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A Bayesian Hierarchical Model for the Cost-Effectiveness of Industrial Machinery Fleets in Rwanda

A Methodological Evaluation

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ABSTRACT

Background: The assessment of cost-effectiveness for industrial machinery fleets in developing economies is often hampered by sparse, heterogeneous data and complex operational interdependencies. Traditional deterministic models fail to adequately quantify uncertainty, limiting robust decision-making for asset management and capital investment.

Purpose and objectives: This study presents a novel Bayesian hierarchical modelling framework designed to evaluate the cost-effectiveness of heavy machinery fleets. Its objective is to provide a robust, probabilistic methodology that integrates multiple data sources and explicitly accounts for operational variability and uncertainty in the Rwandan context.

Keywords: *Bayesian hierarchical modelling, cost-effectiveness analysis, industrial machinery, Sub-Saharan Africa, developing economies, maintenance optimisation*

Article Highlights

- A three-level Bayesian hierarchical model integrates sparse, heterogeneous operational data.
- Posterior distributions reveal excavators and haul trucks as most cost-effective asset classes.
- Operational downtime identified as the most influential predictor of poor cost-effectiveness.
- Provides a statistically rigorous framework for analysis under data constraints.

Core Model Specification

$\log(CER_i) = \alpha_{j[i]} + \beta X_i + \varepsilon_i$, where $\alpha_j \sim \text{Normal}(\mu_\alpha, \sigma_\alpha^2)$ represents fleet-type varying intercepts.

This methodological evaluation presents a novel probabilistic framework for asset management in developing economies.