Enhancing Short-Interval Controls in Open-Pit Mining through the Integration of Business Intelligence Analytics and the Internet of Things: A Case Study of Lumwana Mining Company

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Abstract- **The integration of Business Intelligence (BI) analytics with Internet of Things (IoT) technologies offers significant potential to optimize operational efficiency in open-pit mining operations. This paper investigates the application of these technologies to enhance Short-Interval Controls (SIC) at Lumwana Mining Company, one of Africa's largest open-pit mining sites. The research focuses on leveraging IoT-driven sensor networks, machine telematics, automated data acquisition systems, and BI analytics to derive actionable insights. By employing advanced AI-driven analytics, including predictive modeling and data visualization, the study aims to optimize production scheduling, improve equipment productivity, and reduce idle time. A mixed-methods approach is adopted, combining quantitative analysis of real-time operational data with qualitative insights from industry experts to evaluate the effectiveness of BI-IoT integration for SIC. The findings will contribute new knowledge to the field of data-driven mining operations, offering a flexible and scalable model for improving efficiency, sustainability, and cost management in open-pit mining. Practical recommendations derived from this study will assist mining engineers, data analysts, and decision-makers in effectively implementing digital transformation strategies to optimize mining processes.**

Keywords: Business Intelligence, Internet of Things, Short-Interval Controls, Open-Pit Mining, Predictive Analytics, Digital Transformation, Mining Optimization.

INTRODUCTION

There has been a drastic change within the mining industry motivated by the intersection of new digital technologies and data-driven models. Particularly, the amalgamation of Business Intelligence (BI) analytics with the Internet of Things (IoT) is changing how mining operations monitor, manage, and optimize critical mining processes [1]. Open-pit mining is unparalleled in its scale, complexity, and operational cost, presenting a strategic opportunity to deploy these technologies for productivity optimization and real-time decision-making.

For many years now, Short-Interval Control (SIC) systems have been accepted as the baseline framework for operational efficiency in mining, allowing the execution of on-the-fly changes to production plans informed by real-time actual performance data [2]. However, traditional SIC systems' excessive reliance on manual data extraction, slow reporting, and integration gaps across organizational silos often lead to poorly responsive and high-downtime environments. There is an increasing opportunity for automated data flow, enhanced visibility, and predictive action by utilizing IoT-enabled sensor networks in conjunction with sophisticated BI tools.

This paper explores the Improvement of Short-Interval Controls at the Lumwana Mining Company—a copper open-pit mining operation in Zambia—using a blend of the Internet of Things (IoT) and Business Intelligence (BI) analytics. The enhancement of SICs is achieved through real-time equipment telematics, automated data collection, and BI analytics [3]. The goal is to demonstrate how digital processes can redefine SICs. The primary aim is to minimize equipment idle time, maximize operational throughput, facilitate decision making at multiple organizational levels, and generally optimize organizational performance.

The research adopts a mixed-methods research design that blends qualitative expert insight and system user input with quantitative operational data. The presented case study serves as a basis for the development of a practical digital transformation roadmap tailored toward mining operations while also advancing the dialogue on intelligent mining systems and the application of Industry 4.0 in resource extraction industries.

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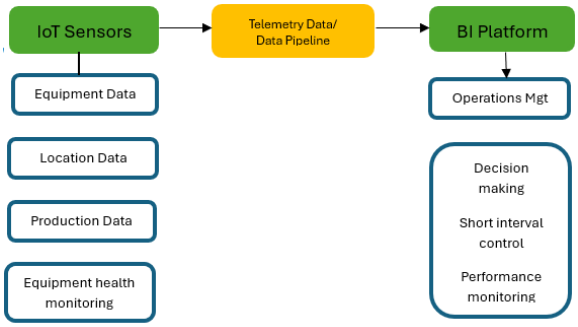

Fig 1. SIC System Overview

Problem Statement

Like other open-pit mining operations, Lumwana Mining Company struggles with having obsolete SIC (Short Interval Control) frameworks based on manual data entry, which cause delayed reporting and creates an operational bottleneck. There lies an opportunity of revolutionizing SIC with IoT technologies and BI (Business Intelligence) analytics, which have the potential to facilitate a true SIC model characterized by the real-time flow of information, predictive guidance, proactive response, and accelerated insight/action cycles. However, the integration of these technologies in mining processes is still in its infancy. The goal of this research is to determine the possibilities of utilizing IoT and BI to minimize data-lags in SIC at Lumwana Mining Company, with the goal of achieving improved operational efficiency, reduced downtimes, enhanced throughput, and enabling effective, intelligent, and automated mining.

Research Objectives

This research aims to:

Analyze the current practices of Short-Interval Control (SIC) at Lumwana Mining Company, focusing on data entry driven operational bottlenecks.

Integrate systems incorporating IoT data extraction within the Business Intelligence paradigm towards improving SIC.

Investigate the effects of IoT-BI integration on equipment usage, production volume, and speed of decisions made at the mining company.

Design advanced and efficient systems for enhanced SIC applications within the context of open-pit mining operations and propose corresponding digital transformation strategies.

Research Questions

How can the integration of Internet of Things (IoT) technologies improve real-time data collection and reporting in open-pit mining operations?

What ways can Business Intelligence (BI) analytics enhance decision-making and operational efficiency within SIC frameworks?

What is the measurable impact of combining IoT and BI analytics on equipment utilization, downtime reduction, and production throughput at Lumwana Mining Company?

What practical roadmap can be developed to guide the digital transformation of SIC systems in open-pit mining operations?

LITERATURE REVIEW

Short-Interval Control in Open-Pit Mining

As IoT, BI analytics, and other data-driven technologies get incorporated, the mining industry is undergoing a significant digital transformation. Within open-pit mining. [4] defines Short Interval Control (SIC) as a framework of structured processes that help identify and act on opportunities to improve the effectiveness and efficiency of production. Short-Interval Control (SIC) systems are instrumental in the high-level functionality organization by providing rapid, data-driven modifications to the production workflows within an operational cycle. Nonetheless, traditional SIC systems suffer greatly from dependance on manual data entry, slow reporting, and siloed functional interdependencies, which leads to low responsiveness and high equipment idle time [5].

Use of IoT in Mining Operations

Internet of Things (IoT) is defined as a network of interconnected physical objects embedded with sensors and software, enabling data exchange and connectivity with other devices and systems via the internet [6]. The Internet of Things leverages Sensors or Devices to gather data from connected environments for real-time processing, and the sensors and devices can be chosen or modified based on the requirement. The mining industry's improvement opportunities through IoT's application have been recently researched and noted. Drilling, hauling and processing that is done in mining operations can be monitored in real time using IoT based sensor networks, telematic equipment and wireless data transmission [7]. This combination of constantly available data allows the enhancement of context awareness in systems, thereby increasing predictive maintenance and unscheduled downtimes. On the other hand, [8]. [9] Gackowiec Explores how the use of the Internet of Things is particularly important in complex processes in mining,

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enabling the extraction of valuable information from data. The integration of physical facilities in the enterprise enables the digitization of production processes and the increase of efficiency and security.[10, 11]

Business Intelligence Analytics in Mining

Business intelligence (BI) is any activity, tool or process used to obtain the best information to support the process of making decisions [12]. Business Intelligence analytics enhances the Internet of Things (IoT) by enabling the processing, visualization, and interpretation of extensive operational data. This, in turn, assists in decision-making across organizational levels—mining companies can observe and monitor critical performance indicators, recognize trends, and make decisions accordingly. In combination with SIC systems, BI offers drastic improvements for production forecasting, resource allocation, and bottleneck identification, thereby increasing operational throughput and decreasing idle time [13]. Several studies and projects offer valuable insights into the adoption and impact of Business intelligence and Internet of things in mining: Acceptance and use of data visualization technologies in mining short interval control systems (SIC) [14]. This examines the impact of miners' performance expectancy, effort expectancy, social influence and facilitating conditions on digital visualization short interval control systems adoption

Integrating BI and IoT

The merger of IoT and BI marks the progression towards intelligent mining systems mindful of Industry 4.0 principles. Scholars and practitioners note that the integration of such systems improves not only operational efficiency on a technical level, but also enhances interdepartmental communication and collaboration, effectively dismantling traditional silos [15]. Those said, the mining industry still struggles with data integration, change management, and the creation of adaptable digital frameworks—especially in emerging markets such as Zambia.

Case study Justification

Focusing on the case of Lumwana Mining Company, improving SIC using IoT and BI frameworks is an opportunity to solve these problems and establish an example for digital transformation in mining activities in Africa. This study will fill the gap in literature by demonstrating the consequences of IoT-BI integration on SIC performance and suggesting an IoT-BI integration model for operational excellence in open-pit mining [16].

METHODOLOGY

Research design

The case study research design was utilized with Lumwana Mining Company as a single, bounded case. As one of Africa's largest open-pit copper mines, located in Northwestern Province of Zambia, Lumwana has already implemented fleet management systems (FMS), dispatch optimization tools, and asset health monitoring technologies. Therefore, there was a compelling need to evaluate the impact of integrating Business Intelligence (BI) Analytics, the Internet of Things (IoT), and other technologies on the enhancement of SIC processes. The methodological approach was predominantly qualitative with a mixture of quantitative operational system data alongside qualitative information from interviews with critical stakeholders. The blend of quantitative and qualitative aspects from different levels of the organization enabled the research to analyze the case from multiple lenses [17]. The exploratory case study method was comprehensive enough to provide insight into the multifaceted constituents of complex real-world systems that are driven by contextual factors [18].

Data Collection

Both primary and secondary sources were used for data collection alongside each other to ensure a well-rounded approach to the problem and to help in finding conclusions or corroborating evidence:

Primary data was obtained from a google forms questionnaire that was shared with critical stakeholders from Lumwana Mining Company such as dispatch engineers, mining engineers, operations supervisors, operations managers, surveyors, geologists, operations technology team and data analysts, all of whom participate in SIC processes and the technology integration. All participants from the above-mentioned positions participated in the SIC processes as well as in the technology integration. This format allowed us to explore diverging themes without getting too far from the main focus which consisted of BI, IoT, and operational efficiency.

Quantitative internal operational data was classified as secondary data. In addition, the quantitative operational data included fleet management logs, dispatch records, equipment health reports, as well as asset utilization dashboards which encapsulated both historical and real time data. Because these data were vital in determining performance change over time and evaluating the effects of BI-IoT integration on crucial operational parameters like truck cycle times, equipment idle time, and throughput, they were considered essential. Business intelligence tools, including Power BI, were used for processing the data in question and generating insights with the aid of data visualization.

RESULTS AND FINDINGS

In examining feedback provided by respondents concerning the integration of IoT technologies and BI analytics in open pit mining operations at Lumwana Mining Company, several

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key themes and insights emerged. These insights provided a detailed understanding of the current state of IoT and BI adoption, their effectiveness in supporting short interval control frameworks and the challenges and opportunities related with digital transformation in mining operations.

The study results show the extent of IoT deployment on mining equipment, the role of BI baseboards in enhancing decision making in real time and the early but promising use of predictive analytics for improved equipment utilization and production forecasting. In addition, the research results highlight the organizational and infrastructure factors that influence the success of IoT and BI integration as well as the barriers that hinder adoption.

Accordingly, this chapter highlights the essential outcomes of the survey conducted. Linking them directly to the study objectives. The survey findings are centered around the four guiding research questions and form the foundation for understanding how the technological tools can be used to optimize operational efficiency in open pit mining.

A. IoT Technology adoption and impact

Almost all respondents (21 out of 24, or 88%) confirmed that IoT-enabled devices are already deployed across Lumwana mining operations. These are installed in haul trucks, shovels/excavators, drills, auxiliary equipment, and fuel monitoring systems, indicating coverage of both production-critical and support assets.

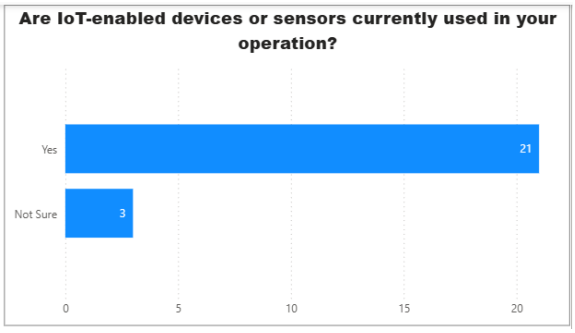

Fig 2. IoT Technology adoption

The most frequently cited benefits was better decision making with real time data. (92%), enabling proactive maintenance and early fault detection.

Faster reporting and analytics (71%) was also noted as a key advantage, supporting quicker troubleshooting and operational adjustments.

Other improvements included improved equipment health and monitoring (67%), and reduced unscheduled downtime (38%), pointing to tangible operational efficiency gains.

However, a minority indicated “minimal impact noticed,” suggesting either incomplete deployment or underutilization of IoT data streams in certain sections.

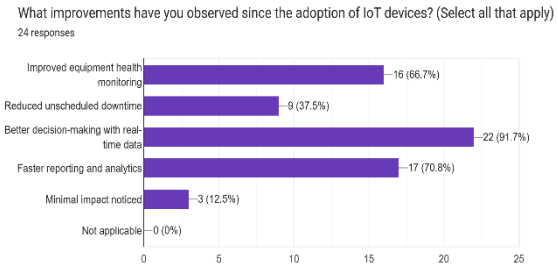

Fig 3. Improvements observed

B. BI Effectiveness

All surveyed departments confirmed the use of BI dashboards and automated reports, making BI tools a common denominator across the mine.

I. On effectiveness, 71% strongly agreed that BI dashboards support real-time decision-making, 17% somewhat agreed, and only 12% were less confident.

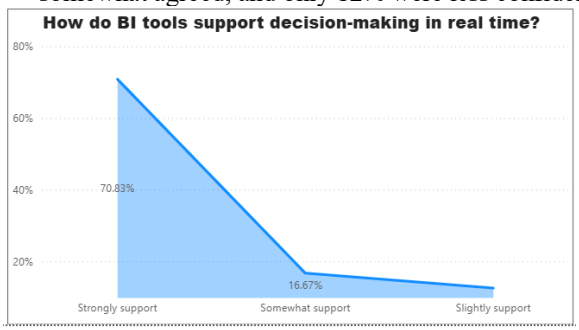

Fig 4. BI supporting decision-making

- The strong endorsement of BI and Fleet management systems (Consisting IoT sensors) highlights its role in translating raw IoT data into actionable intelligence for shift-level performance monitoring and interventions.

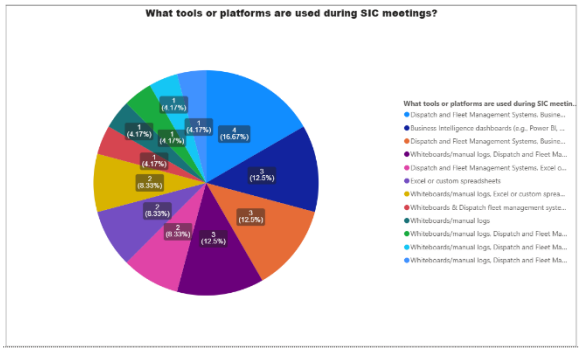

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Fig 5. BI tools used for SIC meetings

Impact of BI-IoT integration

The convergence of IoT devices and BI analytics is starting to deliver quantifiable gains at Lumwana, especially in Short-Interval Control (SIC) operations.

- Equipment Utilization

Persistent monitoring by IoT sensors, combined with telematics, feeds machine state data to BI dashboards that generate key utilization figures. Interviewees noted a sharp uplift in tracking shovel and truck movements, leading to steadier deployment of the fleet. Supervisors can now spot underutilized units in real time and redeploy them before shifts end.

I. Downtime Reduction

Linking streaming IoT data to BI alerts facilitates early fault detection and a swifter react to unexpected delays. Surveyed staff recorded fewer surprise failures and more synchronized maintenance. Compressed reporting times mean that shift teams receive downtime alerts and initiate countermeasures within the same shift, cutting idle minutes.

I. Production Throughput

Routing IoT-generated metrics on truck tonnage and cycle times into BI platforms delivers hour-by-hour and shift-level visibility of output. Respondents observed tighter forecasting and finer production scheduling, as BI models now generate actionable insights within minutes and suggest corrections before the next cycle.

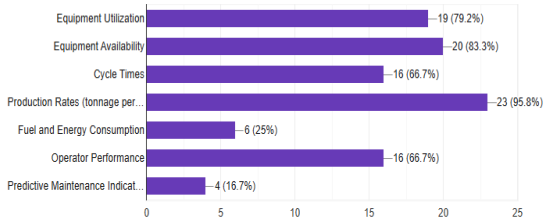

Fig 6. Impact of BI and IoT integration

Practical Roadmap for Digital Transformation of SIC Systems

Insights from the recent Lumwana Mining survey outline a comprehensive pathway for the digital transformation of Short-Interval Control (SIC) systems. Survey participants uniformly agree that realizing the full potential of BI-IoT integration hinges on a phased roadmap that balances technical execution with organizational readiness.

Phase 1: Improving Infrastructure Fundamentals

A dependable network connectivity, complete sensor coverage, and consistent power supply were cited as fundamental enablers. Persistent coverage gaps were reported to impede the accuracy of real-time metrics. Targeted investments to upgrade backhaul and edge communications, along with provisioning spare power for the IoT estate, thus form the essential kick-off.

Phase 2: Integrating Systems and Unifying Data

Data fragmentation remains pervasive, with IoT feeds typically stranded within silos. To establish a sole, credible source for SIC, fleet, dispatch, and sensor components should be fused within a coherent BI architecture. This phase must also align schema, tags, and workflows to ensure seamless interfacing with existing systems.

Phase 3: Strengthening Capabilities and Fostering Adoption

Technical enablement alone will underperform without concurrent capability uplift. Surveyed personnel underscored sustained operator immersion as a pre-condition. Intensive, role-relevant training, consistent reinforcement from leadership, and deliberate peer learning opportunities will equip operators to navigate and act on dashboards confidently and promptly.

Phase 4: Scaling Predictive Analytics and AI

Though models remain early in their development, teams already see their value in projecting output, forestalling asset failures, and shortening downtime. At this stage, the goal is to deploy predictive capabilities broadly, integrating them into standard Smart Industrial Control routines and tying their insights to everyday operational choices.

Phase 5: Governance, Monitoring, and Continuous Improvement

Ongoing sponsorship from executives is the cornerstone for enduring change. By installing clear governance teams, defining relevant KPIs, and scheduling steady review intervals, the Smart Industrial Control platform can be anchored within the organization. Continuous improvement practices will capture actionable insights and cycle them back into system upgrades.

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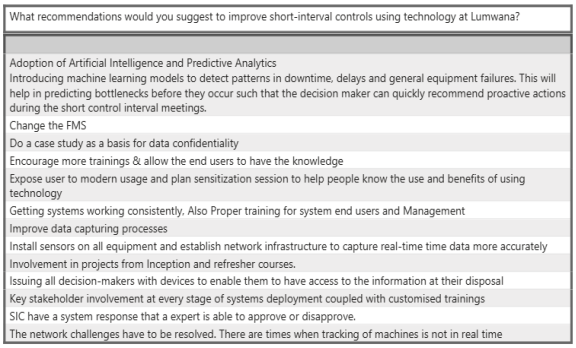

Fig 7. Impact of BI and IoT integration

CONCLUSION

This study confirms that the convergence of Internet of Things (IoT) technology and Business Intelligence (BI) analytics can fundamentally elevate the capabilities of Short-Interval Control (SIC) systems within Lumwana Mining Company. The findings show that IoT adoption has delivered sharper health surveillance of machines, timely broadcast of events, and quicker, evidence-based choices while BI visualization tools have widened operational situational awareness and detailed telemetry at the shift level. Although predictive analytics remain at an early stage, its pilot applications demonstrate measurable gains in reducing downtime, forecasting production, and improving throughput.

The study shows importance in the marrying of IoT and BI, namely a tightly knitted system infrastructure, dependable base architecture, and educated end users while the evidence also lists tenacious vulnerabilities, such as patchy plant wireless, segregated datasets, and antagonism toward new patterns. In summary, the integration of IoT and BI demonstrates a viable and advantageous pathway for optimizing operational efficiency, but its success is largely dependent on a structured roadmap that balances technological investment with organizational readiness.

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