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Research Paper

Value Engineering Optimization of Trestle Works at the Lamongan Oil Tank Terminal, East Java, Indonesia

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ABSTRACT: *Trestle structures in marine oil-terminal projects combine high capital cost, difficult construction conditions, and strict functional and safety requirements. This study applies Value Engineering (VE) to the trestle works of the Lamongan Oil Tank Terminal (LOTT) in East Java, Indonesia, with the objective of improving project value without reducing the required structural function, quality, safety, or service life.*

The research used an Applied Engineering Research approach with quantitative VE analysis supported by interviews with five experienced project stakeholders and secondary project documents, including the Detail Engineering Design (DED), contract cost estimate, and technical specifications. The VE Job Plan covered the information, function-analysis, creative, evaluation, development, and presentation phases. Cost Breakdown Structure and Pareto analysis were used to identify high-cost components; FAST and cost-worth analysis were used to preserve essential functions; three span alternatives (8.7 m, 16.2 m, and 21.2 m) were developed; and the alternatives were assessed through AHP, Life Cycle Cost (LCC), technical verification, and implementation-risk review.

The original trestle cost was IDR 219.249 billion. Concrete spun-pile foundations accounted for 63.92% of that cost, followed by pier head-girder-slab works (24.50%) and pipe racks (11.58%). The AHP consistency ratio was 0.051. Although Alternative 2 obtained the highest AHP score, Alternative 3 produced the lowest LCC and the largest direct saving. Following development-stage technical and risk verification, Alternative 3, with a 21.2 m pier-head span, was selected as the integrated VE recommendation. It reduced construction cost to IDR 162.230 billion, saving IDR 57.019 billion (26.01%), while satisfying the reported structural checks: 22 mm deflection (<25 mm), safety factor 1.95 (>1.50), and utilization 0.92 (<1.00). The results demonstrate that integrating function-based VE with multicriteria, life-cycle, structural, and risk evaluation can provide a practical decision framework for cost optimization of marine trestle structures.

KEYWORDS: *Value engineering, trestle, marine structure, cost optimization, analytical hierarchy process, life cycle cost.*

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I. INTRODUCTION

Large marine infrastructure projects require cost control that does not compromise structural performance or operational function. In this context, Value Engineering (VE) provides a structured way to examine what a facility must do, identify high-cost functions, generate alternative ways of delivering those functions, and compare the alternatives on the basis of value rather than initial cost alone. Previous construction applications have shown that VE can produce meaningful savings in building projects when it is applied to high-cost work items and supported by systematic function analysis [1,2,3].

The Lamongan Oil Tank Terminal (LOTT) is an integrated oil-storage and logistics development in Sedayu Lawas, Brondong District, Lamongan Regency, East Java. The trestle forms a critical connection between the land-side terminal and marine facilities, carrying operational access and pipe-distribution functions toward the jetty. Marine structures of this type must address geotechnical conditions, corrosion exposure, environmental loading, constructability, and continuity of terminal operations. Related Indonesian studies have addressed trestle pile-cap spacing, jetty structural performance, and pier design [4,8,9,10], but the project investigated here also presents a substantial cost-optimization problem because the trestle contains expensive pile foundations and repetitive pier-head, girder, slab, and pipe-rack elements.

The contract design used relatively short pier-head spacing, increasing the number of structural elements and the quantity of Concrete Spun Pile (CSP) and concrete work. Field observation and project interviews further identified high CSP cost, high fabrication and installation cost of girders, and the absence of a life-cycle evaluation in the initial design. These conditions make the trestle a suitable target for VE because the work is high in cost, permits alternative structural configurations, and must retain the same basic functions.

The contribution of this study is an integrated VE application for a marine trestle in which cost concentration, functional requirements, alternative generation, AHP-based screening, LCC, structural verification, and implementation risk are evaluated within one decision process. The study therefore aims to: (1) identify the trestle components and functions with the greatest potential for value improvement; (2) develop and compare feasible design alternatives; and (3) recommend an alternative that achieves substantial cost efficiency while maintaining the required function and reported technical performance.

II. LITERATURE REVIEW

2.1. Value Engineering in Construction

Value Engineering is a systematic and creative method for improving the relationship between function and cost. In construction, VE is particularly useful where a small number of work items account for a large proportion of project cost. Building-project studies cited in the source thesis demonstrate that VE can identify alternative materials, methods, and configurations that lower cost while retaining required performance [1,2,3,5,6,7]. The method differs from simple cost cutting because an alternative should not be accepted if savings are obtained by reducing the required function, quality, safety, or useful life.

2.2. Function Analysis, Cost Concentration, and FAST

The information and function-analysis phases establish where VE effort should be concentrated and what functions must be preserved. Cost Breakdown Structure (CBS) and Pareto analysis locate high-cost items, while function analysis expresses the required performance of components in concise verb-noun terms. The Function Analysis System Technique (FAST) then links functions through how-why relationships, helping the study team distinguish basic from supporting functions. Cost-worth comparison is used to expose components whose cost is disproportionate to their functional contribution and therefore deserve creative attention.

2.3. Multi-criteria Evaluation and Life-Cycle Perspective

A marine-structure alternative cannot be selected on construction cost alone. The source thesis combines AHP with LCC so that cost is considered together with technical and delivery-related criteria, while long-term expenditure is evaluated over the planned 50-year service life. The detailed AHP questionnaire operationalized five criteria: lowest cost, structural calculation/performance, material-delivery distance, construction time, and quality assurance. The later development stage additionally reviewed constructability, implementation risk, structural safety, and service life. This layered evaluation is especially relevant to trestle work because longer structural spans may reduce pile and pier quantities but can increase structural demand, fabrication complexity, and quality-control requirements.

2.4. Research Position

Prior studies in the thesis cover VE in hospitals, housing, apartments, and building structures, as well as structural evaluation of jetties and trestles [1]-[10]. The present case extends those applications by integrating the full VE Job Plan with AHP and LCC for a high-value marine trestle, followed by explicit structural and implementation-risk verification. The analytical position is therefore not simply to redesign the trestle for a lower first cost, but to demonstrate that the selected alternative retains essential functions and remains acceptable under the technical and risk checks reported in the project study.

III. RESEARCH METHOD

3.1. Case Project and Data Sources

The case study concerns the trestle works of the Lamongan Oil Tank Terminal in Brondong, Lamongan Regency, East Java. The research used an Applied Engineering Research approach with quantitative VE analysis. Primary information was obtained from interviews and AHP assessments involving five purposively selected project experts: the project leader/owner representative, planning and document-control manager, quality-control and supervision manager, contractor project manager, and construction-management team leader. Their reported experience ranged from at least 25 years to at least 40 years. Secondary data consisted of the DED, Bill of Quantity, contract cost estimate, drawings, and technical requirements.

Table 1. General characteristics and analytical inputs of the case study

Item	Description
Project	Lamongan Oil Tank Terminal (LOTT) - trestle works
Location	Brondong, Lamongan Regency, East Java, Indonesia
Developer/Owner	PT Natpac Graha Arthamas
Contractor	PT Wijaya Karya (Persero) Tbk
Construction management consultant	PT Virama Karya (Persero)
Original trestle construction cost	IDR 219,249,957,092.11
Primary respondents	5 experienced project stakeholders
Main project documents	DED, BoQ, contract cost estimate/RAB, technical requirements
Design service-life basis	50 years

3.2. Value Engineering Procedure

The analysis followed six VE Job Plan stages. The Information Phase assembled project and cost data and identified high-cost work through CBS and Pareto analysis. The Function Analysis Phase defined basic and secondary functions, developed the Function Cost Matrix, and used FAST and cost-worth analysis. The Creative Phase generated alternatives through literature review, brainstorming with the project team, expert discussion, and technical-economic review. The Evaluation Phase screened and ranked the alternatives using AHP and LCC. The Development Phase performed technical verification and reviewed implementation risk. Finally, the Presentation Phase compared the existing and VE designs and formulated an implementation recommendation.

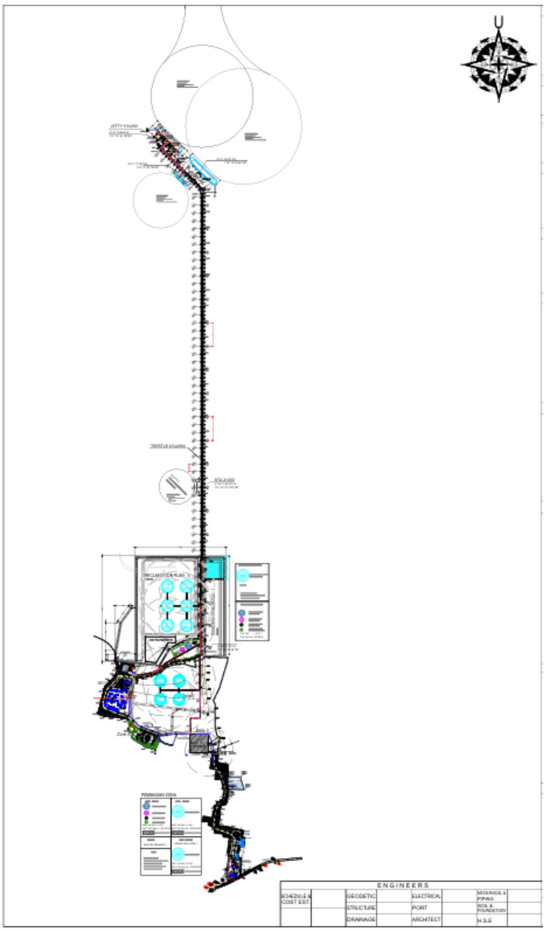

Figure 1. LOTT project layout and trestle connection used as the study context.

3.3. Alternative Development and AHP Evaluation

The existing configuration was treated as Alternative 1 with an 8.7 m pier-head span. The creative stage developed two optimization options by increasing the span to 16.2 m (Alternative 2) and 21.2 m (Alternative 3).

The objective was to reduce the number and quantity of CSP foundations and associated pier-head concrete while retaining load-support, load-transfer, traffic/access, and pipe-support functions. Pairwise comparisons were processed through AHP. The reported maximum eigenvalue was 5.23, the Consistency Index was 0.057, and the Consistency Ratio (CR) was 0.051; because CR < 0.10, the judgment matrix was considered consistent.

3.4. Life Cycle Cost, Structural Verification, and Risk Review

LCC analysis was carried out over a 50-year design life and converted relevant future expenditures to present-value terms. The development stage then checked structural response using the project study criteria, including deflection, safety factor, and utilization. Implementation risk was classified through a qualitative risk matrix covering fabrication delay, erection error, connection failure, and design change. The final recommendation was based on the integrated balance between direct construction saving, life-cycle economy, technical compliance, constructability, and implementation risk.

IV. RESULT AND DISCUSSION

4.1. Cost Breakdown and VE Target Selection

The initial trestle construction cost was IDR 219.249 billion. CBS showed that the CSP foundation dominated expenditure, followed by the pier head-girder-slab system and pipe rack. Pareto analysis therefore confirmed that VE attention should concentrate on these components, particularly the foundation and superstructure spacing that directly controls the number of piles and pier heads.

Table 2. Cost breakdown structure and pareto contribution

Component	Cost (IDR)	Share (%)
CSP foundation	140,137,676,515.45	63.92
Pier head, girder, and slab	53,714,458,266.67	24.50
Pipe rack	25,397,822,310.00	11.58
Total	219,249,957,092.11	100.00

The cost concentration is important for the logic of the study. A change in pier spacing has a multiplier effect: fewer pier locations reduce CSP quantity, pier-head concrete, associated installation work, and repetitive site operations. At the same time, a longer span increases structural demand and therefore cannot be accepted solely because it reduces quantities. This is why the function, AHP, LCC, structural, and risk stages are needed after Pareto screening.

4.2. Function Analysis and Creative Alternatives

Function analysis identified the trestle's principal system purpose as providing access to the marine facility. Key component functions included Support Load for the CSP foundation, Transfer Load/Carry Traffic for the pier head-girder-slab system, and Support Pipe/Distribute Force for the pipe rack. The Function Cost Matrix showed that load-support and traffic-carrying functions contained the largest cost. Consequently, every alternative was required to preserve these basic functions even when geometry and quantities were changed.

Table 3. Design alternatives generated in the creative phase

Alternative	Pier-head Span	Description
Alt-1 (existing)	8.7 m	Contract/DED configuration using CSP foundation
Alt-2	16.2 m	Intermediate-span optimization to reduce repetitive foundation and pier-head quantities
Alt-3	21.2 m	Maximum evaluated span optimization; greater reduction of CSP and pier-head quantities

The alternatives retained the same reported concrete strength basis (f'c = 25 MPa) and 50-year service-life objective. The central design trade-off was therefore between the quantity savings obtained from longer spacing and the increased structural and implementation demands created by the longer span.

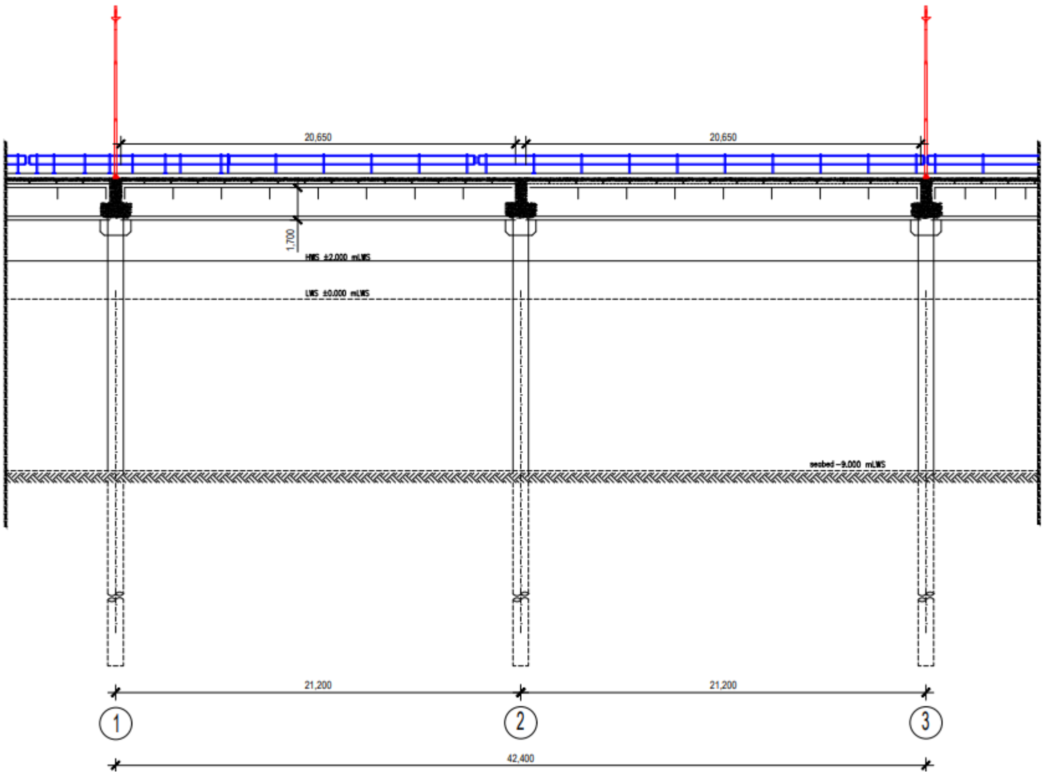

Figure 2. Alternative 3 trestle configuration with a 21.2 m pier-head span.

4.3. AHP and Life Cycle Cost Findings

The AHP calculation produced a Consistency Ratio of 0.051, indicating internally consistent pairwise judgments. The evaluation stage reported that Alternative 2 obtained the highest AHP score, while Alternative 3 produced the lowest Life Cycle Cost. This result is significant because it shows that the multicriteria preference and the long-term cost preference did not point to the same alternative at the first screening stage. Rather than forcing a single-metric conclusion, the study advanced both Alternatives 2 and 3 to the development stage for technical and risk verification.

The LCC result strengthened the economic case for the longer-span Alternative 3, but the thesis also notes that the associated savings come with greater implementation risk and a need for stricter quality control. This is consistent with the basic VE principle that higher value should arise from a better function-cost balance, not from transferring unacceptable risk to construction or operation.

4.4. Cost Saving and Technical Verification

The development-stage comparison shows a clear progression in direct construction saving as the pier-head span increases. Alternative 2 reduced the reported construction value to IDR 197.324 billion, while Alternative 3 reduced it to IDR 162.230 billion. Alternative 3 therefore produced the largest saving, IDR 57.019 billion or 26.01% of the original trestle cost.

Table 4. Economic and structural comparison of the evaluated designs

Parameter	Existing / Alt-1	Alt-2	Alt-3	Acceptance Basis
Pier-head span	8.7 m	16.2 m	21.2 m	Function retained
Construction cost	IDR 219.249 B	IDR 197.324 B	IDR 162.230 B	Lower is preferred
Cost saving	-	IDR 21.924 B (10.00%)	IDR 57.019 B (26.01%)	Higher saving
Deflection	15 mm	18 mm	22 mm	< 25 mm
Safety factor	2.10	2.00	1.95	> 1.50
Utilization	0.82	0.88	0.92	< 1.00
Service life	50 years	50 years	50 years	50-year basis

The structural indicators reveal the expected consequence of increasing span: deflection and utilization rise and the safety factor decreases. Nevertheless, the reported Alternative 3 values remain within the acceptance limits used in the thesis. This finding supports the final VE selection because the largest cost saving was achieved without violating the stated structural thresholds. It also demonstrates why the selected solution should be accompanied by detailed design review and disciplined construction quality control rather than treated as a purely financial substitution.

4.5. Implementation Risk and Final VE Recommendation

Table 5. Implementation-risk review for the developed VE alternative

Risk Event	Probability	Impact	Level
Fabrication delay	Medium	Medium	Medium
Erection error	Low	High	Medium
Connection failure	Low	High	Medium
Design change	Medium	High	High

The risk assessment indicates that the most important implementation concern is design change, classified as high, while fabrication delay, erection error, and connection failure were classified as medium. The source study therefore emphasizes stronger structural review, quality control, fabrication coordination, and field supervision for the longer-span solution. These measures are particularly important because Alternative 3 moves closer to the reported structural limits than the existing configuration.

The integrated decision can be understood as a staged trade-off. Alternative 2 was strongest in the AHP screening, while Alternative 3 was strongest in LCC and direct construction saving. Once Alternative 3 was verified against deflection, safety-factor, and utilization limits and its implementation risk was judged manageable with control measures, it became the final VE recommendation. The selected 21.2 m span changes the cost structure by reducing the quantity of CSP and pier-head concrete, producing a 26.01% saving while preserving the basic trestle functions.

From a construction-management perspective, the result shows the value of separating screening from final selection. AHP is useful for organizing expert preferences, but the final decision for a marine structure also requires life-cycle, structural, and risk evidence. The study therefore contributes a practical integrated workflow for owners, consultants, and contractors considering VE in large marine or port-related projects.

V. CONCLUSION

The Value Engineering analysis of the Lamongan Oil Tank Terminal trestle identified the CSP foundation as the dominant cost component, representing 63.92% of the original IDR 219.249 billion trestle value. Function analysis confirmed that any optimization must preserve load-support, load-transfer, access/traffic, and pipe-support functions. The creative stage evaluated pier-head spans of 8.7 m, 16.2 m, and 21.2 m. The AHP judgments were consistent (CR = 0.051); Alternative 2 ranked highest in the AHP stage, whereas Alternative 3 produced the lowest LCC and the largest direct saving. After technical and implementation-risk development, Alternative 3 was selected as the integrated VE recommendation. Its construction value was IDR 162.230 billion, corresponding to a saving of IDR 57.019 billion or 26.01%. The reported structural checks for Alternative 3 remained within the study limits, with 22 mm deflection, a 1.95 safety factor, and 0.92 utilization. The principal implementation issue is the increased control required for the longer-span configuration, particularly for design change, fabrication, erection, and connection quality. Overall, the case demonstrates that substantial cost efficiency in marine trestle construction can be achieved when VE is combined with function analysis, multicriteria evaluation, LCC, structural verification, and risk control rather than applied as simple cost cutting.

Future research should test the proposed configuration through more detailed design and post-implementation performance data, broaden expert participation, and extend the decision model using methods proposed in the source thesis, such as Fuzzy AHP or ANP, BIM-VE integration, Monte Carlo cost-uncertainty analysis, and Life Cycle Assessment for sustainability evaluation.

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