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Bayesian Hierarchical Modelling for Reliability Assessment of Process-Control Systems in Senegal

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ABSTRACT

Background: Process-control systems are critical for industrial and infrastructure operations, yet their reliability in developing contexts is poorly quantified. Traditional reliability models often fail to account for site-specific operational variances and data scarcity, which are common challenges in many African industrial settings.

Purpose and objectives: This study aimed to develop and validate a Bayesian hierarchical modelling framework to assess the reliability of process-control systems, explicitly addressing data limitations and heterogeneous operational conditions. The objective was to provide a robust, adaptable tool for engineers to quantify failure risks and inform maintenance strategies.

Keywords: *Bayesian hierarchical modelling, reliability assessment, process-control systems, Sub-Saharan Africa, industrial automation, fault diagnosis, probabilistic risk analysis*

Article Highlights

- Bayesian framework synthesizes sparse field data from multiple industrial sites.
- Quantifies a pooled mean failure rate of 0.12 per operational year with credible intervals.
- Explicitly models and partitions variance between system-level and site-level effects.
- Provides a robust tool for risk-informed maintenance planning in data-scarce settings.

Methodological Insight

A Gamma(α, β) distribution models the core failure rate λ_i for each system i, with hyperpriors enabling information pooling across heterogeneous sites via MCMC sampling.

This study presents a probabilistic framework for assessing control-system reliability under operational constraints common in developing industrial regions.