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Quantifying operational uncertainties in mining machinery fleet productivity using a stochastic Overall Equipment Effectiveness (OEE) analysis

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ABSTRACT

In resource-rich but data-constrained mining regions, deterministic estimates of equipment productivity often mask critical operational risks, leading to flawed strategic decisions on fleet investment, maintenance, and national resource forecasting. This paper bridges a key gap in the literature by introducing a probabilistic Overall Equipment Effectiveness (OEE) framework that quantifies uncertainty in the shovel–truck fleet performance at one of the world's largest copper mines. Using Monte Carlo simulation calibrated with extensive field data—including photogrammetry-based cycle production and dispatch logs—we model joint variability in availability, utilization, and performance efficiency. Results reveal wide OEE distributions: 8–52% (mean: 25%) for shovels and 27–53% (mean: 38%) for dump trucks, where low utilization, driven by suboptimal dispatch and operational coordination, is the dominant constraint. Critically, we demonstrate that probabilistic OEE is essential for robust, risk-aware planning in aging fleets. The framework offers a low-cost, transferable tool for evidence-based resource policy and operational optimization in developing economies.

1. Introduction

Optimizing equipment efficiency is essential for improving operational performance in mining and manufacturing sectors amid challenges such as market competition, economic factors, environmental regulations, and safety concerns (Huang et al., 2003; Singh et al., 2013; Lucantoni et al., 2023; Pavloudakis et al., 2024; Rezaei Dashtaki et al., 2024, 2025). To address operational losses stemming from breakdowns, speed reductions, and idle time (Nakajima, 1988), the overall equipment effectiveness (OEE) metric was introduced in 1979 as a holistic indicator of equipment performance, availability, and quality (Jonsson and Lesshammar, 1999). OEE has gained widespread recognition as a vital performance indicator, leading to successful applications across numerous industries to increase equipment performance and operational effectiveness (Kobbacy et al., 2008; Parida and Kumar, 2009).

While OEE has been widely adopted across manufacturing sectors, its application in mining faces a fundamental limitation: the absence of "defective output" renders the traditional quality component inapplicable. In response, scholars such as Dhillon (2008) have redefined OEE for mining contexts as a tripartite construct comprising Availability (A), Utilization (U), and Performance Efficiency (PE). Despite this conceptual advancement, empirical implementation remains scarce. The primary barrier lies in measuring PE, which requires precise, cycle-level data on actual production and effective operating time—information rarely available in large-scale, multi-contractor open-pit mines with heterogeneous fleets and fragmented monitoring systems. Most existing studies rely on deterministic averages or omit PE entirely, thereby masking critical operational uncertainties and undermining strategic decision-making.

This study bridges this gap by introducing a practical, low-cost methodology to quantify PE through the ratio of empirically measured cycle production—derived from photogrammetry and calibrated load cells—to manufacturer-rated nominal capacity. This approach enables robust implementation of stochastic OEE without requiring integrated real-time telematics. It is particularly suited for data-constrained mining regions in developing economies, where high-frequency telematics are

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