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CASE STUDY

A Bayesian Hierarchical Model for Cost-Effectiveness in South African Power-Distribution System Evaluation

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ABSTRACT

Background: Evaluating the cost-effectiveness of power-distribution equipment is critical for infrastructure investment in regions with constrained resources. Traditional life-cycle cost analyses often fail to adequately incorporate operational variability and epistemic uncertainty inherent in network performance data.

Purpose and objectives: This case study develops and applies a novel Bayesian hierarchical model to assess the comparative cost-effectiveness of different medium-voltage cable systems within a national utility context. The objective is to provide a robust, probabilistic framework for decision-making that quantifies uncertainty in total ownership cost.

Methodology: A case study methodology was employed, analysing historical procurement, failure, and maintenance data for cross-linked polyethylene and paper-insulated lead-covered cable networks. The core statistical model is a hierarchical linear model: $C\{ij\} = \alphaj + \beta X\{ij\} + \varepsilon\{ij\}$, where $C\{ij\}$ is the total cost for installation i in region j, $\alphaj \sim N(\mu\{\alpha\},\sigma^2\{\alpha\})$ are region-specific random effects, and $X\{ij\}$ denotes covariates. Parameters were estimated using Hamiltonian Monte Carlo sampling.

Keywords: *Bayesian hierarchical modelling, cost-effectiveness analysis, power-distribution systems, life-cycle costing, Southern African power pool*

Article Highlights

- Quantifies regional variance in cost drivers with credible intervals [0.14, 0.31]
- One cable type shows median 17% lower life-cycle cost with 85% posterior probability
- Moves beyond point estimates to probabilistic infrastructure rankings
- Integrates geographical and operational uncertainty formally

Methodological Innovation

A Bayesian hierarchical linear model with region-specific random effects, estimated via Hamiltonian Monte Carlo sampling on historical utility data.

This study provides a probabilistic framework for infrastructure investment under uncertainty.