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ORIGINAL RESEARCH

A Bayesian Hierarchical Model for Risk Reduction in Ugandan Manufacturing Plant Systems

A Methodological Evaluation

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ABSTRACT

Background: Systemic risk assessment in manufacturing plants within developing economies is often hampered by sparse, heterogeneous data and complex interdependencies between mechanical, electrical, and human factors. Traditional reliability models struggle to integrate these diverse data sources and quantify epistemic uncertainty effectively.

Purpose and objectives: This study presents and evaluates a novel Bayesian hierarchical modelling framework designed to quantify risk reduction in plant systems. The primary objective is to provide a robust methodological tool for engineers to integrate multi-level operational data and infer the efficacy of implemented safety interventions.

Keywords: *Bayesian hierarchical modelling, risk reduction, manufacturing systems, Sub-Saharan Africa, systemic risk assessment, industrial engineering*

Article Highlights

- Electrical subsystem interventions showed highest marginal risk reduction (posterior probability 0.92 >30%)
- Model successfully synthesizes disparate mechanical, electrical, and human factors data
- Robust parameter convergence with 95% credible intervals excluding zero for key hyperparameters
- Hierarchical structure integrates multi-level operational data and intervention status

Core Model Specification

$\lambda_{ij} \sim \text{Gamma}(\alpha_j, \beta_j)$ with subsystem parameters informed by plant-level covariates through log-linear regressions, using Hamiltonian Monte Carlo sampling.

This methodological evaluation demonstrates a statistically rigorous framework for risk assessment in developing industrial contexts.