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Value Engineering in Temporary Cofferdam Works: The Impact of Using Type II Steel Sheet Piles on Cost and Time Efficiency Bridge Reconstruction Project

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Abstract

Temporary cofferdam works in post-disaster infrastructure projects require rapid, safe, and cost-effective technical decisions. This study evaluates the use of Steel Sheet Pile (SSP) Type II as an alternative to SSP Type IV in the temporary cofferdam works of the Palu IV Bridge Reconstruction Project. The study aims to examine the effects of stakeholder perception, material availability, and ease of implementation on cost efficiency; to analyze the effect of cost efficiency on work completion time; and to assess the implementation impact of SSP Type II in terms of material requirements, driving volume, technical control, and direct costs. A descriptive quantitative approach was applied through a survey of 36 project respondents and Structural Equation Modeling-Partial Least Squares (SEM-PLS). The SEM-PLS results show that stakeholder perception significantly affects cost efficiency ($O=0.664$; $t=5.034$; $p<0.001$), material availability significantly affects cost efficiency ($O=0.912$; $t=2.397$; $p=0.017$), ease of implementation significantly affects cost efficiency ($O=1.151$; $t=3.484$; $p=0.001$), and cost efficiency significantly affects project time ($O=0.766$; $t=10.500$; $p<0.001$). Technically, the 18 m SSP Type II system with HB 350x350x12x19 cross bracing met the criteria for stability, deflection, bending moment, and stress ratio based on the project design review. In the pier works, SSP Type II reduced the number of sheets from 420 to 400 units, decreased the driving length from 8,610 m to 7,200 m, and produced cost savings of IDR 11,938,147,636.30 or 64.84% compared with SSP Type IV.

Introduction

Bridge reconstruction projects in aquatic environments require temporary construction systems capable of creating dry, safe, and stable working areas. In pile cap and foundation works, a temporary cofferdam functions to retain water and soil during excavation and substructure construction acivities. The selection of an appropriate steel sheet pile (SSP) type is determined not only by its structural capacity but also by material availability, procurement time, equipment requirements, ease of installation, and its direct cost implications for the project (Mirković & Mirković, 2026; Yasmin et al., 2026; Halimatussadiah et al., 2024; Hu et al., 2024). Post-disaster reconstruction conditions further emphasize the need for adaptive construction decisions. When the original design relies on expensive or difficult-to-procure materials, alternative designs should be systematically evaluated to ensure that the primary function is maintained without compromising safety. Value engineering (VE) provides an appropriate framework for this purpose by placing functional performance at the center of the analysis and assessing whether the same function can be achieved through more economical

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alternatives (Gunarathne et al., 2022; Lavi & Reich, 2024; Russell & Nasr, 2023; Ibrahim et al., 2024). Dell'Isola (1997) defines value engineering as a structured approach to improving value through the evaluation of functions, costs, and technical alternatives. In project management, design modifications must be properly controlled to avoid adversely affecting project cost, schedule, quality, and risk objectives, as emphasized by Kerzner (2017) and the Project Management Institute (2021).

This study is based on the temporary cofferdam works in the Palu IV Bridge Reconstruction Project. The original design specified the use of Type IV Steel Sheet Piles (SSP Type IV), whereas project implementation considered replacing them with Type II Steel Sheet Piles (SSP Type II) through a value engineering approach. This design modification cannot be evaluated solely from the perspective of material cost savings; instead, it must be assessed from two complementary dimensions (Mndlovu et al., 2024): (1) project stakeholder acceptance and (2) technical performance, including temporary structural safety, material requirements, pile driving volume, and direct construction costs.

The practical novelty of this study lies in integrating PLS-SEM analysis with the technical evaluation of cofferdam implementation. Previous value engineering studies have generally been limited to comparing alternative costs, whereas this research links stakeholder perceptions, material availability, and ease of construction to cost efficiency and subsequently examines the relationship between cost efficiency and project completion time. This approach extends the application of value engineering beyond simple cost reduction toward a project decision-making model that simultaneously considers technical, organizational, and operational factors.

Accordingly, this study aims to (1) analyze the effects of stakeholder perceptions, material availability, and ease of implementation on the cost efficiency of temporary cofferdam works; (2) examine the effect of cost efficiency on project completion time; and (3) evaluate the impact of implementing SSP Type II on material requirements, work volume, technical control, and direct costs in pier construction.

Literature Review

Value Engineering and Construction Decision-Making

Value engineering is a systematic approach for evaluating the essential functions of a project and identifying alternatives that provide greater value. In the construction industry, value should not be interpreted merely as achieving the lowest cost, but rather as maintaining an optimal balance among functionality, cost, quality, constructability, and risk. Therefore, value engineering distinguishes legitimate cost savings from indiscriminate cost cutting, which may compromise project performance. Previous studies have shown that construction cost savings can be achieved when alternative analyses are supported by functional evaluation, technical assessment, and transparent cost verification (Ramadhan & Kurniasari, 2024; Fobiri et al., 2025; Islam & Rehman, 2022; Yang & Yang, 2025; Marcus et al., 2024).

In temporary cofferdam construction, the primary function of the sheet pile system is to provide a temporary retaining structure capable of resisting earth and water pressures, limiting lateral deformation, and facilitating substructure construction activities. Although temporary in nature, this function is critical; therefore, any material alternative must continue to satisfy stability and serviceability requirements (Montalbano & Santi, 2023; Zhang et al., 2026; Sadiq, 2022). Consequently, the decision to replace SSP Type IV with SSP Type II must be validated through evaluations of safety factors, deflection, bending moments, and the strength of bracing elements.

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Cost, Time, and Material Efficiency in Construction Projects

Cost and schedule are two closely related measures of project performance. Material substitutions that reduce costs may also influence project duration by affecting work volume, equipment operating cycles, installation complexity, or procurement lead time. Research on the cost–time–quality trade-off emphasizes that schedule acceleration decisions should always be evaluated together with their implications for quality and construction methods (Wang et al., 2021; Lotfi et al., 2022; Sethy et al., 2025).

In the context of temporary cofferdam construction, material efficiency may be achieved through the utilization of existing materials, reducing the number of sheet piles, minimizing the total pile driving length, and simplifying mobilization processes. However, these efficiencies are meaningful only if they do not introduce greater technical risks. Therefore, this study considers material availability and ease of implementation as key variables influencing project cost efficiency (Milind Mehta et al., 2022; Salzano et al., 2024; Aladayleh & Aladaileh, 2024; Yang et al., 2025).

SEM-PLS for Evaluating Relationships Among Variables

Partial Least Squares Structural Equation Modeling (PLS-SEM) is a variance-based structural equation modeling technique widely applied for predictive analysis, theory development, and studies involving latent constructs. Hair et al. (2019) emphasize that PLS-SEM reporting should include assessments of the measurement model, reliability, validity, structural model, path coefficients, and statistical significance. Hair et al. (2022) further provide practical guidelines for evaluating composite reliability, average variance extracted (AVE), R^2, f^2, and bootstrapping results.

Discriminant validity is also essential to ensure that the constructs employed are empirically distinct from one another (Lim, 2024; Cheung et al., 2024; Lambert & Newman, 2023). Henseler et al. (2015) introduced the Heterotrait–Monotrait Ratio (HTMT) criterion to evaluate discriminant validity in variance-based structural equation modeling. In this study, the measurement model is assessed to ensure that the constructs of stakeholder perception, material availability, ease of implementation, cost efficiency, and project completion time are adequately represented before analyzing the structural relationships among them.

Methods

This study employed a descriptive quantitative approach using a survey design. The unit of analysis comprised stakeholders involved in the temporary cofferdam works of the Palu IV Bridge Reconstruction Project, including project management, planning, construction, material procurement, and technical personnel with expertise in steel sheet pile (SSP) application and value engineering implementation. A total of 36 respondents participated in the study. Primary data were collected through a five-point Likert-scale questionnaire, while secondary data were obtained from project documents, including material requirements, design review results, piling quantities, and SSP cost comparisons.

The study included three independent variables: stakeholder perceptions of value engineering (X1), material availability (X2), and ease of implementation (X3). Cost efficiency (Y1) served as the first dependent variable, while project completion time (Y2) was the second dependent variable. The structural model examined four relationships: X1 → Y1, X2 → Y1, X3 → Y1, and Y1 → Y2.

Data were analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS). The first stage involved evaluating the measurement model through internal consistency reliability, rho_A, composite reliability, Average Variance Extracted (AVE), and discriminant validity. The second stage assessed the structural model using R-square, f-

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square, path coefficients, t-statistics, and p-values. Statistical significance was determined at $p < 0.05$. P-values reported as 0.000 by the software were presented as $p < 0.001$ in accordance with standard statistical reporting conventions.

The technical implementation evaluation compared the initial SSP design with the implemented design by assessing reductions in the number of sheet piles, total piling length, and project costs. Cost efficiency was calculated using the following formula: Cost Efficiency (%) = [(Cost of Type IV SSP − Cost of Type II SSP) / Cost of Type IV SSP] × 100%. Time improvement based on sheet pile usage was evaluated by comparing the reduction in the number of sheet piles required for each pier, while work-volume efficiency was determined from the reduction in the total piling length for the pier structures.

Results and Discussion

Respondent Profile

The respondent profile shows that the respondents were predominantly male, aged 25-30, with a Diploma 3 education, and 4-6 years of work experience. A summary of the respondent profile is presented in Table 1.

Table 1. Respondent Characteristics

Category	Dominant Classification	Number	Percentage
Gender	Male	24 out of 36	66.7%
Age	25–30 years	14 out of 36	38.9%
Education	Associate Degree (Diploma III/D3)	13 out of 36	36.1%
Length of Service	4–6 years	15 out of 36	41.7%

Measurement Model Evaluation

The measurement model test results showed that all constructs had Cronbach's Alpha, rho_A, and composite reliability values above 0.90. The AVE values for all constructs were above 0.50, thus demonstrating that the constructs met internal reliability and convergent validity based on general PLS-SEM guidelines. Discriminant validity was examined through cross-loading results on the PLS output; the research indicators showed the highest loadings on their respective original constructs, allowing the constructs to be interpreted separately.

Table 2. Measurement Model Reliability and Convergent Validity Results

Construct	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Stakeholder Perception (X1)	0.938	0.939	0.947	0.642
Material Availability (X2)	0.968	0.969	0.971	0.740
Ease of Implementation (X3)	0.948	0.950	0.955	0.639
Cost Efficiency (Y1)	0.960	0.962	0.964	0.628
Time (Y2)	0.949	0.950	0.957	0.735

Structural Model Evaluation

The R-square value for cost efficiency of 0.949 indicates that the variation in cost efficiency in the model is strongly explained by stakeholder perceptions, material availability, and ease of implementation. The R-square value for time of 0.587 indicates that cost efficiency explains most of the variation in time in the research model. The f-square values for the main paths also indicate a significant contribution of the effects to the endogenous construct.

Table 3. Coefficient of Determination (R^2) Results

Endogenous Variable	R^2	Adjusted R^2
Cost Efficiency (Y1)	0.949	0.944

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Time (Y2)	0.587	0.574

Table 4. Effect Size (f^2) Results of the Structural Model

Construct Relationship	f^2 (Effect Size)
Stakeholder Perception (X1) → Cost Efficiency (Y1)	1.005
Material Availability (X2) → Cost Efficiency (Y1)	1.396
Ease of Implementation (X3) → Cost Efficiency (Y1)	1.269
Cost Efficiency (Y1) → Time (Y2)	1.419

Hypothesis Test Results

Hypothesis testing showed that all relationship paths in the model were significant at the 5% level. Stakeholder perceptions, material availability, and ease of implementation had a positive effect on cost efficiency. Cost efficiency also had a positive effect on project completion time. These results indicate that technical innovation in cofferdam projects is influenced not only by design feasibility, but also by project organization acceptance, material access, and ease of implementation of the method in the field.

Table 5. Structural Model Path Coefficients and Hypothesis Testing Results

Inter-Variable Relationship	Original Sample	t-Statistic	p-Value	Decision
Stakeholder Perception (X1) → Cost Efficiency (Y1)	0.664	5.034	< 0.001	Significant
Material Availability (X2) → Cost Efficiency (Y1)	0.912	2.397	0.017	Significant
Ease of Implementation (X3) → Cost Efficiency (Y1)	1.151	3.484	0.001	Significant
Cost Efficiency (Y1) → Time (Y2)	0.766	10.500	< 0.001	Significant

Technical Evaluation of Type II SSP Implementation

The technical evaluation demonstrated that the Type II SSP alternative not only yielded potential savings but also met the relevant control parameters for cofferdam construction. The analyzed system used an 18-m-long Type II SSP reinforced with 350x350x12x19 HB cross braces. The final safety factor of 1.842 exceeded the minimum criterion of 1.50. The maximum lateral deflection of the SSP was 42.35 mm, which was less than the 56.50 mm limit. The maximum bending moment of 77.59 kN.m was less than the allowable capacity of 138.44 kN.m. The maximum cross brace stress ratio of 0.795 was less than the 1.00 limit.

These technical findings demonstrate that the Type II SSP alternative can be positioned as a viable value engineering outcome, not simply a cheaper material option. This eligibility remains conditional, that is, it applies as long as the field conditions, excavation stages, piling, dewatering, and installation of cross braces follow the assumptions and technical procedures used in the project design review.

Table 6. Technical Evaluation Results of Type II Steel Sheet Pile Implementation

Control Aspect	Criterion/Reference	Analysis Result	Status
Global Stability	Minimum Safety Factor (SF) ≥ 1.50	Final SF = 1.842	Satisfies the Criterion
SSP Lateral Deflection	Maximum 0.5%H = 56.50 mm	Maximum = 42.35 mm	Satisfies the Criterion
SSP Bending Moment	Allowable Capacity = 138.44 kN·m	Maximum = 77.59 kN·m	Satisfies the Criterion

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Cross Brace Vertical Deflection	L/360 = 37.78 mm	Maximum = 7.00 mm	Satisfies the Criterion
Cross Brace Lateral Deflection	L/300 = 33.33 mm	Maximum = 6.273 mm	Satisfies the Criterion
Cross Brace Stress Ratio	LRFD Ratio < 1.00	Maximum Ratio = 0.795	Satisfies the Criterion

Impact on material requirements, time, and cost

The impact of implementation on time was calculated for the pier work because the actual use of Type II SSP in the project data was for the pier work, while the abutment work did not use SSP based on the consultant's approval. In the initial design, the SSP requirement for the pier work was 420 sheets with a total piling length of 8,610 m. In the actual design, the requirement was reduced to 400 sheets with a total piling length of 7,200 m. A reduction of 20 sheets from the base of 420 sheets is equivalent to a sheet-based acceleration of 4.76%. A reduction in piling length of 1,410 m from the base of 8,610 m is equivalent to a work volume efficiency of 16.38%.

In terms of costs, the total cost of the Type IV SSP alternative is Rp18,412,179,564.80, while the total cost of the Type II SSP is Rp6,474,031,928.50. The cost difference of Rp11,938,147,636.30 indicates a 64.84% efficiency compared to the cost of Type IV SSP. This calculation provides quantitative evidence that value engineering provides significant direct savings on the temporary cofferdam work components.

Table 7. Comparison of Steel Sheet Pile Requirements between Design and Actual Implementation

Item	Required Length	Number of Sheets	Weight	SSP Type
Total Detailed Engineering Design (DED)	10,654 m	712	752,931.20 kg	Type IV
DED for Pier	8,610 m	420	654,819.20 kg	Type IV
Actual Total Installation	7,200 m	400	345,600.00 kg	Type II
Actual Pier Installation	7,200 m	400	345,600.00 kg	Type II

The research results indicate that the success of value engineering in temporary cofferdam projects is inseparable from the interaction between people, materials, methods, and technical controls. Stakeholder perception is a crucial factor because the transition from a Type IV SSP to a Type II SSP requires approval, coordination, and readiness to accept design changes. Without stakeholder support, technically feasible alternatives may be delayed or inconsistently implemented.

Material availability has been shown to significantly impact cost efficiency. In this case, utilizing some Type II SSP materials from other projects and combining them with a new Type II SSP reduced reliance on the more expensive Type IV SSP. Easier procurement contributed to controlling mobilization and material costs. However, descriptive findings also indicate that supplier accessibility is not fully optimized. This highlights the need for value engineering to be accompanied by strengthening the supply chain, delivery schedules, and logistics management to prevent savings from being lost due to procurement constraints (Onukwulu et al., 2023; Attah et al., 2024; Zindi & Sibanda, 2022; Kanike, 2023; Donyavi et al., 2024).

Ease of implementation is also a determinant of cost efficiency. A good technical alternative must be able to be installed with available tools, competent labor, and a manageable work sequence. Therefore, implementing a Type II SSP requires detailed work methods, field inspections, piling supervision, deformation monitoring, and dewatering risk control (Xiao et al., 2025).

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The significant relationship between cost efficiency and time indicates that cost savings do not stand alone. In this case, reducing the number of sheets and piling length directly reduces the volume of piling activities. Consequently, the execution time for the pier work can be more efficient. However, the 4.76% figure in this study is based on the reduction in the number of sheets, not a daily time-motion study that records all equipment and worker activity. Therefore, the interpretation of the time should be read as an indication of implementation efficiency based on work volume, not a comprehensive measurement of the entire project duration.

Technically, the structural control results indicate that the Type II SSP still meets the stability and serviceability limits. The 64.84% savings are further strengthened by the data on safety factors, deflections, moments, and stress ratios. In other words, the Type II SSP innovation not only results in cost reduction but also provides the best value through a combination of technical feasibility, material utilization, and reduced work volume.

The managerial implication of this research is that value engineering should begin early in a project, especially for temporary projects that involve significant costs and have the potential for overdesign. Contractors should establish a cross-functional review forum involving engineering, methods, procurement, cost control, quality, and safety. Each alternative should be assessed using a matrix of function, cost, availability, method, risk, and time impact. With this approach, innovation decisions can be accepted as technical decisions, not simply cost-saving policies.

Conclusion

Stakeholder perceptions have a positive and significant impact on the cost efficiency of temporary cofferdam projects. These results indicate that stakeholder acceptance and support are organizational prerequisites for the successful implementation of value engineering.

Material availability has a positive and significant impact on cost efficiency. The use of Type II SSP as a material alternative is effective due to the availability of existing materials and new procurement, which is more economical than the Type IV SSP alternative.

Ease of implementation has a positive and significant impact on cost efficiency. New technical alternatives can generate efficiency if the installation methods, tools, labor, and field controls support their implementation.

Cost efficiency has a positive and significant impact on project completion time. For pier projects, converting from Type IV SSP to Type II SSP reduced sheet requirements from 420 to 400 units, resulting in a 4.76% acceleration in sheet count, and a reduction in piling length from 8,610 m to 7,200 m, representing a volumetric efficiency of 16.38%.

Implementation of Type II SSP resulted in direct cost savings of Rp11,938,147,636.30, or 64.84%, compared to Type IV SSP. The feasibility of this alternative is supported by technical controls, including a final safety factor of 1.842, a maximum lateral deflection of 42.35 mm, a maximum bending moment of 77.59 kN.m, and a maximum cross-brace stress ratio of 0.795. Therefore, the use of Type II SSP can be recommended as a value engineering alternative for temporary cofferdam construction, provided all design assumptions, field conditions, work stages, and technical controls are met.

Limitations and Recommendations

This study has several limitations. First, the number of respondents was 36 and they came from a single project, so generalizations to other projects should be made with caution. Second, the time acceleration was calculated based on the reduction in the number of sheets and pile length, not based on time-motion studies or daily equipment productivity data. Third, the technical data came from project documents and internal design reviews, so public access

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to detailed data is limited. Future research is recommended to add variables such as project risk, occupational safety, environmental impact, equipment productivity, and life-cycle cost. Cross-project comparative studies are also needed to test whether the patterns of stakeholder, material, and method influence on cost efficiency remain consistent across different geotechnical conditions and project organizations.

Ethics Statement, Conflict of Interest, and Data Availability

This manuscript is an extension of a scientific article from a Master of Engineering thesis. Respondent data was analyzed in aggregate and does not reveal any personal identities. The authors declare no conflicts of interest that could influence the interpretation of the research results. Data on costs, time, material requirements, and technical controls are derived from primary data and project documents that form the basis of the thesis; these internal documents do not have public DOIs, ISBNs, or PMIDs. Theoretical and methodological sources used in the bibliography are accompanied by verifiable DOIs or ISBNs.

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