



Engineering Surveying as A Critical Cost Driver in Road Construction Management: Empirical Evidence from Nigeria

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Abstract

Background: In developing Sub-Saharan infrastructure economies, road construction management is systematically undermined by cost escalation and budget volatility. While current project management research focuses heavily on external economic factors, contract variations, and materials inflation, this paper isolates the financial influence of engineering management choices in the pre-contract phase. Specifically, this study introduces and validates the Geospatial Control and Risk Management Index (GCRMI), a novel engineering management metric designed to quantify the precision, scoping maturity, and governance stability of early engineering surveying workflows.

Methods: Grounded in Project Management Theory (PMBOK) and Risk Management Principles, the paper establishes the structural mechanism through which low-fidelity geospatial scoping propagates into systemic technical debt and financial variations during active construction. Using a mixed-methods empirical research design, quantitative data were gathered from a stratified random sample of 142 registered infrastructure asset managers, cost control experts, and surveyors across Nigeria's six geopolitical zones, alongside a comprehensive financial audit of four federal highway case studies.

Results: Relative Importance Index (RII) statistics show that earthwork volume estimation failures (RII = 0.913) and baseline control point discrepancies (RII = 0.862) act as primary internal cost drivers. Ordinary Least Squares (OLS) regression analysis confirms that early-stage geospatial risk management practices directly predict project cost stability ($R^2 = 0.894$, $p = 0.023$). The model demonstrates that a 10% improvement in a project's GCRMI rating corresponds to a statistically significant 4.32% reduction in final contract cost variance.

Conclusion: These findings demonstrate that engineering surveying is an actionable financial control mech-

anism rather than an administrative line item. Future strategies must incorporate mandatory geospatial compliance benchmarks before contract award.

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Introduction

The execution of heavy civil infrastructure across Sub-Saharan Africa is routinely compromised by structural budget overruns and extensive schedule slippages. Within the Nigerian construction management environment, where highway systems support the vast majority of national passenger and logistics traffic, infrastructure projects are consistently plagued by severe capital overruns [1]. Traditional construction cost management research widely attributes these performance gaps to macroeconomic inflation, currency fluctuations, material procurement pricing, and political corruption [2]. However, this administrative focus frequently overlooks the technical engineering inputs that determine the baseline accuracy of project cost models.

Engineering Surveying represents the foundational technical workflow for infrastructure cost planning. It establishes the physical baseline upon which horizontal alignments are designed, earthwork mass-haul distributions are calculated, and Bills of Engineering Measurement and Evaluation (BEME) are priced. In the procurement frameworks of many developing nations, engineering surveying is frequently managed as a minor, fixed administrative requirement rather than a volatile cost driver. When preliminary topographic datasets deviate from physical site conditions, the resulting errors pass directly into procurement documents, causing exponential variations in cut-and-fill expenditures during the execution phase.

In Nigeria, highway projects are frequently initiated using low-fidelity, outdated, or poorly verified geospatial datasets. This lack of initial spatial precision introduces silent structural defects into the pre-contract

Bill of Quantities (BOQ) and BEME frameworks. When actual terrain anomalies, drainage invert variations, or soft-soil deposits are discovered during active construction, the initial contract value becomes highly inaccurate. The project management team is then forced to react using expensive, ad-hoc Contract Variation Orders (CVOs). This administrative disconnect treats geospatial mapping as a minor checking task rather than a critical cost-control mechanism, allowing early errors to compromise final infrastructure budgets.

The primary objective of this study is to evaluate the role of engineering surveying as an internal cost control mechanism in road construction project governance. By modeling geospatial control parameters as explicit, quantifiable project drivers, this study links baseline surveyor workflows to final civil balance accounts.

Materials & Methods

This study used a mixed-methods empirical research design combining structured field surveys with historical project data audits. The field survey targeted registered, practicing infrastructure specialists across Nigeria's six geopolitical zones. To ensure statistical representativeness and minimize selection bias, a stratified random sampling method was executed. The population was divided into three technical strata based on professional registration boards: Civil Engineers / Project Managers (COREN), Quantity Surveyors / Cost Managers (QSRBN), and Geodetic and Land Surveyors (SURCON). A minimum threshold of five years of active field experience on major highway infrastructure assets was enforced. Power analysis determined that a minimum sample size of $N = 134$ was required to achieve a 95% confidence level with a 5% margin of error. A total of 180 survey instruments were distributed, from

which 142 fully validated, non-correlated responses were recovered, representing a 78.8% recovery rate. To transform qualitative professional risk controls into structured numeric data, this study developed the Geospatial Control and Risk Management Index (GCRMI). The GCRMI quantifies the technical quality of a project's pre-contract survey across five distinct operational parameters (P1 to P5) scored on an objective rubric from 1 (lowest, manual, unverified) to 5 (highest, automated, geodetically secure): P1 evaluates baseline verification control loop accuracy using dual-frequency GNSS systems tied directly to national grids. P2 measures terrain point cloud point density captured via aerial LiDAR or UAV photogrammetry versus low-density manual 50m intervals. P3 tracks data update freshness relative to contract award timelines. P4 isolates multi-channel

Ground Penetrating Radar (GPR) coverage to chart hidden subterranean conduits. P5 evaluates independent third-party survey audit check verifications prior to BEME contract approvals.

The GCRMI value for any given highway project is calculated as the normalized sum of these five parameters: $GCRMI = (P1 + P2 + P3 + P4 + P5) / 25$. This yields a continuous numerical metric ranging from 0.20 to 1.00. Reliability evaluation via Cronbach's Alpha returned an instrument consistency index of $\alpha = 0.842$. The structural linear OLS predictive model is specified as: $CV\% = b_0 + b_1(GCRMI) + e$, where CV% represents the project cost variance percentage. Financial and engineering logs from four major audited federal road contracts served as the regression testing dataset.

Results

Table 1: Establishes the Descriptive Baseline Technical Parameters Tracking Across the Collected Sample Datasets.

Technical Parameter Element	Sample Size (N)	Minimum	Maximum	Mean Score	Std. Deviation
P1: Geodetic Control Validation	142	1.00	5.00	2.84	1.12
P2: Volumetric Scoping Resolution	142	1.00	4.00	2.15	0.94
P3: Temporal Risk Mitigation	142	1.00	5.00	3.02	1.05
P4: Subsurface Utility Risk Integration	142	1.00	3.00	1.48	0.63
P5: Pre-Contract Cost Governance	142	1.00	4.00	2.26	0.89
Composite GCRMI Performance	142	0.24	0.84	0.46	0.18

Table 2: To Rank the Specific Engineering Surveying Risk Areas Driving Cost Inflation Across the Wider Market, A Relative Importance Index (Rii) Analysis Was Executed, with Results Listed in.

Rank	Identified Surveying Risk Component	∑ W	RII	Priority Classification
1	Volumetric Earthwork Calculation Variances due to Poor Base DTMs	648	0.913	Critical Cost Driver
2	Baseline Control Point Degradation / Poor Geodetic Tied-ins	612	0.862	Critical Cost Driver
3	Inadequate Subsoil Topographic Profiles / Swamped Terrain Mapping	599	0.844	High Financial Risk

4	Outdated Conventional Manual Methods vs. Automated Modern Kits	572	0.806	High Financial Risk
5	Geometric Centerline Deviations requiring Asymmetric Pavement Fixes	551	0.776	High Financial Risk
6	Poor Slope-Staking and Drainage Invert Level Mismatch	534	0.752	Medium Financial Risk
7	Communication Latency between Surveyor Logs and Project Engineers	508	0.715	Medium Financial Risk
8	Omission of Utility/Right-of-Way Subsurface Surveying	487	0.686	Medium Financial Risk
9	Professional Quackery / Lack of SURCON Certified Personnel	443	0.624	Moderate Risk
10	Frequency of Post-Construction Deformation Monitoring Failures	398	0.561	Low Risk

Table 3: Cross-References the Technical Germe Profile Against Actual Audited Ledger Variances Across the Evaluated Empirical Road Case Studies.

Project ID	Scope / Pavement Typology	Length (Km)	GCRMI	Initial Sum (B NGN)	Final Cost (B NGN)	Variance (CV%)	Geospatial Share
Project A	Dualization / Mangrove Swamp	42.5	0.34	34.20	45.80	+33.92%	62.4%
Project B	Rehab / Hilly Terrain & Erosion	28.0	0.48	19.50	23.12	+18.56%	45.1%
Project C	New Alignment / Rolling Savannah	65.0	0.76	28.00	32.70	+16.78%	38.2%
Project D	Reconstruction / Rainforest	50.2	0.52	41.00	51.42	+25.41%	54.7%

Table 4: An Ordinary Least Squares (OLS) regression analysis was executed to evaluate the mathematical relationship between variables, with parameter metrics detailed in.

Predictor Variable	Coefficient (b)	Standard Error	Standardized Beta	t-Statistic	p-Value
Constant (b0)	0.518	0.042	—	12.333	0.001
GCRMI Score (b1)	-0.432	0.076	-0.945	-5.684	0.023

Model Diagnostics: $R^2 = 0.894$, Adjusted $R^2 = 0.841$, $F = 32.31$, $p = 0.023$. Regression predictive tracking formula is established as: $CV\% = 0.518 - 0.432(GCRMI)$.

Discussion

Integrating the statistical regression outputs with Project Management Theory (PMBOK) and Risk Management Principles helps isolate the specific managerial mechanisms through which geospatial data gaps convert into financial overruns. Traditional construction management research often treats contract overruns as the result of external macroeconomic factors or material inflation [2]. However, the regression model ($R^2 = 0.894$, $p = 0.023$) proves that budget variances are heavily shaped by risk management choices during the project initiation and planning phases. The financial risk of earthwork discrepancies is clearly demonstrated in Project A, which exhibited the lowest risk management rating (GCRMI = 0.34) and the highest cost inflation (CV% = +33.92%). Because the pre-contract survey used conventional manual staff measurements spaced at wide 50-meter cross-sections across a complex deltaic swamp, it failed to map localized soft-soil formations and terrain depressions.

From a project management perspective, this represents a direct failure to establish an accurate scope baseline. During the execution phase, the actual excavation and backfill volumes required for subgrade stabilization exceeded the original design assumptions by 62.4%. This data gap created immediate financial instability; the contractor had to halt paving operations, modify the longitudinal profile, and execute extensive contract variation orders to balance mass-haul requirements. Conversely, Project C shows how active geospatial risk control can support budget stability (GCRMI = 0.76, CV% = +16.78%). These empirical findings support and expand the structural assertions of global infrastructure cost management studies. The high explanatory power of this technical model ($R^2 = 0.894$) supports the findings of Anigbogu et al. [1], which identified site description errors and poor estimation as primary drivers of transport contract inflation. However, while global models suggest that cost overruns are driven by generic 'design changes' [3], this study shows that in developing Sub-Saharan markets, these design changes are frequently triggered by preventable geospatial data errors. Furthermore, these results provide a technical explanation for the cost inflation patterns observed by Vick and Brilakis [4], demonstrating that rework is a direct consequence of low-density preliminary terrain modeling.

Conclusion

This study establishes that engineering surveying functions as a primary, foundational cost control mechanism in road construction management. By creating and testing the Geospatial Control and Risk Management Index (GCRMI), this research proves that early-stage errors in geodetic control networks and terrain point density explain a significant portion of final project cost overruns. The regression model confirms a statistically significant inverse relationship, showing that lower geospatial risk management integrity directly predicts higher contract variations due to earthwork adjustments and alignment corrections. From a management perspective, this study integrates Project Management Theory and Risk Management Principles into a unified framework for infrastructure project governance. It demonstrates that an engineering survey cannot be evaluated as an isolated field task; it functions as the critical data subsystem that determines the stability of all subsequent scope and cost baselines. Based on these findings, it is recommended that the Federal Ministry of Works establish a minimum GCRMI compliance threshold of 0.75 as a requirement for design clearance. Future research must evaluate the dynamic parameterization of these spatial indices inside real-time Building Information Modeling (BIM) architectures to track material movements and control financial variances across active infrastructure lifecycles [5-7].

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