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A Bayesian Hierarchical Model for Manufacturing Systems Risk Reduction

A Methodological Evaluation in Rwanda

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ABSTRACT

Background: Manufacturing systems in developing economies face complex, multi-level risks that are challenging to quantify using traditional risk assessment frameworks. There is a recognised need for robust, data-driven methodologies that can integrate sparse and heterogeneous operational data to inform targeted engineering interventions.

Purpose and objectives: This study presents and evaluates a novel Bayesian hierarchical modelling framework designed to quantify and reduce systemic risk in manufacturing plants. The primary objective is to assess the methodological efficacy of this approach in a real-world industrial context.

Methodology: A Bayesian hierarchical model was formulated and applied to operational performance and failure data collected from multiple manufacturing plants. The core model structure is $y\{ij\} \sim \text{Normal}(\alpha_j + \beta X\{ij\}, \sigma_y)$, with $\alpha_j \sim \text{Normal}(\mu\{\alpha\}, \sigma\{\alpha\})$, where i indexes observations and j indexes plants. Inference was performed using Markov chain Monte Carlo simulation, with posterior credible intervals used to quantify uncertainty in risk estimates.

Keywords: *Bayesian hierarchical modelling, manufacturing systems, risk assessment, Sub-Saharan Africa, developing economies, methodological evaluation, industrial engineering*

Article Highlights

- Identifies significant variation in baseline risk levels between manufacturing plants.
- Quantifies uncertainty in risk estimates using posterior credible intervals.
- Handles sparse and heterogeneous operational data common in industrialising contexts.
- Provides a statistically robust framework to inform targeted risk mitigation investments.

Core Model Structure

$y_{ij} \sim \text{Normal}(\alpha_j + \beta X_{ij}, \sigma_y)$, with $\alpha_j \sim \text{Normal}(\mu_\alpha, \sigma_\alpha)$, where i indexes observations and j indexes plants.

This methodological evaluation demonstrates the practical application of Bayesian hierarchical modelling for industrial risk assessment.

ABSTRACT-ONLY PUBLICATION

This is an abstract-only publication. The complete research paper with full methodology, results, discussion, and references is available upon request.

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