Bayesian Hierarchical Modelling for Process-Control System Reliability

A Case Study from Uganda

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ABSTRACT

Background: Process-control systems in industrial settings are critical for operational safety and efficiency, yet quantitative assessments of their reliability in developing contexts are scarce. Existing reliability models often fail to account for site-specific operational variances and data sparsity, which are common challenges in such environments.

Purpose and objectives: This case study evaluates a Bayesian hierarchical modelling framework for quantifying the reliability of industrial process-control systems. The objective is to demonstrate a method that robustly integrates sparse, heterogeneous field data to provide actionable reliability estimates for maintenance decision-making.

Keywords: *Bayesian hierarchical modelling, Process-control systems, System reliability, Sub-Saharan Africa, Industrial safety, Quantitative risk assessment*

Article Highlights

- A three-level Bayesian model quantifies reliability while characterizing uncertainty from sparse data.
- Plant variability was a major reliability driver, captured via random effects in the hierarchical structure.
- Posterior credible intervals were narrower than non-hierarchical models, improving precision.
- The framework pools information across sites to yield context-aware, actionable reliability estimates.

Methodological Insight

The core model: $\log(\lambda_{ij}) = \alpha_i + \beta X_{ij} + \varepsilon_{ij}$, where α_i represents plant-specific random effects, allowing the model to learn from and share information across operational contexts.

This study presents a statistically rigorous framework for reliability analysis in data-sparse industrial settings.

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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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