World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

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Quantitative Assessment of Safety Risks among Mining Maintenance Employees in West Africa

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World Journal of Advanced Research and Reviews, 2026, 29(01), 858-867

Publication history: Received on 15 November 2025; revised on 12 January 2026; accepted on 15 January 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.4237

Abstract

Mining maintenance employees in West Africa are exposed to significant occupational safety risks. These risks arise from their regular work with heavy machinery, harsh environmental conditions, and the time-sensitive nature of repair tasks. This study provides a quantitative assessment of safety risks among these workers, using accident statistics and standardized safety performance indicators. Data from industrial mining operations were analyzed to compare accident frequency, severity, and lost workdays between maintenance and operational activities. The results show that maintenance work contributes disproportionately to serious and fatal accidents, especially during corrective repairs. The study confirms that preventive maintenance and structured safety procedures are effective in reducing accident rates. These findings offer quantitative support for risk-based safety management strategies tailored to the mining context in West Africa.

Keywords: Mining safety; Maintenance employees; West Africa; Accident statistics; Safety performance indicators

1. Introduction

The mining industry serves as a foundational pillar of economic development across West Africa [1–7]. Countries such as Burkina Faso, Ghana, Mali, Guinea, and Niger rely heavily on mineral extraction for export revenue, foreign investment, and employment [8]. Industrial mining operations in the region utilize extensive fleets of heavy machinery, including excavators, haul trucks, drilling rigs, and processing plants [4, 9–11]. The continuous operation of this equipment is essential for productivity and profitability, making maintenance activities a critical, yet often high-risk, function.

Within mining, maintenance personnel perform tasks that are inherently hazardous. These employees routinely engage with energized systems, work at height or in confined spaces, and handle heavy components under time-sensitive conditions [12–16]. In West Africa, these risks are compounded by challenging environmental and operational factors. High ambient temperatures, pervasive dust, inconsistent power supply, and logistical constraints related to spare parts and technical support can elevate the complexity and danger of maintenance work. Furthermore, maintenance is frequently conducted under operational pressure to minimize equipment downtime, which may encourage shortcuts or reduced adherence to safety protocols [17].

Available industry data and internal safety reports from the region suggest that maintenance-related activities are disproportionately represented in serious incident and fatality statistics [18, 19]. However, much of the existing safety research in mining has focused broadly on operational hazards, such as pit-wall stability or haul-road safety [20–25]. A significant lack of detailed, quantitative studies remains that isolate and analyze the specific risks faced by maintenance

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employees. Without such focused analysis, safety interventions may not adequately address the unique hazards of maintenance work.

This study, therefore, aims to provide a rigorous, quantitative assessment of occupational safety risks specifically among mining maintenance employees in West Africa. By analyzing five years of accident data from active West African industrial mines, the research compares safety performance between maintenance and production operations using standardized metrics: Accident Frequency Rate (AFR), Lost Time Injury Frequency Rate (LTIFR), and Accident Severity Rate (ASR). It further examines how risk varies between preventive and corrective maintenance tasks and identifies the primary hazard categories involved.

The findings of this study are intended to offer evidence-based insights for mine managers, safety professionals, and policymakers. By quantifying the elevated risk profile of maintenance work, this research supports the development of targeted safety strategies, reinforces the value of preventive maintenance programs, and contributes to the broader goal of reducing occupational harm in one of West Africa's most vital economic sectors.

2. Methods

2.1. Data Sources

This study employed a quantitative, retrospective design to analyze occupational safety risks [26–28]. The primary objective was to compare safety performance between maintenance and production (operations) personnel within industrial mining settings in West Africa. The analysis focused exclusively on surface mining operations for precious metals (gold) over five consecutive calendar years (2020–2024). The geographical scope was limited to active, large-scale industrial mines in Burkina Faso and Mali, which represent a significant share of regional production and maintain formalized safety recording systems.

2.2. Data Sources

Accident and exposure data were obtained through formal agreements with three multinational mining companies operating in the region. The provided datasets were anonymized at the source to protect employee and site confidentiality. Each record included fields for: date, work area, employee role, activity being performed, type of incident, injury description, classification of severity, and total lost workdays. Exposure data, in the form of total hours worked, was supplied separately for maintenance and operations departments for each year.

The study included all reportable occupational safety incidents that met the following criteria:

- Resulted in a recordable injury (requiring medical treatment beyond first aid).
- Led to at least one full day of lost work time (Lost Time Injury, LTI).
- Resulted in a fatality.
- Near-misses, first-aid-only cases, and health-related incidents (e.g., illness) were excluded to maintain a consistent focus on traumatic injury risk.

2.3. Variable Definitions and Classification

Each incident was systematically coded based on the following variables:

- **Activity Type:** Coded as *Maintenance* (any repair, servicing, or inspection of equipment or infrastructure) or *Operations* (any direct production-related activity such as drilling, blasting, loading, hauling, or processing).
- **Maintenance Type:** For incidents classified as Maintenance, this was further coded as *Preventive* (planned, scheduled service or part replacement) or *Corrective* (unplanned repair following a breakdown or fault) [29–32].
- **Accident Severity** categorized into three levels [33–36]:
- **Minor Injury (MI):** Injury requiring professional medical treatment but resulting in no lost workdays.
- **Lost Time Injury (LTI):** Injury resulting in one or more full days away from work.
- **Fatality (F):** An incident resulting in death.
- **Hazard Category:** The primary immediate cause was classified into one of four categories [37–40]:
- **Mechanical:** Contact with moving parts, being struck by or caught in machinery, failure of equipment.
- **Electrical:** Contact with live circuits, arc flash, faulty grounding.
- **Environmental:** Heat stress, poor visibility due to dust, slip/trip on surfaces, adverse weather.

- **Ergonomic:** Overexertion, awkward postures during manual handling, repetitive strain.

2.4. Safety Performance Indicators

To enable normalized comparison, three internationally recognized safety performance indicators were calculated independently for the Maintenance and Operations groups [41–45]:

Accident Frequency Rate (AFR): Measures the rate of all recordable injuries per million hours worked, as shown in Equation (1).

$$AFR = (\textbf{Number of recordable accidents} \times \mathbf{1,000,000})/(\textbf{Total hours worked}) \quad (1)$$

Lost Time Injury Frequency Rate (LTIFR): Measures the rate of injuries resulting in lost workdays per million hours worked (Equation (2)).

$$LTIFR = (\textbf{Number of lost time injuries} \times \mathbf{1,000,000})/(\textbf{Total hours worked}) \quad (2)$$

Accident Severity Rate (ASR): Measures the severity of accidents in terms of lost time per thousand hours worked (see Equation (3)).

$$ASR = (\textbf{Total number of lost workdays} \times \mathbf{1,000})/(\textbf{Total hours worked}) \quad (3)$$

2.5. Data Analysis

The analysis proceeded in three stages:

- Descriptive Analysis: Frequencies and percentages were calculated to describe the distribution of accidents by activity type, maintenance type, severity, and hazard category [46].
- Comparative Rate Analysis: AFR, LTIFR, and ASR were calculated for Maintenance and Operations. The ratio of the Maintenance rate to the Operations rate was computed for each indicator to quantify the relative risk.
- Subgroup Analysis: Within the Maintenance group, AFR and LTIFR were calculated separately for Preventive and Corrective activities to compare their risk profiles.

All calculations were performed using Microsoft Excel. Given the aggregated and anonymized nature of the dataset, advanced inferential statistics were not applied; the study relies on descriptive comparison of standardized rates to highlight differences in risk exposure.

3. Results

3.1. Data overview

The dataset comprised a total of 412 reportable occupational accidents recorded across the participating sites over the five years. The total workforce exposure was 28.5 million hours worked, of which 8.0 million hours (28.1%) were attributed to maintenance departments and 20.5 million hours (71.9%) to operations departments.

3.2. Distribution of Accidents by Activity Type

Maintenance personnel, constituting 28.1% of the total workforce exposure, were involved in a disproportionately high share of accidents. As shown in Table 1, they accounted for 46.4% (n=191) of all recordable injuries and 52.2% (n=36) of the most severe outcomes (serious injuries and fatalities). In contrast, operations personnel, with 71.9% of the workforce hours, were involved in 53.6% (n=221) of all accidents and 47.8% (n=33) of serious/fatal incidents.

Table 1 Distribution of occupational accidents

Activity Type	Workforce Share (%)	Accident Share (%)	Serious/Fatal Accidents (%)
Maintenance	28	46	52
Operations	72	54	48

3.3. Comparison of Safety Performance Indicators

The calculated safety performance rates reveal a consistent and substantial risk differential between the two groups. As presented in Table 2, the Accident Frequency Rate (AFR) for maintenance activities (18.4) was 1.9 times higher than the rate for operations (9.6). This pattern of elevated risk is further evidenced by the Lost Time Injury Frequency Rate (LTIFR), which was 2.3 times higher for maintenance personnel. The disparity in consequences is captured by the Accident Severity Rate (ASR); lost workdays occurred at a rate more than twice as high in maintenance compared in operations.

Table 2 Safety performance indicators by activity

Indicator	Maintenance	Operations
AFR (accidents/10^6 h)	18.4	9.6
LTIFR (LTIs/10^6 h)	7.2	3.1
ASR (lost days/10^3 h)	0.92	0.41

3.4. Analysis by Maintenance Strategy

Risk levels within maintenance work varied significantly depending on the type of task performed. Preventive maintenance, which is planned and scheduled, demonstrated markedly lower incident rates. Corrective (or breakdown) maintenance, characterized by unplanned and often urgent interventions, was associated with a sharply higher risk. As shown in Table 3, the Accident Frequency Rate for corrective tasks was 2.4 times higher than for preventive tasks. The disparity was even greater for lost time injuries, with a LTIFR ratio of 3.1.

Table 3 Accident indicators by maintenance strategy

Maintenance Type	AFR	LTIFR
Preventive maintenance	8.9	2.7
Corrective maintenance	21.5	8.4

3.5. Primary Hazard Categories

An analysis of the immediate causes for maintenance-related accidents identified mechanical hazards as the most prevalent, responsible for 44% of incidents (Figure 1). This category includes being struck by or caught between machinery, component failures, and injuries during disassembly/assembly. Environmental factors, such as extreme heat leading to fatigue or dust impairing visibility, constituted 22% of incidents. Electrical hazards accounted for 18%, primarily during work on live systems or electrical troubleshooting. Ergonomic hazards, including strains from manual handling, represented 16% of the total.

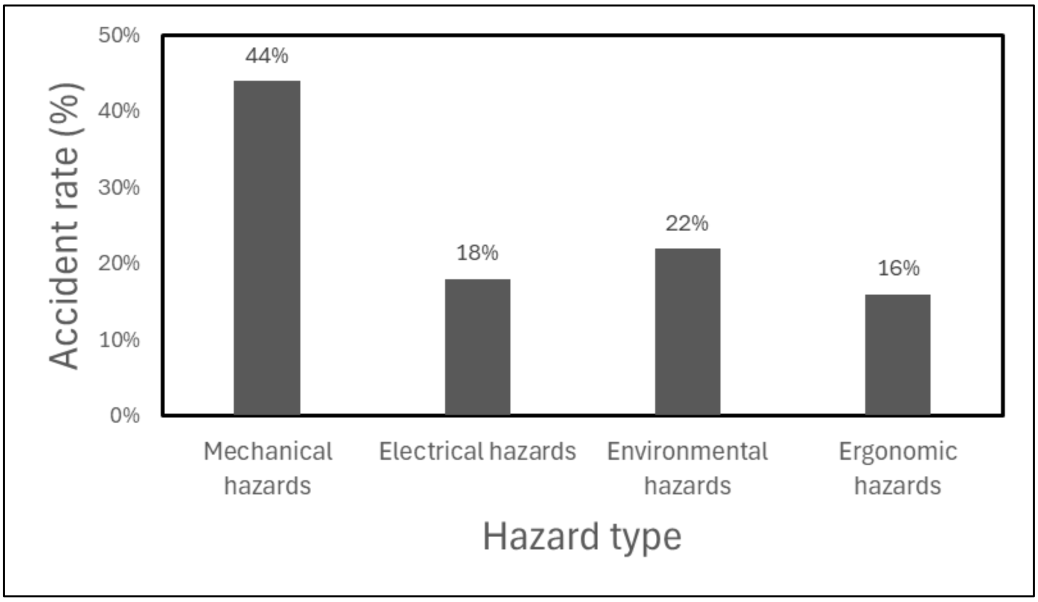

Figure 1 Distribution of maintenance accidents by hazard type

3.6. Severity Profile of Incidents

As presented in Figure 2, within the 191 maintenance-related accidents, the severity distribution was as follows: 55% (n=105) were classified as Minor Injuries, 40% (n=76) as Lost Time Injuries, and 5% (n=10) as Fatalities. This represents a higher proportion of high-severity outcomes (LTI+F) compared to the operations group, where high-severity outcomes accounted for 32% of incidents.

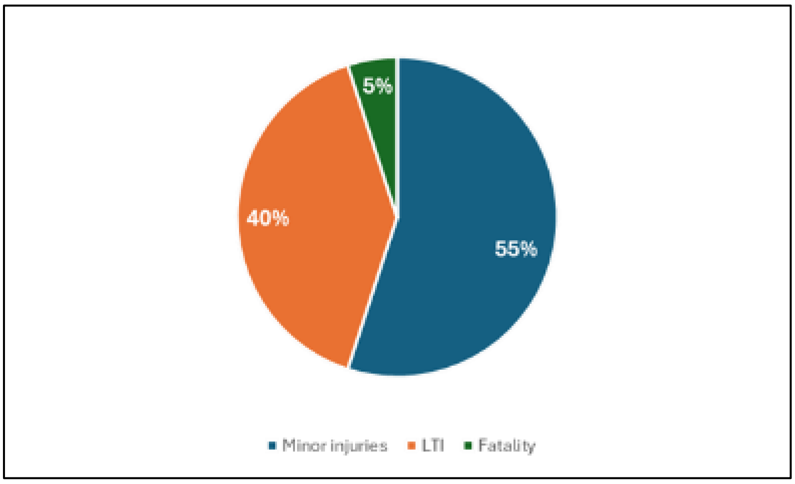

Figure 2 Distribution of maintenance accident severity

4. Discussion

4.1. Interpretation of Key Findings

The results of this study provide clear quantitative evidence that maintenance employees in West African surface mining face a significantly elevated occupational risk compared to their counterparts in production operations. The central finding confirms the hypothesis that maintenance is a disproportionately hazardous activity. This disparity is not merely a function of headcount but is robustly quantified by safety performance rates. The Accident Frequency Rate (AFR) for maintenance was more than double that of operations, indicating that for every million hours worked, maintenance personnel are more than twice as likely to be involved in a reportable incident.

The pronounced difference in outcomes between preventive and corrective maintenance is particularly instructive. The lower AFR and LTIFR associated with preventive work underscore that risk is not inherent to maintenance itself, but is heavily influenced by the context in which it is performed. Preventive tasks are typically planned, conducted under controlled conditions, often with equipment isolated and procedures reviewed. Corrective maintenance, in contrast, is reactive. It is initiated by unexpected failure, conducted under pressure to restore production, and often before a full assessment of hazards can be made. The data suggests that this combination of urgency, unpredictability, and operational pressure creates a high-risk environment where standard safety protocols are more likely to be circumvented.

4.2. Contextualizing the Hazards

The predominance of mechanical hazards (44%) aligns with the physical nature of maintenance work involving heavy, complex machinery. However, the significant contribution of ergonomic factors (22%) highlights a critical regional dimension. The extreme heat and pervasive dust common to West African mines are not merely discomforts; they act as performance-shaping factors. Heat stress can impair cognitive function and physical endurance, while dust can reduce visibility and compromise the integrity of equipment. These environmental stressors likely exacerbate the risks from mechanical and electrical tasks, particularly during the extended physical exertion often required in corrective repairs.

The higher proportion of high-severity outcomes (lost time injuries and fatalities) in the maintenance group suggests that when incidents do occur, they tend to be more serious. This can be attributed to the nature of the energy involved in maintenance tasks—working with stored hydraulic pressure, gravitational potential energy during lifting, or electrical energy in live circuits. An error or failure in these contexts often results in a high-energy release, leading to more severe trauma.

4.3. Implications for Safety Management

These findings have direct and actionable implications for safety management in West African mining operations.

First, they argue strongly for a strategic shift in maintenance philosophy, prioritizing predictive and preventive strategies over reactive ones [47, 48]. Investing in condition monitoring and scheduled servicing is not only an operational best practice but a demonstrable safety intervention. The data provide quantitative evidence that such programs can directly reduce injury rates.

Second, safety management systems must differentiate between maintenance and operations in their monitoring and oversight. Using aggregated site-wide safety statistics can mask the specific, elevated risks within the maintenance department. Safety Key Performance Indicators (KPIs), such as LTIFR, should be tracked separately for maintenance teams. An upward trend in these metrics should trigger a focused review of work planning, tooling, and procedure adherence specific to maintenance activities.

Third, the high risk of corrective work necessitates enhanced controls for non-routine tasks. This includes mandatory and rigorous pre-task risk assessments for all breakdown repairs, even under time pressure. It also underscores the need for specialized training for maintenance personnel that goes beyond technical skills to include robust hazard recognition, lockout-tagout (LOTO) proficiency, and decision-making under pressure.

4.4. Limitations and Future Research

This study has limitations. The data relied on formal reporting systems, and under-reporting of minor incidents is possible. The analysis was conducted at an aggregated level; future research could investigate causal factors in detail, such as by specific trade (e.g., electricians, mechanics) or equipment type. Furthermore, a qualitative component exploring the organizational and cultural factors influencing maintenance safety (such as production pressure, supervisor expectations, and perceived procedural burden) would provide valuable context to the quantitative results presented here.

Abbreviations

The following abbreviations are used in this manuscript:

- AFR: Accident Frequency Rate
- ASR: Accident Severity Rate
- F: Fatality

- KPIs: Key Performance Indicators
- LOTO: Lockout-Tagout
- LTI: Lost Time Injury
- LTIFR: Lost Time Injury Frequency Rate
- MI: Minor Injury

5. Conclusions

This study has provided a detailed quantitative assessment of occupational safety risks specific to maintenance employees within the industrial surface mining sector of West Africa. By analyzing a substantial dataset spanning five years and multiple operations, the research moves beyond general observation to offer measurable evidence of a significant safety disparity.

The findings confirm that maintenance personnel are exposed to a level of occupational risk that is disproportionately high relative to their share of the workforce. The key metrics are unambiguous: maintenance activities exhibit an Accident Frequency Rate and a Lost Time Injury Frequency Rate more than double those of production operations. Furthermore, this work contributes a critical refinement to our understanding of maintenance risk by clearly distinguishing between maintenance strategies. The data demonstrates that the risk is not uniformly distributed; corrective, or breakdown, maintenance carries a substantially higher hazard potential than planned preventive maintenance, with LTIFR values more than three times greater.

The predominance of mechanical and environmental hazards within the incident data points to the specific interaction between the physical demands of the work and the challenging climatic context of the region. This combination creates a unique risk profile that requires tailored management approaches.

Therefore, the primary conclusion of this research is that effective safety improvement in West African mining must involve a dedicated and separate focus on the maintenance function. Reliance on site-wide safety averages is insufficient. Practical progress depends on two parallel strategies: first, a management commitment to shifting maintenance culture and resources toward preventive and predictive paradigms, supported by the quantitative safety benefit shown here; and second, the implementation of targeted monitoring using maintenance-specific safety performance indicators to enable proactive risk management.

Ultimately, safeguarding maintenance employees requires recognizing the specialized and high-risk nature of their work. This study provides the empirical foundation for that recognition. By integrating these quantitative insights into planning, training, and procedural controls, mining companies can make deliberate strides toward reducing preventable harm, enhancing operational reliability, and fostering a more sustainable and safer industry in West Africa.

Compliance with ethical standards

Acknowledgments

The author acknowledges the support of their institution and thanks all contributors who assisted in the completion of this research.

Disclosure of conflict of interest

The author has no conflicts of interest to declare that are relevant to the content of this article.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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