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DESIGNING THE ACCIDENT CAUSATION AND PREVENTION MODEL FOR ZAMBIAN MINES: A CASE STUDY OF MOPANI COPPER MINES (NKANA MINE)

By

STANLEY HANSEELE

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Philosophy in Occupational Safety and Health Environment

Copperstone University

Kitwe, Copperbelt, Zambia

2014

DECLARATION

I, STANLEY HANSEELE, hereby declare that this thesis, submitted for the degree of Master of Philosophy in Occupational Safety and Health Environment, is my original work and has not been previously submitted for any degree or examination at any other university. All sources of information have been duly acknowledged using Harvard referencing.

Signed: .... Date: ....

CERTIFICATE OF APPROVAL

This certifies that the thesis titled "Designing the Accident Causation and Prevention Model for Zambian Mines: A Case Study of Mopani Copper Mines (Nkana Mine)" by Stanley Hanseele has been approved for submission in partial fulfilment of the requirements for the degree of Master of Philosophy in Occupational Safety and Health Environment.

Supervisor:.. Date: ....

Dean of School: .... Date: ....

DEDICATION

This thesis is dedicated to the memory of miners who lost their lives in Zambia's mines before 2014 and to their families, who continue to bear the burden of those losses. It is also dedicated to occupational safety and health practitioners striving to ensure that every miner returns home safely at the end of each shift.

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to my wife Eunice Mweene, My Children Olivia, James Stanley and Precious, supervisors, lecturers, colleagues, safety practitioners, mine workers and institutional officers whose support made this research possible. Special appreciation is extended to those who provided access to historical safety information, regulatory documents, industry reports and professional guidance. I also acknowledge my family for their patience and encouragement throughout the research process.

ABSTRACT

This thesis designs an integrated accident causation and prevention model for Zambian mines, using Mopani Copper Mines, Nkana Mine, as the principal case study. The study responds to the persistent occurrence of occupational injuries, serious incidents and fatalities in large-scale Zambian mining despite improvements in formal safety-management systems and lost-time injury frequency performance before 2014. The research is grounded in a pragmatic philosophy and a retrospective case-study design that combines accident statistics, regulatory documents, historical mine-safety evidence, occupational safety and health theory, and qualitative interpretation of incident causation. The literature review critically examines classical and systems-based accident causation models, including Heinrich's Domino model, Reason's Swiss Cheese model, the Bowtie model, Rasmussen's Risk Management Framework, STAMP, HFACS and Haddon's prevention strategies. It argues that no single imported model adequately explains accidents in a developing-country mining environment where production pressure, ageing infrastructure, contractor work, language diversity, limited regulatory capacity and resource constraints shape work conditions. The thesis develops the Zambian Mining Accident Prevention Model (ZAMPAM), a context-sensitive model integrating five causation layers: regulatory and socio-economic pressures; organisational and management systems; technical and engineering controls; task and workplace conditions; and human performance at the point of work. The prevention component converts these layers into practical interventions involving hazard identification, barrier management, ground control, ventilation assurance, machinery safety, contractor management, training, worker consultation, emergency preparedness, incident learning and regulatory strengthening. The study concludes that sustainable mine safety in Zambia requires a shift from reactive compliance to proactive, systems-based prevention supported by accountable leadership, empowered workers, robust safety data, competent regulators and continuous learning from incidents.

Keywords: accident causation; accident prevention; Zambian mines; Mopani Copper Mines; Nkana Mine; occupational safety and health; safety-management systems; ZAMPAM.

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LIST OF ABBREVIATIONS

Abbreviation	Full form
AEL	African Explosives Limited
CO	Carbon Monoxide
FEL	Front End Loader
HSE	Health, Safety and Environment
ICMM	International Council on Mining and Metals
ILO	International Labour Organization
IOSH	Institution of Occupational Safety and Health
LFI	Learning from Incidents
LHD	Load-Haul-Dump
LTI	Lost-Time Injury
LTIFR	Lost-Time Injury Frequency Rate
MCM	Mopani Copper Mines Plc
MSD	Mines Safety Department
MSHA	Mine Safety and Health Administration
MUZ	Mineworkers Union of Zambia
NIOSH	National Institute for Occupational Safety and Health
OHSA	Occupational Health and Safety Act
OSHE	Occupational Safety, Health and Environment
PPE	Personal Protective Equipment
RMF	Risk Management Framework
SCSR	Self-Contained Self-Rescuer
SHEQ	Safety, Health, Environment and Quality
SMS	Safety Management System
SOP	Standard Operating Procedure
STAMP	Systems-Theoretic Accident Model and Processes
WCFCB	Workers Compensation Fund Control Board
ZAMPAM	Zambian Mining Accident Prevention Model
ZCCM	Zambia Consolidated Copper Mines Limited

CHAPTER 1: INTRODUCTION TO THE STUDY

1.1 Introduction

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis, therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Heinrich, 1931).

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as rock bursts are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Hermanus, 2007).

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and

prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls, such as pre-start inspections, were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent explosives handling unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that underground fire and smoke should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention, therefore requires self-rescuer availability and worker consultation, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model, therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as permit-to-work controls because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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1.2.2 Historical Evolution of Zambian Mining

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1.2.3 Occupational Safety, Health, Environment and Quality

The discussion of 1.2.3 Occupational Safety, Health, Environment and Quality strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation arising from 1.2.3 Occupational Safety, Health, Environment and Quality is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as permit-to-work controls because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, 1.2.3 Occupational Safety, Health, Environment and Quality demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

In relation to 1.2.3 Occupational Safety, Health, Environment and Quality, the central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis, therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Leveson, 2011).

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The analysis of 1.2.3 Occupational Safety, Health, Environment and Quality indicates that fatigue should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires contractor induction and planned maintenance, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

1.2.4 Global Burden of Occupational Accidents

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The analysis indicates that fatigue should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires contractor induction and planned maintenance, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

1.2.5 Privatisation and Mine Safety

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close

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1.2.6 Mopani Copper Mines and Nkana Mine Overview

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1.3 Statement of the Research Problem

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1.4 Research Questions

How can interaction of the worker with equipment in the workplace cause mine accidents?

When can management controls contribute to the cause of mine accidents?

Why should task procedures and systems of work cause mine accidents?

Where in the mine can internal and external environmental conditions cause mine accidents?

What preventive measures should be implemented to improve safety and health systems in mine workplaces?

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1.5 Aim and Objectives of the Study

Main objective: To identify fundamental and underlying causal factors of mine accidents in Mopani Copper Mines workplaces and suggest safety and health policies with best practices for preventing mine accidents and supporting sustainable development.

To study and assess human aspects, environment, materials, systems and management controls as potential causes in Mopani Copper Mines workplaces.

To determine the existence and effectiveness of accident prevention programme elements including safety policy, risk management, training and consultation with employees.

To ascertain how safety and health management beliefs and proactive principles can improve workers' morale and reduce the occurrence of mine accidents.

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1.6 Hypotheses and Main Arguments

H0: Workplace accidents in mines are not caused by failures by the Mine Safety Department and mine SHEQ departments to implement safety policies.

H1: Workplace accidents in mines are caused by failures by the Mine Safety Department and mine SHEQ departments to implement safety policies.

H0: Workplace accidents in mines are not caused by negligence by miners and employees.

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1.7 Scope and Delimitations of the Study

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unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that gas exposure should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires permit-to-work controls and near-miss reporting, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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1.9 Operational Definitions

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

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2.2 Historical Development of Accident Causation Theories

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2.3 Heinrich's Domino Model

Figure 2.1: Heinrich's Domino Model

Source: Author synthesis based on the reviewed accident-causation literature.

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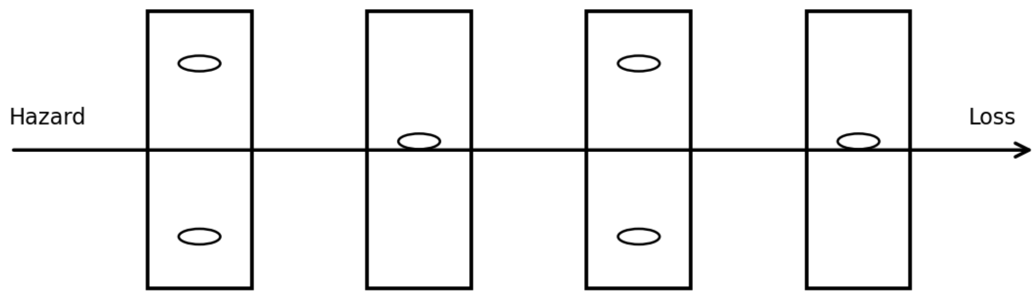
2.4 Reason's Swiss Cheese Model

Figure 2.2: Reason's Swiss Cheese Model



An accident occurs when weaknesses in successive defences align.

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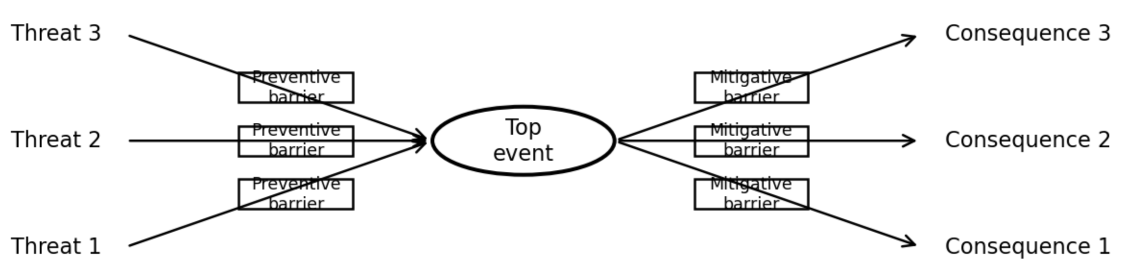
2.5 Bowtie Model and Barrier Management

Figure 2.3: Bowtie Model Schematic



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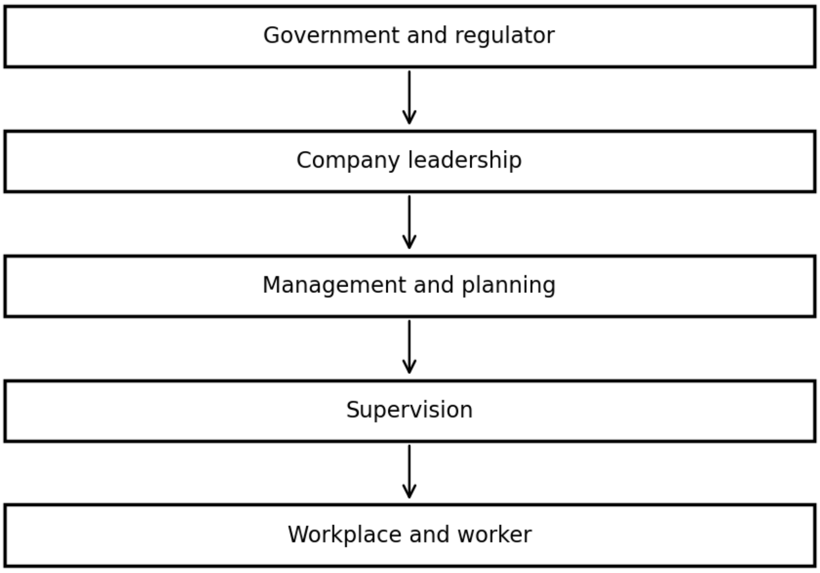
2.6 Rasmussen's Risk Management Framework

Figure 2.4: Rasmussen's Risk Management Framework



Source: Author synthesis based on the reviewed accident-causation literature.

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2.7 STAMP and Systems-Theoretic Accident Analysis

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2.10 Critical Comparison of Accident Causation Models

Table 2.1: Summary of Major Accident Causation Models

Model	Primary focus	Strength for Zambia	Main limitation
Domino	Linear chain of unsafe acts and conditions	Simple communication tool	Overemphasises individual behaviour
Swiss Cheese	Layers of defences and latent conditions	Explains organisational weaknesses	May simplify dynamic interactions
Bowtie	Threats, barriers and consequences	Supports practical barrier management	Requires skill and discipline to maintain
Rasmussen RMF	Socio-technical system and decision levels	Captures production and regulatory pressure	Less prescriptive for daily controls
STAMP	Control structures and feedback	Strong for complex systems	Requires advanced analysis capacity
HFACS	Human error classification across levels	Useful for investigation coding	Can underplay external economic pressure

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The analysis indicates that explosives handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires competency-based training and management review, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

2.11 Historical Background of the Mines Safety Department

Table 2.2: Mines Safety Department Sections and Functions

Section	Core function
Inspectorate	Workplace inspections, compliance verification and enforcement
Occupational health	Monitoring exposure, health surveillance and disease prevention
Mining engineering	Review of ground control, ventilation, machinery and mine plans
Explosives control	Licensing, storage, transport and use of explosives
Information and administration	Incident records, statistics, permits and coordination

Table 2.3: Constraints in Mines Safety Department Operations

Constraint	Safety implication
Limited staffing	Reduced inspection coverage and follow-up
Transport constraints	Delayed access to remote or underground operations
Equipment and laboratory limitations	Restricted technical verification of hazards
Fragmented incident data	Weak trend analysis and learning
Enforcement delays	Slow closure of serious corrective actions
Specialist skills gaps	Dependence on limited geotechnical, ventilation and occupational-health expertise

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The analysis indicates that explosives handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires competency-based training and management review, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

2.12 Occupational Safety and Health in Zambia

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Creswell, 2009).

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as underground fire and smoke are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Heinrich, 1931).

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The analysis indicates that explosives handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires competency-based training and management review, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as worker consultation because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be

escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

2.13 International Perspectives on Mining Safety

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Creswell, 2009).

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information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as self-rescuer availability were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent poor housekeeping unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that explosives handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires competency-based training and management review, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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2.14 Empirical Studies of Zambian Mining Accidents

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as underground fire and smoke are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Heinrich, 1931).

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2.15 Safety Management Systems in Mining

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as self-rescuer availability were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent poor housekeeping unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

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2.16 Regulatory Framework Before 2014

The analysis indicates that explosives handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires competency-based training and management review, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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2.17 Accident Investigation and Learning from Incidents

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model

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The analysis indicates that inadequate supervision should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires ground support audits and ventilation monitoring, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

2.18 Theoretical Framework for the Study

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as worker consultation because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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2.19 Gaps in the Literature

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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CHAPTER 3: RESEARCH METHODOLOGY

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A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers,

review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as planned maintenance because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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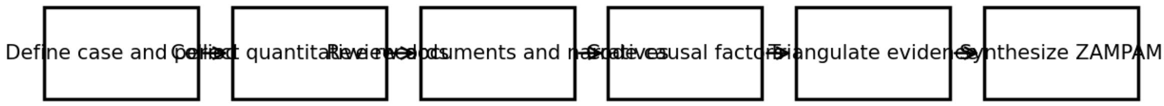
3.3 Research Design

Figure 3.1: Research Design Flowchart



Source: Author synthesis based on the reviewed accident-causation literature.

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3.5 Data Sources

Table 3.1: Data Sources and Variables Used in the Study

Data source	Period	Main variables	Use in analysis
Michelo et al. study	2005-2007	Injuries, fatalities, department, mechanism	Baseline quantitative pattern analysis
Mines Safety Department records	2010-2014	Reported injuries and fatalities	National comparison and regulatory context
Industry safety reports	2000-2014	LTIFR and safety initiatives	Trend interpretation
Regulatory documents	Pre-2014	Legal duties, reporting rules, enforcement requirements	Policy and compliance analysis
Media and public incident reports	Selected events	Incident narratives and consequences	Qualitative causation reconstruction

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3.6 Quantitative Data Extraction Procedures

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards

consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (ICMM, 2012).

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as gas exposure are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Shappell and Wiegmann, 2000).

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as permit-to-work controls were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent electrical energy unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that manual material handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires worker consultation and regulatory inspection, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model

therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as near-miss reporting because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

3.7 Qualitative Data Collection Procedures

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The analysis indicates that manual material handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires worker consultation and regulatory inspection, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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3.8 Data Analysis Methods

Table 3.2: Coding Scheme for Accident Causation Analysis

Code family	**Illustrative indicators**
Human performance	Competence, fatigue, communication, risk perception and procedural deviation
Task and workplace	Work design, congestion, housekeeping, visibility and environmental exposure
Technical controls	Equipment condition, guarding, isolation, ventilation and ground support
Management systems	Planning, supervision, maintenance, contractor control and incident learning
External environment	Regulation, labour conditions, economic pressure and industry governance

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3.9 Model Synthesis Procedure

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as permit-to-work controls were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent electrical energy unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that manual material handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires worker consultation and regulatory inspection, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM

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A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as near-miss reporting because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls

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3.10 Validity, Reliability and Trustworthiness

The analysis of 3.10 Validity, Reliability and Trustworthiness indicates that manual material handling should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires worker consultation and regulatory inspection, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion of 3.10 Validity, Reliability and Trustworthiness strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation arising from 3.10 Validity, Reliability and Trustworthiness is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as near-miss reporting because such controls provide early warning before injuries occur. The results should be reported to senior

management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, 3.10 Validity, Reliability and Trustworthiness demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

In relation to 3.10 Validity, Reliability and Trustworthiness, the central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Reason, 1997).

The literature on 3.10 Validity, Reliability and Trustworthiness shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as language barriers are shaped by complex underground conditions. Rasmussen's Risk

Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Michelo et al., 2009).

Methodologically, the analysis of 3.10 Validity, Reliability and Trustworthiness required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as emergency drills were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent mobile equipment interaction unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

3.11 Ethical Considerations

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

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3.12 Methodological Limitations

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3.13 Chapter Summary

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close

organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Reason, 1997).

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as language barriers are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Michelo et al., 2009).

CHAPTER 4: ANALYSIS OF OCCUPATIONAL INJURIES AND FATALITIES

4.1 Introduction

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Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and

prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as emergency drills were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent mobile equipment interaction unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that falls of ground should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires planned maintenance and self-rescuer availability, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

4.2 Overview of Accident Patterns

Table 4.1: Accident Evidence Variables and Interpretation

Evidence variable	Interpretive purpose
Fatality and serious-injury records	Identify high-consequence hazards and recurring pathways
Lost-time injury records	Assess frequency and departmental concentration
Near-miss reports	Detect weak signals before serious harm
Incident narratives	Identify immediate causes, failed barriers and latent conditions
Exposure and work-hour data	Provide denominators for valid comparison

Table 4.2: Fatality and Injury Reporting Framework

Reporting element	Minimum requirement
Event classification	Fatality, lost-time injury, medical-treatment case or near miss

Reporting element	Minimum requirement
Mechanism	Ground fall, machinery, transport, fire, gas, electricity, explosives or manual handling
Location and department	Shaft, level, workshop, plant or contractor area
Barrier status	Present and effective, present but failed, absent or not applicable
Corrective-action status	Owner, due date, verification evidence and closure approval

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The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as pre-start inspections because such controls provide early warning before injuries occur. The results should be reported to senior

management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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4.3 Fatality Trends and High-Risk Departments

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4.4 Non-Fatal Injury Patterns

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4.5 Falls of Ground and Rock-Related Incidents

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The analysis indicates that poor housekeeping should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires near-miss reporting and contractor induction, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

4.6 Machinery and Mobile Equipment Incidents

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4.7 Ventilation, Gas and Fire-Related Incidents

From a policy perspective, 4.7 Ventilation, Gas and Fire-Related Incidents demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

In relation to 4.7 Ventilation, Gas and Fire-Related Incidents, the central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (ILO, 1995).

The literature on 4.7 Ventilation, Gas and Fire-Related Incidents shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as explosives handling are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Creswell, 2009).

Methodologically, the analysis of 4.7 Ventilation, Gas and Fire-Related Incidents required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as competency-based training were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent contractor interface risk unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis of 4.7 Ventilation, Gas and Fire-Related Incidents indicates that poor housekeeping should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires near-miss reporting and contractor induction, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion of 4.7 Ventilation, Gas and Fire-Related Incidents strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation arising from 4.7 Ventilation, Gas and Fire-Related Incidents is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as management review because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

4.8 Contractor and Supervision Factors

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From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls

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4.9 Worker Perceptions and Safety Climate

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4.11 Regulatory and Reporting Issues

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4.12 Causal Themes Emerging from the Evidence

Table 4.3: Mechanisms and Contributing Factors in Mine Accidents

Mechanism	**Typical contributing factors**
Falls of ground	Geological uncertainty, inadequate scaling, support failure and weak examination
Mobile equipment	Blind spots, traffic interaction, maintenance and congestion
Machinery and energy	Guarding, isolation, stored energy and unauthorised access
Fire, smoke and gas	Ventilation failure, ignition sources, detection and emergency response
Contractor incidents	Induction, role clarity, supervision and inconsistent standards

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The analysis indicates that rock bursts should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires pre-start inspections and permit-to-work controls, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

4.13 Synthesis of Findings

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The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

4.14 Chapter Summary

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator

that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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CHAPTER 5: DESIGNING THE ACCIDENT CAUSATION MODEL (ZAMPAM - CAUSATION)

5.1 Introduction

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Duijm, 2009).

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Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative

information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as ground support audits were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent underground fire and smoke unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that rock bursts should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires pre-start inspections and permit-to-work controls, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

5.2 Rationale for an Integrated Zambian Model

Table 5.1: Model Selection Matrix for the Zambian Context

Model	Useful contribution	Limitation addressed by integration
Heinrich Domino	Simple event sequence and control communication	Overemphasis on individual behaviour
Swiss Cheese	Latent conditions and defence layers	Limited representation of dynamic pressure
Rasmussen RMF	Cross-level organisational interaction	Requires practical barrier translation
STAMP	System constraints and control relationships	Can be complex for routine investigations
HFACS	Structured human-factors classification	Needs stronger engineering and regulatory dimensions
Haddon Matrix	Pre-event, event and post-event prevention	Does not independently explain organisational drift

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The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as ventilation monitoring because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator

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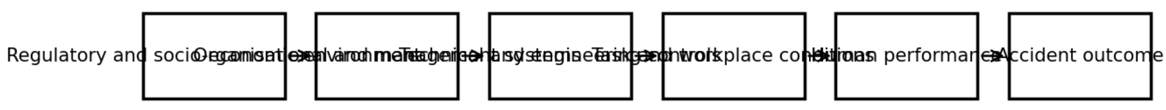
5.3 Model Design Principles

Figure 5.1: Integrated ZAMPAM Causation Model



Source: Author synthesis based on the reviewed accident-causation literature.

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5.4 Layer One: Regulatory and Socio-Economic Environment

Table 5.2: ZAMPAM Causation Layers and Indicators

Layer	Representative indicators
1. Regulatory and socio-economic environment	Inspection capacity, enforcement, labour conditions and production pressure
2. Organisational and management systems	Leadership, planning, resources, contractor control and learning
3. Technical and engineering controls	Ground support, ventilation, guarding, isolation and maintenance
4. Task and workplace conditions	Work design, access, visibility, congestion and environmental exposure
5. Human performance	Competence, fatigue, communication, decision-making and procedural adherence

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5.7 Layer Four: Task and Workplace Conditions

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The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as manual material handling are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (ICMM, 2012).

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The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as regulatory inspection because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

5.8 Layer Five: Human Performance at the Point of Work

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5.9 Barrier Failure and Accident Pathways

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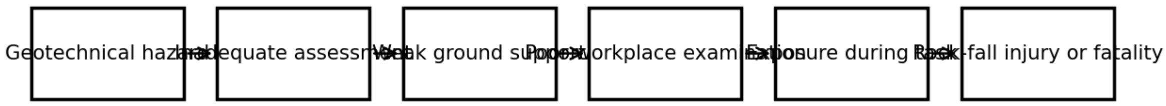
5.10 Example Pathway: Rock Fall Fatality

Figure 5.2: Example Causation Pathway - Rock Fall Fatality



Source: Author synthesis based on the reviewed accident-causation literature.

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5.11 Example Pathway: Gas Poisoning Incident

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5.12 Model Application to Accident Investigation

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5.13 Strengths and Limitations of ZAMPAM Causation

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5.14 Chapter Summary

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls

are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Haddon, 1972).

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as falls of ground are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Reason, 1997).

CHAPTER 6: THE INTEGRATED PREVENTION MODEL (ZAMPAM - PREVENTION)

6.1 Introduction

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Haddon, 1972).

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Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative

information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as planned maintenance were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent gas exposure unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that mobile equipment interaction should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires ventilation monitoring and competency-based training, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

6.2 Prevention Philosophy of ZAMPAM

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as falls of ground are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Reason, 1997).

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The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as self-rescuer availability because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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6.3 Hazard Identification and Risk Assessment

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as planned maintenance were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent gas exposure unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that mobile equipment interaction should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires ventilation monitoring and competency-based training, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as self-rescuer availability because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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6.4 Ground Control and Geotechnical Assurance

The analysis indicates that mobile equipment interaction should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires ventilation monitoring and competency-based training, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption.

The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as self-rescuer availability because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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where hazards such as poor housekeeping are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (ILO, 1995).

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as near-miss reporting were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent language barriers unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

6.5 Machinery, Traffic and Energy Control

The discussion of 6.5 Machinery, Traffic and Energy Control strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation arising from 6.5 Machinery, Traffic and Energy Control is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as self-rescuer availability because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, 6.5 Machinery, Traffic and Energy Control demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

In relation to 6.5 Machinery, Traffic and Energy Control, the central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Hermanus, 2007).

The literature on 6.5 Machinery, Traffic and Energy Control shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as poor housekeeping are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (ILO, 1995).

Methodologically, the analysis of 6.5 Machinery, Traffic and Energy Control required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as near-miss reporting were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent language barriers unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis of 6.5 Machinery, Traffic and Energy Control indicates that contractor interface risk should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires regulatory inspection and ground support audits, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

6.6 Ventilation, Fire and Emergency Preparedness

A practical recommendation arising from 6.6 Ventilation, Fire and Emergency Preparedness is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as self-rescuer availability because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, 6.6 Ventilation, Fire and Emergency Preparedness demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

In relation to 6.6 Ventilation, Fire and Emergency Preparedness, the central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Hermanus, 2007).

The literature on 6.6 Ventilation, Fire and Emergency Preparedness shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as poor housekeeping are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (ILO, 1995).

Methodologically, the analysis of 6.6 Ventilation, Fire and Emergency Preparedness required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as near-miss reporting were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent language barriers unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis of 6.6 Ventilation, Fire and Emergency Preparedness indicates that contractor interface risk should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires regulatory inspection and ground support audits, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion of 6.6 Ventilation, Fire and Emergency Preparedness strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

6.7 Training, Competence and Behavioural Reliability

From a policy perspective, 6.7 Training, Competence and Behavioural Reliability demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

In relation to 6.7 Training, Competence and Behavioural Reliability, the central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Hermanus, 2007).

The literature on 6.7 Training, Competence and Behavioural Reliability shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as poor housekeeping are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (ILO, 1995).

Methodologically, the analysis of 6.7 Training, Competence and Behavioural Reliability required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as near-miss reporting were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent language barriers unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis of 6.7 Training, Competence and Behavioural Reliability indicates that contractor interface risk should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires regulatory inspection and ground support audits, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion of 6.7 Training, Competence and Behavioural Reliability strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation arising from 6.7 Training, Competence and Behavioural Reliability is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as contractor induction because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

6.8 Contractor Safety Management

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The analysis indicates that contractor interface risk should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires regulatory inspection and ground support audits, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

6.9 Worker Participation and Safety Committees

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as poor housekeeping are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (ILO, 1995).

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6.10 Safety Leadership and Accountability

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The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as rock bursts are shaped by complex underground conditions.

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6.11 Incident Reporting and Learning from Incidents

The analysis indicates that contractor interface risk should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires regulatory inspection and ground support audits, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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6.12 Regulatory Strengthening and Policy Reform

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

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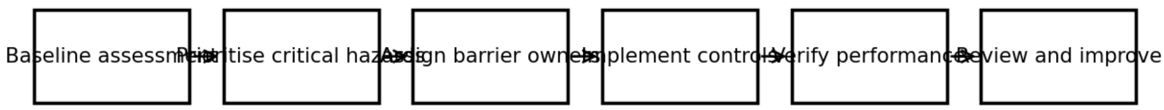
prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as pre-start inspections were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent explosives handling unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that underground fire and smoke should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires self-rescuer availability and worker consultation, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

6.13 Implementation Roadmap

Figure 6.1: ZAMPAM Prevention Model Implementation Pathway



Source: Author synthesis based on the reviewed accident-causation literature.

Table 6.2: Implementation Risk Register

Implementation risk	Potential effect	Control response
Insufficient management ownership	Delayed decisions and weak accountability	Assign executive sponsor and barrier owners
Limited resources	Controls remain incomplete	Prioritise critical risks and phase expenditure
Worker resistance or low trust	Poor reporting and participation	Consult workers and protect good-faith reporting
Weak contractor alignment	Different standards at shared workplaces	Use common minimum requirements and verification
Inadequate performance data	Failure to detect deterioration	Adopt standard definitions and leading indicators

Table 6.1: ZAMPAM Prevention Intervention Matrix

Intervention area	Immediate action	Medium-term action	Responsible owner
Ground control	Verify support in active panels	Develop geotechnical assurance dashboard	Mine Manager / Geotechnical Engineer
Ventilation and fire	Check ventilation and self-rescuer caches	Install stronger emergency readiness audits	Engineering Manager / Safety Manager
Mobile equipment	Refresh traffic rules and visibility checks	Implement energy isolation and route redesign	Engineering / Operations
Training	Audit induction and refresher records	Develop competency-based training framework	Training Department / SHEQ
Incident learning	Review open corrective actions	Create learning-from-incidents database	SHEQ Manager / Department Heads

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as contractor induction because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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The analysis indicates that underground fire and smoke should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires self-rescuer availability and worker consultation, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate

safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

6.14 Monitoring and Evaluation Framework

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Yin, 2009).

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6.15 Budget and Resource Considerations

Table 6.3: Three-Year Implementation Budget Framework

Resource area	Year 1 emphasis	Year 2 emphasis	Year 3 emphasis
Critical engineering controls	Immediate high-risk defects	Planned upgrades	Sustaining maintenance
Training and competence	Baseline assessment and priority training	Role-based certification	Refresher and reassessment

Resource area	Year 1 emphasis	Year 2 emphasis	Year 3 emphasis
Data and incident learning	Standard registers and reporting	Trend analysis and dashboards	Predictive assurance
Regulatory and stakeholder coordination	Compliance gap closure	Joint reviews and benchmarking	Continuous improvement
Emergency preparedness	Equipment and drills	Scenario testing	Maturity verification

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6.16 Chapter Summary

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CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

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7.2 Summary of Major Findings

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7.3 Conclusions by Research Objective

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7.4 Contribution to Knowledge

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The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as electrical energy are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Ndubani and Högstedt, 2006).

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding

process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as management review were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent inadequate supervision unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that fatigue should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires contractor induction and planned maintenance, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as emergency drills because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

7.6 Contribution to Policy

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (Rasmussen, 1997).

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Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as management review were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent inadequate supervision unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that fatigue should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires contractor induction and planned maintenance, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational

discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as emergency drills because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

7.7 Recommendations for Mopani Copper Mines

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as electrical energy are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Ndubani and Högstedt, 2006).

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The analysis indicates that fatigue should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires contractor induction and planned maintenance, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as emergency drills because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards

consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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7.8 Recommendations for Zambian Mine Operators

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as management review were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent inadequate supervision unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

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A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers,

review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as emergency drills because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

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The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as mobile equipment interaction are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Haddon, 1972).

7.9 Recommendations for Regulators and Government

The analysis indicates that fatigue should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires contractor induction and planned maintenance, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

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safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as emergency drills because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

7.10 Recommendations for Worker Representatives

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

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7.11 Limitations of the Study

A practical recommendation is that mines should translate the ZAMPAM layers into a routine assurance schedule. Each department should identify its critical hazards, define the preventive and mitigative barriers for each hazard, assign ownership of each barrier, and test the integrity of those barriers using evidence rather than assumption. The assurance process should include physical verification, interviews with workers, review of maintenance and training records, and trend analysis of near-miss data. Priority should be given to controls such as emergency drills because such controls provide early warning before injuries occur. The results should be reported to senior management and safety committees, and unresolved critical actions should be escalated. This approach changes prevention from a campaign-driven activity into a disciplined management cycle.

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The analysis indicates that gas exposure should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires permit-to-work controls and near-miss reporting, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

7.12 Areas for Further Research

From a policy perspective, the study demonstrates the importance of aligning mine-level prevention with national regulatory capacity. A mine may establish internal procedures, but weak external enforcement reduces the pressure to maintain standards consistently across operators and contractors. The Zambian context requires a regulator that has adequate staffing, transport, technical expertise, inspection tools and legal authority to respond quickly to high-risk conditions. Inspection should not be limited to checking the existence of documents; it should test whether risk assessments, ground

control plans, ventilation standards, emergency preparedness and contractor controls are functioning in practice. Policy reform should therefore strengthen inspection frequency, incident reporting, sharing of lessons learned and penalties for repeated failure to correct serious hazards. These measures would support both prevention and public confidence in mining governance.

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (ILO, 2006).

The literature shows that Reason's Swiss Cheese model remains useful because it offers a simple language for explaining sequence, but its linear logic is insufficient where hazards such as mobile equipment interaction are shaped by complex underground conditions. Rasmussen's Risk Management Framework provides a stronger basis for understanding the alignment of weaknesses across technical, human and organisational barriers. In the mining environment, a worker's error may be the last visible action, yet that action may have been shaped by a poorly designed workplace, inadequate communication, an unavailable tool, a shortage of supervision, or a production target that encourages risk acceptance. For this reason, the present study uses older accident causation theories critically rather than mechanically. Each theory is assessed according to its ability to explain the Zambian setting and to guide practical prevention in a resource-constrained mine. The review supports the conclusion that a combined model is more suitable than importing one theory unchanged (Haddon, 1972).

Methodologically, the study required a design capable of joining numerical accident patterns with contextual explanation. The study therefore treats quantitative

indicators, such as fatality counts, lost-time injury rates and reported mechanisms of injury, as evidence of patterns that require interpretation. At the same time, qualitative information from safety procedures, regulatory requirements, incident descriptions and prevention programmes is used to explain why those patterns persisted. The coding process classified evidence according to human factors, task design, equipment condition, environmental exposure, management control and external regulation. A specific concern was whether controls such as ventilation monitoring were present only as formal statements or whether they were embedded in daily work. This distinction is important because a written procedure does not prevent manual material handling unless workers, supervisors and managers understand it, resource it, monitor it and correct deviations in time.

The analysis indicates that gas exposure should be interpreted as a system signal rather than an isolated event category. Where a fatality or serious injury occurs, the investigation should ask which barriers were expected to be in place, which barriers were absent, which barriers existed but were weak, and which barriers failed during the event. For example, a fall-of-ground event may involve geological stress, insufficient scaling, defective ground support, inadequate workplace examination, weak supervision and limited worker authority to stop unsafe work. Similarly, a mobile equipment injury may involve traffic layout, visibility, maintenance, operator competence and production congestion. Effective prevention therefore requires permit-to-work controls and near-miss reporting, but also requires management to analyse whether those controls are reliable under real operating pressure. The ZAMPAM approach converts such event categories into prevention pathways that can be audited before harm occurs.

The discussion strengthens the central conclusion that safety improvement in mines must move from compliance as paperwork to compliance as operational discipline. In many organisations, policies, procedures and safety slogans exist, but the decisive issue is whether they influence decisions at the workplace when time, cost and production pressure compete with safe practice. The expanded ZAMPAM model therefore treats leadership, worker participation and regulatory inspection as active controls rather than administrative background factors. Management must demonstrate safety commitment through budget allocation, competent appointments, prompt correction of defects and protection of workers who report hazards. Workers must be empowered through training, consultation and stop-work authority. Regulators must be sufficiently resourced to inspect, investigate and enforce. Without these conditions, the formal safety management system remains vulnerable to drift.

7.13 Final Conclusion

The central argument of this thesis is that accident causation in Zambian mines cannot be reduced to a single unsafe act, a single failed component, or a single defective procedure. Mine accidents emerge from the interaction of people, equipment, tasks, working environment, supervision, organisational priorities and regulatory conditions. This expanded analysis therefore treats each accident as a visible outcome of a deeper system. The Zambian Copperbelt mining context demonstrates that immediate triggers are often only the final expression of earlier decisions about planning, resources, training, inspection, maintenance and production. The implication is that prevention must be designed at several levels at once. It must strengthen the physical workplace, improve competence at the point of work, ensure disciplined supervision, close organisational learning loops and reinforce external accountability. This layered position is consistent with systems thinking in accident prevention (ILO, 2006).

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REFERENCES

Acts Online (2004) Mine Health and Safety Act, South Africa. Cape Town: Government Printer.

Creswell, J.W. (2009) Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. 3rd edn. Thousand Oaks, CA: Sage.

Duijm, N.J. (2009) 'Safety-barrier diagrams as a safety management tool', Reliability Engineering and System Safety, 94(2), pp. 332-341.

Fraser, A. and Lungu, J. (2006) For Whom the Windfalls? Winners and Losers in the Privatisation of Zambia's Copper Mines. Lusaka: Civil Society Trade Network of Zambia.

Haddon, W. (1972) 'A logical framework for categorizing highway safety phenomena and activity', Journal of Trauma, 12(3), pp. 193-207.

Heinrich, H.W. (1931) Industrial Accident Prevention: A Scientific Approach. New York: McGraw-Hill.

Hermanus, M.A. (2007) 'Occupational health and safety in mining-status, new developments, and concerns', Journal of the Southern African Institute of Mining and Metallurgy, 107(8), pp. 531-538.

Hollnagel, E. (2004) Barriers and Accident Prevention. Aldershot: Ashgate.

International Council on Mining and Metals (2012) Overview of Leading Indicators for Occupational Health and Safety in Mining. London: ICMM.

International Labour Organization (1995) Safety and Health in Mines Convention, 1995 (No. 176). Geneva: ILO.

International Labour Organization (2006) Promotional Framework for Occupational Safety and Health. Geneva: ILO.

Leveson, N. (2011) Engineering a Safer World: Systems Thinking Applied to Safety. Cambridge, MA: MIT Press.

Michelo, P., Bratveit, M. and Moen, B.E. (2009) 'Occupational injuries and fatalities in copper mining in Zambia', Occupational Medicine, 59(3), pp. 191-194.

Mines Safety Department (2014) Annual Mine Safety Statistics. Kitwe: Ministry of Mines and Minerals Development.

Mopani Copper Mines (2011) Sustainability and Safety Management Information. Kitwe: Mopani Copper Mines Plc.

Ndubani, P. and Hogstedt, C. (2006) 'Accident occurrence and related factors among Zambian mineworkers', Occupational Medicine, 56(6), pp. 452-457.

National Institute for Occupational Safety and Health (2010) A Systematic Review of the Effectiveness of Training and Education for the Protection of Workers. Cincinnati, OH: NIOSH.

Rasmussen, J. (1997) 'Risk management in a dynamic society: a modelling problem', Safety Science, 27(2-3), pp. 183-213.

Reason, J. (1990) Human Error. Cambridge: Cambridge University Press.

Reason, J. (1997) Managing the Risks of Organizational Accidents. Aldershot: Ashgate.

Shappell, S.A. and Wiegmann, D.A. (2000) The Human Factors Analysis and Classification System-HFACS. Washington, DC: Federal Aviation Administration.

Yin, R.K. (2009) Case Study Research: Design and Methods. 4th edn. Thousand Oaks, CA: Sage.

Zambian Mining News (2014) 'Mopani Copper Mines safety performance and LTIFR improvement'. Kitwe: Zambian Mining News.

APPENDIX A: ACCIDENT INVESTIGATION FORM

Table A1: Accident Investigation Template

Field	Details
Incident title	
Date and time	
Location and department	
Injured person(s) and witnesses	
Immediate description of the event	
Hazards involved	
Failed preventive barriers	
Failed mitigative barriers	
Latent organisational conditions	
Corrective actions	
Action owner and target date	
Verification evidence and closure approval	

For operational use, the APPENDIX A: ACCIDENT INVESTIGATION FORM component of ZAMPAM can be converted into checklists, investigation forms, training matrices and departmental scorecards. The checklist should require the investigation team to record the hazard, immediate trigger, failed barriers, latent conditions, responsible owners, corrective actions, completion dates and verification evidence. A training matrix should indicate the competencies required for each role and the date when refresher training is due. A departmental scorecard should combine lagging indicators, such as injuries, with leading indicators, such as inspections completed, corrective actions closed, safety observations, near-miss reports and emergency drills. These appendices make the model usable beyond academic explanation and support implementation by supervisors, safety officers, managers and worker representatives.

APPENDIX B: BARRIER VERIFICATION CHECKLIST

Table A2: Barrier Verification Checklist

Critical hazard / barrier	Required?	Available?	Effective?	Verification evidence	Action owner	Due date

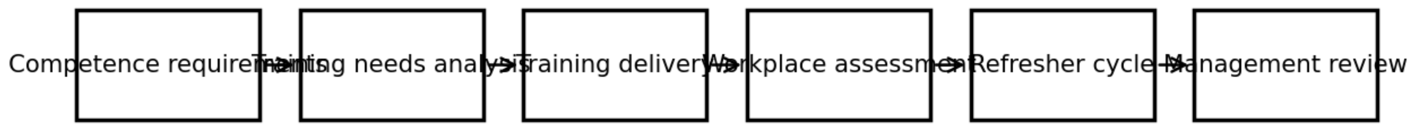
For operational use, the APPENDIX B: BARRIER VERIFICATION CHECKLIST component of ZAMPAM can be converted into checklists, investigation forms, training matrices and departmental scorecards. The checklist should require the investigation team to record the hazard, immediate trigger, failed barriers, latent conditions, responsible owners, corrective actions, completion dates and verification evidence. A training matrix should indicate the competencies required for each role and the date when refresher training is due. A departmental scorecard should combine lagging indicators, such as injuries, with leading indicators, such as inspections completed, corrective actions closed, safety observations, near-miss reports and emergency drills. These appendices make the model usable beyond academic explanation and support implementation by supervisors, safety officers, managers and worker representatives.

APPENDIX C: TRAINING AND COMPETENCE MATRIX

Table A3: Training and Competence Matrix

Role / occupation	Required competence	Training module	Assessment method	Current status	Refresher due

Figure A1: Training and Competence Thematic Network



Source: Author synthesis based on the reviewed accident-causation literature.

For operational use, the APPENDIX C: TRAINING AND COMPETENCE MATRIX component of ZAMPAM can be converted into checklists, investigation forms, training matrices and departmental scorecards. The checklist should require the investigation team to record the hazard, immediate trigger, failed barriers, latent conditions, responsible owners, corrective actions, completion dates and verification evidence. A training matrix should indicate the competencies required for each role and the date when refresher training is due. A departmental scorecard should combine lagging indicators, such as injuries, with leading indicators, such as inspections completed, corrective actions closed, safety observations, near-miss reports and emergency drills. These appendices make the model usable beyond academic explanation and support implementation by supervisors, safety officers, managers and worker representatives.

APPENDIX D: ZAMPAM IMPLEMENTATION SCORECARD

Table A4: ZAMPAM Implementation Scorecard

Indicator	Definition	Baseline	Target	Current result	Status	Owner	Review date

For operational use, the APPENDIX D: ZAMPAM IMPLEMENTATION SCORECARD component of ZAMPAM can be converted into checklists, investigation forms, training matrices and departmental scorecards. The checklist should require the investigation team to record the hazard, immediate trigger, failed barriers, latent conditions, responsible owners, corrective actions, completion dates and verification evidence. A training matrix should indicate the competencies required for each role and the date when refresher training is due. A departmental scorecard should combine lagging indicators, such as injuries, with leading indicators, such as inspections completed, corrective actions closed, safety observations, near-miss reports and emergency drills. These appendices make the model usable beyond academic explanation and support implementation by supervisors, safety officers, managers and worker representatives.

GLOSSARY

Accident: An unplanned, uncontrolled event that leads to injury, ill health, damage or loss.

Barrier: A physical, procedural or organisational control that prevents a hazard from causing harm or reduces the consequence of an event.

Latent condition: A hidden organisational weakness that can combine with active failures to cause an accident.

Lost Time Injury: An injury that prevents the worker from performing normal duties for at least one full shift after the day of injury.

LTIFR: The number of lost time injuries per one million hours worked.

Near miss: An unplanned event that did not cause injury or damage but had the potential to do so.

Production pressure: Economic or managerial pressure to prioritise output in a way that may weaken safety margins.

Root cause analysis: A structured process for identifying the underlying causes of an incident beyond the immediate trigger.

Safety culture: The shared assumptions, values and beliefs that shape how safety is understood and practised.

Safety climate: The measurable perceptions of workers about management commitment, risk control and safety priority.

ZAMPAM: The Zambian Mining Accident Prevention Model developed in this thesis.