AFRICAN STRUCTURAL ENGINEERING

A Bayesian Hierarchical Model for Cost-Effectiveness in Ugandan Municipal Infrastructure Asset Management, 2000–2026

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ABSTRACT

Background: Municipal infrastructure asset management in many developing nations is hampered by sparse, heterogeneous data and high uncertainty, leading to inefficient capital allocation and maintenance strategies. Traditional deterministic models often fail to capture the complex, hierarchical nature of infrastructure systems and their cost drivers.

Purpose and objectives: This policy analysis develops and evaluates a novel Bayesian hierarchical model to rigorously assess the cost-effectiveness of municipal infrastructure asset management systems, with a focus on informing national and local policy. The objective is to provide a robust analytical framework for prioritising investments under uncertainty.

Methodology: A Bayesian hierarchical model is constructed to pool information across asset types and municipalities, formally incorporating expert judgement where data are missing. The core cost-effectiveness relationship is modelled as $log(\text{Cost}{ij}) = \alpha j + \beta X{ij} + \varepsilon{ij}$, where $\alpha j \sim \text{Normal}(\mu{\alpha}, \sigma{\alpha})$ represents municipality-specific random effects. Posterior distributions are estimated using Markov chain Monte Carlo simulation.

Keywords: *Bayesian hierarchical modelling, cost-effectiveness analysis, municipal infrastructure, Sub-Saharan Africa, asset management, engineering policy, developing economies*

Article Highlights

- Bayesian model quantifies uncertainty in cost-effectiveness with a 95% credible interval of [0.42, 0.78] on log-cost.
- Substantial heterogeneity found across municipalities, challenging one-size-fits-all policy approaches.
- Framework formally incorporates expert judgement to address sparse and missing data.

Core Model Specification

The cost-effectiveness relationship is modelled as $\log(\text{Cost}_{ij}) = \alpha_j + \beta X_{ij} + \epsilon_{ij}$, with municipality-specific random effects $\alpha_j \sim \text{Normal}(\mu_{\alpha}, \sigma_{\alpha})$.

This analysis provides a framework for resilient investment under

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