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A Value Engineering Approach to Reduce the Cost of Construction of the Indonesia-Timor Leste Border Post Access Road

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ABSTRACT

This study utilizes the value engineering (VE) methodology for constructing the 27.88 km Oepoli-Noelelo Cross-Border Postal Access Road in Kupang Regency, East Nusa Tenggara Province (NTT)—Indonesia), a road that runs between Indonesia and Timor Leste. The project has an estimated initial cost of IDR 725,935,512,000. This study aims to identify potential cost efficiencies while maintaining the required functionality and quality. The focus is on optimizing areas such as excavation and embankment (earthworks), geosynthetics, and granular pavement, as well as adjusting unit price analysis or a combination of these two approaches, to achieve the maximum overall cost reduction. The VE implementation stages include information gathering, analysis, creativity, and recommendations. Using Pareto's Law and functional analysis, the study identified three highest-cost work items: excavation and embankment, geosynthetics, and granular pavement. The findings indicate that the third alternative offers the lowest cost, resulting in construction savings of IDR 43,234,104,000—equivalent to 5.96% of the total initial design construction cost. Overall, applying value engineering to this road project yields significant savings.

1. INTRODUCTION

The border region between Indonesia and Timor-Leste holds significant economic and social potential. To fully realize this potential, developing adequate access road infrastructure to the state border crossing post (SBCP) or PLBN (in Indonesia), is crucial. This infrastructure will facilitate the movement of goods, services, and people, encouraging local economic growth, improving community welfare, and strengthening bilateral relations [1, 2]. However, the development of this infrastructure often encounters substantial cost challenges, including budget constraints [3], fluctuations in material prices, and potential inefficiencies in project design and implementation [4]. Additionally, budgeting frequently prioritizes routine expenditures over infrastructure development, leading to inadequate and poor infrastructure in the country [5]. For instance, the access road project to the Oepoli–Noelelo PLBN in Kupang Regency, NTT, Indonesia, spans a total length of 27.88 km with an estimated cost of around IDR725,935,512,000, which translates to approximately IDR26 billion per kilometre. This figure is notably higher than that of national road projects in the same area, such as the 15.3 km Kupang Central Axis Road, which has a contract value of about IDR 57 billion, or roughly IDR 3.7 billion per kilometre. This cost disparity can significantly burden the Indonesian Government's State Budget (IGSB) or APBN (in Indonesia). Therefore, a systematic and innovative approach is essential to identify and implement more cost-efficient solutions without compromising quality and functionality.

One approach that can be applied to address this issue is value engineering (VE), which aims to optimize project functionality at the lowest cost without sacrificing quality and performance [6-8]. VE is a systematic approach to increasing project value by optimizing functionality and reducing costs. Although VE has become an important tool in construction and infrastructure development since World War II [9, 10], its application in road construction projects, particularly in specific sectors, has not been fully utilized to address cost overruns and quality issues [11]. Previous research indicates that some of the leading causes of the use of value engineering in construction projects include high project implementation costs, difficulty, long gaps between design and implementation, and project complexity [12]. According to Wood and Gidado [13], construction projects are often called complex projects; however, there seems to be no universally accepted definition of project complexity in the construction industry. However, the ability to measure complexity early in a project will result in a better understanding of the project [14]. Therefore, project complexity in construction will be very beneficial in managing projects successfully and reducing risks associated with complexity. In project management, complexity is recognised as one of the factors that most influence the success of any project, such as planning and controlling activities, organisation selection, identification of goals and objectives, and project outcomes [15, 16]. In addition, construction projects are no exception as many researchers have linked high levels of complexity to construction project outcomes including, but not limited to, cost overruns, delays, low quality, poor safety conditions, disputes between partners, improper risk management, low client satisfaction levels, and poor communication between stakeholders [17-21]. In addition, VE's ability to focus on project functions, harness group creativity, and generate synergies makes it superior to other cost reduction methods.

The primary objective of this study is to apply VE principles specifically and practically to the border crossing access road project between Indonesia and Timor Leste. This involves identifying and eliminating unnecessary work or components while exploring and proposing alternatives that meet project requirements at the lowest possible cost. The goal of cost optimization will be achieved without compromising—and even improving—the project's established performance and quality standards, which aligns with the core value proposition of VE. This study aims to demonstrate how a large-scale road construction project can be completed within the allocated budget by utilising a proactive and systematic approach to cost optimization. This will enhance the overall efficiency and effectiveness of critical transportation infrastructure. VE is a valuable tool for achieving significant cost savings through rigorous analysis and optimization of design parameters, material selection, and construction processes.

The novelty of this study lies in its empirical application of VE to a high-cost and strategic border infrastructure project within the Indonesian context. By applying VE across three scenarios, this research seeks to identify and eliminate unnecessary costs while exploring alternatives that fulfil project requirements at a lower cost—without sacrificing performance. A specific focus on border access road projects, which face unique cost challenges, aims to demonstrate their potential to generate savings in cost, time, and materials, ultimately improving the efficiency and effectiveness of transportation infrastructure in border regions.

2. LITERATURE REVIEW

2.1 Principles of VE

According to Save International 2007, VE is a comprehensive process conducted by a multidisciplinary team that aims to enhance project value by thoroughly analyzing the relationship between project functions and costs [22]. Yan [23] describes VE as a new branch of management technology that effectively reduces costs while increasing economic efficiency. Unlike other value management approaches, VE enhances value by modifying functions and costs (Function Value/Cost). The ultimate goal is to improve project functions to elevate the overall value of the construction outcomes [24]. VE applies to almost all products and projects, making it more than just a method for cost reduction.

To enhance the value of a project, VE requires a systematic approach that involves implementing a structured VE work plan [25]. It is most effective when conducted by a multidisciplinary team of professionals and subject matter experts. The key characteristics of VE include: (1) a VE work plan (also known as a 6-phase workshop) supported by a team of professionals; (2) a focus on functions; (3) an emphasis on value enhancement; and (4) cost-effectiveness. For VE to be successful, all of these components must be in place [26, 27].

VE or value analysis, primarily focuses on function analysis [28]. The main objective of value engineering is to accomplish the essential functions of a reliable product while minimizing costs. It aims to optimize the relationship between product features and costs. In this context, "function" refers to a product's characteristics that fulfil users' specific needs. "Cost" encompasses the entire life cycle cost of the product, including all development, design, manufacturing, and usage expenses. "Value" is the ratio of a product's function to the cost incurred to achieve that function. This relationship is expressed in the following Eq. (1).

$$V = \frac{F}{C} \tag{1}$$

where, V = value; F = function; C = cost.

The relationship between function (F) and cost (C) indicates that a lower cost for optimal function enhances the overall value. VE can be defined as a systematic approach to increasing the "value" of goods, products, and services through functional analysis. VE seeks to find a balance among function, quality, and cost. The main goal of the VE approach is to promote awareness of value while improving a company's professional competence and technological excellence. Key parameters of this concept include function, quality, life cycle cost, total cost, and waste. Based on the established equation, value is directly proportional to function and inversely proportional to cost.

The core principles of VE include:

- **Function-oriented approach:** VE is built on rigorous functional analysis, focusing on what a product or service does rather than its appearance. This analysis aims to achieve essential functions reliably and at the lowest possible cost. By prioritizing functionality, VE adds value instead of merely cutting costs, as it identifies and eliminates non-essential elements while optimizing essential functions.
- **Value enhancement:** The primary objective of VE is to increase value. This can be achieved through various strategies, such as: maintaining the same function while reducing costs; keeping costs constant while significantly improving functionality; making slight cost reductions while greatly enhancing function; reducing non-critical functions for substantial cost savings; or ideally, achieving simultaneous improvements in function while reducing costs.
- **Multidisciplinary team collaboration:** The success of VE relies heavily on forming diverse teams composed of professionals from various fields and subject matter experts. This collaborative approach fosters the generation of creative ideas, enhances decision-making, and improves communication among all stakeholders involved in the project.
- **Systematic work plan:** VE is implemented through a structured work plan, often called a 5- or 6-phase workshop. This methodical approach guides the team through stages of information gathering, creative idea generation, evaluating alternatives, developing proposals, and presenting to stakeholders, ensuring a comprehensive and organized pursuit of value enhancement.

2.2 Systematic VE work plan

Successful VE implementation relies on following a systematic and organized work plan. This structured approach is essential for conducting thorough studies, encouraging creative problem-solving, and generating viable alternatives that enhance the project's overall value. According to Yadav et al. [29], the implementation of VE can be effectively guided by a work plan, which provides an organized framework for the process.

A well-defined VE work plan is crucial for a successful value management exercise. Through this plan, specific areas for value analysis can be thoroughly explored, leading to the development of innovative alternatives. The work plan should involve a multidisciplinary team with representatives from various technical fields to execute this program effectively. This collaborative approach results in a broader range of ideas, significantly impacts decision-making and cost considerations across all services, and promotes better communication among team members.

On the other hand, Mahadik [30] described the implementation of VE in a structured process known as a VE work plan. The purpose of this work plan is to assist the study team in systematically identifying and focusing on the key functions of the project in order to generate innovative ideas that can enhance overall value. A VE work plan typically consists of several interrelated phases:

- **Information phase:** This initial phase involves comprehensive data collection and analysis. It requires gathering all relevant information regarding the project's scope, design, functional requirements, and a detailed breakdown of costs, including life cycle cost estimates. This foundational step ensures a complete understanding of the project's current state and identifies all elements contributing to its overall cost.
- **Creative phase (brainstorming):** After gathering the necessary information, the team brainstorms to generate innovative ideas and alternative solutions. The objective is to explore new ways to achieve the required project functions at lower costs or with higher value, without compromising quality. External expertise can be particularly valuable during this Phase, as it brings fresh perspectives and may reveal missed opportunities.
- **Evaluation phase:** In this phase, all generated ideas and alternatives are rigorously assessed against predetermined criteria. The advantages and disadvantages of each option are compared to the original design and project objectives. This critical evaluation helps select the most promising alternatives with the highest potential for enhancing value.
- **Development phase:** The selected high-potential alternatives are refined and developed into detailed proposals. This includes preparing preliminary designs, cost estimates, and implementation plans, ensuring technical and economic feasibility.
- **Presentation phase:** The final step involves presenting the developed VE proposal to key stakeholders, including the project owner, for approval and subsequent implementation. This phase requires clearly articulating each alternative's benefits, costs, and risks.

2.3 Application of VE to road projects

VE is a widely recognized approach utilized across various industries, with significant application in construction and infrastructure development. It is a proactive process that analyzes project components to identify opportunities for cost reduction without compromising performance or quality. Here are some key benefits and opportunities associated with VE in road projects:

- **Cost efficiency and sustainability:** VE plays a crucial role in achieving cost efficiency and sustainability in infrastructure projects. For instance, using VE in asphalt recycling can significantly reduce material costs, lower carbon emissions, and minimize waste, aligning with broader environmental objectives.
- **Road system optimisation:** VE provides valuable opportunities to optimize various aspects of road systems. This includes minimizing right-of-way requirements, tailoring pavement specifications to traffic patterns, integrating road design with the natural topography to lower grading costs, and establishing shared access arrangements with adjacent properties.
- **Improved risk management:** Through systematic analysis, VE helps identify potential problems and risks before construction starts. This proactive planning enhances preparedness for unforeseen challenges, improving overall project risk management and reducing the likelihood of costly delays.
- **Enhanced efficiency and quality:** Regular assessments of design decisions through VE streamline the construction process by removing redundant steps, increasing productivity. This focus on efficiency results in reduced labour costs and improved overall project quality and timelines.

2.4 Cost analysis methods in VE

Accurate and comprehensive cost analysis is the foundation of practical VE. It empowers project teams to systematically identify cost-saving opportunities without sacrificing quality, enabling informed decisions regarding material selection, labour rates, technology adoption, and equipment utilization. This analytical rigour is crucial for minimizing financial risk, preventing cost overruns, and strategically prioritizing project elements. Some standard cost estimation methods in construction and VE include:

2.4.1 Elemental Cost Analysis (ECA)

This method involves breaking down a construction project into its fundamental constituent elements (e.g., foundations, structural framework, finishes, mechanical systems) and assigning detailed cost estimates to each. These estimates are typically derived from expert judgment, established industry standards, and historical cost data from similar projects.

- **Advantages:** Provides a highly detailed cost breakdown, facilitates the identification of specific cost drivers and potential savings areas within individual project components, and simplifies cost tracking throughout the project lifecycle.
- **Disadvantages:** Requires extensive historical data and expert judgment, and design changes can significantly affect its accuracy.

2.4.2 Comparative analysis

This method estimates project costs by comparing them to similar, completed projects. The underlying principle is that projects with comparable characteristics (size, scope, complexity, type, location) will likely have similar cost profiles.

- **Advantages:** Offers valuable insight into overall project costs, provides a basis for real-world estimates, and helps identify cost drivers and patterns from experience.

- **Disadvantages:** The primary challenge lies in finding comparable project data, and inaccurate comparisons can lead to unreliable estimates, potentially overlooking unique aspects of the current project.

2.4.3 Parametric estimation

This data-driven approach uses statistical and historical data to establish quantitative relationships between key project parameters (e.g., linear length, complexity rating, square footage) and construction costs. This method assumes that specific project characteristics have a predictable impact on costs.

- **Advantages:** Highly efficient for generating early-stage cost estimates, accurate if supported by a robust and homogeneous database, and scalable and adaptable across various project types.
- **Disadvantages:** Highly dependent on the quality and relevance of historical data, and estimates may not adequately account for unforeseen circumstances or unique project conditions.

2.4.4 Life Cycle Cost Analysis (LCA)

This method evaluates the total cost of ownership of a product or service over its lifetime, including initial capital costs, ongoing operating costs, and future maintenance and disposal costs. LCA emphasizes long-term cost savings, even if they require a higher initial investment, by comparing options based on long-term performance and proven cost records.

- **Advantages:** Provides a holistic view of costs throughout the project's life cycle, strongly supports sustainable and resilient design choices, and helps identify the most cost-effective solutions in the long term.
- **Disadvantages:** Requires accurate long-term data projections, which can be challenging to obtain, and the analysis can be complex.

2.4.5 Benchmarking

Involves comparing the project's cost and schedule with other similar projects or established industry standards. This method helps identify areas where the project can learn from the successes or failures of others and identifies opportunities for improving value and efficiency.

2.4.6 Actual cost

While this is the most reliable method because it relies on actual costs incurred, applying it in the early stages of a project or program is generally complex when detailed cost data is unavailable.

2.5 Comparison of equipment-based and unit-pricing VE alternatives

2.5.1 Equipment-based VE alternatives

This approach focuses on optimizing the costs associated with acquiring, operating, and maintaining construction equipment. Since heavy equipment often represents a significant capital and operational expense in road construction, this area provides substantial opportunities for value enhancement. Key cost components to consider include:

- **Variable maintenance costs:** These encompass repairs, consumables, and fluids.
- **Annual fixed costs:** This includes insurance and property taxes.
- **Lifetime fixed costs:** These are related to initial acquisition and major repairs.
- **Variable fuel costs:** Fluctuations in fuel prices can impact overall expenses.

Additional factors influencing total equipment costs are internal and external labor, spare parts, and indirect ownership costs, such as management and utilities. Equipment costs are typically structured using various rate models (e.g., hourly rate, multiple hourly rates, single rate, tiered rate) to ensure accurate allocation to specific projects and cost centers.

Key value engineering opportunities in this approach include:

- **Ownership vs. lease/rent analysis:** A critical VE decision involves determining the best strategy for acquiring equipment. Purchasing equipment for regular, long-term projects may be more cost-effective, offering unlimited usage, customization potential, immediate availability, and asset value. On the other hand, renting or leasing can be more economical for one-time or short-term projects, as it preserves working capital and shifts maintenance responsibilities.
- **Utilization optimisation:** By closely monitoring equipment activity—such as hours worked, idle time, and downtime—VE can pinpoint opportunities to refine scheduling, minimize idle time, and enhance overall fleet efficiency.
- **Maintenance and lifecycle management:** Adopting predictive maintenance strategies, optimizing decisions between repair versus replacement, and planning the equipment lifecycle can significantly reduce long-term costs.
- **Technology adoption:** Investing in modern, more efficient equipment or advanced construction technologies (e.g., automation, digital twins, drones) can significantly lower labour, time, and operational costs.

2.5.2 Unit-pricing-based VE alternatives

This approach focuses on optimizing the costs of individual, recurring work units within a construction project. Payment is based on the quantity of work completed, making unit pricing the primary focus for cost control. Each unit price is designed to reflect all direct and indirect costs associated with performing a specific, defined portion of the work. This typically includes the unit material cost, unit labour cost, allocated equipment cost per unit, and a portion of overhead and profit margin.

VE opportunities within this approach include:

- **Material substitution:** A common VE strategy involves identifying and proposing less expensive but functionally equivalent alternative materials for a specific unit of work (e.g., using recycled asphalt mix, optimizing pavement layer thickness with geogrids).
- **Methodology optimization:** Simplifying or changing construction methods for a specific unit to increase efficiency, reduce labour hours, or minimize equipment time (e.g., adopting prefabrication or modular construction techniques where possible).
- **Design simplification:** Simplifying the design of repetitive elements without sacrificing their essential functionality or quality.
- **Supplier and subcontractor negotiations:** Leverage the clarity of unit prices to negotiate more favourable contracts with material suppliers and subcontractors.

This approach offers high flexibility for projects where final work quantities may be uncertain, simplifies contract negotiations due to straightforward pricing, and allows for cost adjustments as actual quantities become apparent during project implementation. It also facilitates direct comparison of alternatives for specific work packages. However, the disadvantages include the risk of quantity overruns if initial estimates are inaccurate, which may provide less incentive for contractors to seek overall project efficiencies beyond individual units and may lead to disputes over measurement.

3. METHODS

3.1 Research location

Figure 1 shows the location of the Oepoli – Noelelo PLBN Access Road Construction project in Kupang Regency, NTT, with a length of 27.88 km and a width of 6 m, and the road conditions are hilly, have many bends, steep inclines and declines, and are often cut off due to flooding in the rainy season due to the lack of permanent bridges and adequate drainage. In general, the Oepoli – Noelelo PLBN access road is a route that connects the PLBN, which borders Timor Leste, to Noelelo Village or the surrounding area in Kupang Regency, NTT-Indonesia. This road starts from the Oepoli PLBN area (coordinates -9.34368°S, 124.02966°E), a centre of border activity that is busy with cross-country activities. The other end is Noelelo Village (coordinates -9.44865°S, 124.16723°E) or the main road that connects the area with the centre of Kupang Regency or other NTT areas.

Before paving, the road consisted of rocky and dirt surfaces that were easily damaged, especially during the rainy season. The lack of permanent bridges and adequate drainage often cuts the road off and makes it difficult for vehicles to navigate, especially large or heavily loaded vehicles. The poor road conditions left the Oepoli area and its surroundings relatively isolated, hampering the distribution of goods and access to basic services for the local community.

Figure 1. Oepoli – Noelelo PLBN road section

3.2 VE methodology

In this paper, the VE study follows a standard methodology consisting of three main stages: pre-workshop, workshop, and post-workshop, which includes six sequential phases: information, analysis, creative, evaluation, development, and presentation (Figure 2). In the case of the Oepoli-Noelelo PLBN access road construction project, the application of the VE methodology will involve the following steps:

3.2.1 Data collection (information phase)
- **Primary data:** This will be obtained directly from the project owner, the Ministry of Public Works and Public Housing, specifically the National Road Planning and Supervision Work Unit (P2JN) of East Nusa Tenggara Province. This data will include the Owner Estimate (OE) or initial cost estimate.
- **Secondary data:** This will include the detailed engineering design (DED), Engineer Estimate (EE), project site drawings, and other relevant data for the value engineering analysis.
- **Stakeholders** involved in the VE Team will also identify project constraints, schedule, budget, costs, risks, strategic objectives, and logistical requirements. The team includes: (1) Representatives from the project owner; (2) Technical experts (civil engineers, planners, environmentalists) to ensure a comprehensive understanding of the project; (3) Senior managers and decision makers who will receive presentations and select alternatives to implement.

3.2.2 Functional analysis (analysis phase)
- The primary objective of this phase is to understand the project from a functional perspective.
- Project functions will be identified and classified using a verb-noun format, such as "***forming the roadway***" or "***surfacing the roadway***."
- The functional model will be the Function Analysis System Technique (FAST) [31].
- Evaluation will be conducted based on costs, performance characteristics, and user behaviour to select suboptimal functions for focus in the creativity phase. Tools such as cost function analysis and performance function analysis will be utilized.
- Function costs will be estimated to determine focal areas for creativity, using tools such as value indices.

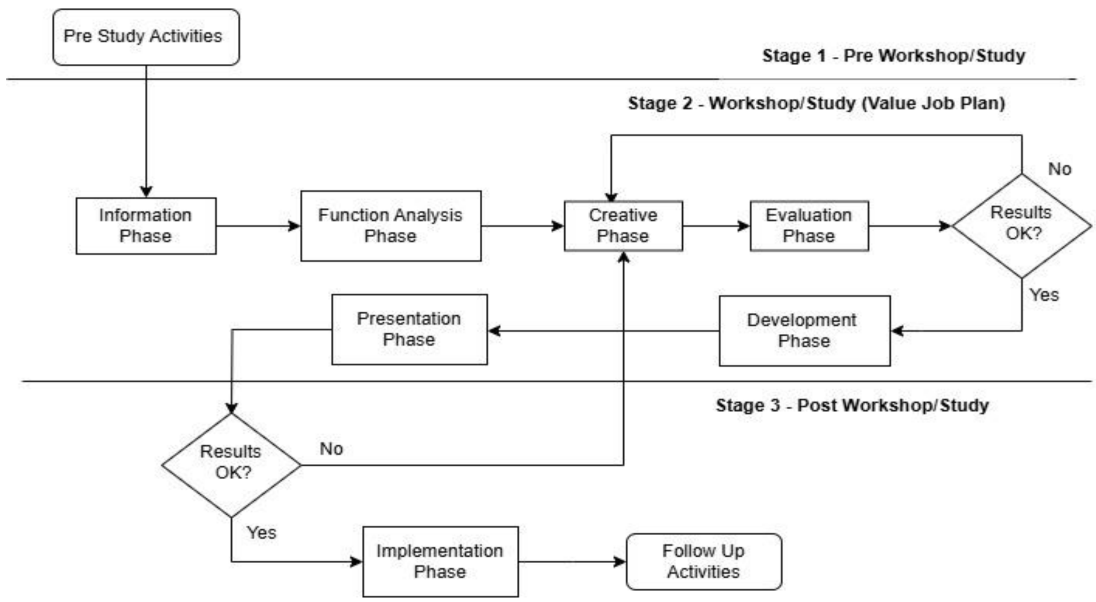

Figure 2. Value study process flow diagram by SAVE International

3.2.3 Alternative development (creative phase)
- The purpose of this phase is to generate various ideas and alternatives to achieve the same function or improve the way the function is implemented.
- Brainstorming techniques generate alternative ideas that can potentially increase the project's value.
- The team will generate diverse ideas to actualize the function and increase the project's value.

3.2.4 Alternative evaluation (evaluation phase)
- The generated ideas will be evaluated and refined into a shortlist of alternatives with the most significant potential to improve the project.
- Tools that can be employed in this phase include Pugh analysis, the Kepner-Tregoe matrix, Life Cycle Costing (LCC), Choosing by Advantage (CBA), and value metrics.
- Decision criteria will be based on the impact of each idea on performance and cost parameters, considering factors such as cost, quality, time, and risk.

In this paper, several decision criteria for selecting the best alternative will be explored, focusing not only on cost but also on the following factors:

- *Performance/functionality*: Ideas will be assessed based on their potential impact on project performance. This includes evaluating how effectively the project's functionality can be achieved.
- *Risk*: Risk assessment will be integrated into the evaluation and development process, presenting scenarios categorized as low, medium, and high risk.
- *Impact on value*: Alternatives will be chosen based on their ability to enhance project value significantly. Here, "value" refers to the ratio of functionality gained to the cost incurred, thereby considering both effectiveness and efficiency.
- *Time*: The information phase will include the research schedule. The time efficiency of implementing alternatives will also be evaluated within the context of feasibility.

3.2.5 Further development (development phase)
- The selected alternatives from the evaluation phase will undergo further analysis and be developed into clear proposals.
- Each value alternative will be documented with text, sketches, diagrams, assumptions, supporting calculations (including capital, operational, and maintenance costs), vendor information, a cost comparison worksheet, and other necessary details.
- A cost-benefit analysis, risk assessment, and evaluation will be conducted.
- Alternative scenarios presenting low, medium, and high risks will be developed and presented to senior management.

3.2.6 Presentation of results (presentation phase)
- The proposed value alternatives will be presented to the management team and project decision-makers.
- Supporting documentation will include comparing study results with initial requirements and a proposed risk-reward investment scenario.
- A formal report will encompass a justification document, risk analysis, cost and price comparisons, present value analysis, and cost-benefit analysis.

3.3 Measuring value

"Value" in VE is generally measured as the ratio of function to cost (Value = Function/Cost). Increased value can be achieved by improving function at the same or lower cost, or by maintaining the same function at a lower cost. In this project, measuring value involves:
- Cost-Function Analysis: Relating costs to the function performed, using tools such as a value index (function cost divided by function price).
- Performance-Function Analysis: Evaluating how alternative ideas affect the project's performance characteristics.
- Quality Assessment: Although not explicitly referred to as "quality" in the metrics, considerations of "performance" and "user behaviour" imply aspects of quality. A panel of experts, a multidisciplinary VE study team, will evaluate and weight these criteria.
- LCC Analysis: Considering the total cost of ownership over the project's lifetime, not just the initial cost.
- Risk Analysis: Assessing the risks associated with each

alternative.

3.4 Pareto testing

Pareto testing is based on Pareto's Law, which determines the highest cost of the project being reviewed. The highest cost obtained from the results of this test has the potential to be analysed as VE. The steps taken include:

1) Sorting the work costs from the largest to the smallest;
2) Adding the work costs cumulatively;
3) Calculating the percentage of work components and adding them cumulatively with Eq. (2):

$$\% \, Cumulative \; of \; total \; component \; cost = \frac{Job \; components}{Number \; of \; job \; components} \tag{2}$$

4) Calculate the percentage of costs for each job against the total cost of the job, using Eq. (3):

$$\% \, Cost \; of \; job \; components = \frac{Job \; components}{Number \; of \; job \; components} \tag{3}$$

5) Create a Pareto chart from the cumulative percentages obtained.

4. RESULTS

4.1 Information stage

At the initial stage of applying value engineering, researchers collected information related to the Oepoli – Noelelo Cross-Border Post (PLBN) Access Road Construction project through the project's technical team. The team utilized a uniform cost model to evaluate each function's cost. This approach enabled them to identify the overall project cost and the specific activities or sub-sections that were significantly impacted and provided the highest value.

The data collection conducted yielded the following information about the research project:

- Project title: Construction of access road for the cross-country border post (PLBN) Oepoli - Noelelo
- Location: Kupang Regency, East Nusa Tenggara Province
- Length of road: 27.88 km
- Owner: Ministry of Public Works and Public Housing, represented by the National Road Implementation Centre of East Nusa Tenggara.

The project Budget Plan (BP) data is collected at this stage. From the BP, similar work items are grouped by their respective functions to facilitate analysis, resulting in a Breakdown Cost Model (BCM). Next, work items are reviewed in order of highest to lowest cost to identify the tasks with the most significant budget weight. Table 1 shows that the main activity descriptions are listed along with the total costs before applying value engineering and the percentage of each task to the total work. Table 1 clearly shows a very high concentration of cost in "Earthworks and Geosynthetics (Division 3)", which reached 85.27% of the total project cost. This proportion is highly unusual for a road project, even in challenging terrain.

Table 1. Cost model

Division	Job Description	Total Cost (IDR)	(%)
1	General	1,843,272,166.67	0.28
2	Drainage	10,904,535,908.21	1.65
3	Earthworks and geosynthetics	562,749,563,567.89	85.27
4	Preventive widening	-	-
5	Granular pavement	34,836,778,325.33	5.28
6	Asphalt paving	30,952,607,324.92	4.69
7	Structure	14,660,016,229.46	2.22
8	Bridge rehabilitation	-	-
9	Daily work and miscellaneous work	3,994,601,022.97	0.61
10	Maintenance work	-	-
	Total cost	659,941,374,545.46	100.
	Value added tax (10%)	65,994,137,454.55	
	Overall Total	**725,935,512,000**	

Based on Figure 3, this Pareto chart shows the total component costs (%) of several types of work, sorted from largest to smallest. This identified Pareto cost model was tested using Eqs. (1) and (2). The orange line (cumulative effect) represents the cumulative cost percentage. That is the sum of the cost percentages of the first two jobs (Earthworks and Pavement and Granular Pavement), resulting in a cumulative point on this line. Next, the blue bars represent the causes/problems, where each bar represents a type of work (e.g., Earthworks and Pavement, Granular Pavement, etc.), and its height indicates the percentage of costs incurred for that particular job.

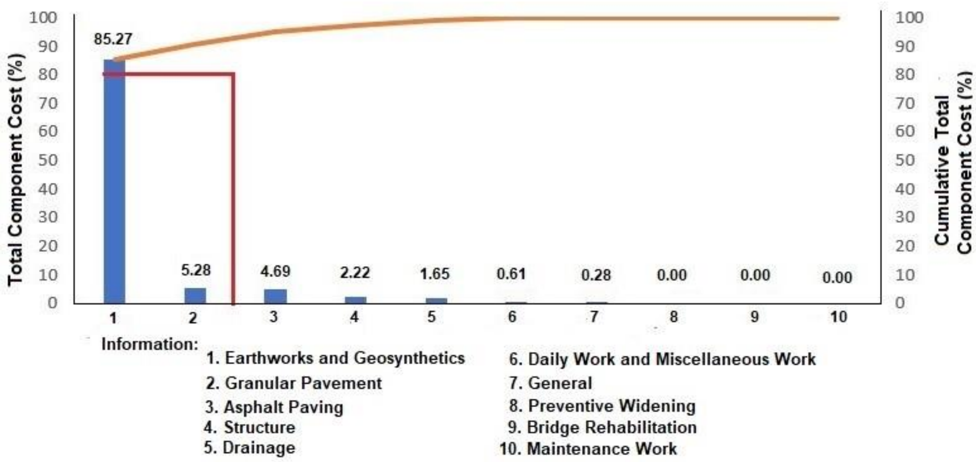

Figure 3. Pareto chart

Based on the Pareto principle (80/20 rule), we can identify the primary problem by looking at the bars contributing approximately 80% of the total cost. In this chart, "Earthworks and Pavement" is the primary cause, contributing 85.27% of the total cost. This is the highest and most dominant bar. Other jobs, such as Granular Pavement (5.28%), Asphalt Pavement (4.69%), and so on, have much smaller cost percentages. Thus, the main priority to focus on is "Earthworks and Pavement." Significant overall cost savings will be achieved by optimizing or reducing costs on these projects. This observation strongly supports the Pareto principle in practice, suggesting that focusing VE efforts on these high-impact areas can lead to considerable savings for the overall project. Thus, the VE process becomes highly efficient by avoiding the dilution of efforts across less significant cost items.

4.2 Analysis stage

At this stage, a function analysis is performed first, where a function is defined as a system related to each other in a relationship (why-why, if-then), consisting of verbs and nouns. Next, a function analysis shows the cost/worth comparison in each work item to be reviewed. The analysis is carried out on the primary function (basic function) symbolized by the letter (B), against the supporting function (secondary function) symbolized by the letter (S). If the cost/worth ratio is > 1, it is necessary to conduct value engineering on the work item. The analysis is carried out on two divisions, namely Division 3 and Division 5, as shown in Tables 2 and 3.

Based on the functional analysis results, a cost/worth ratio greater than 1 was obtained for two reviewed items: earthworks and geosynthetics (1.001), and granular pavement work (1.224). This indicates that both work items have unnecessary costs, suggesting that further analysis is necessary [32]. Although the cost/worth ratio for earthworks and geosynthetics (Division 3) is slightly above 1, at 1.001 (as shown in Table 2), its significance is considerable. This division accounts for over 85% of the total project cost (Table 1). Even minor inefficiencies in cost components of this magnitude can result in substantial monetary waste, making it an excellent target for VE, despite the small ratio. This emphasizes that even small inefficiencies can be significant for high-cost items.

In contrast, the cost/worth ratio for granular pavement works (Division 5) is notably higher at 1.224 (as shown in Table 3). This suggests that this division has a relatively greater level of unnecessary costs per functional unit. Potential reasons for this could include material over-specification, inefficient procurement practices, or suboptimal granular layer construction methods. Therefore, this division offers considerable opportunities for VE efforts, despite its lower overall cost contribution compared to earthworks.

Table 2. Analysis of earthwork and geosynthetic functions (Division 3)

No.	Description	Function (Forming the Road Body)		Type	Cost (in millions, IDR)	Worth (in millions, IDR)
		Verb	Noun			
1	Regular excavation	Forming	Road body	B	507,216	507,216
2	Rock excavation	Forming	Road body	B	48,325	48,325
3	Routine embankment from excavation results	Forming	Road body	B	1,025	1,025
4	Selected embankment from excavation sources	Forming	Road body	B	5,765	5,765
5	Preparation of road body	Tidy up	Road body	S	419	-
	Total number				562,750	562,331
	Cost/Worth				**1.001**	

Table 3. Analysis of granular pavement function (Division 5)

No.	Description	Function (Road Surface Layer)		Type	Cost (in millions, IDR)	Worth (in millions, IDR)
		Verb	Noun			
1	Class A aggregate foundation layer	Coating	Road body	B	28,452	28,452
2	Class S aggregate foundation layer	Coating	Roadside	S	6,385	-
	Total number				34,837	28,452
	Cost/Worth				**1.224**	

4.3 Creative stage

The creative stage is a phase focused on creative thinking, generating various ideas for the VE analysis. During this stage, brainstorming techniques are employed to address specific problems by gathering diverse ideas that must meet certain criteria for success. According to Kumbhar [33], Brainstorming is a creative technique aimed at generating new ideas and solving problems. While it is typically conducted in groups, it can also be done individually. Brainstorming aims to promote free thinking, allowing everyone to express their ideas without fear of judgment. This approach fosters an open and innovative environment. Based on the findings from the analysis stage, the creative stage concentrates on divisions 3 (earthworks and geosynthetics) and 5 (granular pavement work), which have the highest cost weights.

The main problems identified were earthworks and geosynthetics (regular excavation, rock excavation, embankment from excavated materials and selected embankment from excavated sources) and granular pavement works (A and S aggregate base courses). To address these problems, various alternative value engineering techniques were analyzed and quantified to achieve benefits in terms of cost reduction, quality of work, and time savings, including:

(1) Alternative I

This option involves replacing the current transportation equipment, specifically the Dump Truck (DT) with an 8-ton capacity, with a DT that has a 4-ton capacity. This change is due to the limited availability of 8-ton capacity dump trucks, making it more feasible to utilise the more widely available 4-ton capacity dump trucks in Kupang Regency. However, it is important to note that choosing the 4-ton dump truck means we will need to use twice as many units as the 8-ton dump trucks.

(2) Alternative II

This option involves modifying the analysis of unit prices for earthworks and geosynthetics (Division 3) and granular pavement work (Division 5). The adjustments were made by replacing the introductory price based on the Decree of the Governor of East Nusa Tenggara Number 42/KEP/HK/2020, which concerns the Reference Price of Non-Metallic Minerals and Rocks in East Nusa Tenggara Province for the year 2020. The price change is necessary because the introductory unit price set by the NTT Governor is lower than that of the introductory unit price from the NTT Provincial P2JN Work Unit. Therefore, utilizing the NTT Governor's unit price is more economical from a pricing standpoint. However, this alternative does not consider the cost of levies, C excavation taxes, or other factors affecting the implementation.

(3) Alternative III

This alternative proposes a combination of changes from alternatives I and II. The modifications involve replacing the transportation equipment initially planned (DT) with a capacity of 8 tons with one with a capacity of 4 tons. Additionally, we will use the introductory price established by the Decree of the Governor of East Nusa Tenggara Number 42/KEP/HK/2020, which concerns the reference price of non-metallic minerals and rocks in East Nusa Tenggara Province for the year 2020. To support the implementation of these three alternatives, an initial design of work items for Divisions 3 and 5 has been created, as illustrated in Tables 4 and 5. Furthermore, Tables 6 and 7 compare alternative work 1 and 2 price weights for Divisions 3 and 5.

Table 4. Preliminary design for earthworks and geosystems (Division 3)

No.	Description (m^3)	Quantity (in millions, IDR)	Unit Price (in millions, IDR)	Total Price (in millions, IDR)
1	Regular Excavation	12,996,029	39,028	507,215
2	Rock Excavation	251,006	194,193	48,744
3	Routine embankment from excavation results	60,649	16,910	1,026
4	Selected embankment from excavation sources	36,991	155,870	5,766
		Total		**562,749**

Table 5. Preliminary design for granular pavement works (Division 5)

No.	Description (m^3)	Quantity (in millions, IDR)	Unit Price (in millions, IDR)	Total Price (in millions, IDR)
1	Class A aggregate foundation layer	42,514	669,228	28,452
2	Class S aggregate foundation layer	10,665	598,633	6,385
	Total Price of Work			**34,836**

Table 6. Alternative designs for earthworks and geosystems (Division 3)

No.	Description (m^3)	Quantity (in millions, IDR)	Unit Price (in millions, IDR)		Total Price (in millions, IDR)	
			Alternative I	Alternative II	Alternative I	Alternative II
1	Regular Excavation	12,996,029	37,43	39,03	486,467	507,209
2	Rock Excavation	251,006	183,89	194,22	46,157	48,750
3	Routine embankment from excavation results	60,649	16,91	16,906	1,025	1,025
4	Selected embankment from excavation sources	36,991	155,85	45,628	5,765	1,688
		Total Price of Work			**539,414**	**558,672**

Table 7. Alternative designs for granular pavement work (Division 5)

No.	Description (m^3)	Quantity (in millions, IDR)	Unit Price (in millions, IDR)		Total Price (in millions, IDR)	
			Alternative I	Alternative II	Alternative I	Alternative II
1	Class A aggregate foundation layer	42,514	759,973	429,591	32,309	18,264
2	Class S aggregate foundation layer	10,665	907,340	391,000	9,677	4,170
		Total Price of Work			**41,986**	**22,434**

4.4 Evaluation stage

4.4.1 Replacement of material transport equipment (8 tons to 4 tons)

The 27.88 km road construction project on the Oepoli and Neolelo PLBN sections, Kupang-NTT, was initially estimated to cost IDR 725,935,500. After engineering, which involved replacing the transport equipment from a DT with a capacity of 8 Tons to a DT with a capacity of 4 Tons in the Division 3 work, the total project cost was successfully reduced from IDR 562,749,563 to IDR 539,414,210. Table 8 shows a comparison of costs before and after VE, with the details of the revised project costs being:

- Earthworks and geosynthetics: IDR 539,414,210 (A decrease of IDR 23,335,353 or around 4.15%)
- Granular pavement: IDR 41,986,700 (An increase of IDR 7,150,900 or around 20.52%)

The cost reduction was mainly attributed to significant declines in earthworks and geosynthetics costs, which were partially offset by a rise in granular pavement costs. Smaller trucks provided operational advantages in this specific project context, contributing to the overall cost savings. Nevertheless, the increase of 20.52% in granular pavement costs (as shown in Table 9) raises important considerations regarding equipment optimization. This suggests that 4-ton trucks are more efficient for earthworks due to their manoeuvrability in challenging terrains. However, they are less cost-effective for transporting granular pavement materials because more trips are needed to transport the same volume. This situation underscores that the selection of optimal equipment is highly dependent on the context and requires a comprehensive analysis at the project level to ensure that optimizing one area does not lead to inefficiencies in another.

Table 8. Comparison of costs before and after VE

No.	Cost Components	Initial Fee (in millions, IDR)	Revision Fee (in millions, IDR)	Absolute Change (in millions, IDR)	Percentage Change (%)
1	Earthworks and geosynthetics	562,749,563	539,414,210	-23,335,390	-4.15
2	Granular pavement	34,836,778	41,986,700	+7,150,900	+20.52
3	Other jobs (Divisions 1, 2, 4, 6, 7, 8, 9, and 10)	62,355,033	62,355,033	0	0
4	Value added tax (10%)	65,994,137	64,375,594	-1,618,543	-2.45
	Total Project Cost	**725,935,512**	**708,131,537**	**-17,803,960**	**-2.45**

Table 9. Comparison of project costs before and after changes in unit prices

No.	Cost Components	Initial Fee (in million, IDR)	Revision Fee (in million, IDR)	Absolute Change (in million, IDR)	Percentage Change (%)
1	Earthworks and geosynthetics	562,749,563	558,672,410	-4.077.190	-0.72
2	Granular pavement	34,836,778	22,434,170	-12.402.630	-35.6
3	Other jobs (Divisions 1, 2, 4, 6, 7, 8, 9, and 10)	62,355,033	62,355,033	0	0
4	Value added tax (10%)	65,994,137	64,346,161	-1,647,976	-2.49
	Total Project Cost	**725,935,512**	**707,807,774**	**-18.127.730**	**-2.5**

4.4.2 Changes in unit price of work

In the Oepoli–Neolelo PLBN project context, a key value engineering element was the revision of the basic unit prices for materials. The NTT Governor's Decree on benchmark prices for minerals and rocks introduced lower official reference prices for materials such as sand, gravel, and geosynthetics. These prices were established in contrast to previous cost calculations that relied on contractor figures or outdated NTT Provincial P2JN Working Unit estimates. The new unit prices, based on the most recent benchmark (NTT Governor's Decree No. 42/KEP/HK/2020), resulted in savings of approximately IDR 18,127,738,000 from the initial budget, with a total difference of IDR 725,935,512,000 – IDR 707,807,774,000.

The most significant savings were in granular pavement, amounting to approximately IDR 12.4 billion, followed by additional savings in earthworks and geosynthetics, totalling around IDR 4.1 billion. This aligns with the general principle that "total cost = unit price × volume," where a decrease in unit price directly reduces total costs proportionally to the quantity of work.

4.5 Development stage

The study results indicate that Alternative I, which involves replacing the transport equipment from a capacity of 8 tons to a capacity of 4 tons, offers a more favourable option compared to the initial design. This change results in a cost reduction of IDR 708,131,537. Similarly, Alternative II, which entails a minor adjustment in labour costs, leads to a total cost decrease of IDR 707,807,740. When comparing the initial design cost of IDR 725,935,500 with these two alternatives, we see a cost reduction of approximately 2.45% for Alternative I and 2.49% for Alternative II. As a result, the development stage also includes the creation of Alternative III, which combines the features of Alternatives I and II, as illustrated in Figure 4. Alternative III significantly reduces project costs of IDR 682,701,410, resulting in savings of IDR 43,234,090, or about 5.96%.

The impressive performance of Alternative III, which achieved savings of 5.96%, results from operational changes (such as the use of dump trucks) and financial adjustments (like unit price modifications). This outcome highlights a fundamental principle of Value Engineering: synergy. It shows that making isolated improvements may only lead to limited results. In contrast, taking a comprehensive approach that targets multiple cost drivers and leverages various opportunities—such as enhancing equipment efficiency and optimizing procurement—can generate significantly greater value. This demonstrates that the cost inefficiencies within the project require a multifaceted Value Engineering solution.

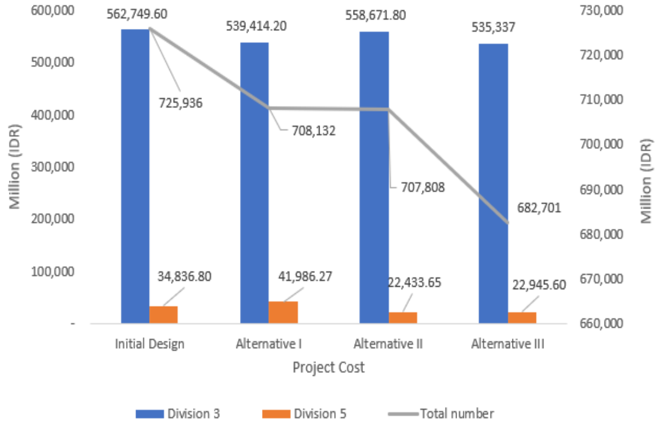

Figure 4. Comparison chart of alternative VE uses

4.6 Recommendation/presentation stage

After analyzing the various alternative ideas, the final stage of value engineering is the recommendation stage. During this stage, recommendations are made based on the results of the analysis. These recommendations serve as input for making cost-saving decisions in the Oepoli – Noelelo PLBN Access Road Construction project. It has been identified that the work elements with the highest potential costs in the Oepoli – Noelelo PLBN Access Road Construction package are earthworks, geosynthetics, and granular pavement work. Additionally, alternatives and innovations have been identified from applying value engineering in the construction package for the Oepoli – Noelelo PLBN section, as illustrated in Table 10.

Table 10. Recapitulation of comparison of access road construction projects before and after value engineering

Division	Job Description	Initial Design Cost (in million, IDR)	Alternative I (in million, IDR)	Alternative II (in million, IDR)	Alternative III (in million, IDR)
1	General	1,843.3	1,843.3	1,843.3	1,843.3
2	Drainage	10,904.5	10,904.5	10,904.5	10,904.5
3	Earthworks and geosynthetics	562,749.6	539,414.2	558,672.4	535,337.0
4	Preventive widening	-	-	-	-
5	Granular pavement	34,836.8	41,986.7	22,434.2	22,945.6
6	Asphalt paving	30,952.6	30,952.6	30,952.6	30,952.6
7	Structure	14,660.0	14,660.0	14,660.0	14,660.0
8	Bridge rehabilitation	-	-	-	-
9	Daily work and miscellaneous work	3,994.6	3,994.6	3,994.6	3,994.6
10	Maintenance work	-	-	-	-
	Total cost	659,941.4	643,755.9	643,461.6	620,637.6
	Value added tax (10%)	65,994.1	64,375.6	64,346.2	62,063.8
	Overall Total	**725,935.5**	**708,131.5**	**707,807.8**	**682,701.4**

5. DISCUSSION

Effective VE begins with identifying critical success factors (CSFs) early. Lin and Lin [34] investigated the theory that identifying CSFs early is key to conducting a VE study. VE implementation involves the client and a cross-disciplinary team of experts to create a project plan that fulfils all required functions at the lowest possible cost. The involved parties are responsible for designing solutions to achieve the same or better project performance at a lower total cost [35].

The challenges of financing large and complex infrastructure are highlighted in this 27.88 km PLBN access road construction project, funded directly by the government through the Indonesian Ministry of Public Works and Public Housing. However, according to Soleymani et al. [36], the increasing need to build and manage infrastructure projects is always a significant challenge, along with a lack of funds to realize them. Therefore, infrastructure project financing is unique in size, complexity, and high investment costs, making financing this project costly.

One key finding is the efficiency of using 4-ton trucks for earthworks with short haul distances and complex site conditions. Medium-sized trucks are more productive, faster, and agile for shorter haul distances [37]. The improved manoeuvrability of 4-ton trucks can speed up work cycles, especially in confined areas or with many turns, and reduce the overall earthwork time. Furthermore, smaller trucks are easier to operate on uneven or muddy terrain, increasing efficiency and reducing the risk of delays. Smaller trucks also have lower purchase and rental prices, resulting in significant cost savings in this project. While the operating cost per trip may be slightly lower for smaller trucks, increased trip frequency can lead to higher transportation costs for these materials. Dobromirov et al. [38] indirectly supports this by showing that operations with smaller trucks can have higher costs.

The total project cost decreased by Rp17,803,960, primarily due to reduced costs for earthworks and geosynthetics. This is due to a combination of potentially lower operating costs per unit of work for a 4-ton truck and increased earthwork efficiency due to better manoeuvrability. However, there is an increase in granular pavement costs from Rp34,836,800 to Rp41,986,700. Although the volume of granular pavement material is the same, using a 4-ton truck requires twice the number of trips compared to an 8-ton truck. This increased trip frequency can lead to higher overall transportation costs for this material, indirectly supported by the fact that operations with smaller trucks can have higher costs.

Another approach in this study involved adjusting material unit prices based on the latest regulations, resulting in direct cost savings through work volume efficiencies. VE has been shown to reduce costs while maintaining project quality standards [39] and achieving essential project functions at the lowest cost [40]. VE implementation also supports sustainable infrastructure by optimizing resource use and controlling long-term costs. Therefore, VE is highly relevant in modern road project management because it prioritizes value and sustainability without sacrificing final road quality.

Additionally, Alternative III was selected as the optimal solution due to its 5.96% cost savings and several strategic reasons, including: local equipment availability, operational flexibility, minimal increase in technical and quality risks, and reduced risk of project delays due to equipment breakdowns. The availability of local equipment, related to replacing 8-ton dump trucks with 4-ton trucks, is highly feasible due to the greater availability of 4-ton trucks in Kupang Regency, reducing dependence on mobilizing heavy equipment from outside the region and supporting the local economy. Smaller dump trucks more easily handle operational flexibility related to winding and muddy road conditions, increasing work cycle efficiency and reducing downtime.

On the other hand, the change in unit prices based on NTT Governor Decree No. 42/KEP/HK/2020 provides a strong and transparent legal basis for adjusting material costs, supported by official and up-to-date market price data. However, Alternative III does not change the technical specifications of the materials or the essential road structure design. Savings are achieved through logistics optimization and unit price adjustments, rather than by substituting lower-quality materials, thus maintaining the quality and durability of the road. Essentially, utilising more common means of transportation in the region and unit material prices relevant to the local market creates a more sustainable ecosystem, potentially reducing long-term operational and maintenance costs. Therefore, Alternative III, which combines logistics optimization and unit price adjustments, is a more practical, lower-risk solution that provides sustainable added value for the project and communities in the border region.

6. CONCLUSIONS

This study successfully applied a VE approach to reduce the Indonesia-Timor Leste Border Post Access Road construction costs in Oepoli-Noelelo. Through a systematic VE methodology, including Pareto analysis, earthworks and geosynthetics, as well as granular pavement, were identified as high-cost items with potential savings. Three alternatives were developed: replacing the hauling equipment from 8-ton DT to 4-ton DT, changing the unit price of work based on the latest regulations, and a combination of both. The optimality of Alternative III lies not only in its cost savings but also in its high feasibility due to the availability of local equipment and regulatory support, minimal increase in technical risks, and potential long-term value through operational efficiency and better budget management. The application of VE was proven to significantly reduce project costs without sacrificing quality and functionality, confirming its crucial role in optimizing infrastructure projects amidst budget constraints and complexity.

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NOMENCLATURE

BP	budget plan
BCM	breakdown cost model
DED	detailed engineering designs
DT	dump truck
EE	engineer estimates
FAST	function analysis system technique
IDR	Indonesian rupiah
RI	republic of Indonesia
SBCP	state border crossing post
OE	owner estimates
VE	value engineering VE