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Methodological Evaluation and Risk Reduction in Uganda's Power-Distribution System

A Multilevel Regression Analysis

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ABSTRACT

Power-distribution systems in many developing nations face significant reliability challenges due to ageing infrastructure and environmental stressors. There is a pressing need for robust methodological frameworks to evaluate equipment performance and quantify the impact of interventions. This study aims to develop and apply a multilevel regression methodology to evaluate the performance of power-distribution equipment and measure the efficacy of targeted risk-reduction strategies within a national grid. We analysed a longitudinal dataset of equipment failures and maintenance records from a national utility. A three-level hierarchical linear model was specified: $y\{ij\} = \beta\{0j\} + \beta\{1j\}X\{ij\} + u\{0j\} + u\{1j\}X\{ij\} + e\{ij\}$, where levels represented components, feeders, and geographical regions. Model parameters were estimated using restricted maximum likelihood with robust standard errors. The multilevel analysis revealed that targeted insulator replacement programmes reduced the likelihood of weather-related outages by 34% (95% CI: 28% to 40%). Component age and vegetation encroachment were the most significant predictors of failure at the feeder level. The methodological approach provides a statistically rigorous framework for isolating the effects of specific interventions from systemic and regional variations, confirming that data-driven maintenance strategies can substantially enhance grid resilience. Utilities should adopt hierarchical modelling for asset management to prioritise investments. Regulatory frameworks should incentivise the collection and analysis of granular, component-level performance data. asset management, hierarchical linear model, infrastructure resilience, power distribution, predictive maintenance This paper presents a novel application of multilevel regression to disaggregate system-wide risk in electrical grids, providing utility managers with a precise tool for measuring the marginal benefit of specific equipment interventions.

Keywords: *Power-distribution reliability, Sub-Saharan Africa, Multilevel regression modelling, Infrastructure ageing, Risk reduction, Uganda*

Article Highlights

Methodological Contribution

• Multilevel regression isolates intervention effects from systemic and regional variations. • Component age and vegetation encroachment are key predictors of feeder-level failure. • The framework provides utilities with a tool to measure marginal benefits of interventions. • Analysis supports data-driven maintenance to substantially enhance grid resilience.	Presents a novel application of a three-level hierarchical linear model to disaggregate system-wide risk in electrical grids, using component, feeder, and regional data. *This analysis offers a statistically rigorous framework for infrastructure asset management.*