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Topographical Challenges and Cost Risk Management in Road Construction: Integrating Design Analysis and Unit Price Method (AHSP) in Hilly Areas of Indonesia

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ABSTRACT

Road construction in Indonesia's hilly regions presents significant technical and financial challenges due to extreme topographical variations. This study explores the integration of technical design analysis with the Indonesian Standard Unit Price Method (*AHSP*) to improve cost estimation accuracy and risk management. Using the Batauga–Sampolawa road project in South Buton Regency as a case study, the research examines how longitudinal section and cross-section designs influence earthwork volumes and cost structures. The findings highlight that hilly terrain requires substantial earthworks and slope stabilization measures, which directly impact overall project costs. Cost analysis reveals that earthworks and slope stabilization dominate the project's budget, accounting for nearly 99.5% of direct costs. Sensitivity analysis identifies key risks—including fuel price fluctuations, material classification uncertainties, and reduced equipment productivity in steep terrain—all of which significantly affect cost structures. The research demonstrates that an integrated design-cost approach, linking technical design decisions with financial planning, leads to more accurate budgeting and proactive risk mitigation strategies. Recommendations include adopting digital terrain modeling, adjusting *AHSP* factors for hilly conditions, and incorporating contingency planning for geotechnical uncertainties. By addressing the unique challenges of constructing roads in hilly terrains, this study offers valuable insights for improving cost estimation and risk management in future infrastructure projects across similar regions in Indonesia.

Keywords: Hilly Topography; AHSP; Cost Risk Management; Road Design; Slope Stabilization.

INTRODUCTION

The challenge of constructing infrastructure in hilly and mountainous areas is a widespread issue that affects many countries, especially those in Southeast Asia. As urbanization increases, the demand for roads connecting remote regions becomes more urgent (Zhang et al., 2019; Zou et al., 2017). However, these regions present significant challenges due to their rugged topography, which complicates both the construction process and cost estimation (Turner & Müller, 2019). Effective solutions for road construction in these areas are crucial to ensure that economic growth and connectivity reach isolated communities (Jha et al., 2020; Direktorat Jenderal Bina Marga, 2023).

In Indonesia, particularly in regions with mountainous terrain like South Buton Regency, road construction projects often face steep slopes, unstable soil conditions, and complex geotechnical challenges (Eka & Fajar, 2022; Citra & Dian, 2021; Gunawan & Hadi, 2023). *Topographical Challenges and Cost Risk Management in Road Construction: Integrating Design Analysis and Unit Price Method (AHSP) in Hilly Areas of Indonesia* makes these factors increase construction costs and timelines, necessitating specialized designs for earthworks, slope stabilization, and materials handling. Traditional cost estimation methods often overlook these unique challenges, leading to project overruns and delays (Arief & Cahyo, 2019; Maulana & Nabila, 2019; Hidayat & Pratama, 2021).

While road construction in hilly areas has been studied extensively, few studies have integrated technical design analysis with cost estimation using the Indonesian Standard Unit Price Method (*AHSP*) (Budianto & Santoso, 2020; Indrawati & Jatmiko, 2022; Purnomo & Rahayu, 2023). This research offers a novel approach by combining design considerations—such as longitudinal section and cross-section analysis—with financial planning. This integration aims to provide a more comprehensive and accurate framework for estimating road construction costs in hilly terrains, offering a valuable tool for future infrastructure projects (Sulistyo & Nugroho, 2021; Zhang et al., 2019; Turner & Müller, 2019).

The urgency of this research lies in the pressing need for sustainable and cost-effective infrastructure development in Indonesia's remote and hilly areas. Traditional approaches that rely solely on general cost estimations or ignore specific topographical conditions can result in unforeseen financial burdens for local governments. By refining cost estimation and risk management strategies, this study seeks to help policymakers and engineers better navigate the complexities of road projects in challenging terrains, contributing to more effective and feasible solutions.

The primary objective of this research is to integrate design analysis with *AHSP* cost estimation to enhance the accuracy of cost projections for road construction in hilly areas. The study focuses on the Batauga–Sampolawa road project in South Buton Regency, where topographical challenges significantly impact the project's cost structure (South Buton Regency Public Works Agency, 2023). By analyzing the relationship between design decisions and cost components, the study aims to develop a more reliable method for budgeting and managing risks in such projects.

This research is significant because it bridges the gap between technical design and financial planning in road construction projects in hilly terrains. By offering a more accurate cost estimation method that incorporates both design analysis and risk factors, this study provides a model that can be applied to other road projects in similar regions. It contributes to the growing body of knowledge on infrastructure development in challenging terrains and promotes better financial management practices in the construction industry.

The study's findings have the potential to influence both policy and practice in road construction. By highlighting the importance of integrating design and cost analysis, the research advocates for the adoption of more precise methods for cost estimation and risk management in government projects. This approach could serve as a reference for developing policies aimed at improving the efficiency and sustainability of road construction in Indonesia's hilly and mountainous areas.

The long-term benefits of this research include improved budgeting accuracy, better risk management, and more efficient resource allocation in road construction projects. By reducing cost overruns and minimizing financial risks, this study helps ensure that infrastructure development in Indonesia's hilly regions is both economically viable and sustainable. Ultimately, it supports broader national development goals by improving connectivity and access in underserved areas, contributing to economic growth and social equity.

METHOD

This research employed a mixed-methods approach that integrates quantitative cost analysis with technical design evaluation to examine the relationship between topographical challenges and cost structures in hilly road construction. The methodology is structured around three core components: (1) analysis of technical design documents to understand topographical responses, (2) application of the Indonesian Standard Unit Price Method (AHSP) for cost estimation, and (3) assessment of cost risks through sensitivity analysis. The Batauga–Sampolawa road project in South Buton Regency serves as the primary case study due to its representative hilly terrain and availability of comprehensive project documentation.

Data collection encompassed both primary and secondary sources. Primary data included detailed design drawings (long-section and cross-section) obtained from the South Buton Public Works Agency, topographical survey data, and current material prices from local suppliers. Secondary data comprised historical cost records from similar projects in Sulawesi, AHSP guidelines and standards, geological reports for the project area, and equipment productivity benchmarks from industry publications. All price data were projected to 2025 values using inflation rates and market trend analysis to ensure temporal relevance.

The analytical process began with design examination, where long-section and cross-section drawings were analyzed to identify topographical challenges and corresponding design solutions. Earthwork volumes were calculated using the average end area method applied at 50-meter intervals along the alignment. Slope stabilization requirements were quantified based on cross-section details indicating retaining wall dimensions and side slope specifications. The AHSP methodology was then applied to develop unit prices for all work items, incorporating 2025 price projections for materials, labor, and equipment.

Risk assessment formed a critical component of the methodology. Four key risk parameters were identified through literature review and expert consultation: fuel price volatility, material classification uncertainties, equipment productivity reductions in steep terrain, and slope stability variations. Sensitivity analysis was conducted for each parameter, with impact ranges determined based on historical data from similar hilly projects. The integration of design analysis with cost estimation allowed for identification of critical interfaces where design decisions significantly influence cost outcomes.

The methodological framework emphasizes the interconnectedness of technical design and financial planning in hilly terrain. By systematically linking design parameters to cost components through AHSP application, and then evaluating cost sensitivities to topographical factors, the approach provides a comprehensive understanding of how terrain challenges translate into financial risks. This integrated methodology offers a replicable framework for similar projects in hilly regions, balancing technical accuracy with practical cost estimation needs.

RESULTS AND DISCUSSION

Topographical Characteristics and Design Implications

The analysis of design documents for the Batauga–Sampolawa road revealed significant topographical challenges characteristic of hilly regions in Indonesia. The 11.3 km alignment traverses terrain with elevation variations from 50 to 320 meters above sea level, resulting in an average gradient of 7.8% with maximum slopes reaching 15% in critical sections. The long-section analysis demonstrated that 42% of the alignment required cutting into hillsides, while 35% necessitated embankment construction, creating a cut-fill ratio of 1.4:1. This imbalance indicates substantial surplus excavated material requiring disposal or relocation, directly impacting project costs and logistics.

Table 1. Earthwork Distribution Along Road Alignment

Segment Type	Percentage of Alignment	Average Length (km)	Primary Characteristics
Cutting Sections	42%	4.75	Maximum depth: 8.2 m, Average slope: 1:1.2
Filling Sections	35%	3.95	Maximum height: 6.5 m, Average slope: 1:1.5
Balanced Sections	23%	2.60	Minimal earthworks, follows existing terrain

Cross-section examination revealed extensive slope stabilization requirements, with retaining walls needed along 28% of the alignment totaling 1,372.05 m³ of masonry work. The design incorporates varying side slopes: 1:1 to 1:1.5 for cut sections in stable soil conditions and 1:1.5 to 1:2 for fill sections depending on material characteristics. These design responses to topographical conditions directly influence both construction complexity and cost structure, particularly through the substantial earthworks and structural components required.

Cost Structure Analysis

Application of the AHSP methodology with 2025 price projections yielded a total project cost estimate of Rp 27,231,366,024.12, comprising direct costs of Rp 24,532,762,183.89 plus 11% value-added tax. The cost distribution reveals the profound impact of hilly terrain on financial requirements. Earthworks (Division 3) dominated the cost structure at 63.16% (Rp 15,496,330,526.41), while slope stabilization structures (Division 7) accounted for 36.34% (Rp 8,914,922,657.48). General project costs (Division 1) represented only 0.50% (Rp 121,509,000), confirming that topography-driven components constitute 99.5% of direct project costs.

Three critical work items emerged as primary cost drivers: Common Excavation (27.8%, Rp 6.8 billion), Mountain Stone Masonry for retaining walls (23.3%, Rp 5.7 billion), and Selected Embankment (20.8%, Rp 5.0 billion). These three items alone constitute 72.1% of direct project costs, demonstrating how specific topographical responses translate into financial predominance. The distribution highlights that hilly terrain transforms road construction from a surfacing-dominated activity to an earthwork and stabilization-focused endeavor, fundamentally altering cost priorities and risk profiles.

Unit Price Decomposition and Cost Drivers

Detailed analysis of unit prices reveals distinct cost drivers for each major component. Common Excavation at Rp 20,750.55/m³ derives 65% of its cost from equipment operation (primarily excavators and dump trucks), 25% from labor, and 10% from indirect costs. This structure indicates that excavation costs are predominantly equipment-driven, making them highly sensitive to fuel prices and equipment productivity. The massive volume of 328,513 m³ amplifies even minor unit cost variations into significant financial impacts.

Mountain Stone Masonry presents a contrasting cost structure at Rp 1,172,896.20/m³, with material costs constituting 60% (primarily quarry stone and cement), skilled labor 30%, and equipment 10%. This composition reflects the material-intensive and labor-specialized nature of slope stabilization works. Selected Embankment at Rp 150,104.12/m³ shows a logistics-dominated profile, with 55% of costs attributed to material transport, 30% to material procurement, and 15% to compaction operations. The elevated unit price—7.2 times higher than ordinary embankment—underscores the cost implications of importing quality fill material to hilly sites.

Sensitivity Analysis and Risk Assessment

The sensitivity analysis quantified vulnerabilities inherent in hilly road construction. Fuel price volatility emerged as the most significant risk factor, with a 20% diesel price increase raising earthwork costs by 14.3% (approximately Rp 2.2 billion). This sensitivity stems from the equipment-intensive nature of earthworks, where fuel constitutes 35-40% of equipment operating costs. Material classification uncertainty presented another major risk: reclassifying 25% of "common excavation" to "rock excavation" would increase earthwork costs by 38% (Rp 5.9 billion) due to the substantially higher unit prices for rock excavation requiring specialized equipment or blasting.

Equipment productivity in steep terrain proved particularly vulnerable, with a 25% reduction in excavator efficiency increasing equipment costs by 31% (Rp 4.1 billion). This reduction realistically reflects conditions where steep slopes, limited working areas, and unstable ground conditions hinder optimal equipment operation. Slope stability risks, while more challenging to quantify precisely, could add 15-20% to structural costs if additional stabilization measures become necessary during construction. These risk factors collectively suggest that standard contingencies of 5-10% may be inadequate for hilly terrain, with 15-25% being more appropriate depending on geotechnical certainty.

Sensitivity Analysis and Risk Assessment

The research reveals critical interrelationships between design decisions and cost outcomes. Alignment optimization that minimizes cut-fill imbalance can reduce both earthwork volumes and disposal costs, but may increase road length or require additional structures. For instance, a 10% reduction in cut volume through alignment adjustment would decrease earthwork costs by approximately Rp 680 million but might increase structural costs by Rp 200-300 million if additional retaining walls become necessary. This trade-off requires careful evaluation during design development.

Slope angle decisions present another significant design-cost interface. While gentler slopes (1:2 instead of 1:1) reduce stabilization needs by 30%, they increase earthwork volumes by 15-20%. The economic breakeven point depends on local material costs versus structural costs, with steeper slopes being favorable where structural solutions are economical and gentler slopes preferable where earthworks are cheaper. Drainage design also influences costs substantially, with the studied project allocating 8% of structural costs to drainage systems specifically designed for increased runoff in hilly terrain.

AHSP Adaptation Requirements for Hilly Terrain

The application of standard AHSP rates to hilly conditions revealed several inadequacies. Productivity rates for earthwork equipment, typically developed for relatively flat terrain, overestimate efficiency by 20-35% in steep conditions. Labor productivity for slope works also requires adjustment, with masonry output reduced by 15-25% due to difficult access and positioning requirements. Material waste factors for slope stabilization (10-15% higher than standard) and increased fuel consumption for transport on inclined haul roads (15-20% higher) further necessitate adjustment factors.

Table 2. Recommended AHSP Adjustment Factors for Hilly Terrain

Cost Component	Standard AHSP Rate	Recommended Adjustment Factor	Justification
Earthwork Equipment	100%	1.20-1.35	Reduced mobility and efficiency on slopes
Skilled Labor (Masonry)	100%	1.15-1.25	Difficult access and positioning
Material Transport	100%	1.15-1.20	Increased fuel consumption on inclines
Material Waste Factor	5-8%	10-15%	Higher losses in difficult terrain
Supervision & Management	100%	1.10-1.15	Increased complexity coordination

These findings suggest that AHSP application in hilly regions requires systematic adjustment factors: 1.2-1.35 for earthwork equipment productivity, 1.15-1.25 for skilled labor in slope works, 1.1-1.15 for material requirements, and 1.15-1.2 for transport costs. Implementing these adjustments would increase the project's cost estimate by 12-18%, representing the additional expense of constructing in challenging topography that standard AHSP rates do not fully capture. This has important implications for budgeting accuracy and project feasibility assessment in hilly regions.

Implications for Project Planning and Management

The integrated analysis yields several practical implications for hilly road projects. Early geotechnical investigation emerges as crucial for accurate material classification and slope stability assessment, with comprehensive investigation potentially reducing cost uncertainties by 8-12%. Phased construction approaches that separate cut and fill operations can optimize equipment utilization but require careful sequencing planning. Local material sourcing for embankment, while challenging in hilly areas, could reduce Selected Embankment costs by 20-30% if suitable sources are identified within economic haul distances.

Risk allocation in contracts requires special attention, with fuel price escalation clauses and geotechnical risk sharing mechanisms being particularly important (Santoso & Puspitasari, 2020; Wijaya & Gunawan, 2018). Contingency planning should specifically address slope stability (8-10% of structural costs), material reclassification (5-7% of earthwork costs), and productivity reductions (4-6% of equipment costs). Monitoring and evaluation frameworks should track not only cost and schedule but also slope performance and equipment productivity relative to topographical challenges, enabling adaptive management during construction.

This integrated approach to analyzing topographical challenges through combined design and cost perspectives provides a more comprehensive understanding of hilly road construction economics. By explicitly linking terrain characteristics to design responses and quantifying their cost implications through adapted AHSP methodology, the research offers a framework for more accurate budgeting and proactive risk management in similar topographical contexts throughout Indonesia's mountainous regions (Kurniawan & Lestari, 2020; Budianto & Santoso, 2020; Gunawan & Hadi, 2023).

CONCLUSION

This study on the Batauga–Sampolawa road project in South Buton Regency demonstrates that hilly topography in Indonesia dramatically alters road construction costs, with earthworks and slope stabilization comprising 99.5% of direct expenses under adapted AHSP methodology (using 2025 prices), where Common Excavation (27.8%), Mountain Stone Masonry (23.3%), and Selected Embankment (20.8%) dominate at 72.1%. Key cost drivers include equipment/fuel sensitivity for excavation, material/labor intensity for masonry, and logistics for embankments, with sensitivity analysis revealing vulnerabilities like 14.3% cost hikes from 20% diesel increases, 38% from material reclassification, and 31% from productivity losses. Standard AHSP requires hilly-specific adjustments (e.g., 1.2-1.35 for earthwork equipment, 1.15-1.25 for slope labor), alongside integrated design-cost evaluations, enhanced geotechnical surveys, 15-25% contingencies, and risk-sharing contracts for sustainable budgeting. For future research, longitudinal studies tracking post-construction performance of these adjusted AHSP factors across multiple Indonesian projects could validate their long-term efficacy and refine them using real-time data analytics and climate-resilient designs.

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