting causal, operational, and control-level evidence. Practically, it provides project managers in remote EPC environments with a defensible basis for prioritizing corrective actions and communicating schedule risks to stakeholders. The novelty of this study lies in its multilevel framework, which connects causal priorities, operational mechanisms, and project-level consequences while distinguishing measured results from design targets that still require verification.

Prior work has largely examined delay factors, value streams, and earned value in isolation or, at most, in pairs: RII studies rank causes but do not locate waste; VSM studies map process flows but do not quantify budget-weighted schedule exposure; and EVM studies identify performance deviations but do not explain their operational origins. To the best of the authors' knowledge, the three methods have not previously been integrated into a single, traceable analytical chain for a remote EPC project. This study addresses that gap and offers three contributions. Theoretically, it reframes RII, VSM, and EVM as complementary levels of a unified

diagnosis–action–verification mechanism rather than as independent tools. Methodologically, it specifies an explicit RII-to-VSM-to-Kaizen Burst-to-EVM sequence in which each method addresses limitations left unresolved by the preceding method and the outputs are cross-checked. Practically, it provides project teams in remote mining environments with a decision-support framework that links dominant causes to specific bottleneck activities and project-level schedule indicators while clearly distinguishing validated findings from the proposed future-state scenario. No claim of superiority over existing frameworks is made because comparative benchmarking was outside the scope of this study.

METHOD

Research Design, Sampling, and Data Collection

This study adopted a single, embedded case study design that combined quantitative perception data with qualitative validation. The unit of analysis was a 34-week renovation of a physiotherapy facility executed within an active mine site. Respondents were selected through purposive sampling based on the following inclusion criteria: direct involvement in the case project, a minimum of three years of EPC project experience, and functional responsibility for time, cost, quality, procurement, or field execution. Thirty respondents met these criteria and completed the questionnaire. This sample size was appropriate for a single-project RII study in which the relevant population was bounded by the project organization. Of these respondents, ten were selected as key informants, with one representing each core function: project management, site management, project control, engineering, procurement and logistics, civil/structural, MEP, QA/QC, cost control, and field supervision. This selection ensured cross-functional coverage for the semistructured interviews and VSM validation.

The questionnaire listed candidate delay factors compiled from the construction-delay literature and rated them on a five-point Likert scale. Content validity was established through expert review by senior project staff and a pilot test conducted before distribution. Internal consistency was assessed using Cronbach's alpha, with an acceptance threshold of 0.70. Interview data were triangulated with project documentation, including progress reports for Weeks 1–34, approval and transmittal registers, procurement and delivery records, and the final bill of quantities (BOQ). This triangulation ensured that the perception data were corroborated by documentary evidence rather than relied upon in isolation.

All participation was voluntary and based on informed consent obtained before data collection. Responses were anonymized, treated as strictly confidential, and used solely for research purposes. Because the study collected operational project information from professionals rather than sensitive personal data, it qualified for an institutional ethics exemption under the applicable research ethics guidelines.

Lean Construction

Lean construction is the adaptation of lean philosophy to the project environment, with the goal of minimizing waste in materials, time, and effort while maximizing customer value (Koskela, 1992). VSM supports this goal by illustrating information and physical flows, identifying sources of waste, and calculating process lead time (Intifada, 2012).

The main difference between lean construction and the conventional approach lies in the emphasis on the production system and flow reliability rather than merely on the completion of individual activities. The benefits of lean implementation include improvements in quality, safety, productivity, and coordination. However, its success depends on personnel understanding, competence, resource availability, and organizational support (Bajjou & Chafi, 2018).

Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a core lean tool used to map information and physical flows from the beginning to the end of a process. It enables organizations to distinguish among value-creating activities, necessary but non-value-creating activities, and activities that constitute waste (Shou et al., 2017).

Current State Mapping

Current State Mapping (CSM) provides a visual representation of the value stream under existing operational conditions. Its purpose is to uncover hidden waste and identify opportunities for improvement. The key parameters assessed in CSM include cycle time (CT), waiting time (WT), value-added ratio (VAR), and lead time (LT), with the following mathematical relationships:

$$\text{Lead Time} = \text{Cycle Time} + \text{Waste Time}$$

$$Value\ Added\ Ratio\ = \frac{Value\ Added\ Time}{Total\ Lead\ Time} \text{ x } 100\%$$

Future State Mapping

Future State Mapping (FSM) represents a proposed flow configuration following interventions designed to address waste and bottlenecks identified in the current state. Necessary but non-value-adding activities, such as engineering drawing preparation, approval, procurement, delivery, inspection, and handover, are retained when required for technical or administrative compliance, while improvement efforts focus on reducing waiting time and flow disruptions. Kaizen Bursts are used to mark problem locations and proposed action packages that bridge the current state and the future state (Mike Rother, 1999). The future state must be distinguished from actual results: the map remains an ex ante design until it is supported by post-intervention timestamps, calibrated simulations, or other operational evidence.

Earned Value Management (EVM)

Earned Value Management (EVM) integrates scope, schedule, and budget through Planned Value (PV), Earned Value (EV), and Actual Cost (AC). The Schedule Performance Index (SPI) and Schedule Variance (SV = EV − PV) measure schedule performance, whereas the Cost Performance Index (CPI) and Cost Variance (CV = EV − AC) require verified actual-cost data.

EVM explains the magnitude of deviations from the baseline but does not reveal the process mechanisms that cause them. VSM complements this limitation by tracing CT, WT, non-value-adding (NVA) activities, and bottlenecks, while RII identifies the factors most relevant to stakeholders. Conceptually, integrating all three methods establishes a factor prioritization–flow diagnosis–project outcome chain. Because validated weekly AC data aligned with the work breakdown structure (WBS) and a common data date were unavailable, the application of EVM in this study was limited to the schedule dimension (PV, EV, SV, and SPI). Budget at Completion (BAC) was not treated as a substitute for AC.

Previous Research

Table 1

Previous Research

No	Name/Year	Research method	Research Results
1	Deng & Jian (2022)	EVM + CPM + Monte Carlo simulation Beta-PERT	Identification of delays and cost overruns in a 32-month commercial expansion project; prioritization of activities J, H, G with P80/P90 range.
2	Elsaid et al. (2025)	Earned Schedule (ES), Earned Duration (ED), monthly analysis of 30 projects	ES is best in the early stages; ED is best in the final stages; highest accuracy using EDM; significant differences at >70% completion.
3	Kim et al. (2022)	Integrated BIM + EVM in highway construction	Accurate cost/schedule estimation; reduction of manual errors; higher monitoring efficiency compared to conventional methods.
4	Morato & Ferreira (2024)	Systematic literature review VSM in the construction industry	Systematic review shows VSM is useful for identifying loss and waste; implementation outcomes vary according to context and data quality.
5	Soliman et al.	Risk Management + EVM;	715-day delay (65.3%); early detection via

(2025)	case study in Kuwait	EV+RM; partial mitigation implementation.

The units of analysis were differentiated by level. At the causal level, RII was applied to the perceptions of 30 respondents to rank delay factors. At the operational level, VSM was used to map 19 activities covering engineering, approval, procurement, delivery, construction, punch-list work, and handover. Process sequences, value classifications, and the feasibility of improvement actions were examined qualitatively through interviews with ten cross-functional informants. At the project level, EVM was used to compare PV and EV at selected data dates. Cross-level linkages were established before interpretation: RII factors had to be traceable to VSM bottlenecks, Kaizen Bursts had to target the identified waste mechanisms, and final verification had to incorporate both flow indicators and project-level indicators.

Nonproductive waiting time was classified as non-value-adding (NVA). All VSM results were expressed in cumulative activity-days rather than contractual calendar days because some activities overlapped. Accordingly, the cumulative figure of 509 activity-days should not be interpreted as 509 calendar days. Because activities overlapped, the actual elapsed calendar duration was shorter and was governed by the contract schedule. The future state was structured as an analytical scenario, S25, to examine the magnitude of NVA reduction required to achieve a reduction of at least 25% in total LT. The 25% figure was not derived from a time–motion study, historical improvement data, simulation, quantitative expert elicitation, or post-intervention data; therefore, it was not treated as a validated forecast or operational target. To avoid relying on a single arbitrary figure, the scenario was framed as the upper bound of a sensitivity band comprising lead-time reductions of 10%, 15%, 20%, and 25%. The 25% level was retained as the most ambitious internally consistent target, while the lower levels illustrated how the required NVA reduction scaled with the selected improvement level (Table S). VA and NVAN were held constant, while the required NVA reduction was calculated using Equations (4) and (5). The allocation across the six bottlenecks represented mathematical scenario consistency and was intended to be replaced with specific activity-level targets once operational evidence became available.

$$\text{LT (FSM)} \leq \text{LT(CSM)} \times (1 - 0.25) \quad (4)$$

$$\text{R(NVA)} = \frac{(\text{NVA(CSM)} - \text{NVA(FSM)})/}{\text{NVA(CSM)}]} \times 100\% \quad (5)$$

The validation status of the future state was assessed in three categories. First, diagnostic validity was supported by triangulation of project documents, observations of 19 activities, and informant interviews. Second, the validity of the improvement mechanism was supported qualitatively through a cross-functional review of process sequences and bottlenecks. Third, the numerical validity of the proposed 128-activity-day reduction had not been established because no post-intervention timestamps, calibrated simulations, or quantitative elicitation results were available. This classification ensured that qualitative agreement was not converted into numerical evidence. No post-implementation validation of the future state was conducted in this study; therefore, the improvement mechanism and its magnitude remained to be confirmed through the time–motion/timestamp protocol outlined below, which was explicitly designated as future work.

Numerical verification was designed to be conducted through a time–motion/timestamp study. For engineering drawings, material approval requests (MARs), procurement, and delivery, each case was to be recorded at the time of complete receipt, with timestamps covering review, return of comments, resubmission, approval, dispatch, and site acceptance. For wall, ceiling, and floor work, observations were to be classified into direct work, support work, waiting, rework, and constraint-related time. Sample sizes were to be determined from preliminary studies using observed variation and a precision level specified before data collection rather than a fixed sample size. Before-and-after time distributions were to be compared alongside their uncertainty intervals. Discrete-event simulation was to be used only when the input distributions had been calibrated using empirical data (Sreram & Thomas, 2026).

The EVM budget baseline was reconciled against the final BOQ. Indirect costs amounted to Rp 1,784,000,000, and direct costs amounted to Rp 5,390,250,245, resulting in a Budget at Completion (BAC) of Rp 7,174,250,245 before value-added tax (VAT). The historical control BAC

of Rp 4,495,623,032.50 was retained solely for denominator sensitivity analysis, rather than as the primary calculation basis or as a measure of actual cost.

$$PV = BAC \times \text{cumulative planned};$$
$$EV = BAC \times \text{cumulative actual};$$
$$SV = EV - PV;\ SPI = \frac{EV}{PV}. \quad (6)$$

RESULTS AND DISCUSSION

Results

Relative Importance Index Analysis

The study involved 30 respondents who ranked delay factors using the Relative Importance Index (RII). Ten of these respondents were purposively selected as key informants for semistructured interviews and Value Stream Mapping (VSM) validation. The informants represented project management, site management, project control, engineering, procurement and logistics, civil and structural engineering, mechanical, electrical, and plumbing (MEP), quality assurance and quality control (QA/QC), cost control, and field supervision. The selection was based on the respondents' direct involvement in the project, professional experience, job authority, and knowledge of information related to time, quality, cost, waiting time, waste, and lean construction. The interviews lasted 15–30 minutes.

Based on the questionnaire results from the 30 respondents, ten factors contributing to performance deterioration were prioritized using the RII. The complete results are presented in Table 2 (Assaf & Al-Hejji, 2006).

Table 2

Results of Relative Importance Index (RII) Analysis of Time Performance Reduction Factors

code	Factors Contributing to Schedule Performance Deterioration	Σ Weighted (n=30)	RII
F1	Delays in the MAR, Calculation, and Drawing Approval Processes	142	0.947
F2	Logistical Disruptions Due to the Remote Location (Lombok–West Sumbawa)	138	0.920
F3	Scope additions or changes through Variance Orders	135	0.900
F4	Third-party work interference within the project area	128	0.853
F5	Delays in HVAC installation and specialized physiotherapy materials	126	0.840
F6	Risk of rework or repair due to dust, vibration, or environmental conditions	119	0.793
F7	Insufficient coordination among MEP, architectural, and structural subcontractors	115	0.767
F8	Revisions to work quantities or inaccuracies in the Bill of Materials (BOM)	108	0.720
F9	Rainfall or extreme weather conditions	98	0.653
F10	Insufficient lean construction knowledge or training within the project team	91	0.607

The RII ranking results indicate that the first-priority group comprises F1–F3, which account for a cumulative contribution of 34.58% and have RII values ranging from 0.900 to 0.947. These factors are delays in MAR, calculation, and drawing approval (0.947); logistical constraints associated with transportation from Lombok to West Sumbawa (0.920); and scope changes through variation orders (0.900). These findings indicate that interventions should focus on standardizing approval workflows, assigning responsible parties and review deadlines, monitoring document status, improving logistics planning, and controlling changes through a change register. Evidence of delays involving MARs and variation orders further supports the prioritization of these factors. The second-priority group comprises F4–F8, which collectively accounts for an additional 49.67%, bringing the cumulative contribution to 84.25%.

Interventions for this group include managing third-party interfaces, improving the readiness of specialized materials, preventing rework caused by environmental conditions, strengthening coordination among MEP, architectural, and structural teams, and validating the BOM before procurement. Meanwhile, F9–F10 account for the remaining 15.75% and constitute the third-priority group, warranting weather mitigation measures and enhanced lean construction training.

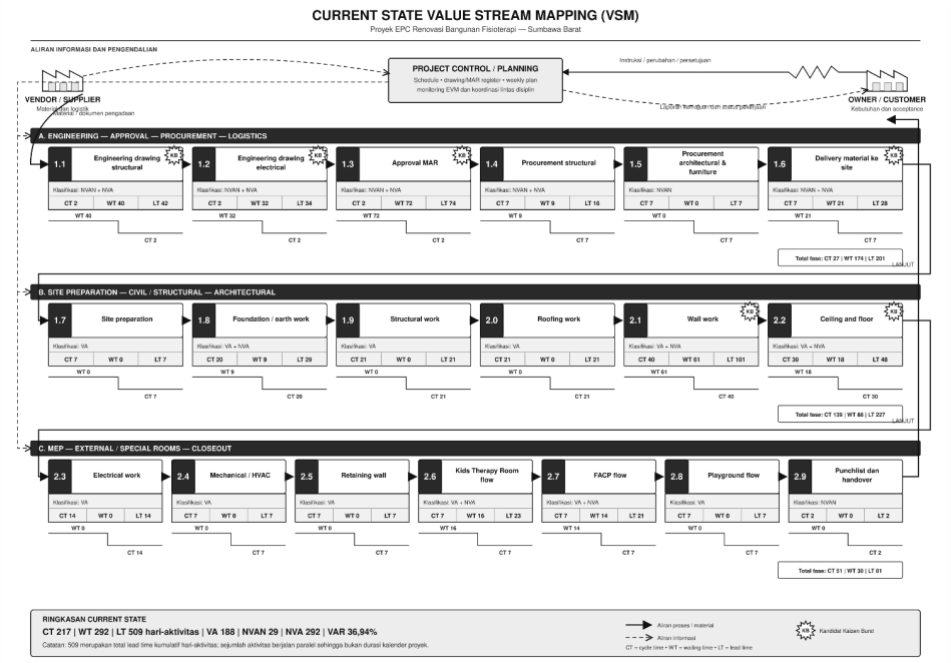


Figure 1. Current-state value stream map of the EPC construction process

Current State, Kaizen Burst, and Future State Analysis

The current-state mapping analysis was conducted to describe the process flow of the physiotherapy building construction project at the time of the study. The analysis focused on activity cycle times, waiting times or delays, and the classification of activities according to their contribution to project value creation. This approach was used to identify process stages that contributed value and those that contained time-related waste (Mike Rother, 1999).

Based on 19 activities, the analysis yielded a total cycle time (CT) of 217 activity-days and a total waiting time (WT) of 292 activity-days, resulting in a cumulative lead time (LT) of 509 activity-days (Table 3). The CT comprises 188 activity-days of value-adding (VA) activities and 29 activity-days of necessary non-value-adding (NNVA) activities. Meanwhile, the entire 292 activity-days of waiting time are classified as non-value-adding (NVA). The WT exceeds the CT, indicating that every activity-day of processing time is accompanied by approximately 1.35 activity-days of waiting time. This finding suggests that the dominant problem in the current state is not merely the technical duration of work but also delays throughout the engineering, approval, procurement, delivery, and construction processes. A closer examination links each major bottleneck to its underlying causes. The 72-activity-day wait for MAR approval reflects sequential reviews, single-reviewer approval cycles, and resubmissions, compounded by the remote location of the approver (factor F1). The 61-activity-day wait associated with wall work stems from dependencies on upstream material deliveries and work-zone clearance (factors F2 and F5). Delays in engineering drawing approvals and releases are associated with late design freeze decisions and gaps in cross-disciplinary coordination (factors F1 and F7). Waiting time is therefore not simply unused time; it is the downstream manifestation of the highest-ranked RII factors.

$$CT = VA + NVAN = 188 + 29 = 217 \text{ Day}$$
$$LT = VA + NVAN + NVA = 188 + 29 + 292 = 509 \text{ Day}$$

The Value-Added Ratio (VAR) measures the proportion of value-adding time relative to cumulative lead time Koskela (1992) and is calculated as follows:

$$VAR = VA/LT \times 100\% = 188/509 \times 100\% = 36.94\%.$$

The results indicate that 188 of the 509 cumulative activity-days contribute directly to creating value in the building's functionality. Conversely, 63.06% of the total time does not directly add value. This proportion comprises necessary non-value-adding (NNVA) activities, accounting for 5.70%, and non-value-adding (NVA) time, accounting for 57.37%.

Table 3
Current-State Map Classification of the Value Stream for the Physiotherapy Building Renovation EPC Project

code	Activity	Classification	CT	WT	LT	VA
1.1	Engineering drawing structural	NVAN + NVA	2	40	42	0
1.2	Engineering drawing electrical	NVAN + NVA	2	32	34	0
1.3	Approval MAR	NVAN + NVA	2	72	74	0
1.4	Procurement structural	NVAN + NVA	7	9	16	0
1.5	Procurement architectural and furniture	NVAN	7	0	7	0
1.6	Delivery material to site	NVAN + NVA	7	21	28	0
1.7	Site preparation	VA	7	0	7	7
1.8	Foundation/earth work	VA + NVA	20	9	29	20
1.9	Structural work	VA	21	0	21	21
2.0	Roofing work	VA	21	0	21	21
2.1	Wall work	VA + NVA	40	61	101	40
2.2	Ceiling and floor	VA + NVA	30	18	48	30
2.3	Electrical work	VA	14	0	14	14
2.4	Mechanical/HVAC	VA	7	0	7	7
2.5	Retaining wall	VA	7	0	7	7
2.6	Kids Therapy Room flow	VA + NVA	7	16	23	7
2.7	FACP flow	VA + NVA	7	14	21	7
2.8	Playground flow	VA	7	0	7	7
2.9	Punch list and handover	NVAN	2	0	2	0
	TOTAL		217	292	509	188

In this study, the VAR serves as a baseline for comparing the current state with the proposed future state. Flow improvement is indicated by an increase in the VAR through reductions in NVA time. However, such improvements can be reported as actual outcomes only after the interventions have been implemented and verified using post-implementation data.

$$NVAN = \frac{29}{509} \times 100\% = 5.70\%;$$

$$NVA = \frac{292}{509} \times 100\% = 57.37\%.$$

NVAN + NVA = (321 / 509) x 100% = 63.06%

Table 4
Future-State Mapping Improvement Targets for the Six Bottlenecks

Rank	Bottleneck of element	CT	WT CSM	WT FSM	Reduction WT	LT FSM
1	Approval MAR	2	72	34	38	36
2	Wall work	40	61	29	32	69
3	Engineering drawing structural	2	40	19	21	21
4	Engineering drawing electrical	2	32	15	17	17
5	Delivery material to site	7	21	10	11	17
6	Ceiling and floor	30	18	9	9	39
	TOTAL	83	244	116	128	199

Based on Table 4, which presents improvement targets for six bottleneck activities under the future-state mapping, the analysis demonstrates the potential for reducing time-related waste in the operational process. The approach focuses on reducing WT while maintaining CT, which represents the time required to perform the activities. Under the current-state conditions, the six bottleneck activities had a combined CT of 83 activity-days and a combined WT of 244 activity-days. Under the proposed future-state design, the WT of these activities is targeted to decrease to 116 activity-days, representing a reduction of 128 activity-days. Consequently, the combined future-state LT for the six bottleneck activities is projected to be 199 activity-days, calculated by adding the CT of 83 activity-days to the future-state WT of 116 activity-days.

Meanwhile, the remaining 13 activities had a combined CT of 134 activity-days and a WT of 48 activity-days, resulting in an LT of 182 activity-days. Because the proposed improvements target the six bottleneck activities, the overall CT remains unchanged at 217 activity-days, while the total WT is projected to decrease from 292 activity-days in the current state to 164 activity-days in the future state. Accordingly, the overall project LT is analytically projected to decrease from 509 to 381 activity-days, representing a reduction of 128 activity-days, or 25.15%. These results indicate that reducing WT at the six bottleneck activities could directly improve process-flow efficiency. These figures describe a proposed future-state scenario; they are analytical targets, not improvements already achieved on-site. They can be considered actual outcomes only after post-intervention verification.

Table 5
Kaizen Burst Action Matrix *and Future State Mapping*

Bottleneck	Kaizen burst	evidence	Verification variable
Material Approval Request	Establish an email reminder system, parallel reviews, and an escalation path.	Emails, transmittals, approval registers, submission and approval dates, as well as approved MARs.	Number of days from complete submission to approval.
Engineering drawing structural	Design freeze and internal review prior to submission.	Drawing register, revision history, reviewer comments, and approved drawings.	Drawing scheduling and the number of resubmissions.
Engineering drawing electrical	Cross-disciplinary coordination	Drawing register, RFI log, MEP coordination, and approved drawings.	Drawing scheduling, number of revisions, and RFI resolution time.
Delivery material	Vendor and delivery monitoring according to site requirements.	Purchase orders, vendor schedules, delivery receipts, material receiving reports, and photos.	Variance between the required date and the actual material receipt date.
Wall work	Look-ahead planning and constraint removal.	Weekly plans, daily reports, manpower, material readiness, progress quantities, and PPC (Percentage of Plan Complete).	Work scheduling, productivity, and weekly plan achievement.
Ceiling and floor	MEP clearance and work zone division	Inspection requests, MEP clearance checklists, daily reports, and progress reports.	Area scheduling, zone release time, and the number of reworks.

Discussion

The following discussion interprets the findings, compares them with prior research, and considers their implications rather than simply restating the results. The findings indicate that schedule deterioration in the case project is driven primarily by upstream managerial and supply-

chain disruptions rather than by field production alone. The three highest RII values—delays in MAR, calculation, and drawing approval (0.947); remote-site logistics (0.920); and scope changes through variation orders (0.900)—indicate that information release, material readiness, and change control are the dominant sources of schedule risk. This finding is consistent with the construction-delay literature, which repeatedly identifies approval, material, coordination, and change-related issues as important causes of delay, although their relative importance varies by project context. In the present case, the remote mining environment intensifies these factors because engineering decisions and material deliveries are strongly interdependent. Therefore, the RII results should not be interpreted merely as a ranking table; they establish the causal priorities that must be traced through the operational process before corrective actions are selected.

The VSM findings explain how these causal priorities translate into operational waste. Across 19 activities, the current state contains 217 activity-days of cycle time and 292 activity-days of waiting time, producing 509 cumulative activity-days and a VAR of 36.94%. The six bottlenecks account for 244 activity-days, or 83.56% of the total waiting time. This concentration supports the use of VSM as a focused diagnostic tool because the greatest improvement opportunities are concentrated in a relatively small number of process interfaces. The result is consistent with Morato & Ferreira (2024), who demonstrate that VSM can identify losses and waste in construction while emphasizing that implementation outcomes depend on project conditions and data quality. It also accords with Ramani & KSD (2021), who demonstrate the usefulness of VSM for improving construction flow. From a process-efficiency perspective, the high proportion of waiting time indicates that the principal inefficiency arises from interruptions to workflow rather than excessive technical processing time. Consequently, the proposed future-state design appropriately retains necessary non-value-adding controls related to safety, quality, inspection, and compliance while targeting avoidable waiting and failed handoffs.

The EVM results complement the process-flow diagnosis by showing the project-level consequences of these disruptions. SPI values of 0.773 in Week 14, 0.847 in Week 27, and 0.970 in Week 34 indicate that the project remained behind the budgeted schedule baseline at all three data dates, although the deviation narrowed toward the end of the observation period. This pattern is consistent with the role of EVM as a performance-control method that signals schedule deviations but does not, by itself, identify their operational causes (Proaño-Narváez et al., 2022). Recent construction studies similarly demonstrate the usefulness of earned-value-based approaches for detecting performance problems and supporting project monitoring (Kim et al., 2022). In this study, the interpretation is deliberately restricted to planned value (PV), earned value (EV), schedule variance (SV), and SPI because verified actual cost (AC) data at the same work breakdown structure (WBS) level and data date were unavailable. Accordingly, a negative SV is interpreted as a schedule deviation expressed in budget-weighted terms, not as a realized financial loss. This distinction is important because it prevents EVM indicators from being interpreted beyond what the available project data support. The practical implication is that the SPI and SV trajectories should trigger schedule-recovery planning focused on the identified bottlenecks rather than cost-based conclusions until verified actual-cost data become available.

Taken together, RII, VSM, and EVM form a diagnosis–action–verification chain rather than three independent analyses. RII identifies the factors that warrant management attention; VSM identifies where these factors generate waiting, NVA time, and bottlenecks; kaizen bursts translate the diagnosis into improvement actions; and EVM provides a project-control perspective for evaluating whether operational improvements are eventually reflected in schedule performance. The proposed S25 scenario reduces total waiting time from 292 to 164 activity-days and cumulative lead time from 509 to 381 activity-days by focusing on six bottlenecks. However, the projected reduction of 128 activity-days remains an analytical future-state scenario rather than a verified project outcome. This interpretation is consistent with literature emphasizing that VSM improvements require empirical validation and that construction-flow interventions are sensitive to data quality and implementation capability (Oyewobi et al., 2025). The practical implication is that management should treat the future-state map as a hypothesis to be tested, not as a guaranteed schedule-recovery commitment. Beyond the case project, the framework contributes to contemporary project-management practice by operationalizing the shift from tool-centered monitoring to integrated, cross-level control. It combines lean process-flow

diagnosis with earned-value governance so that corrective actions are prioritized based on evidence rather than managed within separate disciplinary silos.

For implementation, the findings imply that project control should be organized across functions rather than around separate analytical tools. Approval turnaround time, resubmission frequency, RFI closure time, vendor milestone adherence, required-versus-actual material receipt dates, constraint-removal status, zone-release time, plan reliability, and rework should be monitored as leading indicators. Bottleneck waiting time, total NVA time, LT, and VAR can then serve as intermediate process-flow indicators, while SPI and SV remain lagging project-level indicators. A common issue identifier linking each RII factor, VSM activity, WBS element or control account, kaizen action, responsible owner, due date, and closure evidence would improve traceability. This managerial arrangement is particularly relevant because lean implementation depends not only on technical tools but also on organizational capability, coordination, and staff competence. Studies of barriers to lean construction similarly emphasize the importance of management support, knowledge, and implementation readiness (Oyewobi et al., 2025). Thus, the framework's value lies in establishing a disciplined feedback loop among causal diagnosis, process intervention, and performance monitoring.

Several limitations must be considered when interpreting these findings. First, the study examines a single physiotherapy facility renovation project in a remote mining environment; therefore, the ranking of delay factors and the magnitude of process waste cannot be generalized directly to other EPC projects. Second, the RII assessment is based on 30 respondents, while qualitative validation involved ten key informants. Consequently, the results remain dependent on the experience and perceptions of the participating project team. Third, VSM uses cumulative activity-days rather than contractual calendar days because some activities overlap. Fourth, the proposed future-state reductions have not yet been validated using post-intervention timestamps, time-motion observations, or a calibrated simulation. Fifth, the absence of verified AC data prevents conclusions about the Cost Performance Index (CPI), cost variance (CV), estimate at completion (EAC), or actual cost savings. Future research should apply the framework to multiple projects, collect longitudinal pre- and post-intervention data, calibrate a discrete-event simulation using empirical distributions as suggested by Sreram & Thomas (2026), and reconcile PV, EV, and AC at the same WBS level and data date. Such research would test whether reductions in waiting time consistently translate into sustained improvements in VAR, SPI, and cost performance.

CONCLUSION

This study demonstrates that RII, VSM, and EVM provide complementary levels of evidence for controlling a remote EPC renovation project. RII prioritized approval delays (0.947), logistical constraints (0.920), and scope changes (0.900). VSM then identified the operational consequences across 19 activities, where 292 cumulative activity-days of waiting time exceeded the 217 activity-days of cycle time and resulted in a VAR of 36.94%. EVM indicated project-level schedule exposure, with SPI values of 0.773, 0.847, and 0.970 in Weeks 14, 27, and 34, respectively. Taken together, these methods establish a traceable chain from causal priorities to waste mechanisms and budget-weighted schedule consequences, thereby supporting more focused corrective decisions than any of the methods could support in isolation. The principal contribution is therefore the integrated, traceable framework itself rather than any single index value.

The proposed kaizen bursts and S25 future-state scenario provide an improvement design, not evidence that 128 activity-days have already been recovered. Their effectiveness must be verified using post-intervention timestamps, time-motion observations, and consistent project-control data. Because validated AC data were unavailable at the same WBS level and data date, SV represents a budget-weighted schedule variance and must not be interpreted as an actual financial loss; cost performance therefore cannot yet be determined. Future research should test the integrated framework across multiple EPC projects and compare pre- and post-intervention distributions to determine the extent to which reduced waiting time produces sustained improvements in VAR, SPI, and cost performance. Finally, because the evidence comes from a single physiotherapy facility project in a remote mining environment, the specific factor rankings

and magnitudes of process waste should be treated as context-specific and should not be generalized to other EPC projects without replication.

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AUTHOR CONTRIBUTION STATEMENT

Ifan Ariosandi contributed to conceptualization, methodology, investigation, data curation, formal analysis, visualization, manuscript drafting, and project administration. Oki Setyandito, contributed to methodology, supervision, validation, and interpretation of findings. Tota Pirdo Kasih contributed to methodology, supervision, validation, technical review, and refinement of the research methodology and manuscript. All authors collaboratively analyzed the results, reviewed and approved the final version of the manuscript for submission, and take full responsibility for the integrity, accuracy, and accountability of all aspects of the research.

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