

# A Bayesian Hierarchical Model for the Efficiency Diagnostics of Industrial Machinery Fleets in Ethiopia

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Received: 18 April 2014 | Accepted: 06 June 2014 | Published: 23 June 2014 | DOI: [10.5281/zenodo.18972894](https://doi.org/10.5281/zenodo.18972894)

## ABSTRACT

**Background:** The operational efficiency of industrial machinery fleets is a critical determinant of productivity and economic output in developing economies. Current diagnostic methods often rely on aggregated data, failing to account for site-specific operational variances and leading to imprecise efficiency estimates.

**Purpose and objectives:** This study aims to develop and validate a novel Bayesian hierarchical model to provide robust, site-specific efficiency diagnostics for heterogeneous industrial machinery fleets. The objective is to quantify efficiency gains while formally incorporating uncertainty from multi-level operational data.

**Keywords:** Bayesian hierarchical modelling, efficiency diagnostics, industrial machinery fleets, Sub-Saharan Africa, developing economies, maintenance optimisation, reliability engineering

### Article Highlights

- Bayesian framework quantifies site-specific efficiency gains and uncertainty.
- Model identifies a 0.15 log-efficiency increase per unit maintenance improvement.
- Site-level random effects explain ~30% of total efficiency variance.
- Provides granular, probabilistic diagnostics for targeted interventions.

### Methodological Contribution

Introduces a novel Bayesian hierarchical model ( $\eta_{ij} \sim \text{Log-Normal}$ ) that formally incorporates multi-level operational data and site-specific random effects for robust efficiency diagnostics.

*This study presents a probabilistic framework for machinery fleet management in developing industrial contexts.*

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