AFRICAN STRUCTURAL ENGINEERING

ORIGINAL RESEARCH

A Bayesian Hierarchical Model for Reliability Diagnostics of Municipal Infrastructure Asset Systems in Nigeria

Adebayo Adewale[1,2] | **Chiamaka Okeke**[2,3]
Ibrahim Suleiman[1,2]

1 *University of Benin*
2 *Bayero University Kano*
3 *Department of Electrical Engineering, University of Benin*

Correspondence: aadewale@gmail.com

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ABSTRACT

Background: Municipal infrastructure asset systems in Nigeria face significant reliability challenges, yet conventional reliability assessment methods often fail to account for the hierarchical structure of these systems and the substantial epistemic uncertainties present in sparse inspection data.

Purpose and objectives: This study develops and validates a novel Bayesian hierarchical modelling framework to diagnose the system-level reliability of municipal infrastructure networks, explicitly integrating component-level data with network topology to provide robust probabilistic reliability estimates.

Methodology: A three-level Bayesian hierarchical model was constructed, where the reliability of individual assets is modelled at the first level, their aggregation into subsystems at the second, and overall system reliability at the third. The core system reliability function is given by $R\{system\}(t) = \prod\{i = 1\}^{k} \[1 - \varphi\(\(ln(t) - \mui)/(\sigmai)\) \]^{wi}$, with parameters $\mui$ and σ_i estimated via Hamiltonian Monte Carlo sampling. The model was applied to condition assessment data from water distribution and road networks in three Nigerian municipalities.

Keywords: *Bayesian hierarchical modelling, infrastructure asset management, reliability diagnostics, Sub-Saharan Africa, municipal engineering, probabilistic risk assessment, systems engineering*

Article Highlights

- A three-level Bayesian model integrates component data with network topology for system reliability.
- Model application reveals high posterior probability (0.92) of system reliability below target threshold.
- Critical subsystem assets, constituting ~15%, drive over 60% of predicted system unreliability.
- Framework provides rigorous uncertainty propagation from component to system level.

Core Reliability Function

$R_{system}(t) = \prod_{i=1}^{k} \left[1 - \Phi\left(\frac{\ln(t) - \mu_i}{\sigma_i}\right) \right]^{w_i}$, with parameters estimated via Hamiltonian Monte Carlo sampling.

This study presents a novel probabilistic framework for diagnosing municipal infrastructure reliability in data-sparse contexts.