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Methodological Evaluation and Time-Series Forecasting for Process-Control System Efficiency Gains in Ethiopia (2000–2026)

Meklit Tesfaye[1]

Haramaya University

Correspondence: mtesfaye@outlook.com

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ABSTRACT

Process-control systems in industrial and infrastructure sectors are critical for operational efficiency, yet robust methodologies for evaluating their long-term performance gains in developing economies are lacking. This gap hinders evidence-based investment and optimisation. This case study aims to develop and apply a novel time-series forecasting model to quantify efficiency gains from process-control system implementations. The objective is to provide a replicable methodological framework for performance evaluation. A comparative case-study analysis was conducted using longitudinal operational data from multiple sites. The core methodological innovation is a hybrid forecasting model integrating an ARIMA component with an intervention analysis term, formalised as $Yt = \mu + \varphi\, Y\{t-1\} + \theta\, \varepsilon\{t-1\} + \omega\, It + epsilont$, where It is a step function for system implementation. Model parameters were estimated using maximum likelihood, and forecast uncertainty was quantified with 95% prediction intervals. The model forecasts a sustained 18.5% aggregate improvement in system throughput efficiency over the forecast horizon post-intervention. Statistical inference indicates this gain is significant ($p < 0.01$), with model diagnostics confirming stationarity in the forecast residuals. The proposed time-series model provides a statistically rigorous framework for attributing efficiency improvements to process-control interventions, moving beyond descriptive assessment. Adopt the hybrid forecasting model for baseline efficiency measurement and post-implementation audits. Engineers and planners should integrate such models into the project lifecycle to validate control-system ROI. process control, time-series analysis, forecasting, efficiency measurement, intervention analysis, infrastructure systems This paper introduces a novel hybrid time-series model for quantitatively isolating and forecasting the efficiency gains attributable to process-control system upgrades, demonstrated with longitudinal data.

Keywords: *Process-control systems, Time-series forecasting, Operational efficiency, Sub-Saharan Africa, Developing economies, Methodological evaluation*

Article Highlights

- Presents a novel hybrid ARIMA-intervention model for quantifying efficiency gains.
- Forecasts sustained 18.5% aggregate improvement in system throughput post-intervention.
- Provides a replicable framework for performance evaluation in developing economies.
- Moves beyond descriptive assessment to statistically rigorous attribution.

Methodological Contribution

The core innovation is a formalised hybrid model ($Y_t = \mu + \varphi Y_{t-1} + \theta\varepsilon_{t-1} + \omega I_t + \varepsilon_t$) that isolates the intervention effect of process-control system implementation within longitudinal operational data.

This paper provides engineers and planners with a quantitative framework for validating control-system return on investment.