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Risk Drivers and Safety Improvement Strategies in Gas Power Operations

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ABSTRACT

Gas power facilities are among the more hazardous settings in modern industry. Workers, contractors, and site visitors face serious physical risks daily, from mechanical energy release to fall hazards and line-of-fire exposures. Controlling those risks requires a Health and Safety, Environmental system that works in the field—one that coordinates engineering controls, administrative procedures, and personal protective equipment (PPE) rather than treating them as independent layers.

This paper examines the safety framework applied in gas power operations across the Middle East and North Africa (MENA) regions. It pays particular attention to Life-Saving Rules (LSRs), which were drawn from historical incident data and Root Cause Analysis (RCA) to target the activities most often linked to fatal and life-altering injuries. The study draws on 202 occupational records, of which 38 were operational incidents relevant to causal analysis. It identifies the principal drivers of Class A (fatal) and Class B (life-threatening or permanently disabling) events and evaluates how engineering barriers, administrative controls, and PPE held up in each case. Three activities—uncontrolled mechanical energy release, working at heights, and mechanical lifting—account for the majority of severe outcomes. Administrative controls failed more often than any other layer, at 55.3% of incidents, despite documented procedures and established LSRs being in place. The data points to a persistent gap between what is written in the safety system and what supervisors enforce on site.

Keywords:
Gas Power Operations; Health and Safety, Environmental (HSE); Safety Management Systems.

Abbreviation	Full Term
EHS	Environment, Health, and Safety
HSE	Health, Safety, and Environment
ILO	International Labour Organization
IOGP	International Association of Oil and Gas Producers
ISO	International Organization for Standardization
LSRs	Life-Saving Rules
MENA	Middle East and North Africa
PPE	Personal Protective Equipment
RCA	Root Cause Analysis

Table1: List of Abbreviations

I. INTRODUCTION:

Gas turbines are the backbone of electricity supply across much of the industrial, commercial, and residential world. As demand has grown, so has the volume of maintenance outages, equipment overhauls, commissioning work, and field operations needed to keep them running. Each of these activities brings workers into contact with mechanical lifting, confined spaces, electrical systems, energy isolation procedures, elevated work platforms, and line-of-fire hazards (International Organization for Standardization, 2018; Centre for Chemical Process Safety, 2007).

HSE Management Systems are the standard response to these risks. At their best, they connect policy to field practice through risk assessment, hazard identification, incident investigation, and structured feedback loops (International Labour Organization, 2001; International Organization for Standardization, 2018). The problem is that this connection often breaks down. Organisations can have detailed procedures, regular audits, and strong performance metrics on paper while serious injuries still occur (Reason, 1997).

Safety objectives function best when they are anchored to specific operational hazards, legal requirements, and corporate risk tolerances—and then translated into measurable action plans that field supervisors can actually execute (International Organization for Standardization, 2018). Objectives that exist only at the policy level do not change what happens when a technician is working at height on a maintenance outage under schedule pressure.

That gap is the central problem this study addresses. Despite comprehensive HSE programs across the gas power sector, high-severity incidents have not been eliminated (Hollnagel, 2014).

The question is not whether procedures exist—they do. The question is why those procedures consistently fail to prevent the same categories of serious injury.

This study analyses operational safety records from MENA gas power operations, applies Root Cause Analysis to Class A and Class B incidents, and identifies which organisational

and operational factors most reliably predict a severe outcome (Centre for Chemical Process Safety, 2019).

Unlike previous studies that primarily describe accident trends, this study integrates Root Cause Analysis (RCA) with the Hierarchy of Controls to develop a practical risk prioritization framework for gas power operations in the MENA region. Rather than limiting the analysis to identifying accident causes, the proposed framework links root causes to the effectiveness of preventive control measures, enabling organizations to prioritize safety interventions based on the most critical operational risks. Furthermore, the findings provide practical guidance for strengthening safety management practices within Libyan power facilities, extending the application of existing HSE knowledge to a regional context that has received limited research attention. This framework can also support decision-makers in the Libyan electricity sector by prioritizing preventive actions based on the most critical operational risks.

II. LITERATURE REVIEW:

The field of occupational safety has moved steadily away from treating accidents as the product of individual error. Research over the past three decades makes clear that serious incidents in industrial settings arise from overlapping failures—technical, procedural, supervisory, and organizational—not from a single worker making a single bad decision (Reason, 1990; Reason, 2000).

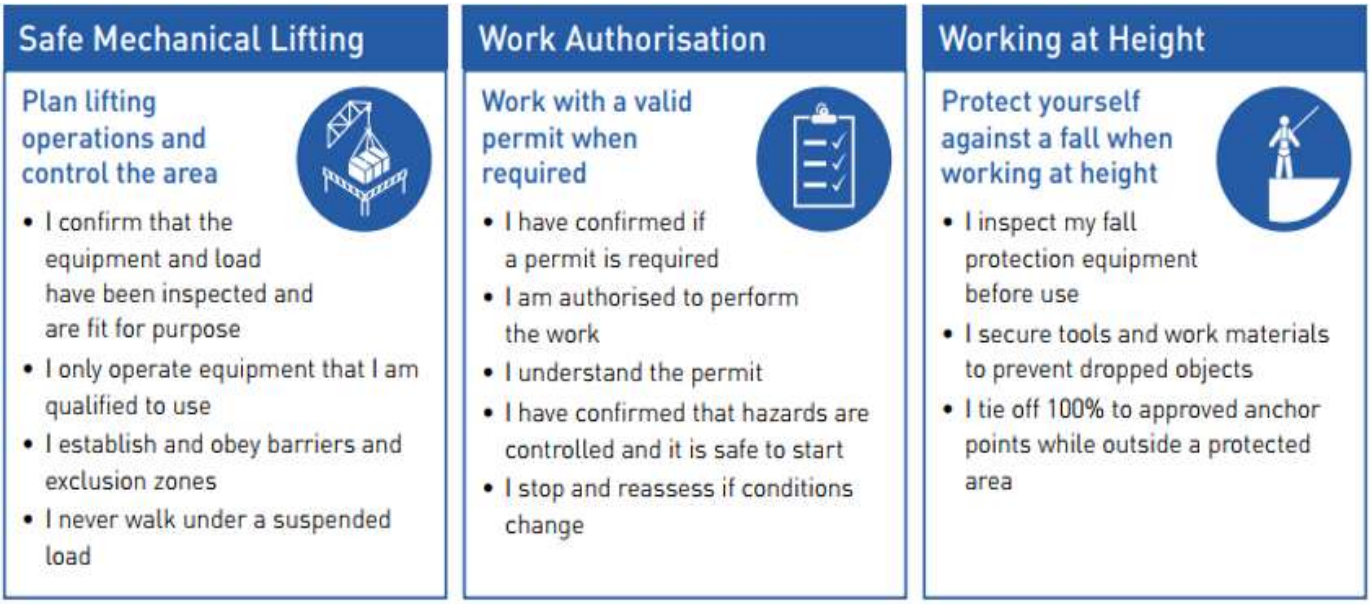
Reason's Swiss Cheese Model remains one of the most cited frameworks for explaining this. It treats engineering controls, administrative procedures, supervision, and PPE as successive defensive barriers, each with gaps (Reason, 1997). Accidents occur when those gaps align. The practical implication is that investigators should look upstream—at inadequate procedures, poor training, weak communication, and safety culture failures—rather than stopping at frontline behaviors (Reason, 1990).

The Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI) applies this logic across organizational levels, mapping how conditions at the management and regulatory level filter down into unsafe acts on the job (Theophilus et al., 2017). Studies using this framework in oil and gas contexts consistently find that contractor operations generate a disproportionate share of fatal incidents that directly inform the present study, given that much of the MENA gas power workforce is contracted or subcontracted (Nwankwo et al., 2022).

HSE Management Systems are now standard in high-risk industries, yet the research record shows they do not automatically prevent catastrophic events. Organizations can achieve high audit scores and full documentation of international standard compliance while the rate of severe incidents remains unchanged (International Labour Organization, 2001; International Organization for Standardization, 2018). What actually determines whether a formal safety system influences field behaviors is a combination of management commitment, how production pressure is managed, and whether safety information reaches workers in a form they can use (Hopkins, 2008). Safety objectives that stay in management reports do not reach the technician on the scaffold (Hollnagel, 2014).

The International Association of Oil and Gas Producers (IOGP) developed the Life-Saving Rules (LSRs) specifically to close that gap (International Association of Oil and Gas

Producers, 2018). The rules cover the ten activities historically responsible for most fatal occupational accidents in the sector (International Association of Oil and Gas Producers, 2018). work authorization, energy isolation, confined space entry, hot work, mechanical lifting, working at heights, line-of-fire exposure, bypassing safety controls, and diving and driving. Where organizations have applied LSRs consistently and backed them with real supervisory enforcement, fatality rates have fallen. Where they have been treated as a documentation requirement, compliance remains selective. Site supervisors who look the other way, workers who find that shortcuts have no consequences, and contractors operating under tight deadlines all contribute to that selective compliance (Hopkins, 2008). Root Cause Analysis has evolved from a post-incident reporting tool into a predictive capability (Center for Chemical Process Safety, 2019). Bayesian networks, AI-assisted incident classification, and automated pattern recognition now allow organisations to identify recurring failure pathways from historical data before they produce another injury (Hollnagel, 2014). This shift matters for how safety managers allocate attention and resources. What the literature establishes is that engineering controls, management behaviour, and workforce practices cannot be evaluated in isolation. A serious incident is rarely caused by one thing. Understanding what went wrong requires examining both the physical failure and the organisational environment that permitted the failure to occur (Reason, 1997).



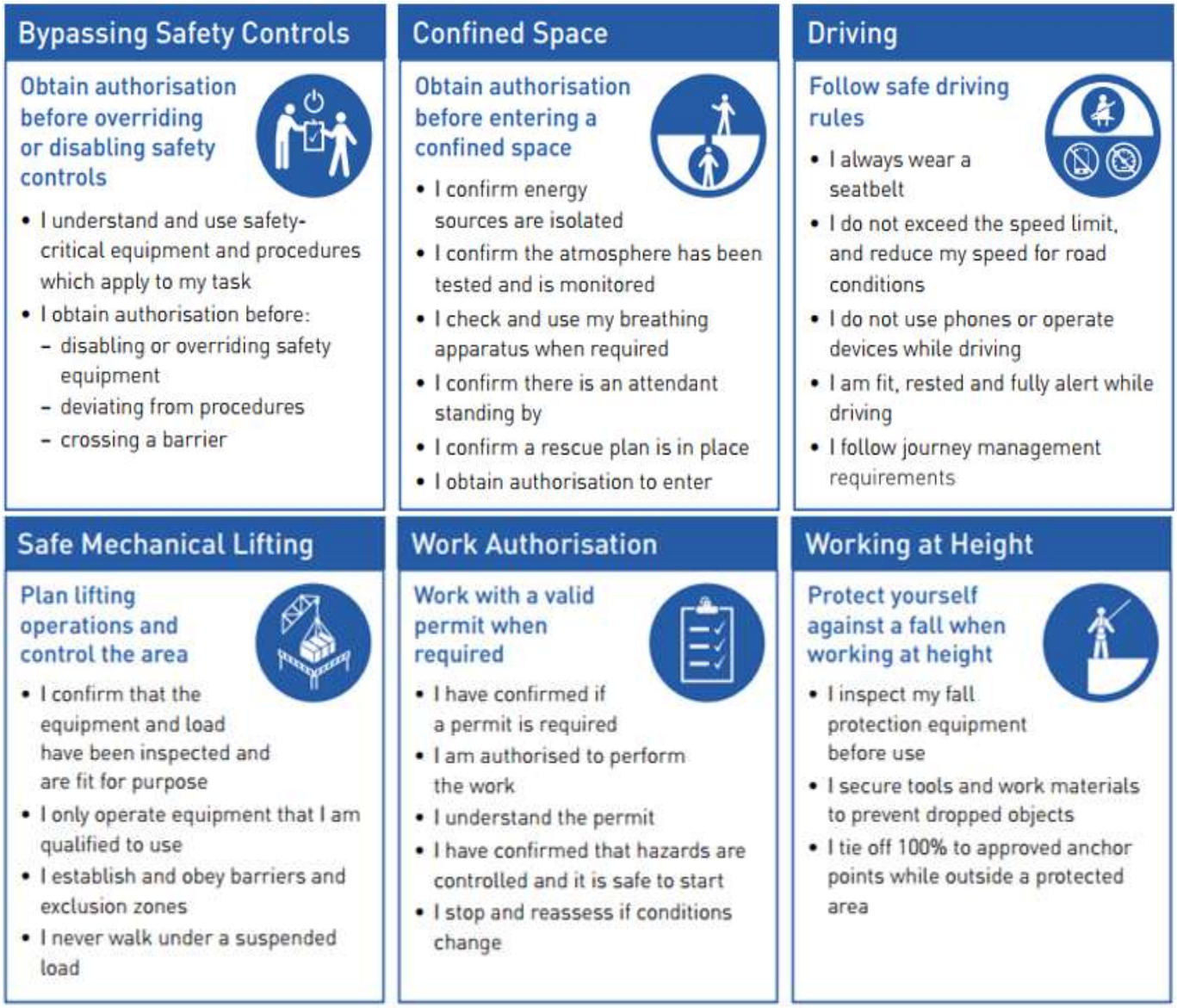


Table **2**: The 9 IOGP Life-Saving Rules

III. METHODS AND MATERIAL:

3.1 Research Design

This study adopted a quantitative analytical research design to investigate the relationship between Environmental, Health, and Safety (HSE) management practices and occupational safety performance in gas power operations across the Middle East and North Africa (MENA). The study focused on gas turbine maintenance, scheduled overhauls, commissioning activities, unplanned outages, and field service operations.

3.2 Data Collection

Operational Health, Safety and Environment (HSE) records were obtained from a global energy service provider operating across the MENA region. The original dataset consisted of 202 documented occupational records, including industrial incidents and occupational health cases. Following data screening and cleaning, only 38 incidents directly related to gas

turbine power generation, maintenance, commissioning, and field service operations were retained for detailed analysis, while occupational illnesses and non-operational events were excluded to ensure that the analysis remained focused on relevant operational safety risks.

3.3 Data Preparation

The retained incident records were cleaned and standardized before analysis. Records with incomplete operational variables were excluded, multilingual incident descriptions were unified, and severity classifications were standardized to ensure consistency across the dataset. Each incident was subsequently classified according to work activity, severity level, immediate cause, underlying root cause, and the applicable Life-Saving Rule (LSR) before proceeding with the analytical stages.

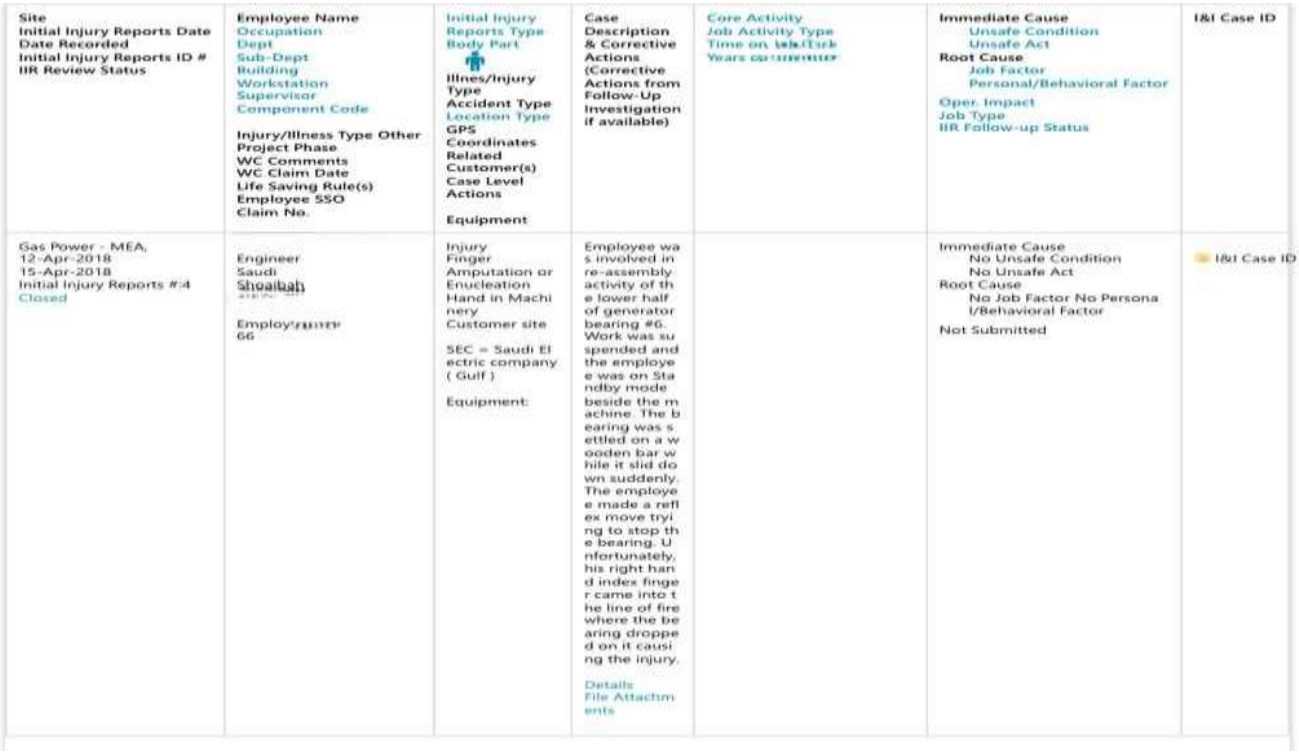


Figure 3.1: Data Preparation and Normalization Methodologies

3.4 Data Analysis

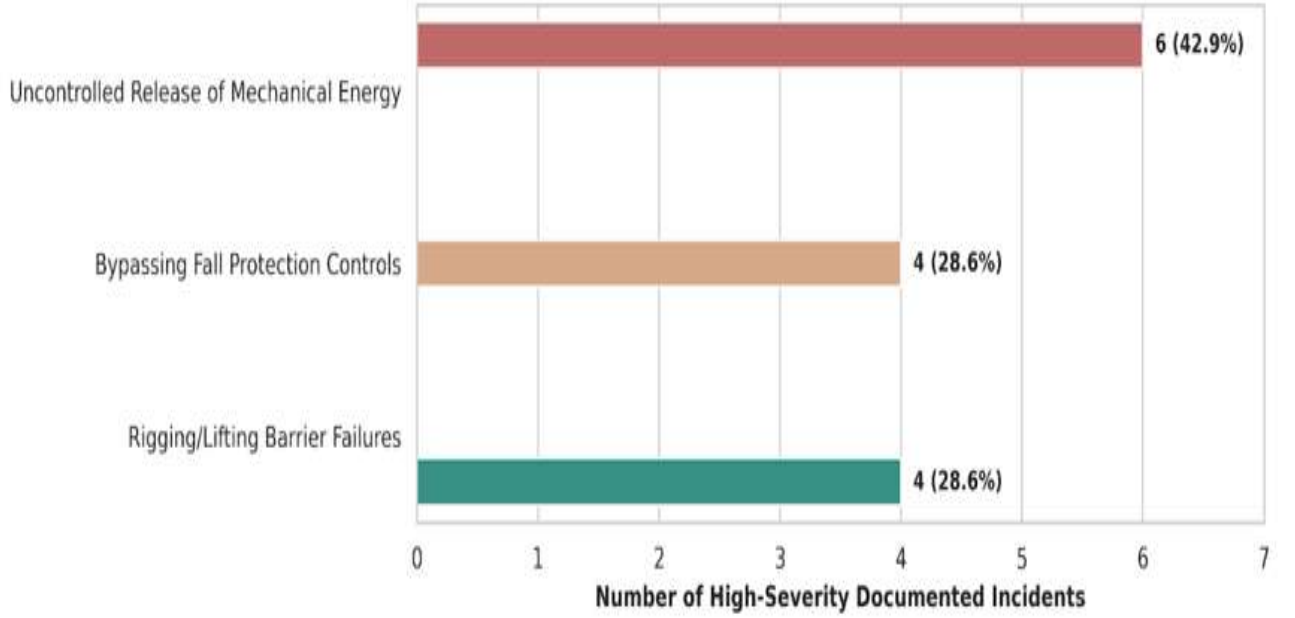
The analysis consisted of three sequential stages:

- Descriptive statistical analysis to determine the distribution of incidents by activity type and severity.
- Root Cause Analysis (RCA) to identify the dominant causal factors associated with Class A and Class B incidents.
- Evaluation of control effectiveness using the Hierarchy of Controls, including engineering controls, administrative controls, and personal protective equipment (PPE).

Analytical Category	*Case Count (n)*	*Relative Share (%)*
Core Kinetic Operational Risks	*38*	*18.8%*
General Non-Work-Related Illnesses	*123*	*60.9%*
Sub-Saharan Endemic Hazards	*15*	*7.4%*
Other Logged Peripheral Events	*24*	*11.9%*
Specific Regional Outbreaks	*2*	*1.0%*
Total Portfolio Data Universe	*202*	*100.0%*

Table 3.1: Distribution of the Combined Dataset

Figure 3.2: Root Cause Analysis (RCA) Drivers for Class A & B Events (n =



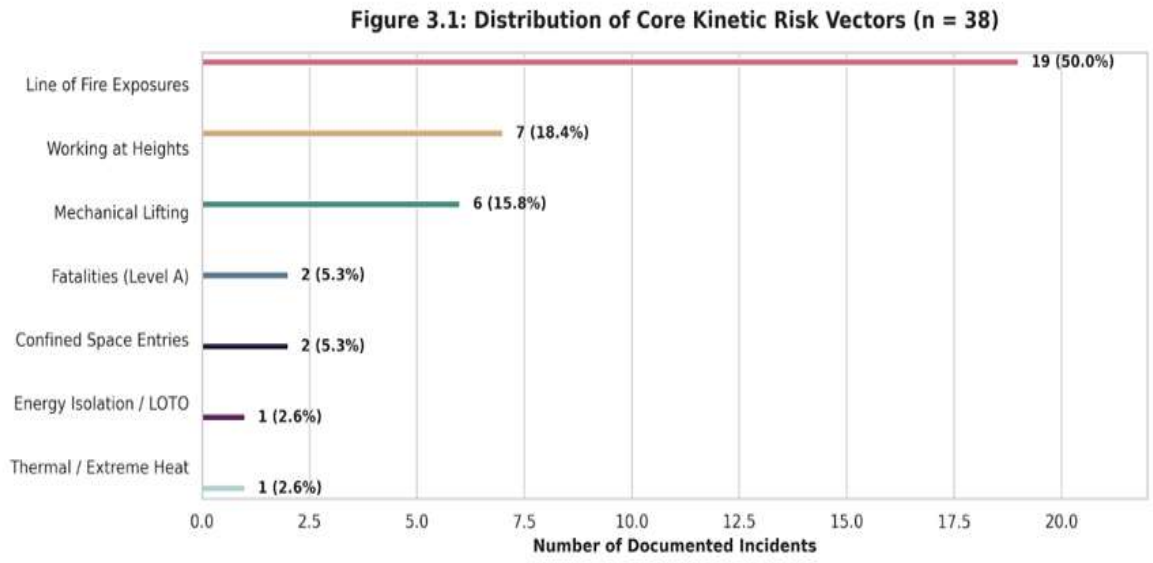
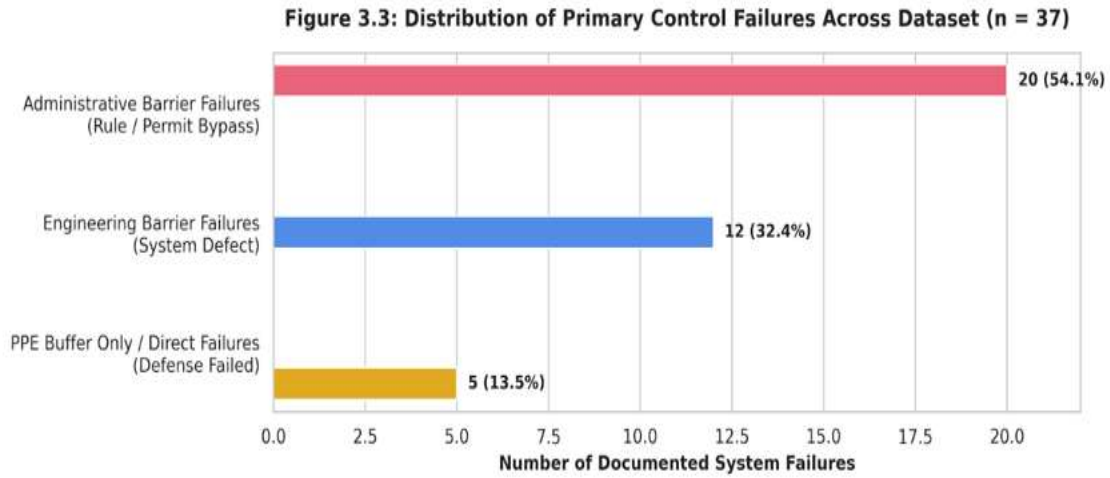


Figure 3.2: Root Cause Analysis (RCA) Drivers for Class A & B Events (n = 14)

Work Activity Vector	Engineering Barrier (System Defect)	Administrative Barrier (Rule/Permit Bypass)	PPE Buffer Only (Defense Failed)
Line of Fire	4	12	3
Working at Heights	3	4	0
Mechanical Lifting	4	2	0
Confined Space	0	2	0
Energy Isolation (LOTO)	1	0	0

Table 3.2: Control Failure Vector Cross-Tabulation



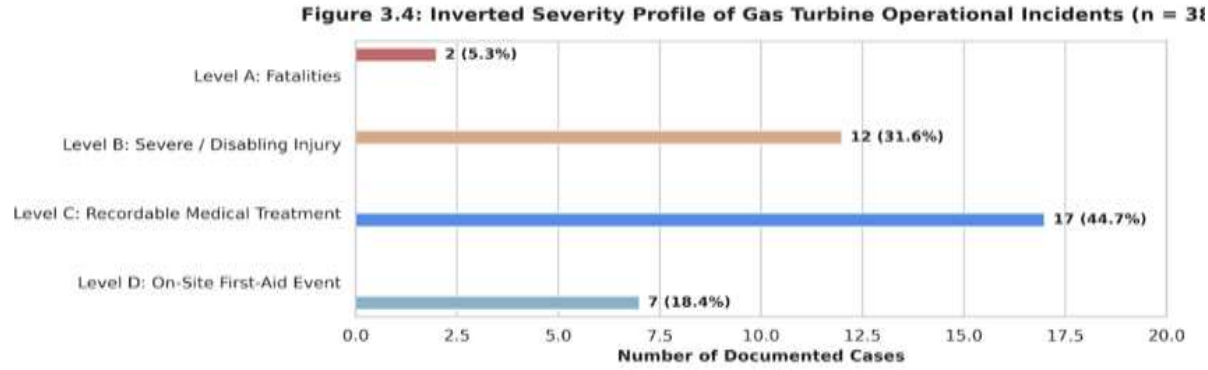


Figure 3.4: Inverted Severity Profile of Gas Turbine Operational Incidents

IV. RESULTS AND DISCUSSION:

1 Distribution of Operational Risk Drivers

Three activity categories accounted for the substantial majority of recorded incidents. Across the 38 operational incidents, Line of Fire was the most frequently recorded category (50.0%), followed by Working at Heights (18.4%) and Mechanical Lifting (15.8%). When the analysis was narrowed to Class A and Class B events only, the picture shifted: uncontrolled mechanical energy release became the leading causal factor, responsible for 42.9% of severe cases. Working at heights and mechanical lifting each accounted for 28.6% of the high-severity incidents. This concentration is significant. Three activity types produce most of the serious injuries in gas turbine maintenance and field operations—which means targeted intervention in those three areas would address the majority of catastrophic risk (International Association of Oil and Gas Producers, 2018; Centre for Chemical Process Safety, 2007).

2 Evaluation of the Hierarchy of Controls

Administrative controls were the most common failure point, cited in 55.3% of operational incidents. JSAs, permit-to-work systems, toolbox meetings, and procedural controls were documented and formally in place at the sites studied. Incident investigations showed,

however, that field personnel bypassed them regularly—particularly during maintenance outages when schedule pressure was high (Reason, 1997; International Organization for Standardization, 2018). A procedure that exists in a binder but is not enforced on the job provides no protection (Hopkins, 2008).

Engineering control failures accounted for 31.6% of incidents, involving incomplete machine guarding, inadequate scaffolding, and lifting equipment deficiencies. The severity outcomes associated with these failures were consistently high: when an engineering barrier broke down, the result was nearly always a Class A or Class B event. This confirms that removing hazards through design is a more reliable protective strategy than relying on workers to follow procedures correctly under pressure (Centre for Chemical Process Safety, 2007; International Organization for Standardization, 2018). PPE failures represented 13.1% of incidents. PPE compliance was relatively high across the facilities studied, but compliance with PPE requirements did not prevent serious injuries when the engineering and administrative layers had already failed. PPE is the last line of defence—it cannot substitute for the controls above it in the hierarchy.

3 Integration of Life-Saving Rules

The incident records showed an inverted reporting pattern: Class A and Class B events were documented more frequently than minor first-aid cases or near misses. In a well-functioning reporting system, the reverse should be true—many small incidents and near misses reported for every serious event. The inversion here indicates that workers and supervisors were not recording low-level safety deviations, which means those deviations accumulated undetected until they produced a serious injury (Reason, 1997; Centre for Chemical Process Safety, 2019). This pattern was most pronounced among subcontractors and temporary workers brought in during major outages. These workers operated under tighter deadlines, with less site familiarity and less supervisory continuity than permanent staff. Under those conditions, LSR compliance became selective (International Association of Oil and Gas Producers, 2018). Daily briefings and permit-to-work processes were completed as paperwork, not used as tools for identifying real hazards before work began (Hopkins, 2008).

The broader dataset also recorded regional health problems—malaria cases in Central African operations, communicable disease outbreaks in North African facilities—that are relevant to safety even though they are not mechanical hazards. Workers dealing with illness or fatigue from illness are less attentive, slower to respond to hazards, and less likely to follow procedures correctly. Regional health conditions belong in the operational risk picture (International Labour Organization, 2001).

V. CONCLUSIONS:

This study examined HSE management system performance and occupational safety outcomes in MENA gas power operations. Drawing on 202 documented records and Root Cause Analysis of 38 operational incidents, it found that Line of Fire, Working at Heights, and Mechanical Lifting account for the majority of Class A and Class B events.

Administrative control failures are the dominant gap in the existing safety systems studied. Documented procedures and established LSRs are in place, but they are not consistently enforced at the field level. That enforcement gap does not close on its own. It requires supervisory accountability, near-miss reporting cultures that workers trust, and

management willingness to act on what incident data reveals. Systematic Root Cause Analysis, applied to trends rather than individual events, is the tool that makes that improvement possible.

Beyond identifying the principal causes of severe occupational incidents, this study makes a practical contribution by developing an integrated risk prioritization framework that combines Root Cause Analysis (RCA) with the Hierarchy of Controls. The proposed framework enables organizations to focus preventive efforts on the most critical operational risks and to allocate safety resources more effectively. Its application is particularly relevant for electricity generation companies in Libya and across the MENA region, where strengthening supervisory accountability, improving the implementation of Life-Saving Rules, and enhancing data-driven safety decision-making can significantly improve operational safety performance.

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