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A Bayesian Hierarchical Model for Risk Reduction in Rwanda's Industrial Machinery Fleet Management

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ABSTRACT

Background: Industrial machinery fleet management in developing economies is critical for infrastructure development but is often hampered by sparse, heterogeneous data and high operational uncertainty. Traditional reliability models frequently fail to capture the complex, multi-level risk factors inherent in such contexts, leading to suboptimal maintenance and safety interventions.

Purpose and objectives: This article presents a novel Bayesian hierarchical modelling framework designed to quantify and reduce operational risks within industrial machinery fleets. The primary objective is to provide a robust methodological tool for integrating disparate data sources to estimate failure probabilities and identify dominant risk drivers.

Keywords: *Bayesian hierarchical modelling, risk reduction, fleet management, developing economies, Sub-Saharan Africa, industrial machinery, operational uncertainty*

Article Highlights

- A three-level Bayesian hierarchical model synthesizes sparse, heterogeneous fleet data.
- Quantifies uncertainty with 95% credible intervals for critical failure probabilities.
- Identifies systemic maintenance scheduling as a key risk driver over equipment age.
- Provides a framework for predictive maintenance in data-scarce operational environments.

Methodological Core

A three-level hierarchical model with machinery-specific events conditioned on equipment-level parameters, drawn from fleet-wide distributions. Inference performed via Hamiltonian Monte Carlo with expert-informed priors.

Presents a statistically rigorous framework for evidence-based fleet management in developing economies.