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Value engineering using Indonesia’s 2022 National Guideline through decision-making framework for cost optimization in highway infrastructure projects: a case study

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Abstract

Infrastructure project often requires a balancing manage between design needs, functional performance, and limited financial resources. It has driven the need for Value Engineering (VE) methods to enhance projects and optimize cost without reducing the quality and performance. This study aims to explore the field implementation of Indonesia’s National Technical Guideline No. 4/P/BM/2022 by the Directorate General of Highways (Bina Marga) on VE within a toll road infrastructure project, using the Solo–Yogyakarta Toll Road (Package 1.2) as a case study. Emphasizing value optimization and cost optimization, the study adopts a mixed-method approach that integrates a Pareto principle-based identification of major cost components, a zero–one decision matrix to assess several common borrow material (CBM) sources, a cost–benefit evaluation, and expert insights from fifteen experienced highway engineers. The findings show that combining the use of both Wedi and Sampang quarries provides the best overall value, offering the optimal balance of haul distance, material quality, operational feasibility, and total project costs. The recommended choice results in a cost saving of IDR 51.16 billion (5.05%) while maintaining the required functional performance. Results of the study confirm that systematically implementing the national VE guideline can effectively guide decision-making, enhance project value, and deliver measurable economic benefits. The evaluative process developed offers a practical and replicable framework for applying VE procedures in infrastructure projects.

Introduction

Infrastructure project in Indonesia faces increasing pressure to carry out effectively with the minimum cost while maintaining high quality. Toll roads project is essential for national connectivity and it requires efficient resource allocation under predetermined budget (Ptarama, Shodik, Mahendra, & Abma, 2024; Sari, 2023). The 2020 General Specifications for Toll Roads identifies several activities, and each has its own technical and financial implications (Sari, 2023). Project management can help in managing an efficacy that is good enough to attain stated outcomes but be low to limit cost overruns (Al-Fadhli, 2020; B.D, A.M, & Falola, 2022; Osman, El-Dhaba, & Muhammad, 2023). However, the industry suffers from day-to-day inefficiencies that stem from poor planning and logistics (Mum et al., 2025; Uğural, 2023).

Worldwide, the construction industry has been struggling with managing project performance, cost effectiveness, and sustainable practices. Value engineering method provides managers a systematic approach to optimize function and performance versus cost. Studies in Libya (Youssef, AlDeep, & Olwan, 2023), Thailand (Jaisai, Mandal, & Upadhyay, 2022), Malaysia (Lin, Mazlan, & Ismail, 2022), and China (Li et al., 2021, 2022) provide evidence that when VE is applied consistently during the design phase, there can be cost savings between 3% to 10%. More recently, there have been applications of VE aligned with digitalization (Elsayed, A.M, Elhakeem, & S.O.M., 2024), particularly with respect to Building Information Modeling (BIM), which contributes to improving the accuracy of design evaluation and further exemplifies lifecycle cost analysis through detailed costing (Aldrees, Al-Gahtani, Alsugair, Aljadhai, & Alsanabani, 2025; Khan, Alaloul, Musarat, & Fayyaz, 2025; Mohamed, Alqahtani, Ismail, & Nabawy, 2024).

Well-documented research has shown that particular elements within the working conditions dramatically influence costs. For instance, JaiSai et al. (2022) established that, in construction, structural components account for 28%–30% of total project costs. Similarly, Rozanova and Syarifudin (2022), identified earthworks and structural works as primary cost drivers in road and bridge projects. These findings suggest that focusing on these key components can effectively reduce costs (Khan, Alaloul, & Musarat, 2024; Sheladiya, 2025). When applied during the planning and design phases, VE method can help cut unnecessary costs while maintaining or improving performance (Almansour & Krarti, 2022; Taher & Elbeltagi, 2023). The benefits of VE are optimized when it is used early in the design development phase (Gunarathne, Zainudeen, Perera, & Perera, 2022; Rozanova & Syarifudin, 2022; Sutikno, Husin, & Iswidyantara, 2023).

The Indonesian government has required the use of VE to improve project efficiency and accountability (Fauziyah, Sholeh, Hartono, & Nurjihad, 2020; Putra, Setiono, & Handayani, 2024). The Ministry of Public Works and Housing (PUPR) issued the Technical Guideline for VE Implementation No. 4/P/BM/2022 from the Ministry of Public Works and Housing aims to standardize VE across national infrastructure projects and align it with function performance-based minimization of budgets (Direktorat Jenderal Bina Marga, 2022). However, there is still limited evidence on how this guideline is actually put into practice, as most studies focus on theoretical models or specific cases. Therefore, this study aims to assess the practical implementation of the 2022 VE Guideline in achieving value and cost optimization in toll road construction. The novelty of this study comes from its practical use of the 2022 national VE guideline in a large infrastructure project, filling the gap in the current lack of documented evidence on how the guideline is implemented in practice.

The Toll Road Project of Solo-Yogyakarta (Package 1.2) provides an opportunity a specific chance to address this gap. By implementing a national VE method that optimizes value by assessing costs, this study aims to provide both empirical insights and practical recommendations for VE-based decision-making in large infrastructure projects.

Methodology

This study used a case study to explore how the implement of 2022 National VE Guideline within a structured decision-making framework for value optimization in large infrastructure projects. The Solo-Yogyakarta Toll Road Project was selected as the case because it is one of the earliest and most thorough practical applications of the VE guideline. The recommended VE process, outlined in the 2022 guideline, includes 11 (eleven) phases.

1. Preparation Phase
2. Information Phase
3. Function Analysis Phase
4. Creative Phase
5. Idea Evaluation Phase
6. Alternative Development Phase
7. Alternative Evaluation Phase
8. Recommendation Phase
9. Presentation Phase
10. Reporting Phase
11. Evaluation and Feedback Phase

In this study, a mixed-method approach was used to ensure analytical through the combining quantitative and qualitative with expert judgements. Quantitative data was extracted from data project documentation, including the Bills of Quantities (BoQ), DED, and detailed cost. Qualitative data was collected through semi-structured interviews with fifteen professionals from the part of project team. These parties included membership comprised of project team from the Directorate General of Highways, the design consultant, and the main contractor. Each membership had more than ten years of experience on the road construction and related cost management, thus guaranteed reliability and credibility behind their professional judgments. The following is a flowchart of the method (Figure 1).

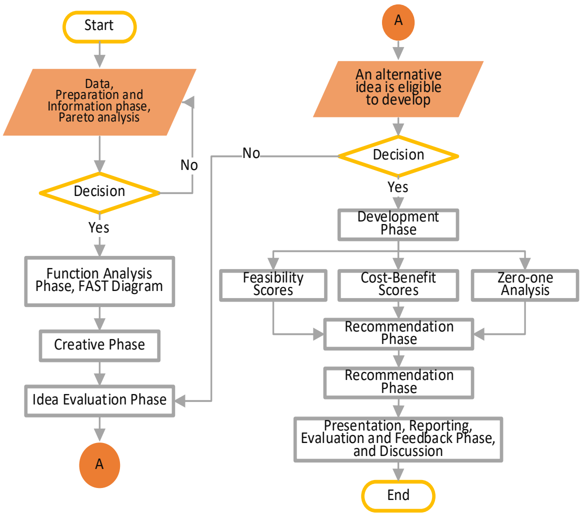

Figure 1. Flowchart method.

The case study examining specifically the alternative procurement methods that would try to arrive at decisions include the following:

1. Pareto analysis to identify dominant cost items.
2. Functional Analysis Systems Technique (FAST) to determine key cost-driving functions.
3. Multi-criteria decision-making (MCDM) using feasibility checks, cost–benefit ratios, and zero–one matrices to evaluate quarry alternatives.
4. Sensitivity and comparative analyses to validate cost optimization results.
5. Professional verification to to ensure alignment with the national VE guideline.

This multi-phase plan merges quantitative analysis with the validation by experts and evaluates both analytical findings and practical application.

Result and Discussion

This section outlines the VE objectives based on Guideline No. 4/P/BM/2022, with findings structured according to the eleven mandated phases and supported by project data and expert input.

Preparation Phase

The initial phase was centered on the development of an all-encompassing VE planning document. This document would, at a later time, be used to help frame the workshop activities. The data assembled will consist of nation-wide guidelines, articles of interest, and project-related documents. Table 1 summarizes general information about the Project.

Table 1. General Project Information

Description	Information
Project Name	Solo-Yogyakarta Toll Road (STA 22+300 – STA 42+375)
Project Type	Expressway
Location	Klaten (Central Java) – Sleman (Yogyakarta)
Project Owner	PT. Jogja Solo Marga Makmur
Design Consultant	Perentjana Djaja

Source: Project Data (2022).

Information Phase

In the assessment phase, costs were initially assessed using the Pareto Principle to assess the distributions of incurred costs in the primary work items, which then identified the major contributors to cost, or financial contingencies.Earthworks represented 39.5% of the total project spending, emphasizing their significant financial importance (See Figure 2).

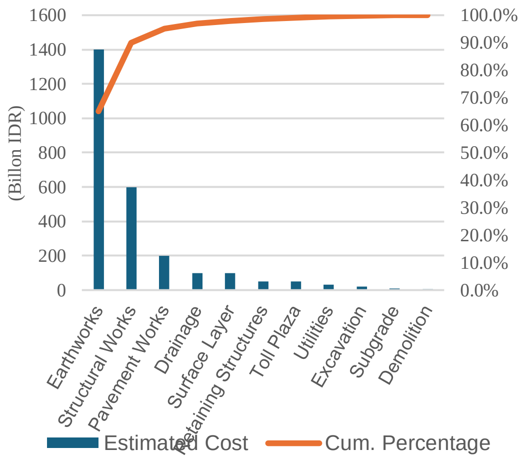

Figure 2. Pareto Diagram of the Solo – Yogyakarta Toll Road Construction Project

A detailed Pareto analysis of the Earthwork category (Figure 3) identified CBM as the dominant cost driver, representing 72.87% of earthwork expenditures (≈ IDR 1.013 trillion). Accordingly, CBM was prioritized for the subsequent VE decision-making process.

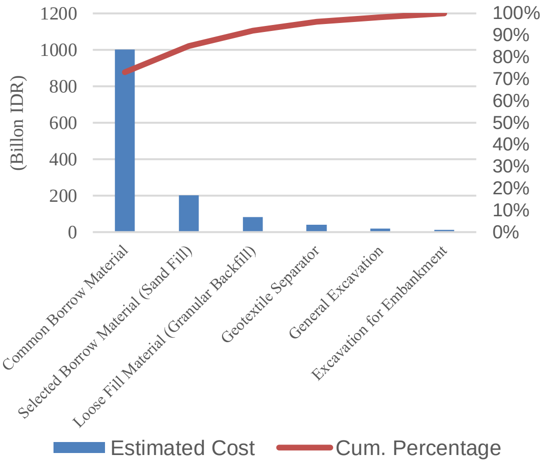

Figure 3. Pareto Law Diagram of Earthwork Activities

Function Analysis Phase

Following the precise identification of the dominant cost driver is CBM, the FAST to determine the key functions related to this important cost factor. The main function was recognized as "Providing a stable embankment", This function is supported by "Ensuring compaction quality" and "Controlling subsidence risk". In the subsequent evaluation, we recognized and looked at six potential borrow sources. The detailed functional relationships derived from this analysis using the FAST diagram are visually represented in Figure (4).

Creativity Phase

A brainstorming session with project engineers produced several quarry alternatives. Table 2 lists the six proposed options, providing details on soil types, unit costs, transportation distances, and material volume availability.

Table 2. Alternative Quarry Sources

Quarry Source	**Soil Type**	**Unit Price (IDR)**	**Distc (km)**	**Avail. ($\times10^6$ m^3)**
Godean	Organic/inorganic silt and clay	142,000	19.2–26.3	± 1.9
Wedi	Fine sand, inorganic silt, and rock powder	130,000	15.7–23.4	± 5.0
Sampang	Fine sand, inorganic silt, and rock powder	131,000	19.2–23.8	± 6.0
Imogiri	Organic/inorganic silt and clay	141,000	19.3–27.2	± 1.75
Prambanan	Fine sand, inorganic silt, and rock powder	139,000	14.2–24.5	± 2.0
Dayakan	Fine sand, inorganic silt, and rock powder	140,000	15.9–24.3	± 2.5

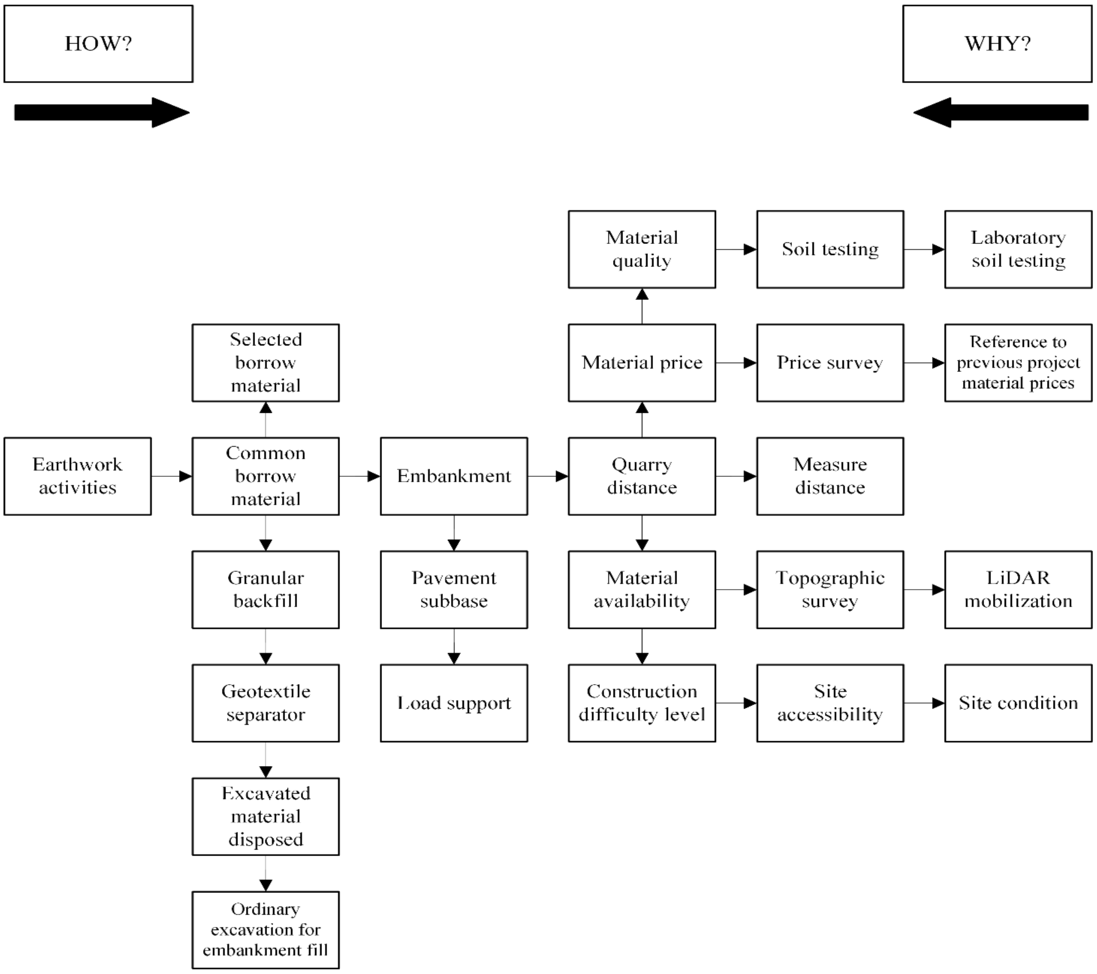

Figure 4. FAST Diagram for Earthwork Activities

Figure 4 presents the FAST diagram for the project's earthwork component. The "How" side breaks down core functions CBM sourcing, embankment work, and pavement subbase, while the "Why" side links these to key justification factors, including material quality, cost, quarry distance, site conditions, and testing requirements. This functional mapping supports identifying value-enhancement opportunities during the VE Creativity Phase.

Idea Evaluation Phase

Each quarry alternative was evaluated using four eligibility criteria:

a. Criteria I: Material should have low plasticity and CBR ≥ 6% (SNI 1742:2008 or AASHTO T199-15(2015)).
b. Criteria II: Quarry distance should be ≤ 25 km from the project site.
c. Criteria III: Quarry must have material availability ≥ 2,000,000 m³.
d. Criteria IV: Unit price within the range of IDR 130,000–140,000.

Based on these criteria, four quarries were deemed eligible (shown in Table 3).

Table 3. Evaluation Summary

No.	Quarry	Result
1	Godean	Not Eligible
2	Wedi	**Eligible**
3	Sampang	**Eligible**
4	Imogiri	Not Eligible
5	Prambanan	**Eligible**
6	Dayakan	**Eligible**

The eligible ideas from this creativity stage will then be developed into the next stage, namely the alternative development stage.

Alternative Development Phase

The Creative Phase generated several alternative sourcing options for the CBM. These alternatives were later proposed for detailed development and evaluation to improve the value from the Earthworks. After initial technical (see Table 2), four nearby quarries from Wedi, Sampang, Prambanan, and Dayakan were deemed eligible for detailed development.

Alternative Evaluation Phase

The evaluation approach used MCDM. This phase combained quantitative cost analysis with qualitative from insight 15 expert judgment with experienced road engineers (including personnel the project implementers and supervisors). The experts provided input based on three main criteria decision metrics: Feasibility Scores, Cost-Benefit Scores, and Zero-One Analysis.

a) Feasibility Scores (Table 4)
Quarry of Wedi (11.8), Sampang (11.6), Prambanan (8.8), Dayakan (7.9).

Table 4. Feasibility Scores

Quarry	A	B	C	D	Total Score
Wedi	2.8	2.8	3.2	3.0	11.8
Sampang	2.8	2.6	3.1	3.1	11.6
Prambanan	2.4	2.4	1.9	1.9	8.8
Dayakan	2.3	2.3	1.5	1.5	7.9

b) Cost-Benefit Scores (Table 5)
The cost benefit score of quarry Wedi and Sampang is highest (11.33 each).

Table 5. Cost-Benefit Scores

Material Quarry	Total Score
Wedi	11.333
Sampang	11.333
Prambanan	7.467
Dayakan	7.333

c) Zero-One Analysis (Table 6):
The Zero–One evaluation, applying weighted performance criteria, identified Wedi (45.56) and Sampang (41.11) as the leading alternatives, thereby substantiating their selection within the VE framework.

Table 6. Zero-One Analysis

Alternative Quarry	Criteria I 22,0	 II 13,3	 III 38,0	 IV 26,6	Total Score
Wedi	2/6 7.3	3/6 6.67	3/6 19	3/6 13.3	**45.56**
Sampang	3/6 11	2/6 4.4	2/6 12.6	2/6 8.8	**41.11**
Prambanan	0 0	1/6 2.2	1/6 6.3	1/6 4.4	31.11
Dayakan	1/6 3.67	0 0	0 0	0 0	22.56

In this stage, the selected alternatives were refined into implementable options, with expert input focused on feasibility, cost-benefit considerations, and zero-one criteria. The results confirmed Wedi and Sampang as the most suitable choices.

Recommendation Phase

Based on the evidence built through the previous phase, three scenario were developed for a final cost estimate as:

1. Scenario 1 is using Wedi Quarry for STA 22+300 – STA 39+300.
2. Scenario 2 is using Sampang Quarry for STA 22+300 – STA 39+300.
3. Scenario 3 is using a quarries combination of Wedi (STA 22+300 – STA 33+300) and Sampang (STA 33+300 – STA 39+300).

The first step of the analysis of the scenarios is to understand the distance that will be hauled from each quarry to the project station by using tools such as Google Earth (see Figure 5).

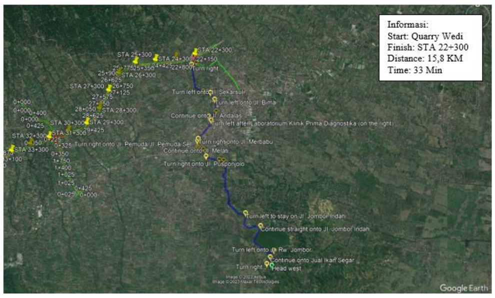

Figure 5. Distance from Wedi to STA 22+300

Next, the CBM volume was calculated. The total required volume (V_{Total}) for the embankment fill was determined for the project segment STA 22+300–39+300, with detailed shown in Figure 6.

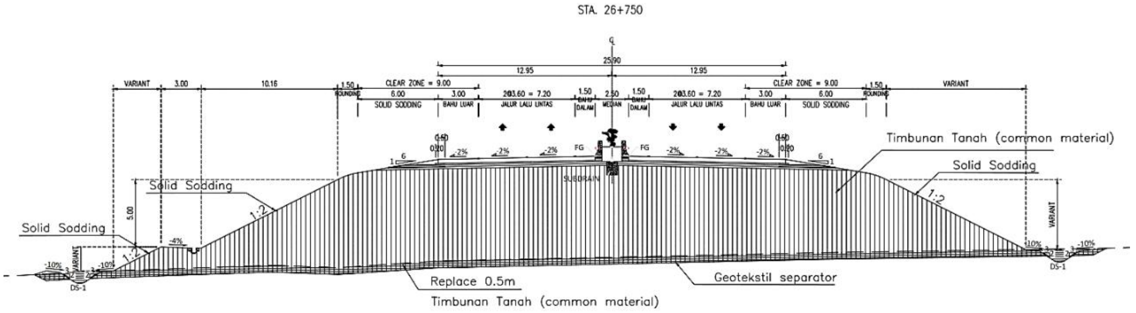

Figure 6. Drawing engineering detail (DED) of section STA 26+750

V Replacement = p×l×t
= 1685×332,177×0.5
= 279,859.25 m^3
V fill work = p×l
= 1685×277.275
= 467.208,375 m^3
V Total = 279,859.250 + 467,208.375
= 747,067.625 m^3

Next, the cost calculation for each STA is based on distance. The Basic Unit Price of Embankment Material (M44) was then calculated, exemplified by the material transport from the Wedi Quarry to STA 22+300

M44 = IDRM44 + IDR1 + IDR2
= 80,000 + 3,670.78 + 32,954.70
= 116,625.48
= IDR 116,000.00

Based on the analysis conducted using Quarry Wedi for all STAs 22+300 – 39+300, the total cost is IDR 962,154,756,656.83.

Therefore, the cost for transporting material from the Wedi Quarry to the project site at STA 22+300 is IDR 116,000.00 per truck.

Savings = Cost Estimate Plan – Cost Estimate Alt = 1.013.172.563.000,00 – 962.154.756.656,83
= IDR51.017.806.343,17

Percentage (%) = (Savings/Cost Estimate Plan)×100 %
= (51.017.806.343,17)/ (1.013.172.563.000) × 100
= 5,03%

The next phase is evaluating of quarry alternatives. The comparison of the three scenarios options to the base project cost of IDR 1,013,172,563,000.00 is as follows. Below is summary of the cost comparison for Wedi, Sampang, and combining both quarries:

1. The total cost in using material from Wedi Quarry only is IDR 962,154,756,656.83, yielding a savings of 5.03% or IDR 51,017,806,343.17. However, this alternative cannot be applied to all STA locations, as the material supply from Wedi is insufficient to supply overall project requirements.
2. The total cost of material used from Sampang quarry only is IDR 974,991,948,005.76, with a 3.76% or IDR 38,180,614,994.24 cost reduction. Similar with previous situation, this alternative is not feasible as an option as the supply of material from Sampang Quarry will be limited material and not be able to be used on all STA locations.
3. The use of a combined material source from both quarries, the overall cost in utilizing material from Wedi and Sampang is IDR 962,011,988,010.04, achieving the highest savings of 5.50% or IDR 51,160,574,989.96.

The analysis confirmed that the combined sourcing approach (Scenario 3) yielded the highest cost effectiveness, achieving 5.05% savings while maintaining adequate material supply. This scenario proposes procuring CBM from the Wedi quarry for STA 22+300–33+300 and from the Sampang quarry for STA 33+300–39+300. As the most value-efficient option, it optimizes cost, logistics, and material availability. Nonetheless, further evaluation may be required to ensure that decisions account not only for initial construction costs but also for total cost of ownership through life cycle cost analysis (Baskhara, Susapto, & Riskijah, 2023; Sugiandhari, Respati, & Saputra, 2024).

Presentation Phase

The last phase of the VE process involved completing mandated steps as assigned. The results and recommendation of the combined quarries were presented to all stakeholders in the Presentation Phase, enabling an objective decision making based on evidence by all stakeholders involved.

Reporting Phase

The entire process was then documented for formality and approved by the complusory project management team in the Reporting Phase.

Value Engineering Evaluation Phase

To formally evaluate adherence to the eleven phases of national guidelines, the Evaluation phase was carried out. The implementation was rated as "Very Good" with a mean score of 8.5 out of 10 as can be seen in Table (7) and this confirmed total compliance with the regulatory requirements of the Directorate General of Highways.

Table 7. Evaluation of the VE implementation

No	Document Requirement	Compliance	Score	Remarks
1	Preparation Phase	Yes	9	Good
2	Function Analysis Phase	Yes	9	Good
3	Creativity Phase	Yes	8	Good
4	Idea Evaluation Phase	Yes	8	Good
5	Idea Development Phase	Yes	8	Good
6	Alternative Evaluation	Yes	9	Good
7	Presentation Phase	Yes	8	Good
8	Reporting and Implementation	Yes	8	Good
9	Duration, Cost, and Benefit of the VE Study	Yes	8	Good
10	Evaluation of the VE Study	Yes	9	Good
11	VE Report	Yes	8	Good
	Main Results of the Study	Yes	9	Good
	Total Average score		**8,5**	**Good**

This study provides robust empirical evidence for the integration of Indonesia's National VE Guideline (No. 4/P/BM/2022) shown to support the translation of regulatory requirements to a engineering practice. Its implementation proposed a rational and objective framework to prioritize alternatives and finally select the optimal solution by using the Pareto principle to identify cost drivers, with MDCM tools.

The optimal alternative was a hybrid combination of two quarries, Wedi and Sampang where Wedi was best for STA 22+300 to STA 33+300 and Sampang was best for STA 33+300 to STA 39+300. Recommendation in this phase verified this alternative achieved the optimum project cost savings.

a) Combined cost: IDR 962,011,988,010.04
b) Savings: IDR 51,160,574,989.96
c) Percentage savings: 5.05%

The VE approach, which is oriented on decision making, clearly enhanced the clarity and traceability of engineering decisions, which is consistent with other studies from road construction (Khashaba & El-Shourbagy, 2023; Putri, Widyawati, & Wardono, 2023; Sitorus & Huda, 2020), and many other projects, such as residential buildings (Chandra, Sutandi, & Anondho, 2023), high-rise buildings (Ferdinan & Adianto, 2022; Irfanto, W, & Dermawan, 2023; Salsabila, Setyowulan, & Arifi, 2024), architectural works (Aung, Liana, Htet, & Bhaumik, 2024; Sihite & Setiawan, 2024), and structural works (Alsanabani, Al-Gahtani, Bin Mahmoud, & Aljadhai, 2023; Nanda, Riswanto, & Kurniawati, 2023). An important finding is that using an established decision framework is an effective way to directly improve objectivity and confidence in evaluating important materials alternative. In addition, this success further legitimizes the 2022 Indonesian VE Guideline as a practical and artifact of resource optimization in national infrastructure.

This study had limitations, despite the success of securing the cost optimization. Limitations included fixed cost guess, the calculation factor, and the use of experts. Future work should utilize digital construction technology to further precision in this analysis (Al-Gahtani, 2022; Woodhead & Berawi, 2022), and BIM integration to enhance analytical precision (Amoah & Amoah, 2023; Zaidi, Abd-Karim, Mohamad, & Yun, 2023). Moreover, future studies need to consider incorporating VE more broadly so it complies with Lean construction, sustainability, targeted activities at minimizing waste (Shihata, Fekry, & Abbas, 2023), adopting green building principles (Kumara, Tapa, Indrashwara, Pancane, & Predana, 2025), and intregiting with sustainability development objectives (Shelote, Agrawal, Kumar, Gupta, & Ralegaonkar, 2018). Future studies also need to increasingly create BIM-VE simulations incorporating probabilistic sensitivity analysis to increase prediction to reality integrity.

Following the findings and successful process of the VE analysis it is proposed that the following central recommendations be made:

a) Early adoption: Implement VE as early as the initial planning stage to maximize impactful on decision-making and prevent the embedding of unnecessary costs.
b) Scope expansion: Broaden the application of VE to encompass a greater variety of task other than just earthworks to fully leverage cost savings opportunities.
c) Digitalization: Digitally develop VE processes to introduce technologies such as BIM, AI and IoT for flexible, data rich and accuracy-based analysis.

These findings highlight the transformative potential of guideline-based VE and underscore the need for broader digital and methodological integration to advance value-driven infrastructure planning in the years ahead.

Conclusion

This study demonstrates that Indonesia’s 2022 VE Guideline has the potential to achieve value and considerable cost savings while improving outcomes in the adoption of project-wide decision-making frameworks for highway infrastructure. The multi-criteria analysis indicated that having the combined use of both Wedi and Sampang quarries as the most value-optimal scenario, achieving a 5.05% cost reduction (IDR 51.16 billion). The cost reduction was solely related to one major work item (CBM) but does exemplify the potential of the VE method to discover major efficiencies for scaling up large project work items. Overall, these findings adds to the existing knowledge by implementing a national VE guideline into a flexible decision-support framework to optimize value for infrastructure development.

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Declaration Statement

The authors declare that ChatGPT (OpenAI) was used solely for language proofreading, grammar correction, and improvement of writing clarity during the preparation of this manuscript. All scientific content, including the study design, methodology, data analysis, interpretation of findings, and conclusions, were developed and verified exclusively by the authors. The authors take full responsibility for the accuracy, originality, integrity, and validity of the manuscript's content.

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