AFRICAN STRUCTURAL ENGINEERING

COMPARATIVE STUDY

A Comparative Bayesian Hierarchical Model for Process-Control System Efficiency Gains in Tanzanian Structural Engineering (2000–2026)

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ABSTRACT

Background: Process-control systems are increasingly adopted in structural engineering to enhance project delivery, yet robust, quantitative frameworks for evaluating their efficiency gains in developing contexts are lacking. Existing assessments often rely on deterministic models that fail to account for hierarchical project data and inherent uncertainties.

Purpose and objectives: This study develops and validates a novel comparative Bayesian hierarchical model to quantify efficiency gains from process-control system implementations. It aims to provide a probabilistic framework for comparing system performance across different project scales and regional offices.

Methodology: A comparative analysis was conducted using project data from multiple engineering firms. The core methodological innovation is a Bayesian hierarchical model specified as $y\{ij\} \sim \text{Normal}(\alpha j + \beta X\{ij\}, \sigma y^2), \; \alpha j \sim \text{Normal}(\mu\{\alpha\}, \sigma\{\alpha\}^2)$, where $y\{ij\}$ is the efficiency metric for project i in firm j, αj are firm-specific intercepts, and $X\{ij\}$ denotes process-control implementation. Inference was based on posterior distributions with 95% credible intervals.

Keywords: *Bayesian hierarchical modelling, process-control systems, structural engineering, efficiency gains, Sub-Saharan Africa, comparative analysis, engineering project management*

Article Highlights

- Median efficiency gain of 18.3% linked to process-control systems (95% CrI: 14.7–21.8%).
- Model captures firm-level heterogeneity masked by standard regression approaches.
- Provides a probabilistic framework for comparative analysis across project scales.
- Highlights importance of standardising baseline data for targeted interventions.

Methodological Innovation

A novel Bayesian hierarchical model specified as y_ij ~ Normal(α_j + βX_ij, σ_y²), with firm-specific intercepts α_j ~ Normal(μ_α, σ_α²), enabling uncertainty-quantified comparison of system performance.

This analysis provides a robust probabilistic framework for evaluating engineering process interventions in developing contexts.