



**UNIVERSITY
OF
LUSAKA**

SCHOOL OF POSTGRADUATE STUDIES

**A FRAMEWORK FOR PREVENTING UNDERGROUND DRILL RIG
BREAKDOWNS: A CASE OF LUBAMBE COPPER MINE**

BY

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Submitted to the School of Postgraduate Studies in fulfilment of the
requirement for the Doctor of Philosophy Degree in Project Management
of the University of Lusaka

2019

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DEDICATION

A special dedication to my beloved wife Mable and my Children Natasha (Jaff), Joshua (Lion), Timothy (Senshi), and the little Jewell, Keturah (Duddy).

ACKNOWLEDGEMENT

I wish to sincerely thank all the people that contributed in one way or another to the long journey I took of conducting and writing this study/thesis, without their humble and continuous support, it was going to be difficult if not impossible to bring this work to fruition.

Most sincerely, I wish to thank Professor Grant Keeble Kululanga and Eng. Dr. Richard Kasongo Mwale, my Co-Supervisors, for guiding me conscientiously in the writing of the report. I will remain greatly indebted to them for their commitment and dedication to academic work.

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Special thanks go to my wife Mable and my Children Natasha, Joshua, Timothy, Hope and the little Jewell, Keturah for the support they gave me and indeed all my friends too many to mention who helped me with little things that I could not have done without in my studies.

I will be failing in my appreciation if I leave out Moses Simuchimba who was very instrumental in helping out with all IT related issues, my mentor Dr. Floyd Banda and my elder brother Obet Galatia for his encouragement during tough times: my friends and colleagues, I appreciate them for their guidance.

MOTIVATION

Most of the work described in this thesis was carried out at Lubambe Copper Mine in Zambia and the reason for conducting the study was to identify the major causes of drill rig breakdowns at Lubambe Copper Mine and develop a framework for identifying potential causes of breakdowns.

During my service in the mining industry, I had observed that the challenges faced with the mining industry in terms of underground equipment in Zambia were similar in nature. Therefore, drill rigs being the primary equipment in ore extraction from underground, I found it necessary to conduct a study to identify the major causes of drill rig breakdowns, thereafter, develop a framework for identifying potential causes of breakdowns. The rationale behind was that, the study findings could potentially be useful to Lubambe Copper Mine Management in finding mitigation measures for drill rig breakdowns and that these measures or strategies may be extended to organisations in the industry that may be faced with similar challenges.

The dictum in the mining industry is the same, emphasis is on production, therefore, due to production pressure, the maintenance personnel tend to concentrate on repairing the broken down equipment so that it could go back into production at the least possible downtime and usually neglect the idea of conducting studies into factors that lead to equipment breakdown. This tendency creates a situation where the mine goes through the same process of resolving problems and expecting different results, a condition which develops into a culture of rigidity in maintenance and resistance to change. However, to keep up with the dynamic technological advancement in the modern world, it is important to continuously seek knowledge and be more fully engaged in finding solutions to problems.

Therefore, the motivation to conduct this study was drawn from the epistemological and ontological perspective of the aviation industry which through its superior maintenance culture of precision operates with the least number of equipment breakdowns unlike the mining industry where the underground equipment is subjected to numerous breakdowns. The aim of the study was to identify the causes of drill rig breaks and finding a way of mitigating the potential causes before the actual breakdown occurs.

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ACRONYMS AND ABBREVIATIONS

ARM	– Africa Rainbow Minerals
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BH	– Breakdown Hours
CBM	– Condition based Maintenance
CM	– Corrective Maintenance
DJ	– Drilling Jumbo
DLH	– Long Hole Drill Rig
EMR	– Energy Mineral Resource
FMECA	– Failure Mode Effects and Critical Analysis
GDP	– Gross Domestic Product
HR	– Human Resources
JIT	– Just-In-Time
KML	– Konjole Minerals Limited
KPI	– Key Performance Indicators
LHD	– Load Haul Dump
MARC	– Maintenance and Repair Contract
Mbgl	– Meters Below Ground Level
MH	– Maintenance Hours
MTBF	– Mean Time Before Failure
MTTR	– Mean Time To Repair
NDT	– Non-Destructive Test
OE	– Overall Equipment Effectiveness
OEM	– Original Equipment Manufacturer
PTO	– Planned Task Observation
RBM	– Risk Based Maintenance
RCM	– Reliability Centered maintenance
SADC	– Southern Africa Development Community
SSH	– Service Shift Hours
TPM	– Total Productive Maintenance
TQM	– Total Quality Management
ZCCM	– Zambia Consolidated Copper Mine
LCM	– Lubambe Copper Mine

DEFINITION OF KEY TERMS

Different studies present words or expressions that have a precise meaning in a specified field of research that may not be easily understood by people not in that field, such words or expressions therefore, need explaining to the reader to ensure clarity.

In this section, the study defines terms that may be beyond common language to some readers:

Project

A project is a temporary endeavor undertaken to create a unique product, service, or result. The temporary nature of projects indicates that a project has a definite beginning and end. The end is reached when the project's objectives have been achieved or when the project is terminated because its objectives will not or cannot be met, or when the need for the project no longer exists. A project can also be terminated if the client (customer, sponsor, or champion) wishes to terminate the project (Project Management Body of Knowledge – PMBOK Guide, 2013).

In this study, a project was considered as the phase from 2010 when the feasibility studies and construction of the mine commenced to 2014 when the planned production target of 200,000 tons of copper ore per month was expected.

Equipment Productivity:

Singla and Gupta (2016) defined equipment productivity as the ratio of per hour cost and productivity, it provides an amount which equipment cost for one unit of productivity and is calculated as;

$$\text{Productivity} = \frac{\text{average output per period}}{\text{total cost of production}}$$

The study considered productivity as the measure of the ore generated in a specific target time against the cost of production within the same time frame.

Efficiency

Harry and John (2007) defined efficiency as the ratio of what we get out of something relative to what we put in. efficiency is calculated as;

$$\text{Efficiency} = \frac{\text{Usefull Output work}}{\text{Input Work}} \times 100$$

According to this study, efficiency refers to the actual ore produced from underground in a specified time (taken as 19.92 hours by LCM) to how the resources were utilised to generate the intended tonnage. This included such aspects as the accuracy of drilling, use of explosives, use of the machines and how labour was utilised.

Overall Equipment Effectiveness (OEE)

OEE is a simple tool that helps managers to measure the effectiveness of the equipment. It takes the most common and important sources of productivity loss (Elevli, 2010).

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

Overall equipment effectiveness in the study was taken as the product of the time the drill rig was available for work, the amount of meters drilled against the set standard and the quality of product obtained.

Equipment Breakdown

The study considered equipment breakdown as a condition when a machine (in this case a drill rig) was prevented from functioning in a normal way due to a developed fault or faults on the machine.

Drill Rig

Ai-Chalabi (2014) maintained that, a mining drilling rig is a machine used to create holes in the ground and on the other hand, a drill rig as promulgated by Vaclav (2011), is defined as a machine that makes holes in the earths sub-surface.

The study considered a drill rig as a machine used for making holes in the rock in readiness for blasting operations.

Equipment Availability:

Hillon (2008), defined availability as the probability that a piece of equipment is functioning satisfactorily at a specified time, when used according to specified conditions, where the total time includes operating time, logistical time, active repair time, and administrative time and from Pinto and Xavier (2001) availability is defined as the ratio of possible working hours to calendar hours. It is an important indication for reliability analysis and calculated as;

$$\text{Availability} = \frac{\text{Run Time}}{\text{Planned Production Time}} \times 100$$

Equipment availability in the study was taken as the time a piece of equipment (in this case the drill rig) was readily available for work whether the site was available or not and the units were expressed in hours.

Equipment Performance

Equipment performance is an evaluation of how well the equipment operates in relation to the set standards (Lubambe Engineering Maintenance Strategy document, 2017). Equipment performance is calculated as;

$$\text{Performance} = \frac{\text{Ideal Cycle Time} \times \text{Total Count}}{\text{Run Time}}$$

Equipment performance from the study's stand point was defined as the measure of equipment's attainment of the set Mean Time To Repair, Mean Time Between failure and the Pareto Analysis.

Major Component

From the study, a major component was termed as that part of a machine taken to have a longer life cycle and usually of a higher value. At LCM, the replacement of components was planned and bases on operating hours or distance covered.

Maintenance

Maintenance is an activity, in which repairing is carried out at certain intervals, to extend useful life of the machine, it can further be defined as those activities required

to keep a facility in 'as built' condition and therefore, continuing to have its original productive capacity (Reason, 2000).

Maintenance as defined from the study was considered as the process or activities taken to ensure that the equipment continues to operate as required and being available when required for use.

Condition based maintenance

Hall (1997) contended that, Condition Based maintenance is a kind of maintenance that involves knowing the condition of the equipment in order to schedule maintenance. The axiom of this kind of maintenance is that, servicing is permitted only when measurements show it to be necessary.

Condition based maintenance as described from the study, is expresses the kind of maintenance where the condition of components on the machine are monitored for wear and corrective action planned for a later date or immediately depending on the severity of wear or deterioration. For example at LCM, the wear of drill rig axle internal parts was monitored through oil analysis.

Corrective maintenance

In this study, corrective maintenance was termed as the kind of maintenance carried out when a piece of equipment or system shows signs of failure and in line with EN 13 306 (2001) corrective maintenance is the maintenance carried out after fault recognition and is intended to put an item or system into a state in which it can perform its required function.

Total Productive Maintenance

Total Productive maintenance is a kind of maintenance that seeks to develop a 'maintenance-free' design, asking all employees to help improve maintenance productivity by stimulating their daily awareness (Nakajima, 1988).

The study considered total productive maintenance as a kind of maintenance where all members of the company are involved in equipment maintenance, thus, the ideas of how to maintain the equipment and the identification of faults is open to all members of the organisation.

Reliability Centred Maintenance

Catola (1988) defined Reliability centred Maintenance as a methodology intended for use in developing the preventive maintenance tasks which, together comprise the preventive maintenance programme.

The study further defined reliability centred maintenance as the kind of maintenance where the maintenance tasks carried out on equipment or a system are monitored and assessed in order to improve the quality of maintenance through revised maintenance processes.

Mechanised Operations

The study considered mechanised operations as carrying out work by the use of machines

Mean Time To Repair (MTTR)

Esmaeili (2016) asserted Mean Time to Repair as the mean time required to repair a component and is expressed as the total repair time divided by the total number of repairs.

In line with the study, Mean Time To Repair was expressed as the ratio machine downtime to the number of times the machine was repaired and this was stated in hours.

$$MTTR = \frac{\Sigma (\text{Breakdown Time})}{\# \text{ Breakdowns}}$$

Mean Time Before Failure (MTBF)

Esmaeili (2016) expressed Mean Time Between Failures (MTBF) as the mean time of the failure distribution of a machine or component and for a constant failure rate, it is expressed as the total operating time divided by the total number of repairs.

$$MTBF = \frac{\text{Operating Hours}}{\# \text{ Failures}} = \frac{1}{\lambda}$$

Mean Time Before Failure in the study was considered as the time recorded from one failure of the equipment or system to another and expressed in hours.

Capacity

The study considered capacity as the ability to contain things, for example, capacity was created in the workshop through scheduling of machines on breakdown and those on planned maintenance. This was done to avoid congestion in the workshop and having machines to miss scheduled maintenance time slots or being maintained late due to non-availability of free service bays.

Capacity has to do with collective ability, thus, that combination of attributes that enable a system to perform, deliver value, establish relationships and to renew itself. Or put this way, the abilities that allow systems - individuals, groups, organisations, and groups of organisations - to be able to do something with some sort of intention and with some sort of effectiveness and at some sort of scale over time (Morgan, 2006).

Ore

Gilbert and Charles (1986) defined ore as a type of rock that contains sufficient minerals with important elements including metals that can be economically extracted from the rock. The study held the definition of Ore as a mass of rock containing a mineral or minerals.

Refurbishment

Scott (2015), stated that refurbishment is the distribution of products that have been previously restored to a manufacturer or vendor for various reasons.

Refurbishment from the stand point of the study meant restoring the life of a machine through a major scheduled maintenance that involves replacement of major components and repair or replacement of the machine frames. It is scheduled according to the machine hours and drill rigs at LCM underwent the first planned refurbishment at 8,000 percussion hours where the boom was rebuild.

Failure rate

Failure rate is the frequency with which a piece of equipment, system or component fails and expressed in failures per unit of time (Consultants in Lean Manufacturing Strategy, 2017).

$$\lambda = \frac{\# \text{ Failures}}{\text{Operating Hours}}$$

Failure rate as described from the study denotes the number of times a machine breaks down in a specified period of time.

Skill

A skill is the learned ability to carry out pre-determined results often with the minimum outlay of time, or both. In other words, the abilities that one possess (Princeton's World Net, 2018)

Skill as described from the study implies the ability of employees to perform their work in accordance with the mine set standards and in line with the learnt abilities.

Reliability

Walter and Samuel (2013) defined reliability as the probability that the item will perform its intended function throughout a specified time period when operated in a normal (or stated) environment and Margaret (2013) declared that, reliability is the ability of a person or system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances.

The study considered reliability as the chance that a machine works within a specified time without breaking down (at least 19.92 hours in 24 hours as set by LCM) and Princeton's WorldNet (2018) defined reliability as the abilities that one possessed.

Utilisation

Veloso (2009) defines utilisation as the ratio of worked hours to possible working hours.

With reference to the study, utilisation was termed as being the time a piece of equipment is in active production and the units expressed in hours.

Reaming

From the study, reaming implies drilling through a drilled hole to open it to the next lager size

ABSTRACT

Mining is the key sector to Zambia's economic development. The sector is a major contributor to national export earnings and employment. Nevertheless, the importance of mining industry to the economy depends on sustained high levels of production output. As such, Lubambe Copper Mine (LCM) under Konkola North project was commissioned in 2010 with the view of producing 200,000 tonnes of Ore per month by 2014. However, this target could not be achieved due to the high rate of drill rig breakdown. Despite several attempts to address the problem of equipment breakdown, the situation still remained unresolved at Lubambe Copper Mine.

This study therefore, sought to investigate the cause of the frequent drill rig breakdown. To explore and identify the causes of drill rig breakdowns at LCM, a multimethod approach was adopted and qualitative data provided deeper insights and explanations of the problem. A total of 134 copies of questionnaires were answered and 35 key informants were interviewed. Transcripts from qualitative questionnaires and interviews with key informants were uploaded and coded in NVivo and the Chi-Square from SPSS software package was used to determine association between variables and determining the p value, while the Z-Test was carried out to test the hypothesis, determine whether the identified factors influenced drill rig breakdowns at LCM and it was also used to validate the Chi-Square results.

The result of the study showed that human factors, environmental factors, maintenance factors and Supply Chain related factors were the cause of drill rig breakdowns at LCM. However, human related factors were identified as the major cause of drill rig break downs at LCM. The identified human related factors were low motivation and fatigue for drill rig operators and maintenance staff and inadequate training and development for drill rig operators.

In Conclusion, a framework was proposed that could aid Executive Management to identify potential causes of drill rig breakdowns. The study further recommended that management at LCM should establish measures to improve and monitor the motivation of employees through appropriate compensation, reward systems and job design. Additionally, a maintenance culture based on precision was recommended.

KEY WORDS: Productivity, Break down, Reliability, Maintenance, Availability

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 Introduction

The study starts with the introduction which highlights the importance of the mining industry to the Zambian economy and presents some of the critical equipment used in mining. The chapter further introduces the background of the study which provides context to the information discussed throughout the study, it explains conditions which motivated the study. Further, the chapter presents the statement of the problem which brings forth the problem to be investigated and followed by the research objectives which describe what the study expects to achieve from the investigation being carried out. The research questions are also highlighted to help address the study problem, the hypothesis is equally explained in this chapter giving reasons why it was used in the study. The significance of the study has also been described and determines who would benefit from the study and how the specific audience may benefit from the study findings, the scope of the study has equally been specified including the delimitations which are choices made in the study and outline the boundaries set along the study. Additionally, the study site location and the thesis structure are clarified and the chapter ends with a conclusion and introduces chapter two of the study, the literature review which takes note of the current knowledge including substantive findings, as well as theoretical and methodological contributions to the topic under review.

Mining is the key sector to Zambia's economic development and the sector is a major contributor to national export earnings and employment. Nevertheless, the importance of the mining industry to the economy depends on sustained high level of production. According to the Press Information Sheet 1 (2018:4), mining is the major income generating industry in Zambia and it plays an important role in contributing to the country's Gross Domestic Product (GDP).

To sustain the high level of production, new mine projects are required and the existing mines need to be operated efficiently for sustainability.

As such, this study seek to develop a framework for identifying drill rig breakdowns by conducting a study at Lubambe Copper Mine (LCM) in Zambia in order to investigate the major caused of drill rig breakdowns at LCM.

Drilling is very important to the ore extraction process underground. Additionally, drilling is the process of making holes in the mining room face and from an economic point of view. The drill rig dominates a mine's production rate, since drilling is the first process of a typical mining cycle. Further, economic competition has pushed mining companies to achieve higher production rates by enhancing techniques of drilling and blasting and increasing mechanisation and automation. Figure 1.1 shows a drill rig with its major components.

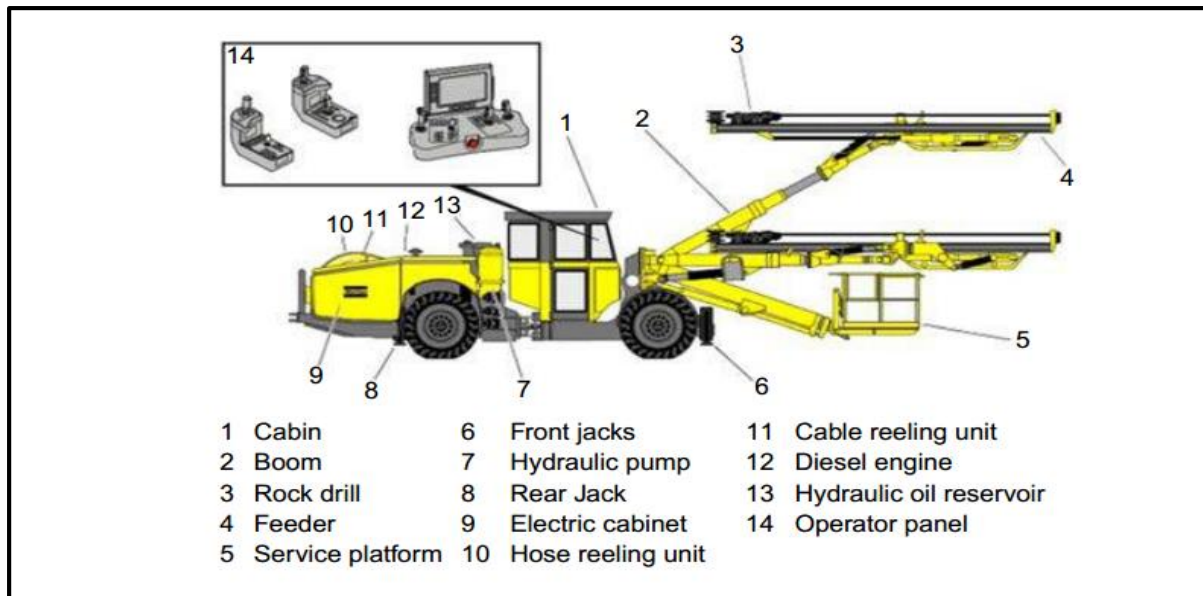


Figure 1.1: Underground Drill Rig

Source: Adopted from Al-Chalabi, 2013.

The basic functions of the individual major components of a drill rig are explained below:

- i. Engine – the engine provides power for tramming the machine.
- ii. Hydraulic system – provides power to working parts of the machine such as cylinders and hydraulic controls.
- iii. Axles – provide motion to the machine, this is where wheels are fitted.
- iv. Boom – carries the drilling mechanism of the machine.
- v. Drifter – component on the machine that is used for drilling, it carries the drill rod.
- vi. Operator's cabin – carries operational controls and monitoring gauges for the operator and shelters the operator.
- vii. Electrical cabinet – carries electrical controls and power protection gargets.
- viii. Lighting – the machine is fitted with clear drilling lights on the canopy and and warning lights behind the carrier.

To stress the importance of a drill rig further, Al-Chalabi et al (2014:307) commented that, more than 15 per cent of unplanned downtime (breakdowns) of underground

mobile equipment is related to the drilling machine and further indicated that, since the drill rig machine is key to production, it is important to find solutions to reduce breakdowns. To this effect, they performed a downtime analysis of drill rigs at Kiruna mine in Sweden to identify the machine components and the type of problems (maintainability and/or reliability problems) which contributed to downtime and to determine the kind of strategies, designs for maintainability or designs for reliability that could be applied to minimise drill rig breakdowns.

1.2. Background

In line with sustaining the mining industry in Zambia , Lubambe Copper Mine (LCM) under Konkola North Project was commissioned in 2010 with the view of producing 200,000 tonnes of copper ore per month by 2014 (Lubambe Copper Mine Project Talon, 2016: 28).

However, this production plan of producing 200,000 tonnes of copper ore per month could not be achieved due to various challenges and one of them being the numerous drill rig breakdowns at the mine.

Table 1.1 shows the production profile for the mine from 2014 to 2017. Further, figure 1.2 shows graphically the ore production trend for the same period.

Table 1.1: Average Ore Production per Month

Average Monthly Ore Production (Tonnes/Month)			
2014	2015	2016	2017
136,845	120,795	86,556	88,094

Source: Lubambe Production Summary Report, 2017.

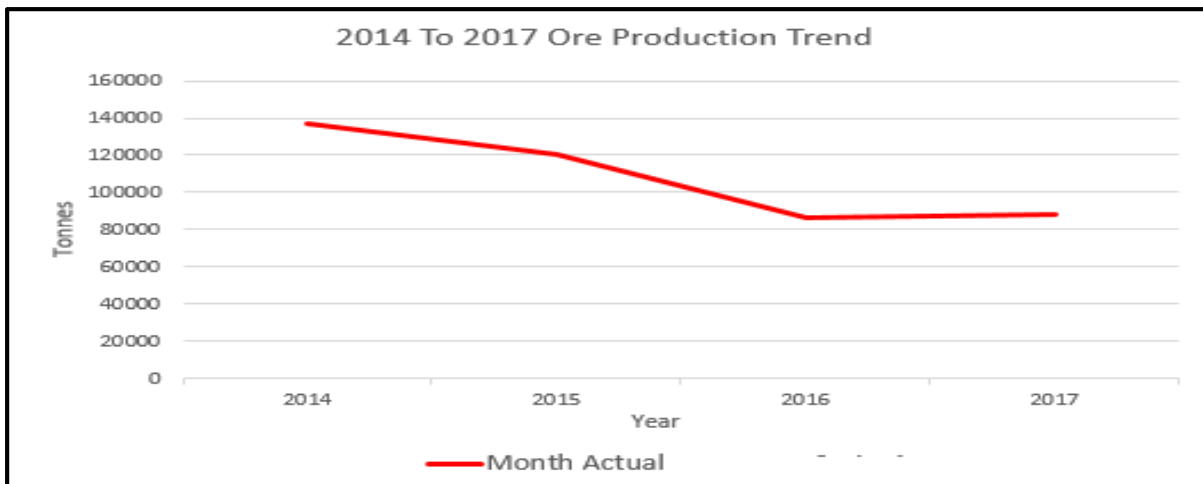


Figure 1.2: Ore Production Profile (Annual Production)

Source: Lubambe

Production Summary Report, 2017.

Further, Table 1.1 shows that the average production for LCM by 2014 was 120,000 tonnes of ore per month and this productivity continued declining and averaging 85,000 tonnes per month by 2017. This production output was below the projected project target of 200,000 tonnes of ore per month.

On the other hand, despite having allowed for 17% for drill rig downtime, the target availability of 83% could not be met consistently due to breakdowns. Figure 1.3 shows the drill rig availability trend from 2014 to 2017.

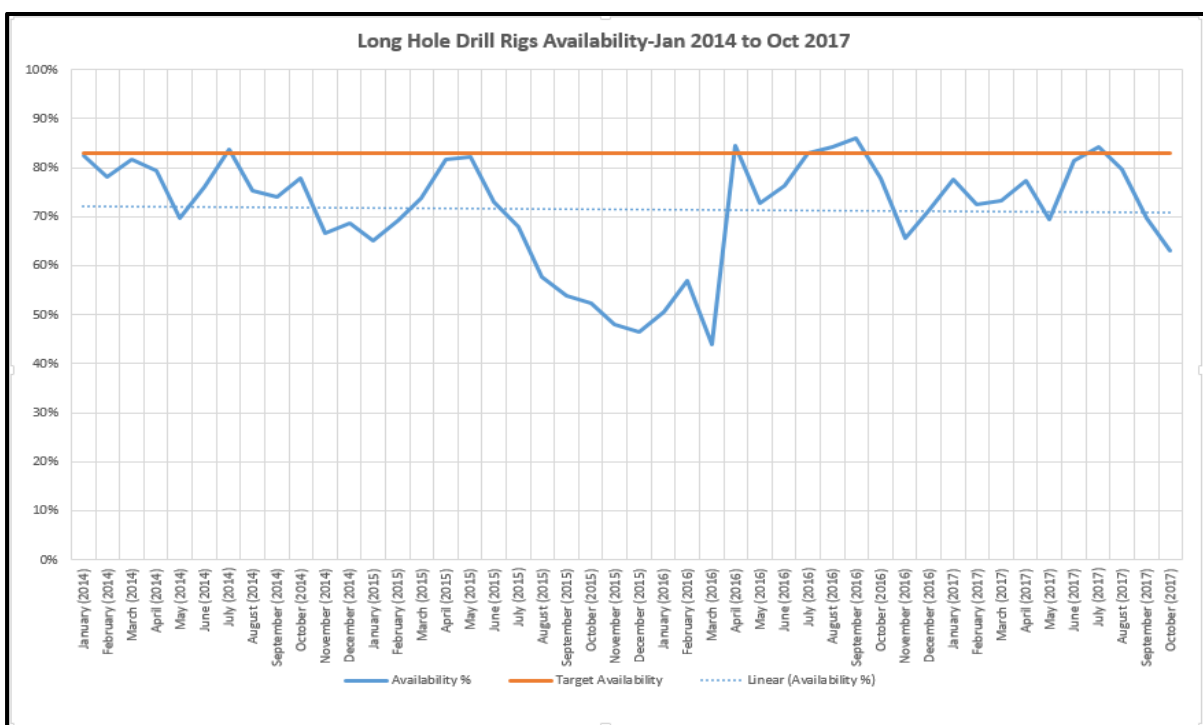


Figure 1.3: Drill Rigs Availability 2014 - 2017

Source: Author, 2017.

Though maintenance was carried out on drill rigs to ensure that the equipment operated effectively, the rate of equipment breakdown was still high and the mine management identified the numerous drill rig breakdowns as one of the contributing factors to low productivity. The drill rig availability budget was set at 83% and the expected tonnage from one drill rig was 40,338 tonnes per month, however, this capacity could not be achieved and the data in Table 1.2 show how the mine planning department derived at the expected production tonnage per month. Additionally, before any machine was purchased, a mine site sheet was prepared and sent to the equipment supplier. This meant to ensure that the equipment purchased was fit for purpose as all machine specifications were highlighted in this document (Appendix 1).

Table 1.2: Drill Rig Productivity Analysis

Item	Input	Unit
Equipment Availability (at full utilisation)	83.00	%
No. of Days in a Month	31.00	Days
Productive days in a month	27.00	Days
Metres/Rig/Shift	150.00	Metres
Shifts/Rig	2.00	Shifts
Tonnes/metre	6	Tonnes/metre
Effective Operating time/shift	8.00	Hours
Number of shifts/day	2.00	
Effective Operating time/day	16.00	Hours
Productivity	15.56	Metres/hour
Productivity	124.50	Metres/shift
Productivity	249.00	Metres/day
Drilled Reserves/day/rig	1,494.00	Tonnes/day
Drilled Reserves/Month/rig	40,338.00	Tonnes/month
Expected Production/month/5 Rigs	201,690.00	Tonnes/month
No. of rigs required (Sandvik DL320)	5.00	Drill Rigs

Source: Author (adopted from Lubambe Production Report, 2017:4)

Further, the drill rig availability target was calculated per machine on a weekly basis as follows:

- i. Total week hours excluding Sunday – 144
- ii. Daily inspection 2hours by 6 days – 12 (to be added to maintenance hours)
- iii. Maintenance hours (MH) – 12
- iv. Scheduled Week hours (SSH) - 120
- v. Breakdown hours (BH) – not allowed for

Therefore, the weekly availability target was:

$$(i) \quad A = \frac{SSH - (MH + BH)}{SSH} \times 100$$

Where **A** is the equipment availability; **SSH** is the total time allowed for the operation of the drill rig during in a week, it excludes break times, change over times, safety and production meeting times and other inevitable delays within the shift; **MH** is the maintenance hours and **BH** is the breakdown hours.

$$(ii) \quad A = \frac{144 - (24 + 0)}{144} \times 100 = 83.33 \text{ rounded off to } 83\%$$

Source: Adopted from Lubambe Copper Mine Production Report, 2016:4.

The allowable equipment operating time (availability) was set on the pretext that, equipment of any kind is bound to breakdown at one time as Tanwari (2011:36) postulated, 'equipment of whatever type no mater intricate or simple, however, cheap or costly, is liable to breakdown and that not only procedures exist for equipment maintenance, but also the possibility of breakdowns and interruption of operation must be considered during capacity planning and activity scheduling'. This can be graphically interpreted as shown in Figure 1.4.

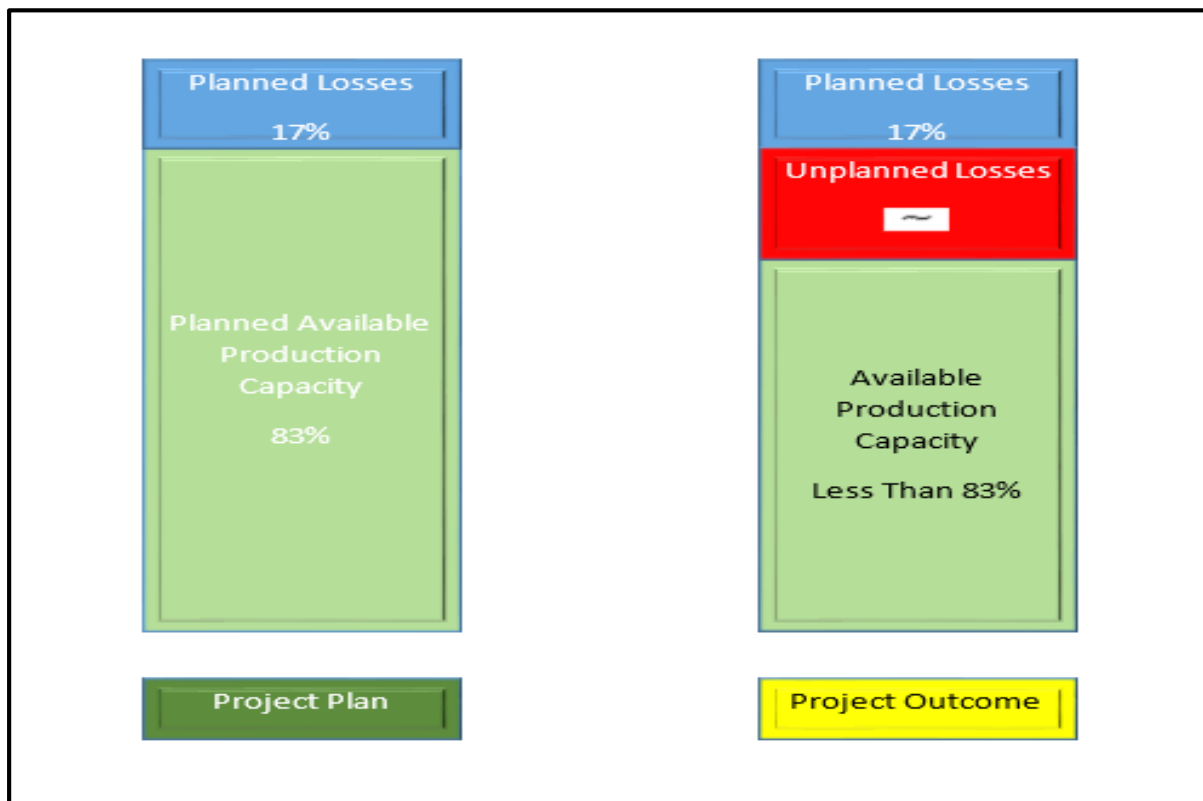


Figure 1.4 Drill Rig Availability Pattern

Source: Author, 2018

Figure 1.4 shows that the planned downtime for maintenance and other identified tasks were allocated 17% of the total time and 83% as equipment availability time. However, the budgeted machine availability time of 83% was not consistently achieved due to the frequent breakdown of the equipment.

1.3 Statement of the Problem

Though Lubambe Copper Mine generated ore from the mining faces using drill rigs like any other underground mine, the projected production budget could not be met and the mine management identified the numerous drill rig breakdowns at the mine as one of the major causes of low productivity.

Further, the causes of the numerous drill rig breakdowns were not identified to enable the mine maintenance personnel implement proactive measures to minimise breakdowns at the mine. It was for this reason that this study was conducted to identify the major causes of drill rig breakdowns at LCM for the purpose of developing a framework that could help in identifying the potential causes of drill breakdowns so as to proactively implement correct maintenance strategies.

It is however, worth noting that, breakdowns of underground drill rigs may not only be unique to Lubambe Copper Mine, but have been experienced in other mines too. The study conducted by Kansake and Suglo (2015:524-532) at Konjole Minerals in Ghana suggested that there were numerous drill rig breakdowns at the mine and it was established from the findings of the study that the major causes of the numerous drill rig breakdowns were hose bursts, overheating, shank adapter breakage and rod breakage, low flushing, percussion and rotation pressure, track removal and breakage and drilling rope breakage. Further, Al-Chalabi (2013:307) indicated that historical data over a period of one year from an underground mine in Sweden reviewed that more than 15 per cent of unplanned downtime (breakdowns) of mobile machines was related to drill rigs.

Similarly, Song (2012:61) analysed the failure behaviour of the critical sub-asset groups of four drill rigs at Granny Smith Mine in Australia where the reliability of drill rigs was low. To improve the drill rig reliability, he conducted a study and suggested changes in maintenance tactics which reduced the number of drill rig breakdowns and improved availability. By implementing these changes, the drill rig monthly productivity

increased from 108,000 tonnes to 132,000 tonnes per month. Further, Eleveli and Eleveli (2010:96) in general claimed that, maintenance policies have been implemented to improve equipment (mostly, trucks and loaders) reliability and utilisation, but little attention has been paid to the impact drill rig breakdowns and utilisation has on mine productivity.

1.4 Research Objective

The main objective of the study was to identify the main causes of drill rig breakdowns at LCM and formulate a framework which could help minimise the frequency of drill rig breakdowns, thereby improving productivity.

The main objective was further dissected into sub research objectives for simplicity of understanding the various factors that could be responsible for causing drill rig breakdowns. These factors were stated as follows:

1.4.1 Specific Objectives

- i. To determine the influence of human related factors on drill rig breakdowns.
- ii. To ascertain the impact of underground environmental conditions on drill rig breakdowns.
- iii. To establish the effect of maintenance related factors on drill rig breakdowns.
- iv. To find out whether Supply Chain factors contribute to drill rig breakdowns.

1.5 General Research Question

The general research question in this study provided a focus and direction of the study and proceeded as follows:

What were the major causes of the numerous drill rig breakdowns at Lubambe Copper Mine?

1.5.1 Sub Research Questions

In order to deal with the general research question, sub research question were used:

- i. Do human related factors contribute to drill rig breakdowns?

- ii. What implications do underground environmental conditions have on drill rig breakdowns?
- iii. In what way can maintenance related factors contribute to drill rig breakdowns?
- iv. Can Supply Chain factors contribute to drill rig breakdowns?

1.6 Research Hypothesis

The study defined a research hypotheses as a statement created by researchers when they speculate upon the outcome of a research or experiment. Further, Trochim, (2007:97) explained that one of the most important concerns when starting research work and formulating the research problem is building the hypothesis. Generally, hypothesis offer clarity so that focus is on a research problem.

In order to test whether there was any significant difference in the results of the data collected for the study, a Z-Test analysis was carried out. This test also helped to ascertain if results obtained from various tests were valid or repeatable. Further, the Z-Test was used to validate the results of the Chi-Square tests.

1.7 Significance of the Study

The study was undertaken in order to determine the factors that led to the numerous drill rig breakdowns at LCM and to develop a framework for identifying the potential causes of drill rig breakdowns. Therefore, the results of the study could enable the management of Lubambe Copper Mines to make informed decisions in addressing the drill rig breakdowns.

The framework for identifying the causes of drill rig breakdowns could assist both the maintenance personnel and management at LCM to identifying potential causes of drill rig breakdowns and implement appropriate maintenance strategies that could assist in minimising breakdowns. A condition of reduced breakdowns could avail the maintenance and mining personnel adequate time for planning.

Further, in the mining industry, the dictum is the same: to minimise the input and maximise productivity of resources with the core aim of providing the best value to shareholders and other stakeholders such as employees and the government. Therefore, management of other mining companies could also utilise the framework

to identify the potential causes of drill rig breakdowns in their organisations. This may allow such management to proactively implement preventive maintenance approaches to reduce drill rig breakdowns.

Reduced equipment breakdowns translate into increased machine operating hours which in turn may result into increased productivity.

Finally, the outcome of this study could contribute to the already existing body of knowledge in this area.

1.8 Scope

The study was set around establishing the causes of drill ring breakdowns at LCM and to develop a framework for identifying potential causes of drill rig breakdowns. Further, the study was conducted at Lubambe Copper Mine and the respondents were drawn for departments that were involved with the operation and maintenance of drill rig and those with expert knowledge in the equipment and the environment where the drill rig operates.

1.9 Delimitation

The study collected the data from Lubambe Copper Mine and did not include other mines, all respondents were drawn from LCM.

Other department within LCM such as Security and Corporate Social Responsibility were not included due to their limited knowledge of the equipment and environment under study. As such including such department in the study could dilute the results of the study by obtaining responses that may be given for convenience purposes only.

1.9.1 Study Location

The study was conducted on the Copperbelt Province of Zambia at Lubambe Copper Mine. Lubambe Copper Mine is an underground operation owned by VALE of Brazil and ARM of South Africa and each of these companies had a shareholding of 40% with Zambia Consolidated Copper Mine (ZCCM) maintaining the remaining 20% (Lubambe Copper Mine Project Talon, 2016). Figure 1.5 shows the location of Lubambe Copper Mine on the Zambian map.



Figure 1.5: Map of Zambia **Source:** Lubambe Copper Mine Project Talon, 2016

The proceeding Figure 1.6 shows the position of Lubambe Copper Mine on the map of the Copperbelt Province of Zambia.



Figure 1.6: Map of the Copperbelt **Source:** Google Map, 2018.

Additionally, Figure 1.7 shows the map of Lubambe Copper Mine license area and other surrounding structures.

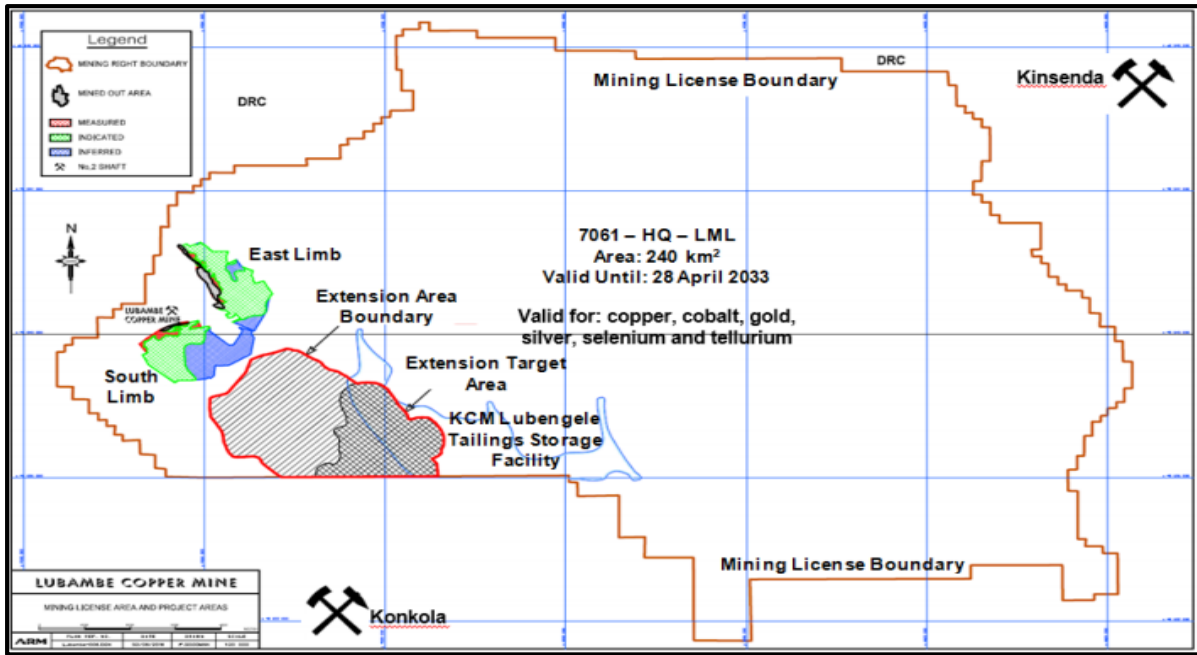


Figure 1.7: Mine Licence Area Source: Lubambe Copper Mine Project Talon, 2016.

Finally, Figure 1.8 shows the sub division of the mine where mining equipment under study operate.

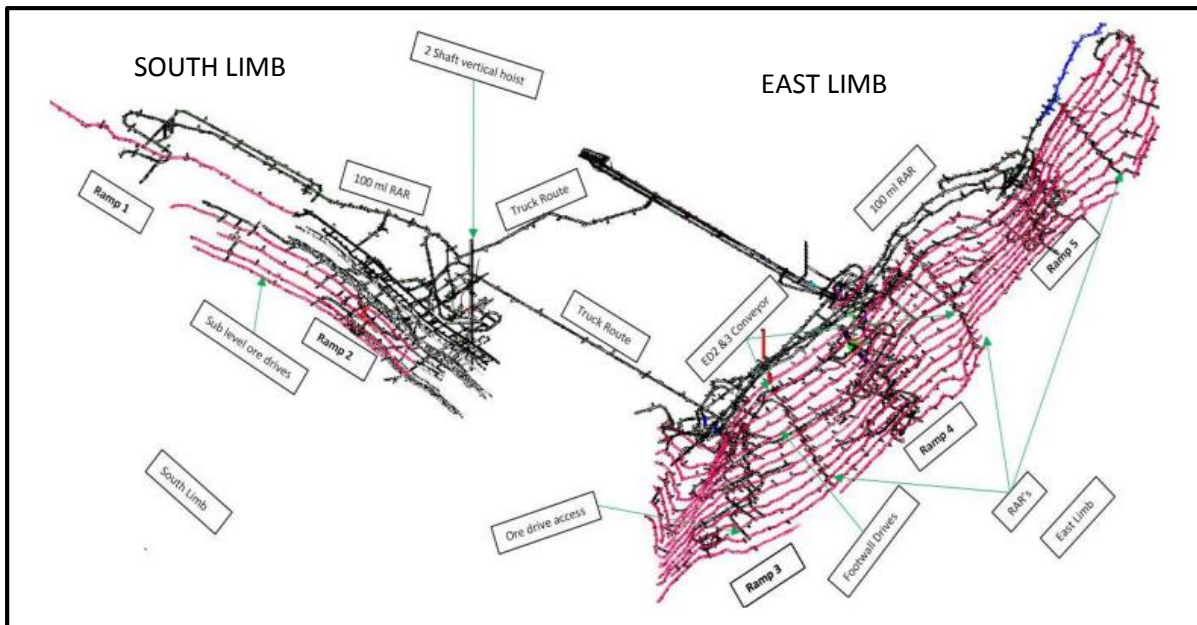


Figure 1.8: Mine Sub-Divisions Source: Lubambe Copper Mine Project Talon, 2016.

As shown from Figure 1.8, the mine is sub-divided into two sections, the East limb and the South Limb. The East Limb is located on the Eastern side of the mine and is

accessed by a decline (roadway) and the conveyance of ore from underground to surface is through a series of conveyor belts.

The South Limb is located on the Southern side of the mine and accessed by a vertical hoist. The transportation of ore from underground to surface is through a rope winder (hoist).

1.10 Thesis Structure

The study defined a thesis structure as the layout of the study, it starts by setting out each chapter, section and sub-sections. The logical structuring of chapters, sections and sub-sections helped the study to introduce the topic under study thoroughly to the essential background and introduced new concepts and conclusions which guided the study. Each chapter has a principal idea which is introduced, discussed and concluded. The study was organised in eight chapters, chapter one is the Introduction. It consists of the introduction, the background of the study, the statement of the problem, the general objectives including the main objective, specific objectives and the research questions.

The hypotheses of the study was discussed in this chapter and other areas of the study discussed are the significance of the study, the scope and delimitation of the study and finally the thesis structure and the conclusion ending chapter one and introducing chapter two of the study.

Chapter two is the literature review which gave the study an opportunity to review and constructively criticise or support related work done by other writers in order to identify gaps with the view of adding or creating new knowledge to the already existing body of knowledge.

The literature review took a global stand point and adopted a funnel model reviewing the literature from a global perspective, continental, regional (SADC) and finally the local level. The chapter ends with a conclusion and sets out a platform for chapter three.

Chapter three introduces the theoretical and conceptual framework which highlight and discusses the relevant theories and concepts to the study and set out a stage for the operationalisation of concepts in order to show how the problem at hand may have

emerged. The ending of this chapter summarises the section and gives an introduction to chapter four.

Chapter four covers the Methodology of the study which highlights a general overview of how the study was conducted and the research philosophy which assisted in directing the study and dealing with the foundational assumptions and preconditions.

Other components making the chapter are the target population, sample size and sampling procedure, the research instruments, validity and reliability of the study and also highlighted in the chapter are the data collection methods and data analysis techniques including the ethical considerations. The pilot study has also been described in this section. The summary concludes the chapter and introduces chapter five.

Chapter five covers the data analysis, presentation and results, it presents the data gathered, the results of the statistical analysis done and interpretation of findings.

Chapter six is the study discussion of results. The purpose of this chapter is to interpret and describe the significance of the findings in light of what was already known about the research problem being investigated and to explain any new understanding or insights that could emerge as a result of studying the problem.

Chapter seven of the study presents the data that forms the basis for investigation and the findings of the study. It is based upon the methodology applied to collect information.

The Conclusions and recommendation form chapter eight and summarises the key points of the study, the essential features of the design, and the significant outcomes of the investigation. It also indicates the extent to which the aims were achieved and highlights the significance or usefulness of the study. The recommendations on the other hand address the limitations and give way for areas of further studies. Further, a framework for identifying potential drill rig breakdowns is presented. The framework is meant to identify the potential causes of drill rig breakdowns and by identifying the potential causes of drill rig breakdowns, appropriate maintenance strategies may be implemented to address these causes before the actual breakdown could occur.

1.11 Conclusion

The background of this study help in stating the prevalent conditions that lead to the identification of the problem to be studied and the dimension of the study. Therefore, the chapter discussed Lubambe Copper Mine project from 2010 to December 2017 and sought to investigate the factors that led to the numerous drill rig breakdowns at LCM which the mine management alleged to have been one of the major contributing factors to low productivity.

The chapter introduced the statement of the problem, research objectives and research questions which were set and asked to help find a solution to the main causes of the high frequency of drill rig breakdowns at LCM.

Finally, the location of the study was described and the thesis structure was outlined. The following chapter presents the literature review which gave the study an opportunity to review and constructively criticise or support related work done by other writers for the sake of identifying gaps in these studies. Additionally, the identification of gaps from the studies conducted by other researchers enabled the study to determine the causes of drill rig breakdowns at LCM.

CHAPTER TWO LITERATURE REVIEW

2.1 Introduction The chapter starts with the introduction which describes the literature review and the importance of the literature review to the study. Further, the body or frame of the literature review is introduced, showing the route taken in presenting the literature review. The chapter ends by summarising the literature and picking out the most prominent issues to the study and introduces chapter three, the theoretical framework which is the “blueprint” for the entire dissertation inquiry and conceptual framework which represents the synthesis of literature and further maps out the actions required in the course of the study given prior knowledge of other studies and findings obtained on identifying the factors that led to drill rig breakdowns at LCM.

The study describes literature review as an overview of what may be known and of what might not be known about a given topic and include the major work on the topic under study. Additionally, it is a critical analytical account of the existing studies on a particular topic and summarises, synthesises and analyses the arguments of other authors. It uncovers similarities, differences or consistencies and inconsistencies within the existing studies and finally helps to identify a gap within the body or study.

Good (2005:69) contended that, to solve a problem, one needs to understand the problem and from Hart (2000) perspective, the first stage of most research projects is to undertake a review of the literature to determine what research has already been conducted in a particular field. Therefore, the literature review helped to formulate research questions and to determine how to conduct the study.

In summary, the purpose of the literature review section is to summarise the previous literature and to provide a clear rationale for the current study in light of what has been done before.

2.2 Body

In this study, the literature review followed a funnel approach, starting with the broad topic and why it is of interest and then narrowing down gradually to focus on the specific area where the study was drawn from. As such, the literature was drawn from a global, continental, regional, national and finally the local perspective at the

point of the problem, Lubambe Copper Mine. Further, Ridley (2008) and Hart (2000), emphasised that, it was import to use a funnel approach in building the literature review and further explained that the idea of the funnel approach is to draw towards the area of study as well as doing the practical task of summarising past studies.

Therefore, the funnel approach was adopted in order to enable the study gather and understand views of other writers from various parts of the world on the factors that lead to breakdowns of underground mining equipment which includes drill rigs. It covered Europe, United States of America, Asia, Australia, Africa and coming down to Southern Africa Development Community – SADC, Zambia and finally, Lubambe Copper Mine, where the study was conducted.

It may therefore, be concluded that, the literature review presented an extensive inquiry into the writing of various writers on the topic under study.

2.2.1 Europe

Though the European mines may be more advanced in technology in comparison with African and Asian mines, the study considered Europe in order to understand the nature of breakdowns they are faced with in relation to underground mobile equipment as underground environmental conditions are similar.

Further, Thunberg (2016:49) indicated that a drill rig is a machine working in harsh environments which cause frequent breakdowns to the machine and its subsystem and he further went on to say, nearly all subsystems have reliability problems; a problem caused both because of the operation of the machine and by the maintenance procedure and strategy. He highlighted five subsystems that fail more frequently than others with the most critical subsystems being hoses and rock drills. He concluded that an implementation of reliability-based maintenance together with a hose and rock drill replacement policy could increase the reliability and decrease the number of corrective maintenance action needed.

Hoses and the rock drill are critical sub systems of a drill rig and the implementation of a reliability-based maintenance program together with a hose and rock drill replacement policy could increase the reliability and reduce the corrective maintenance action required, however, these actions may only mitigate part of the factors responsible for causing equipment breakdowns, other factors such as operator

competencies, underground environmental conditions among other variables could equally be part of the factors leading to breakdowns.

Mkemei (2011:43) conducted two case studies from a mine in Sweden and the other one in Tanzania. The work was limited to maintenance of mobile mining equipment with special focus on Load Haul Dump machines (LHDs), where the research approach included questionnaires, oral interviews, discussions with stakeholders and data collection. As it was not possible to interview all department members, he selected the key personnel responsible for the maintenance department activities; the selection process was based on covering all levels of maintenance department processes. Discussions and interviews took place with maintenance managers, maintenance planners, maintenance supervisors and operator of the LHD machine. The results of the study established hydraulic systems, electrical systems, engine, flat tires and filter blockages as the major causes of equipment breakdowns. The evaluation of the maintenance problems which then existed at the mine maintenance department indicated that there was a lack of an effective training program for the staff members; therefore, he suggested that effective planned schedule for training was required.

Though lack of maintenance schedules was picked as one of the major contributing factors to underground equipment, there is need to understand how these breakdowns are caused. Scheduling of equipment for maintenance may be affected if the organisation is faced with numerous equipment breakdowns, even before scheduling equipment for maintenance, it is important to understand the major causes of equipment breakdowns so that planning and scheduling can be executed appropriately.

Further, Al-Chalabi et al (2014: 306) performed a downtime analysis of four drill rigs to identify which components and what type of problems (maintainability problems and/or reliability problems) contributed the most to downtime. To determine which strategies, designs for maintainability and/or designs for reliability could be applicable. To better understand the downtime of the drilling machine, they conducted an analysis of the historical data for three machines of the same model used in one Swedish mine. To analyse the data collected, they used jack-knife diagrams with confidence intervals. The study reviewed that there were notable differences in the down time of studied

components for all machines, the hoses and feeders had relatively high down time and the study further suggested that there was need to improve reliability of critical components in order to reduce down time of drill rigs.

This study analysed the down time of different components of a drill rig and the researcher suggested that the hoses and the feeder had the longest down time. However, comparing down time of the different drill rig components may not help in determining the factors that lead to breakdown of drill rigs, but may only show the repair time (MTTR) of a specific component. Furthermore, comparing parts that carry out different functions on a piece of equipment and having a different life cycle may not give a true measurement as different parts of a machine do different functions and are exposed to different environment and operating conditions. Hence, their failure rate may not be similar.

Elevli (2010:95) showed that maintenance policies have been implemented to improve equipment (mostly trucks) availability and utilisation, but little attention has been paid to the impact drill rigs' availability and utilisation has on mine production. From a similar study, Al-Chalabi (2013:307) indicated that historical data over a period of one year from an underground mine in Sweden reviewed that more than 15 per cent of unplanned downtime (breakdowns) of mobile machines is related to drill rigs. The study collected failure data for a period of two years from four drill rigs and performed reliability analysis as well as downtime analysis using loglog diagrams with confidence interval. He further suggested that, since the drill rigs are key to production, it is important to find solutions for machine problems and reduce breakdowns.

From the outcome of the above studies, it may be suggested that various mining operations may be faced with different kinds of drill rig breakdowns and this could be as a result of different operating environmental conditions, operator and maintenance personnel competencies, and the genuineness of spare parts used etc. Therefore, it may be important to develop a framework that could assist in identifying the causes of drill breakdowns in a particular location or mine.

Gustafson et al (2011:865) suggested that in underground mines, mobile mining equipment is critical to the production system. Drill rigs for development and production, vehicles for charging holes, LHDs for loading and transportation, scaling rigs and rigs for reinforcement and cable bolting are all important units in the process

to generate a continuous ore flow. He further commented that high equipment availability is essential to reduce operational and capital costs and to maintain high production. High and controllable reliability is also important especially in attempts to automate the production equipment. This study outlined the importance of high underground equipment availability to a mining operation as well as the need for high and controllable reliability, however, the study did not explain the tools or systems to be used in order to attain a high equipment reliability and on the other hand the study did not explain the factors that affect reliability.

Roy (2013:163) analysed mining shovels to determine the failure and repair pattern and their reliability and maintainability characteristics. The nature of failure of various equipment components and systems was identified and classified according to downtime to ascertain the component or systems that contributed the greatest downtime.

The study suggested different intervals for maintaining the equipment, thus, inspections, modified inspection frequencies with reference to safety considerations, cost effectiveness and the nature of failure. From the study conclusion, the implementation of the aforesaid resulted into reduction of total breakdowns of the equipment.

The study highlighted the nature of breakdowns of the equipment and modifications made to the maintenance frequencies in order to reduce equipment downtime and it was further stated that, the implementation of the above initiative reduced the number of equipment breakdowns. However, what may not have been explained from the study is the level to which breakdowns were reduced to give a set or desired equipment availability.

Further, though equipment inspections may reduce the number of equipment breakdowns, caution is required in carrying out inspections in both the short term and long term. Too close inspection intervals may lead to frequent operational stoppages which could result into production loss. On the other hand, if the interval between inspections is over-extended, frequent failure of components may arise due to prolonged use.

Total Productive Maintenance (TPM) is a kind of maintenance that consists of a range of methods known to improve equipment reliability, quality and production, it aims at maximising equipment effectiveness by changing the corporate culture to improve a company's personnel and plant, however, cultural change at a plant could be difficult; it involves personnel working in small groups, machine operators having a role in the maintenance program and the maintenance department providing good support (Wilmott and McCarthy, 2001; Mishra et al, 2013; Samantha, Sarkar; Anyouf,2009 and Mukherjee, 2004).

Though TPM may be perceived as one way of minimising equipment breakdowns, the researcher may not have indicated how training could be planned for all employees to enable them understand the functions of the equipment they are involved with. Mkemai (2011:43) indicated that training of maintenance personnel was key to reducing equipment breakdowns through proper identification and resolution of equipment faults. In Mkemai's study, the data was collected through document studies, questionnaires and oral interviews with workers and the collected data was analysed in time scale of the project, however, it may have been helpful if observations were conducted to determine how tasks were physically carried out. If not well managed, TPM could pose a serious danger to employees as employees may be exposed to tasks they are not fully trained to undertake.

In implementing Total Productive Maintenance (TPM), caution may be required not to direct all resources to maintenance and neglect the impact of efficiency losses such as speed losses.

Kumar et al (1989:241) analysed the operational reliability of a fleet of diesel operated load-haul-dump (LHD) machines in Kiruna mine in Sweden and he stated that although the reliability investigation was not completed, the conclusion of the study suggested that preventive maintenance of the engines of LHD machines could reduce breakdowns and subsequently maintenance cost. This study used the ML methods together with TTT-plots to analyse the TBFs. The ML method was used as it was found to be versatile and can be applied to most distributions and statistical models and also to various types of data. However, this method is complicated as it often requires computer programs to solve the various partial differential equations.

However, it may be noted that underground environment from which loaders and drill rigs operate may not be similar and other parts of the equipment other than the engine could be affected different environmental conditions, therefore, preventive maintenance of the engine alone may not be a solution to reducing equipment breakdowns and to this effect it is necessary to investigate all critical components of the machine and suggest maintenance strategies that may be used to identify and mitigate the causes of equipment breakdowns

Wijaya (2012:330) developed a model in the equipment age-based replacement policy with the view of minimising maintenance cost. Further, the study aimed at investigating the downtime of four drill rigs in two underground mines in Sweden in order to compare the nature of problems the equipment faced and to determine the strategies to be implemented in mitigating these problems. To arrive at the conclusion, the study collected failure data for the four drill rigs and performed reliability analysis as well as downtime analysis using a loglog diagrams with confidence interval.

Though this study outlined the robust optimal multi-attribute based replacement policy, the model may have been based on the cost attribute and assumed the model parameters were known and linear in nature. However, in practice, the model parameters may not be obvious and this could bring uncertainty into the model.

Furthermore, replacement schedules could be developed and maintained, but if the cause and factors leading to breakdown of equipment are not determined and mitigated, the replacement schedule may not be precise due to stochastic failure pattern of parts.

Ljungberg (1998: 495-507) stated the human factor represented by maintenance technicians and other related staff is the backbone of the maintenance system in any organisation. As such, the effectiveness of the different facets of the performance system is very much dependent on the competency, training, and motivation of the overall human factor in charge of the maintenance system. Further, Cabahug (2004: 119-122) commented that factors such as, years of relevant work experience on a specific machine, personal disposition, operator reliability, work environment, motivational management, training and continuing education, are all relevant factors which tend to impact the effectiveness of the performance of the maintenance system. These factors may affect the effectiveness of performance of maintenance system,

but it may be important to determine what causes these factors to negatively impact on equipment performance and leading to equipment breakdown.

Based on Eleveli (2010:100) 'the utilisation of equipment can only be improved and controlled successfully if an appropriate performance measurement system is used and he concluded that Overall Equipment Effectiveness is a known and effective method to measure performance of production equipment in manufacturing industries and now adapted for mining industry. The method aims to identify unproductive time losses within the system and how these time losses affect availability, performance and quality.'

To measure performance of equipment, this system takes into account equipment availability, performance and quality. However, this method (OEE) gives post activity results and does not work to investigate the causes of breakdowns. Therefore, the results of this method may not give a true reflection of the equipment performance, as any poor outcome in one or two variables may result in very low OEE and it may not provide the factors that may lead to low performance of equipment.

2.2.2 United States of America

Most of the research findings obtained from various writers on the causes of breakdowns of underground mobile equipment in the United States of America identified environmental conditions, lack of understanding and the non-implementation of maintenance strategies among other factors as the major causes of equipment breakdowns. Hall (1997:2) cited that, in the mining industry, specialised equipment, more especially mobile equipment was affected by various environmental factors under which the equipment operated. These conditions include wide temperature variations, restricted access, poor lighting, vibration and shock. Further, he explained that the operating environment of the mine is dynamic with many unknown factors that may affect the life of equipment. However, though this statement may hold true, operator practices, varying production demands and changes within the ore characteristics could all have significant influence on the performance of underground equipment.

Hamilton (2015:5) commented that most underground mines recognise that preventive maintenance is much less costly and disruptive to production cycles than breakdown

maintenance. The disruption to an operation due to equipment failing during scheduled production may be obvious to everyone. Additionally, conflict between maintenance and operation departments usually occur when maintenance attempts to establish a routine of planned outages for preventive inspection and defect correction. If the planned outage is too short, necessary maintenance checks may not be completed. If the planned outage is too long, it becomes economically unreasonable to the operator and negatively impact on productivity. This problem could be resolved to the satisfaction of both parties if the preventive maintenance programs balance maintenance and production time.

Further, Roy (2013:163-171) indicated that though preventive maintenance may reduce the number of breakdowns of mining equipment, caution is required in carrying out equipment inspections in short as too close inspection intervals could lead to frequent operational stoppages arising from incomplete maintenance. On the other hand, if time intervals between inspections were increased, this could cause frequent failures of components during operations and initiate wear-out problems for working components. However, to make this possible, it may be important to determine economical maintenance intervals by the use of appropriate methods and taking into consideration other factors that may affect the performance of equipment. These factors may include, maintenance practices and facilities, environmental conditions, human factors etc.

Dehayem (2010:98-103) formulated a semi-Markov decision process in determining the problem of repair/replacement and preventive maintenance policies and numerical methods were given in order to compute optimal policies which could minimise the average cost incurred by preventive maintenance, repair and replacement over an infinite planning horizon. Decisions to repair or to replace the machine upon a failure were modified by performing preventive maintenance. However, though preventive maintenance may aim at preventing equipment breakdowns from one maintenance period to the other, unexpected breakdowns could occur due to adverse environmental conditions from which these machines operate. Additionally, Hall (1997:2) contended that, in the mining industry, specialised equipment, more especially mobile equipment was affected by various environmental factors under which the equipment operated.

Vagenas (2001:302-311) performed a reliability assessment of mining equipment using genetic algorithms; he developed and tested mobile mining equipment reliability models. Equally, Flores (1998:419) developed optimisation models for repair, replacement and inspection of systems subject to stochastic deterioration to assess the failure rate of various equipment components.

The described models determine the replacement period of equipment parts by determining the life of components through probability measures, however, these methods may not go further to investigate the causes of equipment breakdown which if identified and mitigated could bring the maintenance cost further down and improve productivity.

Roy (2013:163-171) statistically analysed the failure and repair patterns of a fleet of four $10m^3$ electric rope shovels to ascertain their reliability and maintainability characteristics. Different subsystems and the types of failures in each subsystem were coded so that the failure and repair data of each subsystem could be collected, sorted and the faults therein classified separately. Common graphical tools, e.g. trend and serial correlation tests, were used to validate the assumption of independent and identically distributed failure/repair data for each subsystem before they were fitted with theoretical probability distributions. To determine the failure interval, a technique known as the split system approach was used together with a model for interactive failures. This approach was applied in order to stimulate data. The results of this study indicated that failure interaction increases the hazard of newly repaired components. Further, it was concluded that, the interval of preventive maintenance actions of a system with failure interaction becomes shorter compared with scenarios where failure interactions do not exist.

Identifying the failure and repair pattern of each equipment sub system may assist the maintenance personnel in determining maintenance intervals and balancing of stock levels, however, a strategy or framework for determining factors that may lead to breakdown of equipment may still be required. This could make the determined maintenance intervals to be followed without interruptions created by breakdowns of equipment.

Further, in trying to determine the failure pattern of equipment components, Sun et al (2009:30-39) classified the failures of a repairable system into two categories in

reference to the failure relationships of the components of a machine system. The first class they termed, Independent failure; the failures of the components in a system that did not affect each other and the second; dependent failure; failure in one or more of the components in a system that could interact with or cause failures of the other components in the system. Identifying the failure pattern of components may assist in replacing components in time before the actual failure occurs, however, it may be important to identify the causes of these potential failures in order to find mitigation measures and avoid the escalated failure of components.

Paraszczak (1994:123-127) argued that productivity and efficiency of mining equipment are among the most important factors contributing to unit mining cost, and measuring and benchmarking them is one of the best ways of identifying the possibilities of improvement. It was in this context that he presented and discussed the notion of overall equipment effectiveness (OEE). The study reviewed the main components of OEE, availability, utilisation and production efficiency and discussed some of the factors influencing those components as well as different means of quantifying them, and proposed a number of key performance indicators (KPI) associated with them. The study critically reviewed metrics already in use by mining companies and equipment manufacturers and proposed a number of other measures whose implementation could be beneficial for mine operators. The indicators were also analysed from the point of view of their meaningfulness, practicality and usefulness for further analysis. Finally, the study also addressed the question of data quality and it provided a number of recommendations concerning performance reporting and follow-up of equipment efficiency.

The concept of OEE has been used in various industries including mining to determine the effectiveness of the equipment (Ljungberg, 2001; Jonsson and Lesshammar, 1999; De Ron and Rooda, 2006; Elevli, 2010; Zandieh, Nilipour and Ghandehary, 2012; Amol, Seyed and Behad, 2016 and Fourie, 2016).

OEE measures the effectiveness of the equipment and may not identify the factors leading to breakdowns of equipment as it deals with post performance data (such as availability, utilisation and quality) to determine the effectiveness of equipment. On the other hand, performance measurement such as OEE require a lot of focus from management which could be costly and time consuming. Therefore, in order to utilise

maintenance performance measurement and management to promote positive and proactive organisational change, the maintenance performance management system should be designed to track and improve the different aspects of the maintenance effort. Further, Tsang, (1999 691-715:) indicated that a better maintenance process should be guided by the integration of critical success business factors, which should be derived from the overall organisational strategy.

Moubray (1997:10) stated that Reliability centred Maintenance (RCM) is the framework of conserving system functions, other than preserving physical asset. Further, it was indicated that, RCM is used to evaluate planned maintenance schedule which offers availability of equipment with both reliability and maintainability. Moubray presented a case study of ABC Automobile Company, where planned maintenance was possible with application of predictive maintenance strategy, which allows to take decisions of maintenance action with evidence and reduce unnecessary maintenance. The core principle of predictive maintenance is to investigate significant performance characteristics of equipment to choose the most indicative parameters of condition which reflect functional failures. It was also proposed that, vibration was selected as an important performance characteristic of rotating components and that through vibration monitoring, numerous mechanical failures could be effectively predicted.

The study adopted a qualitative approach and primary data sources were used to collect data. The method of data collection was observation (non-participant) and structured interviewing of maintenance staff. This study mainly described the problems that preventive maintenance faced at the company. A test case was presented to analyse the validity of proposals to improve the situation. Further, the maintenance strategy adopted by ABC Automobile Company was preventive maintenance with manually collected condition monitoring data. The data typically indicated anomalies when actual failure occurred. Additionally the study included determination of the effectiveness of existing maintenance strategy at the company and its comparisons with other strategies with improvement proposals. It outlines RCM analysis process and a test case of fans of paint booth process. Finally, the study concludes that RCM enables to evaluate planned maintenance action and in case of rotating components, the vibration monitoring technique may be used effectively in predictive maintenance strategy.

RCM is a maintenance approach that involves planning to ensure systems continue to do what they are intended to do in their current operating context and further, successful implementation of RCM could lead to increased cost effectiveness, reliability, machine uptime and a greater understanding of the extent of risk the organisation may be managing. Therefore, this may only suggest better maintenance strategies, but fails to identify the actual causes of equipment breakdowns as the reliance is on how to improve equipment maintenance strategies.

Taylor (1947:30) commented that in the modern age, the changes in maintenance practices are testing the attitude and skills of the maintenance personnel. Maintenance personnel are having to adopt completely new ways of thinking and acting as engineers and as managers. At the same time, the limitations of maintenance systems are becoming increasingly apparent, no matter how much they may be computerised. This could mainly be because of the urge to address different characteristics of the cause and factors that lead to breakdowns of equipment and the dynamic technologies in the technical circles. However, a piece of equipment may be maintained according to plan, but the machine could breakdown at an unexpected time due to the various uncertainties associated with environmental conditions as well as factors relating to human resources such as motivation. Further, human resources aspect of maintenance has been playing an increasing role in relation to operational environment safety and in addressing issues related to organisation, communication, problem solving, and decision making (Rankin et al., 2000:261; Patankar and Taylor, 2000:2).

2.2.3 Asia

Studies conducted on the causes of breakdown of underground mobile equipment from Asian mines were also considered, this was with the view that since most of the Asian countries were underdeveloped, the mining industry could have similar conditions as most of the African mines and the results of researches conducted from the Asian mines on the causes of breakdowns of underground mobile equipment could be used to determine the factors behind breakdowns of equipment in the mining industry in Africa and in particular the mine under study.

Sarkhel (2015:854) evaluated different parameters of mine machine performance, such as reliability, availability, maintainability and factors responsible for unavailability.

It was found out that the steady state availability of the SDL was 73.19%. A few significant causes of machine unavailability were detected and demanded special attention. The main reasons for machine unavailability advanced were hydraulics, electrical and others, bucket subsystems with 7.29%, 6.15% and 4.33% of working hours respectively. The study determined availability, reliability and maintainability of the machines investigated with failure and repair data by Markov modelling.

Therefore, from this study, it may be apparent from the fact that there is an opportunity for better maintenance planning which could lead into improving the reliability and maintainability of the machine from this kind of modelling and quantitative analysis by the markov process.

Further, Kansake and Suglo (2010:524-532) established that the causes of drill rig breakdowns observed in study conducted at Konjole mine in Ghana included hose burst, overheating, shank adapter breaking, drilling rods getting stuck in holes, rod breaking, drill rod breakage, poor flushing, low percussion and rotation pressure, drill chain breakage and truck removal and breakage. The data was collected through field visits and much of the data used was secondary data from the mine, further some primary data were gathered during field visits. Data analysis was carried out by statistical methods using MS Excel 2013.

The above study identified the immediate causes of breakdowns, however, the causes of the identified breakdowns were not identified and explained. For example, failure such as hose bursts is an immediate cause of breakdown, but what may be significant are the factors that lead to hoses failing.

Mouli et al (2014:255) explained that reliability of machinery was essential particularly, in production process, such as mines and heavy machinery, since the breakdown of any machine is causes an unpredictable loss or damage. The study further stated that it is obvious that the reliability of such machines could have considerable impact not only on production but also machine life and human life.

They further suggested that prevention was better than cure. Instead of allowing the occurrence of failure and suffering from huge loss or damage of assets, lives and environment, it is always worthwhile forestalling the occurrence. The study sought to

understand the reliability, maintainability and availability of the machines under study with failure and repair data by KME method.

The field data was collected for the machines considered under repaired items in the form of time between failures and time to repair. Whereas, the data inconsistencies and errors were removed and the refined data was analysed by both types of models viz, graphical and analytical methods. On the other hand, great importance was given to graphical method as it provided better simple understanding and could be easily reproduced. Graphical tests such as eye-ball analysis, cumulative plot test and serial correlation was used to determine the presence of trend. Further, the machines which showed the presence of strong trend were further analysed and fitted into non-homogeneous process (NHPP) model.

However, trends analysis show results of past events and may not determine the actual causes of variations in the trends. For example, both mean time between failure and mean time to repairs may only be determined once activity results have been produced. Therefore, it may be important to devise a model that could identify potential breakdown causes and mitigate them before the actual breakdown occurs.

The study carried out at Jajarm Bauxite Mine in Iran by Barabady (2008:647-653) concluded by stating that the performance of mining machines depends on the reliability of the equipment used, the operating environment, the maintenance efficiency, the operation process, the technical expertise of the miners, etc. It was also highlighted that as the size and complexity of mining equipment continues to increase, the implications of equipment failure became ever more critical. Therefore, the study recommended that reliability analysis is required to identify the bottlenecks in the system and to find the components or subsystems with low reliability for a given designed performance.

However, though the study acknowledged reliability analysis as a method of identifying bottlenecks in machine systems and to find components or subsystems with low reliability, the method deals with post activity data to determine the reliability of the equipment or components of a machine. To minimise equipment breakdowns, what may be required is a model that may identify the causes of equipment breakdowns so as to mitigate them before the actual breakdown occurs.

In studying equipment reliability, Jordan and Tsang (2013) observed that Reliability Centred Maintenance determines the type of maintenance tactics to be applied to an asset in order to prevent system failure. While Reliability Centred maintenance answers the question of 'what type of maintenance action needs to be taken for a specific type of equipment', the issue of when to perform the maintenance action that may produce the best results still remains to be addressed. The maintenance intervals may be highly influenced by various factors such as maintenance practices, environmental conditions or human factors.

Esmaeili (2011: 629-640) carried out a study to assist the engineers at Sangan Iron mine in Iran to determine the reliability of loaders and he suggested that, the low reliability of loaders was prominent towards the end of working life of the machine. However, he further stated that to achieve the high reliability, a review of the maintenance program was required. The study also identified the critical and sensitive subsystems in the loader fleet for better maintenance planning, leading to enhanced equipment availability, reduced maintenance and production costs. The study focused on assessing the reliability of loaders through identifying the critical and sensitive subsystems of the machine and thereafter, finding a better way of maintaining the equipment. The study used a basic maintenance approach and a reliability based approach to analyse the data. Trend and serial correlation test were used to validate the assumption of independent and identical distribution. Further, K-S test was carried out with the aid of Easy-Fit software to select best fit distribution.

This strategy could help the maintenance personnel plan and develop better maintenance schedules, though the factors responsible for causing breakdown of equipment may not be determined through this process. It may be important to set a clear maintenance strategy and to evaluate the competencies of the operators and maintenance personnel as these could equally be one of the contributing factors to equipment downtime. The operating environmental conditions, motivation of employees and the genuineness of the spare parts used on equipment could also lead to equipment breakdowns.

In terms of maintenance personnel, Campbell (2006:5) stressed the point of qualified maintenance personnel by indicating that, with the current dynamic technology it was challenging to find qualified maintenance personnel and that this was mainly because

of the aging labour force and further concluded that this was one of the major contributing factors to equipment breakdowns.

2.2.4 Australia

Face drilling is one of the most important parts of the mining process. The drilling rigs operate in hot, humid, and dusty conditions and are subjected to constant vibration as they drill or bolt into hard rock. Because of the harsh operation environment, drills can fail to deliver their required performance. The service targets set for the drilling fleet must be met to accommodate the expansion of the underground mine and ensure a desirable production profile.

The project conducted at Granny Smith Mine by Song (2012:61) analysed the failure behaviour of the critical sub-asset groups and sought opportunities through changes in maintenance tactics to improve the asset availability and reduce the costs associated with the failures. There were four development drilling rigs in service at the mine. The target monthly drilled metres of each existing drill rig was 22,000, whereas the performance by the time of the study was only 18,000 metres.

The above project was initiated after Barrick Gold Granny Smith reviewed the site condition and the age of the fleet and concluded that the equipment performance was acceptable, but could not be at its optimum. The project utilised historical maintenance cost reports and work orders from the mine to analyse the failure behaviour and potential changes to the maintenance strategy on the selected sub-systems of the development drills. Weibull analysis was conducted on both the sub-systems and component level to identify the failure modes and the corresponding maintenance strategies. Failure modes were also identified for the sub-systems using the FMEA process. Maintenance tactics addressing those failure modes were developed using RCM decision diagram in the later stage of the project Song (2012:61).

The constant hazard rate found for most of the sub-asset groups resulted from a combination of multiple failure modes. Therefore, further investigations were recommended on a component level for failure modes identification and maintenance strategy decision. Recommendations for the boom system and major components under the boom system and the feed rail system were made based on the RCM

decision diagram Song (2012:61). The data was collected through document review and interviews with maintenance personnel.

The project above helped the mine to identify the failure mode which could assist the maintenance personnel identify failure by category and determine the most common. However, what may not be clear is how the causes of breakdowns may be identified as the emphasis is on the failure mode and not the failure cause.

2.2.5 Africa

This section presents studies carried out from some mines in Africa highlighting factors assumed to be the major contributors to mining equipment breakdowns.

2.2.5.1 Ghana.

Most of the literature reviewed from studies carried out from mines in Ghana highlighted the most common type of failure experienced on underground equipment.

kansake and Suglo (2010: 524-532) carried out a study at Konjole Mine in Ghana and established that hose burst, overheating, shank adapter breaking, drilling rods getting stuck in holes, rod breaking, drill rod breakage, poor flushing, low percussion and rotation pressure, drill chain breakage and truck removal and breakage were the major causes of drill rig breakdowns at the mine. The duo identified the nature of breakdowns which could only show the failed component with its failure mode. To minimise or eliminate such breakdowns, it could be important to identify the cause of these failures and find a better way of addressing such causes. Further, the results of the study showed that production of the mine is dependent on the average hours used for drilling which is dependent on availability and utilisation of the drill rigs. Also, the analysis of logged data indicated that the mine did not schedule drill rigs to undergo regular planned maintenance and to this effect the study recommended that regular maintenance schedules should be prepared form drill rigs to minimise breakdowns.

Field visits were conducted for data collection and most of the data used was obtained from interviews and document review. Further, the data analysis was conducted through statistical methods using MS Excel 2013. The study highlighted the effect of drill rig availability and utilisation on productivity and also reviewed the nature of breakdowns that were experienced on drill rigs, however, identifying the causes of

breakdowns and developing a mitigation framework could help in reducing breakdowns as potential breakdowns could be mitigated before the actual breakdown occurs.

Ray and Euler (2017:651-655) suggested that heat management required being maintained within the mine working environment to minimise stress on equipment and personnel. It was further stated that, the issue is a growing concern as mines continue to expand in size, depth and infrastructure and that heat management is a concern as it relate to both heat sensitive equipment and more importantly the health and safety of the workers found within the mine. However, a proper application of engineering protocols and work practice controls such as provision of ventilation fans and proper mine design may control temperature acceptable levels and have a positive impact on the health and safety of workers. It may also be important to determine the level at which these factors could affect equipment performance.

Barabadi (2017:647-653) echoed that maintenance cost was a significant part of production costs and that logistics and spare part management should be considered early in the design. He further stated that operational the phase and reliability characteristic of a piece of equipment can be used effectively to determine spare part prediction (SPP). However, spares projection may assist in holding economical stock levels and avoid stock run-outs which may result in prolonged equipment downtime and in other cases, the use of alternate parts. The accuracy of an economical stock holding may be compromised as some parts may be subjected to stochastic failure caused by factors such as operating conditions and human factors.

Due to the low number of breakdowns experienced in the aviation industry, the study was motivated to get some views from certain senior members working for the airline industry to ascertain the nature of maintenance carried out on critical equipment such as aeroplanes and how such maintenance practices are sustained. Basvi (2019) gave the following as the baseline to maintenance in the aviation industry:

- i. The industry has adopted a culture of accuracy/precision in maintenance.
- ii. The maintenance personnel are encouraged not to relay on memory, but to follow steps as indicated from the maintenance check sheet.

- iii. The use of chapters in maintenance is encouraged, this is where a piece of equipment is apportioned into sections during maintenance and specific responsibilities given to maintenance personnel.
- iv. Safety is combined with maintenance.
- v. Emphasis is given on the consequences of failure (breakdown).
- vi. Firm inspection is encouraged.
- vii. Training and following changes through bulletins.
- viii. Feedback is encouraged.
- ix. Failure analysis is carried for each breakdown.

Lubambe Copper Mine had a maintenance system which incorporated check sheets, inspections, carried out failure analysis and emphasised safety. However, the mine still experienced a number of drill rig breakdowns. Therefore, it may be essential to determine what could be missed out in the maintenance of equipment carried out by the mine maintenance personnel.

2.2.5.2 Tanzania.

Most researchers from Tanzania identified the nature of breakdowns associated with the underground equipment as hydraulic systems, electrical systems, wear and tear caused by friction and contraction of materials as seen from the Tulawaka mine responsibility report (2010:3). Though these failures could highlight the nature of breakdown which could help the maintenance personnel determine the maximum and minimum level of spare parts, it may be pertinent to understand the variables that could lead to termination of operation of a component or system and at the same time finding mitigation measures.

Modak, kalita and Burua (2007: 48-51) investigated factors that cause equipment breakdown and they suggested two factors to be the major causes of downtime of drill rigs. The factors identified were, high pressure and leakage of the H-manifold hammer union joint which were all caused by vibration generated while pumping mud. The recommendation made was that, the alignment of the high-pressure lines be checked periodically to ensure reduced vibration and a redesign of the system was suggested.

The study identified the factors responsible for down time as indicated above, thus, high pressure line and H-manifold hammer union join repairs. This analysis may assist the maintenance personnel in developing timely components replacement programmes and effective repair processes, however, it may be necessary to determine the cause of high temperature and the breaking of the H-manifold hammer union joints. Identifying the causes of these two failures and devising corrective measures could minimise the failure and reduce drill rig breakdowns.

2.2.6 Southern Africa Development Countries (SADC)

This area analyses researches conducted by various writers within the SADC region that focus on identifying the cause and factors that could lead to breakdown of underground mobile equipment with emphasis on drill rigs which were the subject of this study.

2.2.6.1 South Africa

From the South African context, most of the researcher identified lack of skills as being one of the major issues contributing mining equipment breakdown and this situation was attributed to most of the skilled personnel leaving the country for better opportunities outside South Africa.

Callow (2006: 821-830) indicated that advances in technology in mining has resulted in general improvements in mining conditions, especially in the fields of ventilation, mechanised mining equipment and drilling and blasting techniques. Unfortunately, many of the operating mines are designed around less efficient technologies such as handheld drilling resulting in irregular tunnel dimensions, uneven footwall conditions and poor fragmentation in drawpoints. Despite improvements over the past few years, many mining methods require operating in areas where established workshops are located far away from the production environment. This contributes to extended down time of broken-down equipment as in certain circumstances, maintenance personnel cover longer distances to move machines to the workshop for repair.

Additionally, other conditions that lead to poor equipment performance are:

- i. Workshops—size, location, tooling, lighting, drainage, contamination control
Ventilation—cooling, visibility, operator efficiency

- ii. Haulages—dimensions, clearance, obstructions, footwall, drainage, water, gradients
- iii. Operator efficiency—training, motivation, salary, incentives.
- iv. Haul distance—drawpoint to tip, ramp tramming
- v. Maintenance practice—planning, mechanical skills, servicing on time,
- vi. fluid analysis

The data collection in this study was through interviews and document review and tables and graphs were used to analyse the data. Both bar charts and line graphs were used to show trends and severity of variables. The variables analysed included cycle time, payload, operator efficiency and tonnes moved.

The study identified the factors that affected productivity and the cost implication associated with equipment downtime, however, the study failed to identify the main causes of equipment breakdowns. Other factors such as fatigue and operator efficiency were highlighted, but the cause of these factors was not investigated.

To support the above, Rabinbach (1990:56) pointed out, the linkage between fatigue and energy depletion gave rise to the widespread assumption that fatigue was as a direct effect of long, unbroken periods of work. Long working hours could make an employee lose concentration while carrying out his task and this could result in damage to equipment or injury to personnel.

Barabady (2008: 647-653) stated that, failure of capital intensive equipment and its consequences has a strong impact on production cost. He further indicated that, since failure can be prevented entirely, it is important to minimise both its probability of occurrence and the impact of failures when they occurred. Therefore, he recommended an effective maintenance program in running mining equipment. The objective of the study was to describe reliability and availability of the crushing plant at Jajarm Bauxite Mine in Iran. The results of the analysis showed that the conveyor subsystem and secondary screen system were critical from a reliability point of view and on the other hand, the secondary crusher subsystem and conveyor subsystem were critical from an availability stand point. To analyse the data the Weibull, exponential and lognormal distributions were estimated using ReliaSoft's Weibull ++6 software.

The Weibull distribution may not determine the cause of equipment failure, but may be used in analysing failure, mostly it mimics distributions where the failure rate varies over time. Therefore, it may be regarded as a post activity investigation tool that may assist in determining maintenance intervals.

Fourie (2016: 275-281) conducted a study at Mogalakwena mine in South Africa to determine how OEE improvement initiatives could trigger an improvement in all areas of the mine. The data was collected through interviews, document review and observations and the data was analysed through bar charts, line graphs and scatter diagrams. The study concluded that through management and worker participation, visible measurement and controls and by carefully choosing the improvement elements, the mine productivity improved. Further, the turnaround in productivity enabled the organisation to start achieving production targets and on the other hand, employee relations and motivation including safety began to improve considerably. OEE is an efficiency improvement program which uses equipment availability, utilisation, productivity, and quality to determine the effective of a system or equipment. However, one of the demerits of this method is that it used post activity data to arrive at a conclusion and does not concentrate on identifying the major causes of the factors that affect productivity.

Gagné (2005: 331-336) claimed that, positive attitudes in work, effective performance and job satisfaction are some of the out comes from a work environment which provides satisfaction of basic needs. He further stated that, in work environment, motivation plays a greater role and if the employees are not motivated they may not perform their duties as expected. Further, Gagné (2005 331-336) added that, although the correlation between motivation and work performance has been studied and confirmed, many organisations still seem to be designed to destroy motivation. It may therefore be important for management to pay attention to the needs of employees in order to ensure that all employees are adequately motivated. This is so because people have different needs or different levels at which they are satisfied. Satisfying a single need may not necessarily mean motivating an employee.

Agbeno (2011:111) carried out a study to identify problems that affect drill rig availability thereby determining whether they are reliability problems and/or maintainability problems. He explained that the factors that affect performance of a

drilling system are categorised as design, or operating variables, uncontrollable/dependant variables, drillability factors and service /job factors. Design or operating variables were categorised as those factors that are linked directly with the components of the drilling system such as the drill source, rod, bit or circulating fluid. These were referred to as controllable factors. He further stressed the importance of skills assessment in performing quality work by stating that the objective behind conducting a skills needs assessment is to identify the organisational goals and the effectiveness of training in achieving these goals.

2.2.6.2 Rwanda.

The non-availability of technical institutions was cited as the major reason for the lack of technical skills in the mining industry in Rwanda (Rwanda Skills Survey, 2012:41).

Though the Zambian Mines, Energy and Water Development Minister (Zambia Daily Mail, 2013:3) implored that there was a shortage of technical skills in the Zambian mining industry, the Rwanda Skills Survey (2012:41) to some extent contrasted this statement, the Rwanda Skills Survey indicated that the mineral rich and exporting countries in the region like South Africa, Tanzania, **Zambia**, Botswana, Egypt and Namibia had training institutions with specific training programs/courses in Geology, engineering and Mining and offered both under and postgraduate and diploma/certificates a condition that makes them have adequate skills.

To carry out a credible and informative skills survey in the selected sectors, a rapid assessment methodology, applying qualitative and quantitative techniques was used. The sample size was determined using a formula developed by Yamane (1967:888). For data collection, focus groups, interviews conducted by trained bilingual enumerators and questionnaires were used. The outcome of the study showed that there were no training institutions in Rwanda to offer training programs in mining and that there was an urgent need to address the skills gap of professionals like technicians and Artisan that are needed in the industry.

2.2.6.3 Zambia

The study did not find literature on the performance or causes of breakdown of underground equipment from Zambian writers though some scholars and government

officials mentioned shortages of technical skills the Zambian mining industry was facing.

Yaluma (2013:3) established that there was a wide gap in the mining industry's expertise which if not addressed, could worsen the situation. He added that, the shortage of skilled manpower in the Zambian mining sector, no doubt had a telling effect on the industry and the overall performance of the economy. He further stressed that, such trends could result in losing out on the opportunity of creating a mass of skilled labour that could drive the industrialisation process of the country.

Though the issue of skilled manpower leaving the Zambian mining industry may be critical and known, what may be significant is finding a way of retaining the remaining skills and developing the current skills more especially those from Universities and Trades Schools. The introduction of apprenticeship could equally add value to the existing maintenance programs.

Chishimba (2017:1) regretted seeing people taking mining skills for granted, assuming that there was an unlimited supply of highly qualified, highly experienced men and women to work in the world's mines, he stated that the reality was quite different, the exponential growth in global mining production in the last 20 years has drained the global talent pool; the industry has become the victim of its own success.

2.2.7. Lubambe Copper Mine

The mine was facing numerous drill rig breakdowns and the equipment availability had generally been lower than the mine set target of 83% per month despite allowing for planned time losses and carrying out maintenance on the equipment.

The mine has a training school for operators and personnel who carry out maintenance are trained technicians who undergo the OEM training related to specific equipment that is used on the mine.

Despite having numerous drill rig breakdowns, no research had been conducted on the mine to determine and understand the variables that contributed to the numerous breakdowns.

2.2.8 General

Arkkelin (2014:10) defined Statistical Package for Social Science (SPSS) as an analytical tool that enables one to obtain statistics ranging from simple descriptive numbers to complex analyses of multivariate matrices. He further stated that, the program can plot the data in histograms, scatterplots and other ways. Additionally it can combine files, split files and sort files as well as modifying existing variables and create new ones. The study may therefore, use this package to analyse quantitative data obtained from questionnaire and the Chi-Square test may be used to determine associations between the variables measured by category.

Further, Lundau and Everitt (2004:1) commented that SPSS is a powerful, user friendly software package for the manipulation and statistical analysis of data and further said it is particularly useful for students and researchers in various field such as social science as it does an extensive range of both univariate and multivariate procedures much used in these fields.

Bazeley and Jackson (2013:3) stated that NVivo is a tool used to understand and analyse qualitative data. It helps in managing data, thus to organise and keep track of records that go into making a qualitative report, managing ideas by organising and providing rapid access to conceptual and theoretical knowledge generated by asking simple and complex questions of the data and it equally shows data visually in order to display content and/or structure of cases. This package may be used in the study to enter qualitative data more especially comments from the key informants.

2.2.9 Emerging Issues/Lesson Leant

From the literature review, four factors believed to be the major caused of drill rig breakdowns have been identified as human factors, environmental conditions, maintenance factors and Supply Chain factors. However, what may not have been explained is how these factors interact to cause the equipment to breakdown. If the root causes are identified, it may be possible to develop a framework that may be used to detect potential breakdowns before the actual breakdown occurs.

CHAPTER THREE

THEORETICAL AND CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter consists of four sections. The first part discusses the theories and their respective theoretical framework and the second part describes the conceptual framework and the operationalisation of the concepts. The third section described the variables involved in the study.

The study reviewed various theories because theories are developed for the sake of explaining, forecasting and mastering phenomena such as associations, events and behavior. They make generalisation about observations and may consist of an interrelated rational sets of ideas and models. Therefore, in the study, the theoretical framework presented a rationale for predictions about the relationship among variables of the study and these predictions were derived from observations, enquires and documents from the LCM.

The theoretical framework is considered as the “blueprint” for the entire dissertation inquiry. It serves as the guide on which to build and support the study, and also provides the structure to define how one approaches philosophically, epistemologically, methodologically, and analytically the dissertation as a whole. Thus, the theoretical framework consists of the selected theory (or theories) that undergirds a researchers’ thinking with regards to how one understands and plans to research a topic, as well as the concepts and definitions from that theory which may be relevant to the topic (Cynthia and Azadeh, 2014: 12-26).

Whereas, a conceptual framework may be used to outline likely courses of action or present a preferred method to an idea or thought, McGaghie et al. (2001:922) emphasises that, a conceptual framework “sets the stage” for the presentation of the specific research questions that direct the investigation being reported based on the problem statement. The problem statement of a thesis presents the context and the issues that cause the researcher to conduct the study.

In this study, the search for a theoretical framework narrowed the research questions and helped to direct the study. From the various literature review, the study highlighted different definitions of the same terms and the varying methodologies to find answers to key questions. Consistent definitions were developed for each concept and formed the theories upon which the study was constructed. The study reviewed some of the theories that helped to understand certain behaviours and characteristics of people, work environment and systems. These theories were picked as most of the literature review centred on these theories. Among the theories studied were;

- i. Motivation Theories
- ii. Training Theories
- iii. Human Capital Theory
- iv. Quality Theories
- v. Production Theory
- vi. Maintenance Theories

Therefore, the conceptual framework was developed from the literature review and from the theories investigated in this study. The conceptual framework further represented the synthesis of literature on how to explain a phenomenon and it mapped out the actions required in the course of the study given prior knowledge of other studies and findings obtained on identifying the factors that led to drill rig breakdowns at LCM.

3.2 Theories

The study considered theory to be a rationally interrelated set of propositions about observed reality and these suggestions being descriptions, operational definitions and functional relationships within a specific area.

As such, the study reviewed various theories to understand the area being studied as these theories describe, predict and extend knowledge within the boundaries of critical bounding assumptions. The knowledge gained from these theories helped in building the conceptual framework of the study. Wacker (1998:362) advised that, theory building in research seeks to find similarities across many different domains to increase its abstraction level and importance.

3.2.1 Motivation Theories

Motivation could be defined as those forces within a person that push or propel him to satisfy elementary needs or wants. This theory was reviewed in order to determine the extent to which motivation could impact on the performance of employees and how performance could in turn be linked to equipment breakdowns at LCM.

3.2.1.1 Maslow's Hierarchy of Needs theory

Abraham Maslow (1954:75) believed that man was naturally good and argued that individuals possessed a continuously growing internal drive that has great potential. His theory involves five categories of motives organised with lower-level needs on the bottom which must be satisfied first, before the higher level needs could come into effect and positioned them as follows:

- i. **Physiological needs:** This level consists of shelter, food and water. These needs are essential for the workers to perform effectively. As such this need was assessed to determine whether employees at LCM were satisfied with such provisions as food provided by the company and facilities like change houses, office space and workshops. This was meant to determine whether physiological needs could have an impact on the employee's performance at LCM more especially those involved with the maintenance and operation of drill rigs.
- ii. **Safety needs:** This need entails the protection against danger, threat, and deficiency. This need also takes into consideration the security of employment and discrimination-. Unpredictable administration of procedures are influential motivators of the safety needs in the employment relationship at every level. This need was taken into consideration in order to investigate the influence of the working environment on the performance of employees at the mine. This involved getting views of employees on work-site environmental conditions, the kind of safety attire provided to the employees at the mine and the nature and reliability of transport used to and from underground work places as well as the relationship between the employees and management.

- iii. **Social needs:** This level concerns relationships at a place of work and includes belonging, love and affection, friendship, association, and acceptance. It was equally important to understand the social environment of the employees and to assess the impact this could have on the employee's performance at the mine. This included reviewing among other issues, the process of handling employees' complaints and conflict as well as the treatment the employees received from their superiors and how their grievances were channelled or escalated.
- iv. **Ego needs:** This need takes into account strength, adequacy, achievement, and freedom. It may be described as the need for independence or autonomy. This is the need for self-esteem or self-worth and in reference to the study, this need was considered in order to understand whether the employees' ego could be related to their performance.
- v. **Self-actualisation needs:** This is the need to recognise one's potentialities for sustained self-development and the aspiration to become more of what someone is and what a person is capable of becoming. The study equally reviewed this need to ascertain the ambitions of employees and how their promotion framework was designed and to further determine possible gaps in these areas. This included reviewing the career development and succession programs for employees. This was made possible by reviewing documents from Human Resources Department.

3.2.1.2 Herzberg's Motivation Hygiene Theory

Herzberg's motivation hygiene theory also known as the two factor theory focuses on the sources of motivation which are relevant to the achievement of work. Further, job satisfaction and dissatisfaction are the products of two separate factors: motivating factors (satisfiers) and hygiene factors (dissatisfiers) Satisfiers respectively. These need are outlined as shown in Figure 3.1.

Satisfiers	Dissatisfies
Achievement	Company policy
Recognition	Supervision
Work itself	Working Conditions
Responsibility	Interpersonal relationship
Advancement	salary
Growth	Status
	Job Security
	Personal Life

Figure 3.1: Motivation Factors

Source: Herzberg (1976)

Regarding Herzberg Motivation Hygiene theory, external factors are factors that have an extrinsic existence at the place of work and derive from environmental matters that may be supported by the company and its policies; they may be structured by managers and leaders in an organisation. These external factors may include salary, work, co-worker, supervision, career up-grade etc. (Tan and Waheed, 2011:74). Effects of external factors could be the same as internal factors, though their sources may be different, significantly. These factors derive from environmental factors and most of the time depend on numerous situations in work set-up (Mohammad, Quoquab Habib, and Alias, 2011:149).

Therefore, factors that lead to job satisfaction are predominantly intrinsic, whereas factors that lead to job dissatisfaction are fundamentally extrinsic in nature. Understanding this theory also guided the study in determining the level of influence satisfiers and dissatisfiers could have on the employees in relation to their performance at work.

Further, Wallace and Burke (1987:150) maintained that there are three primary psychological states that significantly affected worker satisfaction and these being:

- i. Knowledge of results, or performance feedback.
- ii. Knowledgeable meaningfulness of the work itself.
- iii. Experienced accountability for the work and its results

As more work is designed to enhance these conditions, the more satisfying the employee becomes. This though process, made the study to review how performance

feedback of employee's performance and training was given to the employees at the mine and how the employees perceived this phenomenon. Further, the role definition and how employees perceived the job design was equally sought through views of respondents collected through questionnaires as well as expert views of key informants.

3.2.1.3 McClelland's Need for Achievement Theory

The theory implies that, when a need is strong in a human being, its effect may motivate the person to use behaviour which may lead to satisfaction of the need. The central theme of McClelland's theory was that needs are learned through adapting to one's environment and since needs are learned, behaviour which is rewarded tends to recur at a higher rate.

Wallace et al (1987:155) indicated that, McClelland established a descriptive set of factors which echoed a high need for achievement and these were:

- i. Achievers like circumstances in which they may take individual obligation for discovering solutions to problems.
- ii. Successful individuals have, a tendency to set reasonable achievement goals and take note of the risk involved.
- iii. Self-starters want well-founded feedback about how well they may be performing.

This theory stimulated the study into finding out how the drill rig operators and maintenance personnel perceived achievement within their work environment and how this could affect their performance at work. This also assisted in determining the level of involvement of employees at the mine in decision making and setting of performance goals or objectives. In appreciating McClelland's theory, Herzberg (1968:53) implored that, if the management of employees is fairly good, but employees expressed little positive attitudes concerning their work and are unwilling to extend any extra effort in their performance, then the business may have a motivation problem at hand.

Therefore, this theory, highlights the importance of the role of management in motivating employees and it directed the study in finding out how management related

with the employees at the mine. This included how management reacted to the needs or grievances of employees. The study further considered this theory in order to ascertain the cause of certain behaviours in the organisation and the impact of such behaviours on individual or group performance.

In summary, it may be deduced that, when managers incorporate motivational elements in work settings rather than simply eliminating adverse hygiene factors, higher productivity could be expected due to the performance of motivated employees. This may seem to be a paradox in many working environments where a great deal of time, energy and effort may be expended on extrinsic factors which may not lead to job satisfaction/motivation, but only serve to reduce job dissatisfaction.

The thrust of all of the motivational theories reviewed could be that, managers are expected to carefully review what they incorporate into reward systems. Therefore, motivation may be achieved only by satisfying a very limited area of complex needs, which could be additive in nature and whose satisfaction results could have much more long lasting effects. To sustain this motivation, managers may be required to consistently review factors that lead to motivating or demotivating employees.

From the preceding motivation theories, it may be deduced that motivation theories provided to the study an insight into what makes an employee perform better or otherwise. It also offered solutions of how management could use certain tools in motivating employees and avoiding various negative behaviours that could lead to poor performance and consequently low productivity.

3.2.2 Training Theories

The study viewed training as the formal and organised modification of behaviour through learning which transpires as a result of, instructions, education, development and planned experience. Further, the study saw training theories as a guide to understand the impact training could have on the employee's performance at LCM.

3.2.2.1 Situated Learning or Cognition Theory

Situated learning could be one of the most significant structures of the scientific methods which positions the learner into an operational context which is followed by the identification of issues and problems, where the learner is, to a certain extent, familiar with and involved in a definite context. Additionally, Anderson et al (1996:5-

11) established that situated learning was based on situations in which trainees are involved on a regular basis and the situational skills that trainees gain are supposed to be utilised in related situations. Further, the training activities are shared and, to some extent, actively created in cooperation with other trainees working together to identify and resolve problems.

The study sought to appreciate this kind of learning in order to understand the concepts of situated learning and its impact on employee performance. This knowledge was important in assessing the kind of training offered to both the drill rig operators and maintenance personnel and the impact such training could have on the performance of employees at LCM. Figure 3.2 gives a diagrammatical expression of the theory:

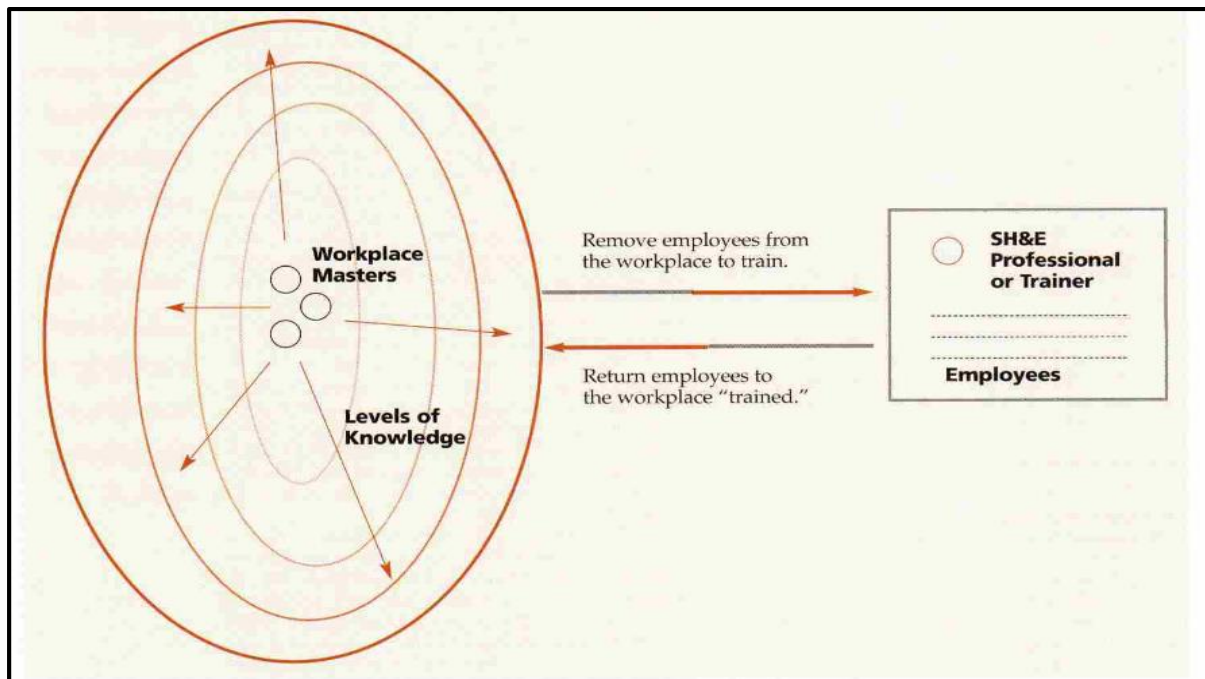


Figure 3.2: Situated Learning framework

Source: David (2013)

The indication from Figure 3.2 is such that, the employee is removed from his work place and taken out for training in line with his work. After training, the employee is retained to his substantive place of work and his performance is measured in line with the training he underwent. In supporting this kind of training, Senge (1994:36-47) explained that, learning is a much more intricate phenomenon which can never be restricted to classroom learning only, learning should therefore be connected to how

people live and the enthusiasm, encounters, motivation and support merged through day-to-day experience.

The mine had several training programmes where employees were removed from their work place and spent some time undergoing theoretical and practical lessons in such areas as maintenance and drill rig operations (appendix 2). This was conducted both onsite and offsite.

In summary, the idea of situated learning directed the study in framing questions on the training aspect of both the drill rig operators and maintenance personnel, looking at the training organisation, content, location and duration.

3.2.2.2 Constructivism and Experiential Learning Theory

According to the study, constructivist learning was taken as a kind of learning where the learner constructs own knowledge based on past knowledge and the knowledge may be subjective and could be individually and/or socially constructed. The learning stresses personal change and growth, believing that learning is learner driven, comprehensive, and centred on the process over the result. Additionally, Jonassen (1991:28-33) stated that, constructivist learning perception suggests that knowledge and skills can be enhanced in different ways without essentially any one ideal answer.

Jonassen (1994:34-37) further explained that in skills shaping in a specific environment, the different aspects of performance require to be defined, established, and understood. This approach enables individuals and groups to outline gaps and deficiencies in performance in a particular skills area. Additionally, Carver (1996:8-13) emphasises that this type of dynamic social engagement can also speed up the learning process as the multidisciplinary theory of experiential learning is to a greater extent based on constructivism and uses psychology, philosophy, sociology, anthropology, and cognitive sciences to obtain a greater insight into the learning process. Figure 3.3 shows the process of experiential learning.

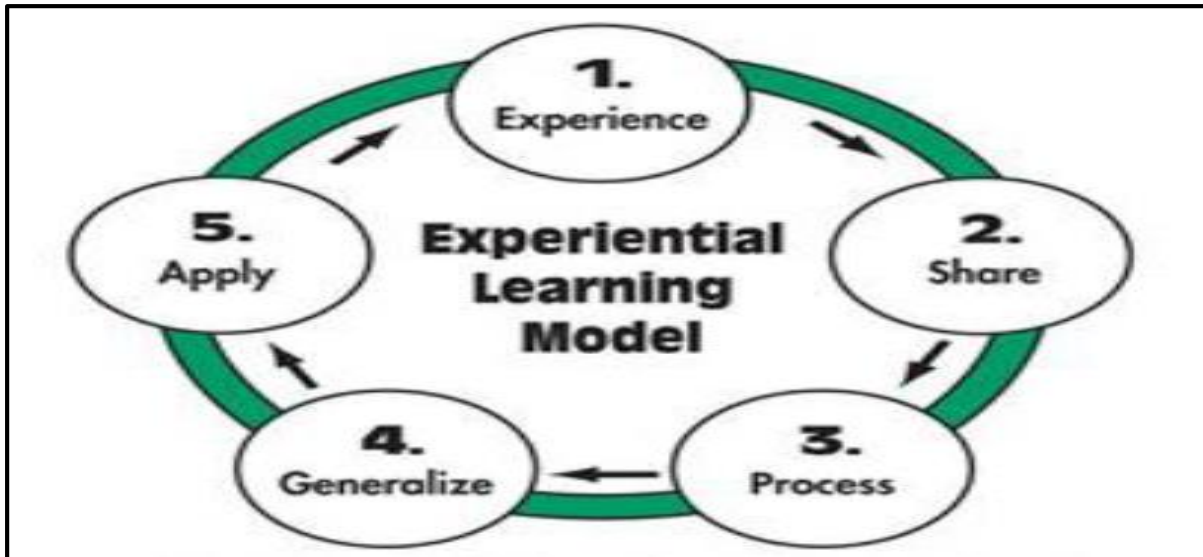


Figure 3.3: Experimental learning Model (Theoretical Framework) **Source:** Kolb (1984)

The illustration from Figure 3.3 indicates that the learner starts by grasping the skills through apprehension and then transformation occurs via intention and observation. After reflective observation, there is a state of abstract conceptualisation where the student grasps the skills via comprehension and finally, comes the transformation via extension and leading to active experimentation.

Additionally, experiential learning in combination with scientific approaches may allow and motivate learners to contribute actively in determining the content and application of learning undertakings. Further, personal job satisfaction and commitment could also be a significant characteristics of this kind of empowered learning. In line with this explanation, Marcinelli (1997:37) analysed employee creativity and concluded that, the possibility of making decisions and risks that affect motivation and productivity in a positive way is practical with this kind of learning. He further explained that transformative and experiential learning are concerned with using delegation, discretion and participation in decision-making processes.

In summary, experimental learning is where the learner acquires skills and develops knowledge through real-world, hands-on experiences. This kind of training was found to be present at mine where apprentices learnt through working with trained and experienced personnel. They were allocated work and observed by trained technicians

and their progress was recorded. On the other hand, delegation was equally present as seen from the leave roster where acting roles were defined.

3.2.2.3 Action Theory

Action theory attempts to define how learning is organised and how people change their behaviour to dynamically meet goals in normal and/or rare situations. Further, Salisbury (2008:131) explained that action theory is viewed as an orderly tool for understanding how knowledge of cognitive practises in a performance condition can be regulated by using the action structure mechanisms, focus, sequence and the basics of the theory which interact dynamically.

Understating the Action theory was an important aspect of the study as it helped in appreciating how employees applied their knowledge in the daily work situations and how they managed to resolve complex issues that they were faced with in executing their tasks. This knowledge equally assisted in determining how the drill rig operators and maintenance personnel mitigated the challenges they encountered in the workplace and the extent to which such issues impacted their performance. This was noted through document review where performance, training, succession and follow-up plans were documented at the mine.

3.2.3 Human Capital Theory

Human capital theory is based on neo-classical theories of labour markets, education and economic growth. It takes for granted that workers are productive resources and endeavours to find out whether highly trained employees could be more productive than other workers. Further, Garcia (2005:1691) pointed out that, as employees do not obtain considerable pay increases due to increased productivity after attending specific training sessions, they are not motivated to finance their own training requirements. The mine had a training school located at the mine site where the drill rig operators were trained and no employee was expected to pay any form of training fees, the mine took up all the bills related to training. Further, the mine paid for all specialise training such as those aimed at improving employees skills. This was confirmed through documents reviewed from the training school and Human Resources Department at the mine.

3.2.4 Quality Theories

Quality has been defined as those features of a product which meet the customer needs thereby providing customer satisfaction. The process of quality may be expressed as:

$$(i) \quad Q = P/E$$

Where:

Q = quality

P = performance

E = expectation

If Q is greater than 1.0, then there is a good feeling about the product or service and on the other hand, determination of P and E are based on perception with the organisation determining performance and the customer determining expectation.

Therefore, the study pursued quality theories in order to understand the influence quality could have on both equipment and personnel. The various quality theories assessed are outlined below:

3.2.4.1 Deming's Theory

Deming's theory of Total Quality Management rests upon fourteen points of management, the system of profound knowledge, and the Shewart Cycle (Plan-Do-Check-Act). He is known for his ratio - Quality is equal to the result of work efforts over the total costs. He states that if a company is to focus on costs, the problem is that costs rise while quality deteriorates.

The fourteen points of management included:

- i. **Creating consistency of purpose** - The improvement of products and services with the sole purpose of becoming competitive and stay in business and providing jobs.
- ii. **Adopt the new philosophy** - To take responsibilities, and take on leadership for change.

- iii. **Cease dependence on inspection to achieve quality** - To eradicate the need for inspection on a mass basis by building quality into the product in the first place.
- iv. **End the practice of awarding business on the basis of price tag** - To minimise the total cost and move towards a single supplier for any item on a long term relationship of trust and loyalty.
- v. **Improve constantly and forever the system of production and service** - To improve quality and productivity, thereby constantly decreasing costs.
- vi. **Institute training on the job** - Training is important in understanding quality
- vii. **Institute leadership** - The goal of supervision should be to help personnel, equipment and gadgets to perform a better job. Supervision of management is in need of overhaul, as well as supervision of production employees.
- viii. **Drive out fear** - To allow all employees to work effectively for the organisation.
- ix. **Break down barriers** - All departments to work as a team to foresee problems of production which the organisation may face.
- x. **Eliminate slogans, exhortations, and targets** - To eliminate work standards, thus quotas, and management by objective.
- xi. **Remove barriers that rob the hourly worker of his right to pride of workmanship** - The responsibility of supervisors should be changed from mere numerical numbers to quality.
- xii. **Remove barriers that rob people in management and in engineering of their right to pride of workmanship** - Abolishment of annual or merit rating as well as management by objective.
- xiii. **Institute a vigorous program of education and self-improvement** – To ensure training of employees across the organisation.
- xiv. **Put everybody in the company to work to accomplish the transformation** – Transformation is the responsibility of every employee.

Source: Besterfield et al, 2015:24

Further, the Deming's system of profound knowledge as indicated above consists of the following four points:

- i. **System Appreciation** - an understanding of the way that the company's processes and systems work. Therefore, understanding work method in an organisation could help create a culture that may lead to improved productivity by doing things in a systematic way.
- ii. **Variation Knowledge** - an understanding of the variation occurring and the causes of the variation. Additionally, the idea of identifying variations in any system is critical. Variation may only be resolved if the causes of variation is known. Therefore, it is important to understand the causes of variations in order to devise mitigation measures and address the problem.
- iii. **Knowledge Theory** - the understanding of what may be known. The study used the concept of this theory to ensure that the study addressed the correct problem.
- iv. **Psychology Knowledge** - the understanding of human nature. To this effect, the study reviewed the human factors to understand their impact on employees' performance and how the outcome of such behaviours could affect the organisational activities.

Additionally, the Plan-Do-Check-Act (PDCA) is a cycle created for continuous improvement and in the planning phase, objectives and actions are outlined. Then, actions are carried out and improvement processes are implemented. Next, checking is conducted to ensure quality against the original. Finally, acting implies determining where changes need to occur for continued improvement before returning to the planning phase (Besterfield et al, 2015:8). The logic of the PDCA cycle assisted in determining how the maintenance department and the mining department conducted their planning and how they identified and resolved problems relating to personnel and equipment. This mainly involved reviewing documents and interviewing key informants.

3.2.4.3 Crosby's Theory

McCabe and Wilkinson (1998:18-29) commented that when money was spent on quality, it was money that was well spent and that Crosby based his theory on four

absolutes of quality management. Further, they indicated that, Crosby developed four absolutes of quality and these being:

- i. Quality is defined as adherence to requirements
- ii. Prevention is the best way to guarantee quality
- iii. Zero Defects (mistakes) is the performance standard for quality
- iv. Quality is measured by the price of nonconformity

Crosby, further developed prevention process to help address potential problems before they resulted into actual problems. Figure 3.4 diagrammatically presents this process.

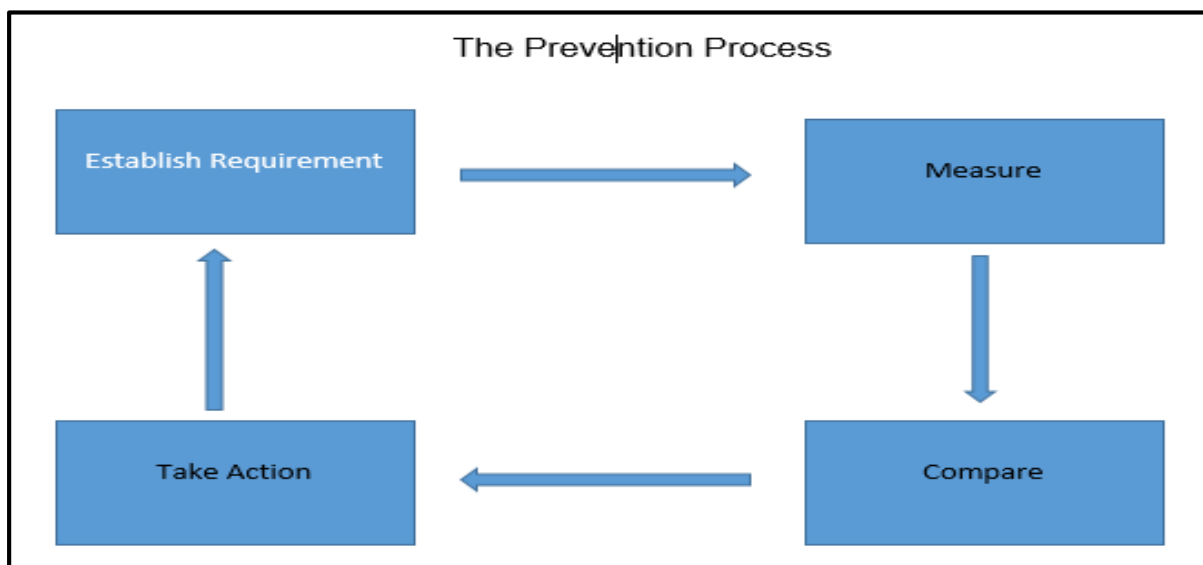


Figure 3.4: Prevention Process (Theoretical Framework) **Source:** Crosby (1987)

From Figure 3.4, Crosby defines the process of prevention by stating that the first thing in the process of prevention is to establish what is required, then determine the level of requirement and then compare the actual against the plan. If there any deviations, corrective action should be taken.

This theory guided the study in determining how the maintenance department approached planning and monitoring of activities. This was mainly accomplished through observation.

3.2.4.4 Joseph Juran's Theory

Joseph Juran pioneered what has become known as the "Quality Trilogy" and it is made up of quality planning, quality improvement, and quality control.

This theory shows that, if a quality improvement project is to be successful, all quality improvement actions are expected to be planned carefully and controlled. Further, Juran specified ten steps to quality improvement namely, an awareness of the opportunities and needs for improvement must be created, improvement goals must be determined, organisation is required for reaching the goals, training needs to be provided, initialise projects, monitor progress, recognise performance, report on results, track achievement of improvements and repeat. However, human dimension that leads to organisational inertia is a major obstacle for quality improvement (Duncan and Neuhauser, 2006:380-382). The quality trilogy is shown in Figure 3.5.

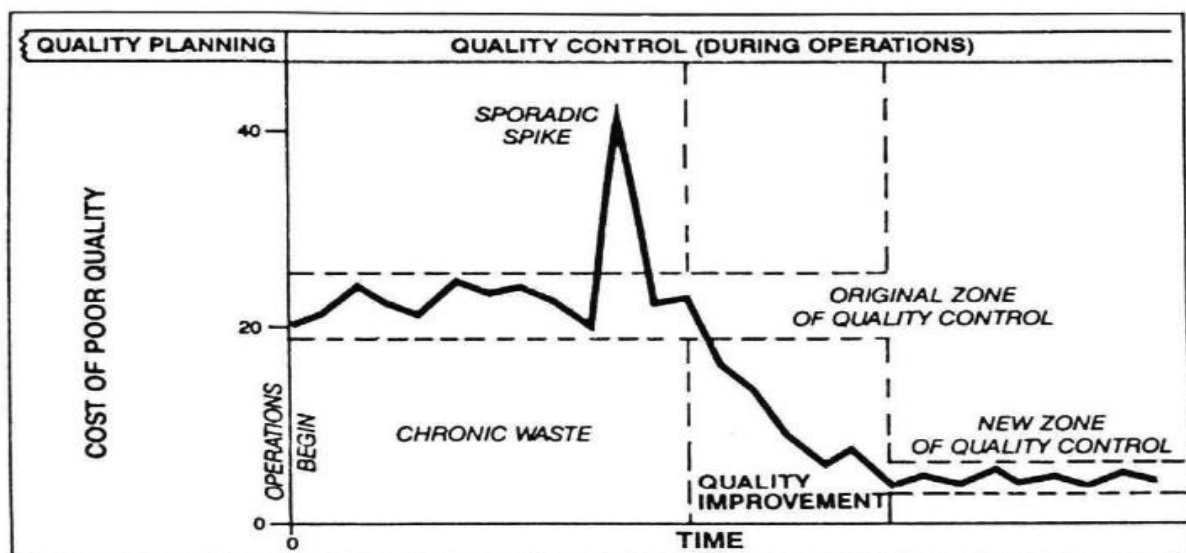


Figure 3.5: Quality Trilogy (Theoretical Framework)

Source: Juran (1986)

Figure 3.2 indicates that the first thing in quality is planning which involves understanding the customer need and how to satisfy the need. Later, as the need is being supplied to the customer, improvements must be made to the product to ensure continued satisfaction of the customer and finally corrective measures are taken where deviation from plan occurs.

Two aspects of Juran's ten steps to quality were imperative to the study and these are, provision of training needs to employees and recognising of performance. This allowed

the study to investigate how the drill rig operators and maintenance personnel were trained and how their performance was recognised. This was done to determine how these aspects could affect performance of employees. To understand this, training records, performance review records and employee appraisal were evaluated.

3.2.4.5 Ishikawa's Theory

Dr Kaoru Isikawa is known for his cause and effects diagram, but he also developed a theory of how companies should handle their quality improvement projects. Ishikawa takes a look at quality from a human standpoint. He points out that there are seven basic tools for quality improvement. These tools are:

- i. Pareto Analysis – Helps to identify the big problems in a process.
- ii. Cause and Effect Diagrams – Helps to get to the root cause of problems.
- iii. Stratification - Analyses how the information that has been collected fits together.
- iv. Check Sheets - Look at how often a problem occurs.
- v. Histograms - Monitor variation.
- vi. Scatter Charts- Demonstrate relationships between a varieties of factors.
- vii. Process Control Charts - Help to determine what variations to focus upon.

Ishikawa justified the appropriate use of problem solving tools in the improvement of quality. His theory of the Quality Control (QC) Circle was to bring production employees, maintenance, design engineers and managers together in structured meetings to resolve problems. The quality control circles were significant in the whole root-cause analysis of any problem. The quality control circles were responsible for identifying problems and developing lasting solutions for problems. Thus, Ishikawa emphasised that every member of the company was responsible to quality matters. Quality Circles” are a small number of employees (Usually is 5-10 staff) that discuss quality problems of their workplace, by the investigation, identification of problems, and finding solutions for quality problems (Neyestani, 2017:8).

The awareness and use of Ishikawa’s tools enabled the study to determine how the maintenance management identified problems of equipment and how they got to the root cause of such problems. This was achieved by reviewing the maintenance plans and failure analysis reports of the equipment parts (appendix 3). At the same time, the

study was able to determine and understand how the maintenance personnel monitored and controlled variations in their operating systems and this was done by reviewing log books and failure trends including equipment history files. Figure 3.6 demonstrates how to arrive at a root cause of a failure through the use of the Ishikawa diagram:

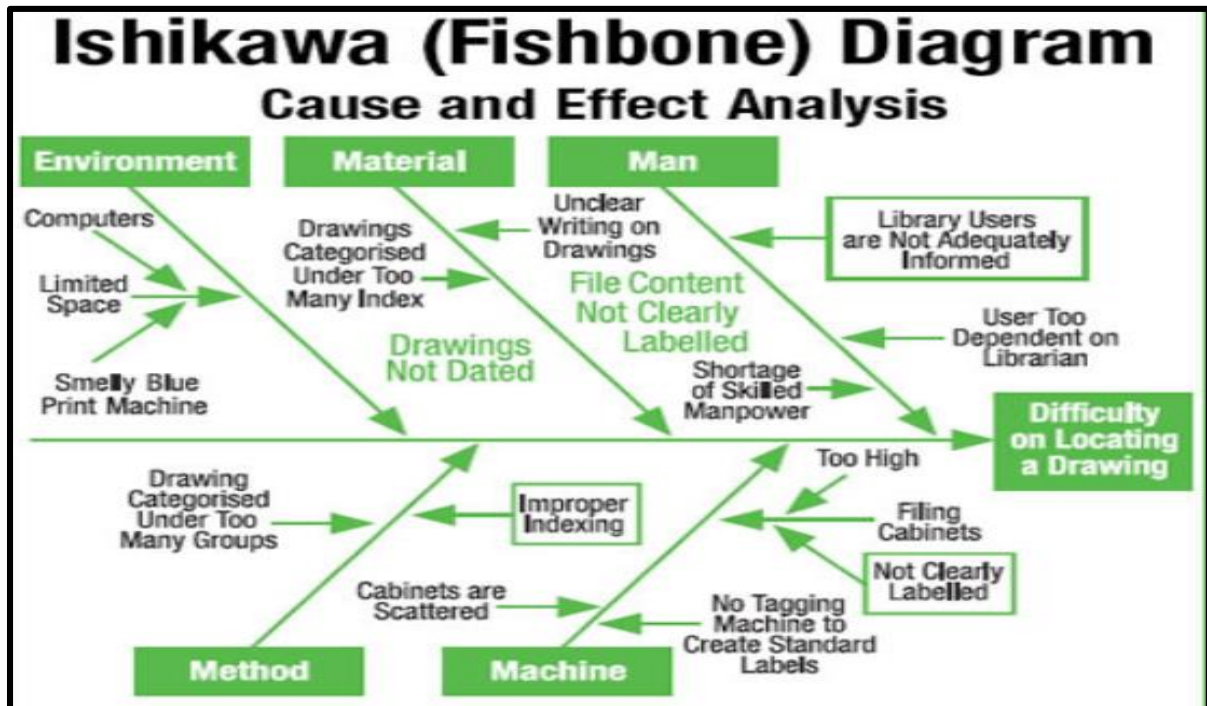


Figure 3.6: Cause and Effect Diagram

Source: Mosaic’s PMKI (2018)

The study was carried out to identify the causes of the numerous drill rig breakdowns despite the equipment being maintained and major components replaced at stated intervals. Therefore, this theory gave the study an opportunity of defining the drill rig breakdowns from their root cause point of view other than the immediate cause. This was done by following the principles of the fishbone diagram which looks at a problem right from its root cause.

The use of quality circles to address equipment failure causes at the mine was not present, equipment failures were only discussed in daily performance review meetings and documented.

3.2.5 Production Theory

The theory of production explains the principle by which a business decides how much to produce (output) and how much of each kind of labour, raw material, equipment etc., that it employs (inputs or factors of production) in order to produce such output. Additionally, Robert (2016:4) narrated that, the various decisions a business enterprise makes about its productive activities can be classified into three layers of increasing complexity. The first layer includes decisions about methods of producing a given quantity of the output in a plant of given size and equipment. It involves the problem of what is called short-run cost minimisation. The second layer, includes the determination of the most profitable quantities of products to produce in any given plant, and deals with what is called short-run profit maximisation. The third layer, concerns the determination of the most profitable size and equipment of plant, relates to what is called long-run profit maximisation.

This interaction can be expressed in terms of what is called the production function, i.e., an equation that expresses the relationship between the quantities of factors employed and the amount of product obtained. It states the amount of product which can be obtained from each and every combination of factors. This relationship is written mathematically as:

$$y = f(x_1, x_2, \dots, x_n; k_1, k_2, \dots, k_m).$$

Where, y denotes the quantity of output. The firm is presumed to use n variable factors of production that is, factors like hourly paid production workers and raw materials, the quantities of which may be increased or decreased. In the formula the quantity of the first variable factor is denoted by x_1 and so on. The firm is also presumed to use m fixed factors, or factors like fixed machinery, salaried staff, etc., the quantities of which may not be varied readily or habitually. The available quantity of the first fixed factor is indicated in the formula by k_1 and so on. The entire formula expresses the amount of output that results when specified quantities of factors are employed.

Therefore, the theory looks at how the factors of production combine to produce a desired level of products and services and at an economically accepted cost. The desired level of production can only be attained if all factors of production are present, reliable and serving the purpose they are intended. This theory made the study to

confirm that the numerous drill rig breakdowns at the mine could affect productivity as the drill rigs were one of the factors of production at the mine and their unreliability could make the production circle ineffective. Therefore, it was essential to investigate the major causes of drill rig breakdowns and develop a framework that could be used to determine potential equipment breakdowns before they result into actual breakdowns.

3.2.6 Maintenance Theory

It was not until 1950 that some groups of Japanese engineers began a new theory in maintenance that involved following the manufacturers' recommendations about the care that should be taken in the operation and maintenance of the equipment and devices. The new phenomenon was called "Preventive Maintenance". As a result, plant managers were stimulated to have their managers, mechanics, electricians and other professionals, develop programs for lubricating and making significant observations to avoid damages of the equipment. Although it helped minimise downtime, it was an expensive alternative. The reason: Many equipment parts were replaced on a time-basis, while they could have lasted longer. Also many unnecessary man-hours were put into it and in not few cases excess lubrication caused more damage than good (Management through Leadership, 2011:16).

The study considered maintenance as a grouping of all technical, administrative and managerial activities carried out throughout the life cycle of a piece of equipment or system intended to retain it in its operating state, or restore it to, a condition in which it can perform the required function. Maintenance practices may be grouped into two major categories, namely Preventive Maintenance (PM) and Corrective Maintenance. Li et al (2015:220) explained that maintenance is classified into two main categories: corrective and preventive maintenance. Figure 3.7 shows the theoretical framework of maintenance;

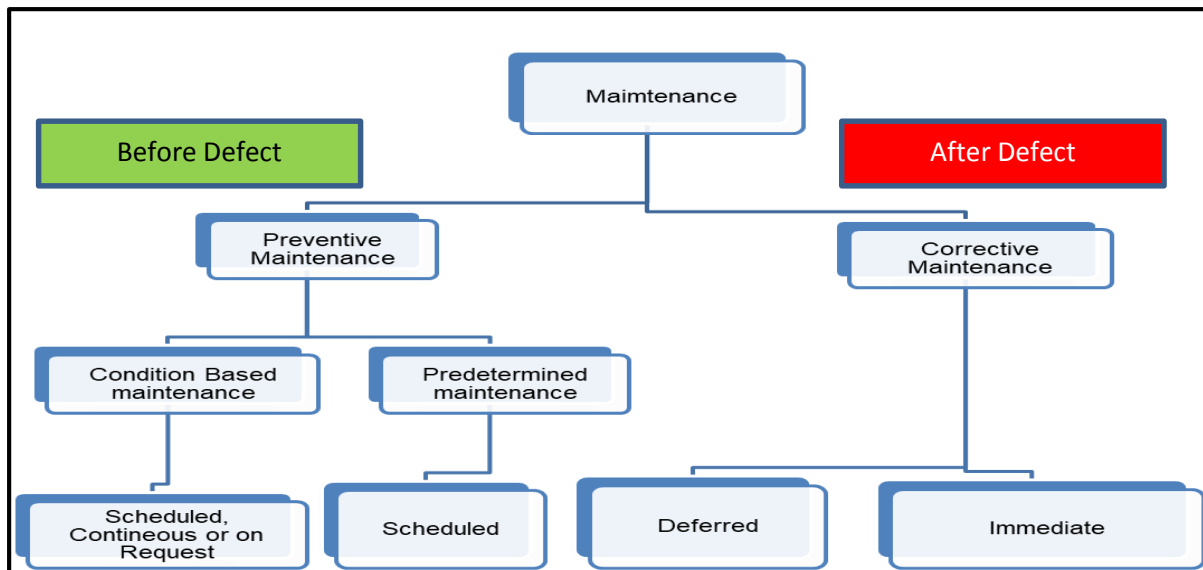


Figure 3.7: Theoretical Framework of Maintenance **Source:** Author (adopted from Mkemai, 2011).

From Figure 3.7, it can be noted that maintenance may be carried out before a defect occurs or after a defect. It all depends on the type of equipment and/or component maintained as well as the maintenance strategy adopted. Condition based maintenance can either be scheduled, continuous or may be carried out on request, whereas, predetermined maintenance can only be scheduled. On the other hand, corrective maintenance may be deferred or carried out immediately depending on the state of the equipment or component.

The maintenance department at the mine carried out different forms of maintenance depending on the equipment type of equipment and recommendations from the OEM. Drill rigs underwent a weekly planned maintenance and components were replaced according to the component replacement schedule where components were replaced based on predetermined hours (appendix 4). The purpose of component replacement is to ensure that the equipment continues performing without major unplanned stoppages (breakdowns). To enhance maintenance activities on drill rigs at LCM, the OEM (Sandvik) was hired to help maintain the equipment as drill rigs were specialised machines which required specialised expertise. The contractor also helped in skills transfer to the mine Technicians and this was done through the onsite observation as well as off-site training carried out by the OEM to lift the skills of the mine maintenance personnel.

The theory also helped to understand the operation of the various maintenance types, tools and strategies, their implementation and the relationship between equipment maintenance and the equipment reliability.

3.2.6.1 Types of Maintenance

Figure 3.7 (maintenance framework) shows that maintenance is divided into unplanned and planned maintenance. Unplanned maintenance, also called reactive maintenance, is conducted when a failure has occurred and when the original condition is to be restored (i.e. corrective maintenance) or when action is immediately needed in order to avoid catastrophic conditions. Whereas, planned maintenance is the kind of maintenance carried out before failure occurs.

Both preventive and corrective maintenance were carried out at the mine by the mine maintenance personnel and this was determined by a variety of factors among which were the machine design, operating conditions, age of the equipment and recommendations from the OEM.

3.2.6.1.1 Predetermined Maintenance

Predetermined maintenance is maintenance carried out on a regular basis at predetermined intervals. The maintenance actions are performed periodically in order to prevent degradation and sudden failure. Additionally, Au-Yong et al (2016:68) gave caution that the effectiveness of scheduled maintenance can be greatly influenced by the length of predetermined maintenance interval which needs to be schedule in such a way that it does not lead the equipment to fail due to prolonged usage or become costly by replacing components too early in their life cycle. Figure 3.8 shows the deterioration of performance and the maintenance interval in a predetermined program.

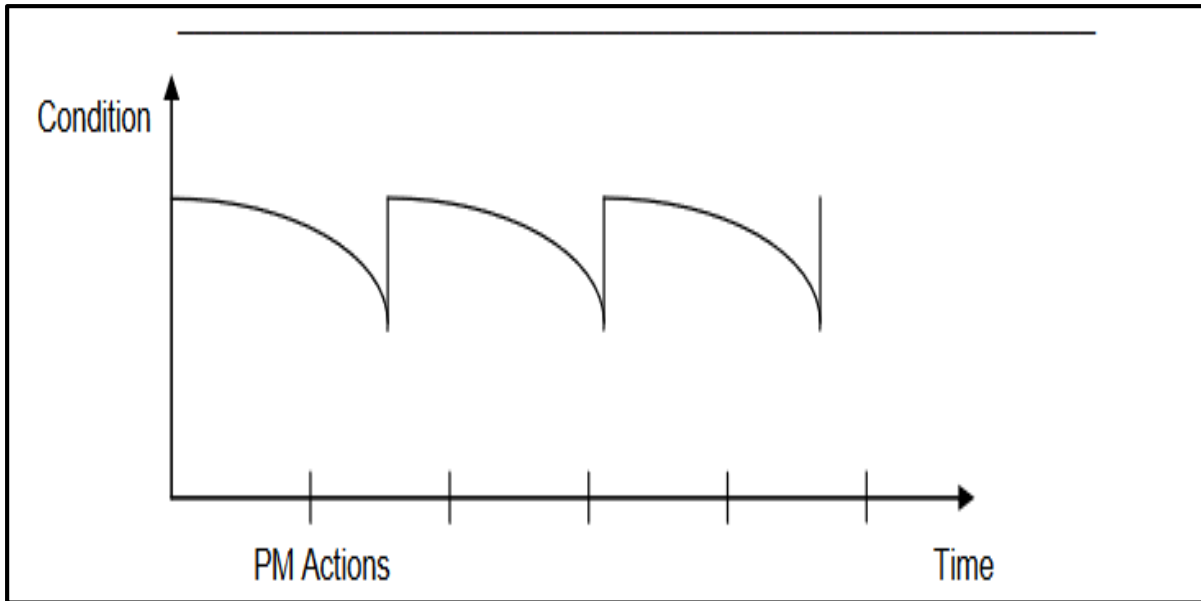


Figure 3.8: Predetermined Maintenance

Source: Milje, 2011.

The intervals shown from Figure 3.7 may be determined using the formula:

$$T = m \cdot \eta + \gamma$$

Where: m is the cost ratio C_f/C_p .

η is the shape parameter.

γ is the location parameter.

Source: Au-Yong et al (2016:68)

From the equation above, T is the dependent variable which is the point at which maintenance may be carried out, however, this may be influenced by η which is the independent variable. In terms of the maintenance scheduling process, this could be influenced by factors such as environmental conditions, human factors or maintenance related factors.

Therefore, though the formula may provide calculated maintenance intervals, caution may be taken to ensure that all other factors that may influence the performance of the machine are taken into consideration. In case of drill rigs at LCM, the drill rigs were maintained on a weekly basis, however, daily inspections were also carried out to look for any anomalies or physical damage to the equipment. Maintenance records and

schedules from planning office were reviewed to ascertain the maintenance strategy used in maintaining drill rigs.

3.2.6.1.2 Total Productive Maintenance (TPM)

The TPM concept originated in Japan and was an equipment management strategy intended to support the Total Quality Management (TQM) approach. The Japanese recognised that companies could not produce a consistent quality product with poorly-maintained equipment. TPM thus began in the 1950s and focused predominantly on the preventive maintenance. As new equipment was introduced, the focus was on implementing the preventive maintenance recommendations by the equipment manufacturer (Wireman, 2004:160).

Innovative maintenance approaches, along with business integration efforts at all levels and across all function/departments, have been advocated as important factors to improving organisational competitiveness (Bamber et al., 2004:26-36). As such, total productive maintenance (TPM) drives and facilitates an integrated production management system capable of supporting the different operational sub-systems. This integrated maintenance management methodology within a production environment puts the maintenance activities at the centre of the production system.

Further, Total Productive Maintenance consists of a range of approaches known to improve reliability, quality and production. Largely, TPM centres on maximising equipment effectiveness by changing the corporate culture to improve a company's personnel and equipment. Cultural change at an organisation may be difficult; it involves personnel working in small teams, machine operators having a role in the maintenance program and the maintenance department providing good support (Willmott and McCarthy 2001:56).

Nakajima (1988:78) argues that, Total Productive Maintenance when implemented fully, dramatically improves productivity and quality, and it is not a maintenance specific policy; but a culture, a philosophy and a new attitude towards maintenance and Ahuja and Khamba (2008:709) maintained that, the concept of TPM appeals for the knowledge and teamwork of operators, equipment vendors, engineering, and support personnel to augment machine production, thus causing elimination of breakdowns, reduction of un-prepared and planned downtime, better utilisation, higher

output, healthier product quality and entire participation of all total productive maintenance employees in pursuing the key feature of economic efficiency.

TPM is an innovative approach to plant maintenance that is complementary to Total Quality Management, Just-in Time Manufacturing, Total Employee Involvement, Continuous Performance Improvement, and other world-class manufacturing strategies (Khamba, 2008:709; Wakjira and Sigh, 2012:25-32 and Kamath and Rodrique, 2014:476).

Ahuja and Khamba (2008:709) suggested that TPM was anchored on eight pillars namely; autonomous maintenance, focused maintenance, planned maintenance, quality maintenance, education and training, safety, health and environment, office TPM and development management. Figure 3.9 shows the eight anchors of TPM:

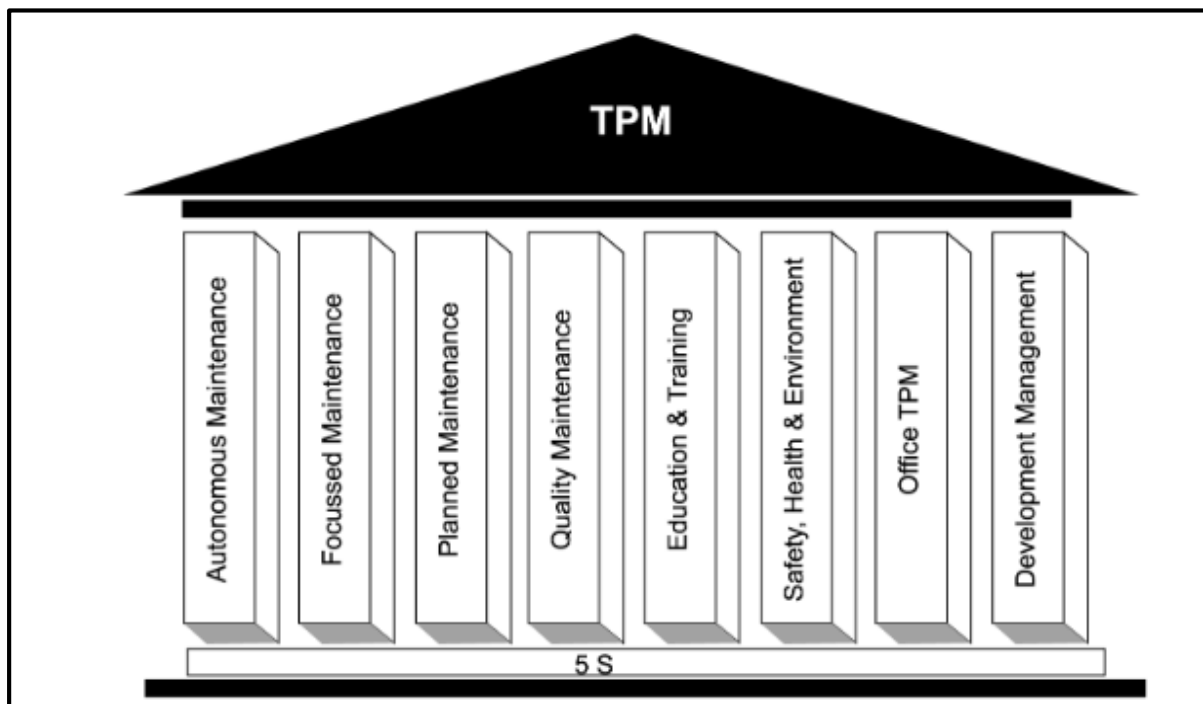


Figure 3.8: Eight Pillars of TPM

Source: Ahuja and Khamba, 2008.

However, Mishra and Anand (2008:48-53) descend that, though the objective of implementing a TPM strategy could be similar from different organisations, it may be important to conduct a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis before implementing Total Productive Maintenance in order to identify weaknesses that could render the system ineffective. From a similar stand point, Nagaraj and Lewlyn (2018:476) suggested that autonomous maintenance, equipment

technology importance, dedicated leadership, tactical planning, cross-functional training and employee involvement are the utmost practices contributing to Total Productive Environment.

However, LCM did not incorporate TPT in any of the maintenance systems as it was alleged by the mine management to be a complex and expensive system to maintain. The other reason advanced by the same management is that it takes a long time to train a large number of employees in the operations of the system which could equally mean pulling out personnel from their routine responsibilities.

Finally, Total Productive Maintenance may be considered as a system of maintaining and improving the integrity of production and quality systems through the machines, equipment, processes, and employees that add business value to an organisation.

3.2.6.1.3 Reliability Centred Maintenance (RCM)

The study defined Reliability Centred Maintenance as a corporate level maintenance strategy that is implemented to enhance the maintenance of equipment or systems. The main objective of RCM is to identify failure modes that could affect the equipment or system function, ranking the failure modes in order of criticality and selecting appropriate and effective strategies to control the failure modes.

Figure 3.10 illustrates diagrammatically a Reliability Centred Maintenance (RCM) decision diagram which integrates all the maintenance processes into a single strategic framework. It classifies failures into three groups founded on their consequences, hidden failure, safety and environmental failure and operational failure.

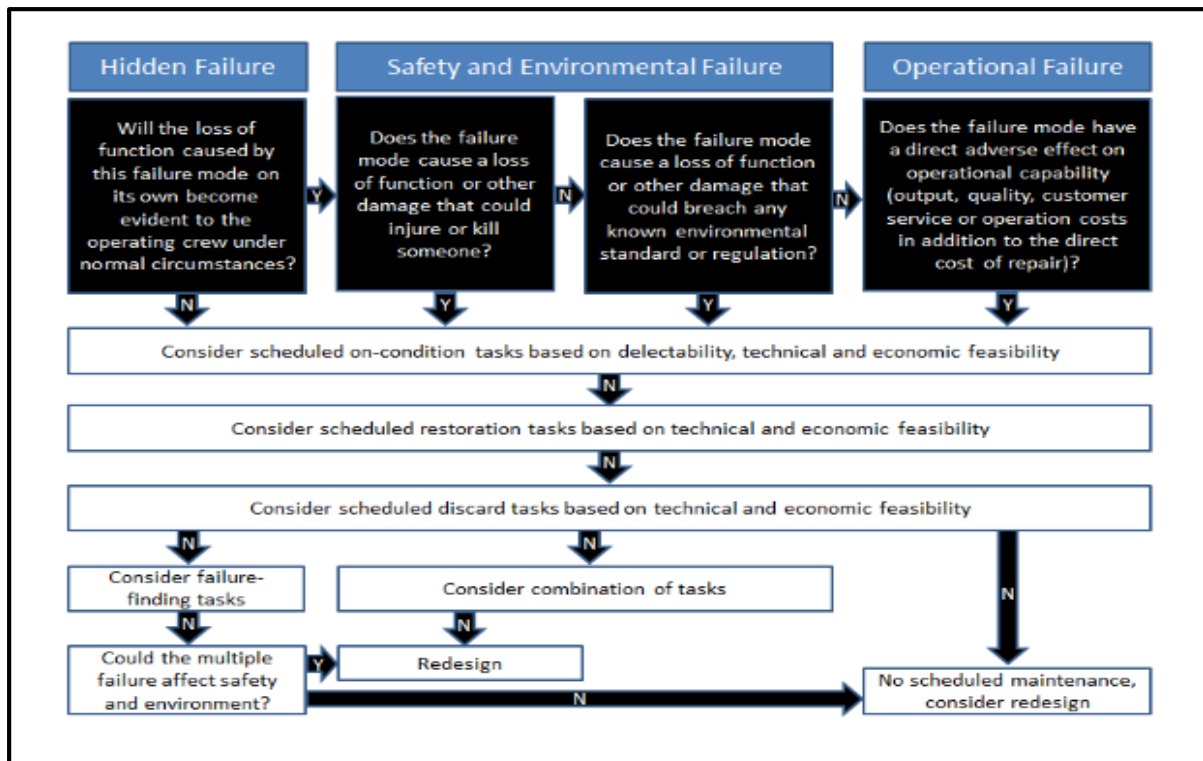


Figure 3.10: RCM Decision Diagram

Source: Moubary, 1997

Figure 3.10 shows that, Reliability Centred Maintenance philosophy is based on a system development method that keeps a cost effective view while identifying and devising operational, and maintenance polices and strategies. This is carried out in order to manage the risks of a system’s functional failure in an economically effective manner, and is especially applicable to situations where there are low or constrained financial resources.

Rausand and Vatn (2008:4) stated that, a high number of standards and guidelines have been issued where the RCM methodology can be tailored to different application areas. The major advantage of the RCM analysis process, though not adopted by LCM, is that, it is a structured and traceable approach to determine the optimal type of planned maintenance. This is achieved through detailed analysis of failure modes and failure causes.

Further, Knowles (1994) concludes by saying that, the use of RCM in mining industry has been very minimal, however some of the mines have implemented the method carefully with successful results. He cited Hammersley (Open pit Mine) in Australia. The fact that RCM may handle complex system operations with optimal results makes

it an attractive technique to be utilised in the mining industry to optimise the maintenance activities and the logic of the system is described in Figure 3.11.

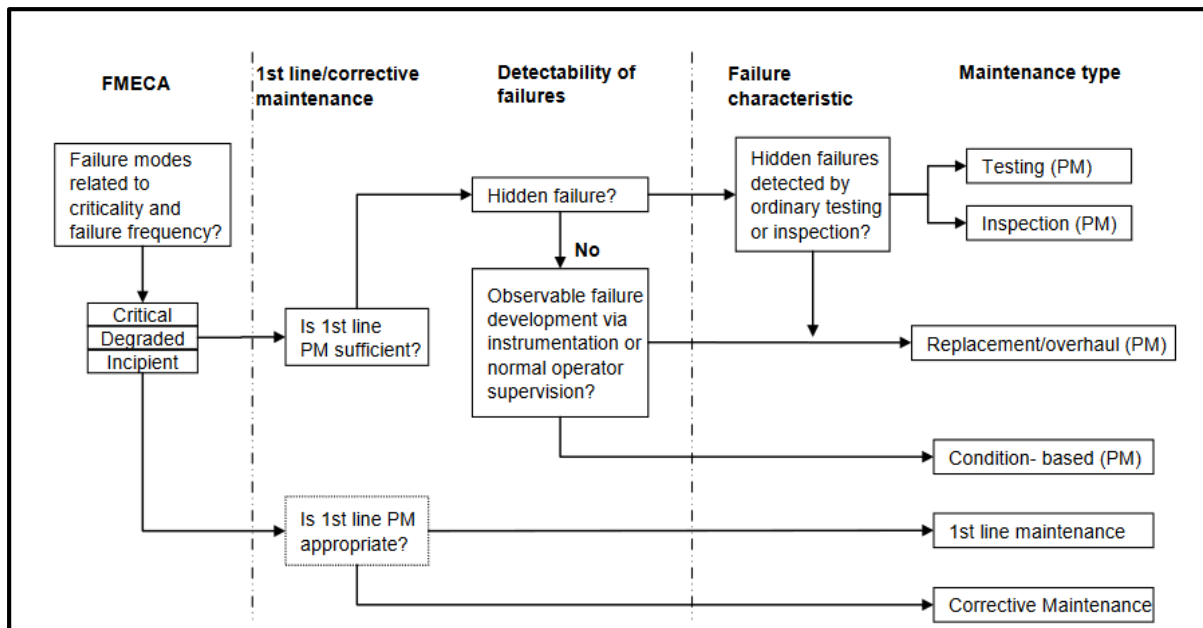


Figure 3.11: RCM Decision Logic

Source: Aker Solutions, 2010a

From Figure 3.11, it can be seen that the process commences with identifying the failure mode of a component or system, then the first line corrective method or maintenance is assessed to determine its practicality. Further, the characteristic of the failure is examined to determine the most appropriate maintenance to apply. Several maintenance types can be applied to arrive at the most appropriate maintenance system to adopt in preventing or minimising the recurrence of such failure.

Form the LCM maintenance documents reviewed, RCM was not used, however, some of the processes or components of RCM could be seen implemented by the maintenance personnel. The cost and impact of component failure was analysed including conducting of various reliability tests, however, these were not analysed through RCM process.

In summary, Reliability Cantered Maintenance may be viewed as an engineering framework that enables the definition of a complete maintenance regime. It regards maintenance as the means to maintain the functions a user may require of machinery in a defined operating context. As a discipline, it may enable machinery stakeholders to monitor, assess, predict and generally understand the working of physical assets.

It may equally be observed as a systematic approach to defining a planned maintenance program which may be cost-effective and at the same time preserving critical equipment functions by specifying a specific maintenance system for a specific equipment or function.

3.2.6.1.4 Risk Based Maintenance (RBM)

The study viewed Risk Based Maintenance as a form of maintenance that is carried out through an integrating analysis, measurement and periodic test activities to standard preventive maintenance. It takes into consideration the safety as well as the economic aspect of a piece of equipment or system.

In commenting on RBM philosophy, Bertolini et al (2009:244) ascertained that RCM allows for a methodical and as far as possible automatic approach to management of failure and that it makes substantial improvements in the organisation of work and in the decision-making processes through an in-depth analysis of the work environmental factors and related cost.

RBM methodology comprises six modules and these being: identification of the scope, functional analysis, risk assessment, risk evaluation, operation selection and planning, J-factor computation and operation realisation. Further, this system takes into consideration historical data regarding near accidents, operating drawbacks, occupational and environmental accidents that may have occurred over the previous years. A panel of experts define a risk matrix in order to evaluate the risk associated with critical events and maintenance activities.

The overall objective of RBM maintenance process is to increase the profitability of the operation and optimise the total life cycle cost without compromising safety or environmental issues. The risk assessment incorporates reliability with safety and environmental matters and therefore, may be used as a decision instrument for preventive maintenance planning.

Clarifying the merits of RBM, Faisal and Haddan (2003:561) explained that maintenance planning based on risk analysis can minimise the probability of system failure and its consequences (related to safety, economic, and environment).

Linking operations in high risk areas to RBM, Arzaghi et al (2017:928) descended that sound decision making methodologies for maintenance planning in areas of uncertainties associated with the deterioration of equipment could be made possible through the use of RBM principals. Further, the development of this method can assist the asset managers to select the optimum approach for mitigating the consequences of failure while minimising the maintenance costs.

Though some components of this maintenance strategy were implement by the mine maintenance personnel, the mine did not adopt a complete RBM program. The mine maintenance personnel used such methods as non-destructive testing to detect cracks on equipment chassis and oil analysis for monitoring the wear rate of major components such as engines and transmissions.

In summary, Risk Based Maintenance may be defined as a system that gathers information in the context of the environmental, operational and process condition of the equipment in the system to ascertain the asset condition, risk assessment and define the appropriate maintenance program.

3.2.6.1.5 Condition Based Maintenance (CBM)

Condition based maintenance in the study was considered to be the kind of maintenance which occurs when the need arises and may be performed after one or more indicators show that the equipment is going to fail or that equipment performance is deteriorating. It is based on using real-time data to prioritise and improve maintenance resources. In defining CBM, Wang et al (2007:151) claimed that, CBM applies the deterministic approach for analysing, interpretation, diagnosis, prognosis and decision making

Further, Alaswad and Xiang (2017:54) stressed that condition-based maintenance (CBM) was a maintenance strategy that collects and assesses real-time information, and recommends maintenance decisions based on the current condition of the system.

Condition monitoring and inspection are therefore, the two main strategic approaches to condition monitoring of an item. In condition monitoring, parameters are measured to ensure that maintenance is done before failure and is performed based on predetermined standards. Inspections are performed at regular intervals by a person

involved with maintenance to ensure that maintenance is implemented as soon as it is required. Through regular inspections, measurements or tests, or continuous monitoring, one may determine when a component or equipment is planned for replacement, servicing or adjustments. These checks could be performed in one of the three ways; scheduled, continuous or on request. Figure 3.12 shows the three stages involved in condition monitoring.

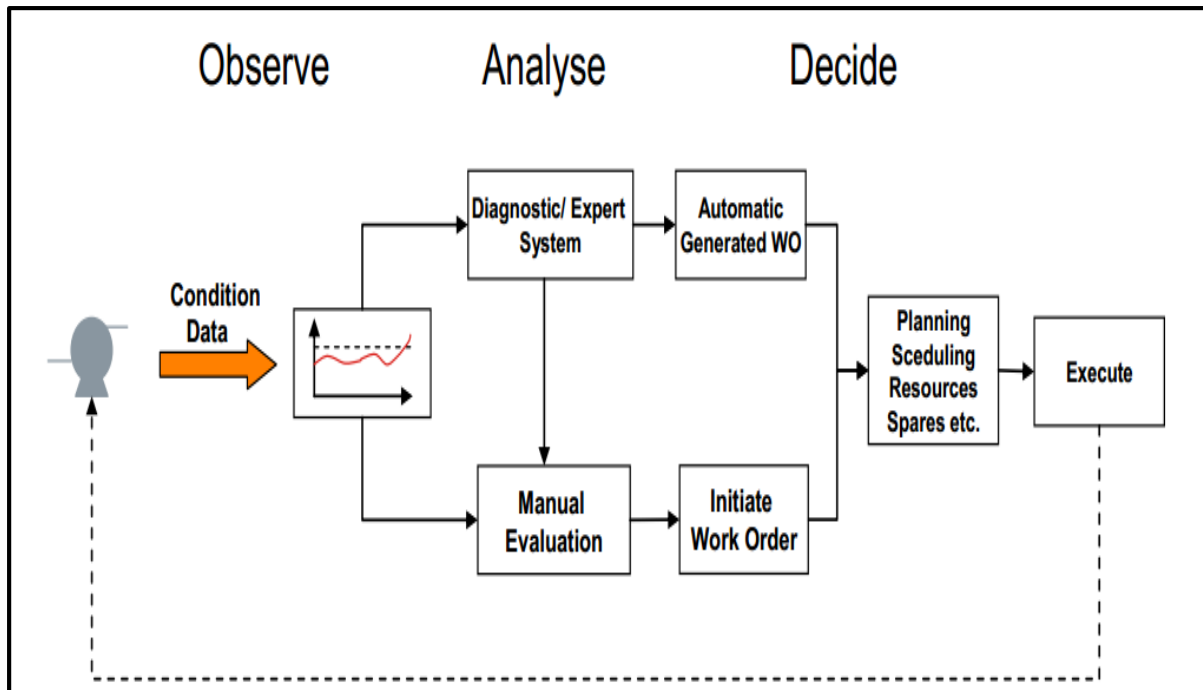


Figure 3.12: Condition Based Maintenance Work Process **Source:** Aker Solutions, 2009.

The condition of the component is first observed and then diagnosed either by some automated expert system or through manual evaluation. Depending on the outcome of the analysis, a works order is generated either automatically or manually depending on the maintenance strategy used. This leads to planning and scheduling of resources and finally the execution of work.

The mine maintenance personnel had certain equipment components that they monitored at stated intervals to ascertain the condition of such parts. Each time the inspection was carried out, the results were analysed and a decision was made by the maintenance and planning personnel. The decision suggested whether to replace the

part or keep it in service for a specified period of time. Figure 3.13 shows the deteriorating trend of a component monitored under condition based maintenance:

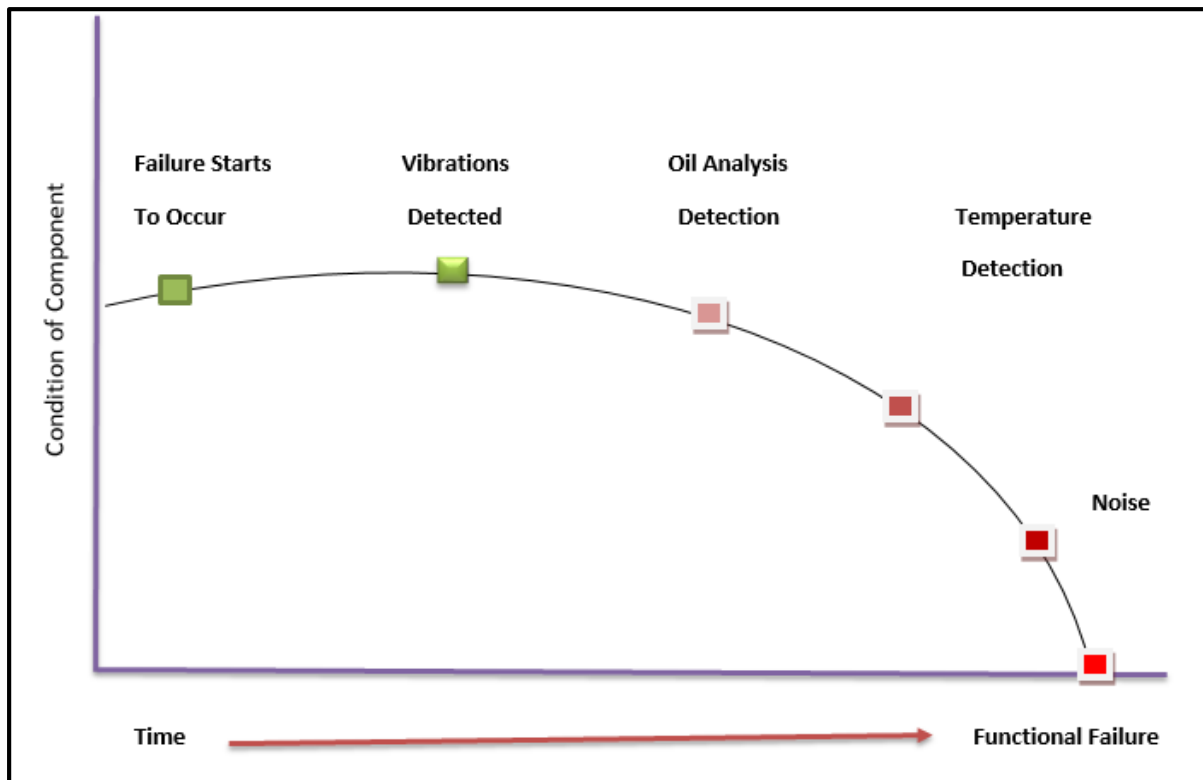


Figure 3.13: Failure Detection Trend **Source:** Author (adopted from Ho Shin and bae Jun, 2015).

From Figure 3.13, after installation of a component, failure starts to occur when the component is in active use, at this time the component is subjected to various types of monitoring to determine the level of deterioration. These tests include, vibration monitoring to determine clearances and alignment, oil analysis, to ascertain the level of metal particles in oil as well as other deterrents such as water and gases, temperature and finally noise.

LCM carried out various tests to monitor the condition of equipment components and the tests included oil analysis, vibration monitoring, visual inspection and other forms of non-destructive tests. If any of these went beyond the approved limits, the component was replaced or repaired to avoid complete sudden functional failure.

However, Hong et al (2014:276) gave caution by indicating that, components in engineered systems are subjected to stochastic deterioration due to the operating environmental conditions, and the uncertainty in material properties. The components

need to be inspected and possibly replaced based on preventive or failure replacement principles to provide the intended and safe operation of the system.

From the above decision making process, it may be noted that, the inspection criteria of the equipment components may not only be dependent on the predetermined intervals alone, but other factors such as the equipment operating conditions and the quality of parts. The attitude of the equipment operators and maintenance personnel should equally be considered since the manner in which they handle the equipment could have serious implications on the machine. Disgruntled or demotivated employees may be negligent in handling machines or may even sabotage the equipment.

In summary, condition monitoring provides the users with information of the actual condition of the equipment and early detection of failure. Early detection of failure may be an important factor in preventing serious damage to a component or system. By using CBM, the condition of a component or system can be monitored regularly, and the number of unexpected failures could be minimised as potential failure conditions could be detected before catastrophic failure. The reduction in unexpected and serious damages to the component or system can increase the system's operating life and reliability.

3.2.6.1.6 Corrective Maintenance (CM)

The study defined corrective maintenance as a maintenance undertaking performed to identify, isolate and correct a fault so that the failed equipment, machine, or component may be restored to an operational condition within the time limits established for in-service operations. Corrective maintenance is therefore, a type of maintenance carried out after failure detection and is designed to restore an asset to a condition in which it can perform its intended function. Corrective maintenance may be deferred or immediate depending of the criticality of the identified fault. Additionally, Wang (2002:469) explained that corrective maintenance is a kind of maintenance performed after system failure.

The main challenge posed by Corrective maintenance is that it does not involve forecasting of the failure when an item tends to fail. However, corrective maintenance could be seen as a maintenance strategy applied most often when it is difficult to

predict when an item could fail. Figure 3.14 shows the failure trend of a component or system subjected to corrective maintenance:

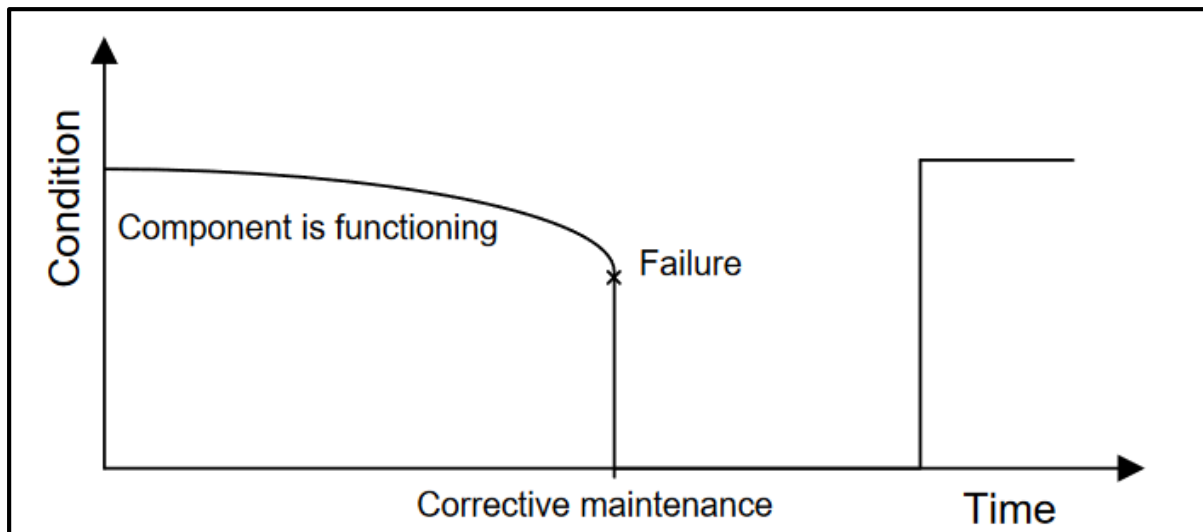


Figure 3.14: Corrective Maintenance Trend

Source: Milje, 2011.

From Figure 3.14, it can be seen that corrective maintenance may introduce unexpected equipment downtime in the system if a component fails before the predetermined replacement period (when replacement is deferred) and this failure could be as a result of stochastic wear pattern of certain components.

The maintenance personnel at LCM carried out corrective maintenance on specific equipment by looking for potential failures on machines, where serious faults were identified, the fault was immediately addressed, however, if the fault was not serious and could be corrected at a later date, the correction was deferred.

Corrective maintenance may therefore, be summarised as a kind of maintenance performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system could be restored to an operational condition within the tolerances or limits established for in-service tasks.

3.2.6.1.7 Breakdown Maintenance

Breakdown maintenance from the stand point of the study was viewed as maintenance performed on equipment or system that has broken-down and is unusable. It may be based on a breakdown maintenance trigger and could either be planned or unplanned. This kind of maintenance is usually performed on low value items or systems and it

can also be viewed as a form of material or equipment remediation that can be performed after the equipment or material has lost its functioning capabilities or properties. Breakdown maintenance is often the last option in an attempt to restore or extend the life of a given asset.

In summary, the mine carried out breakdown maintenance only on low cost equipment parts such as light bulbs which had a low correction time and no risk to both machines and personnel. The unpredicted failure of such parts did not contribute much to equipment downtime and no effort was expended in determining the cause of failure of such parts. Failure of such parts was only recorded for accountability purposes and no failure investigation was carried out by the mine maintenance personnel.

3.3 Critical Review of Theories

The critical review summarises and evaluates the ideas and information brought up by other writers on the subject under study. The theories were critically reviewed in relation to the factors that cause breakdowns of underground equipment in particular drill rigs.

3.3.1 Critical Review of Motivation Theories

Though motivation could be defined as those forces within an individual that push or propel him to satisfy basic needs or wants, different people may be motivated differently as individuals differ in characteristics and how they perceive things. Therefore, there may be need to understand what factors motivate or demotivate specific employees in a place of work.

To further describe the above thought, Lee and Lawrence (1991) argued that Maslow's needs theory did not apply precisely to specific individuals and that an ambitious manager could become unpopular to achieve advancement, sometimes taking considerable risks with personal financial security and even working to physical and psychological exhaustion. Further, an equally difficult problem for the practicing supervisor could be that, employees often obtain need satisfaction outside of the work environment and not within their work place.

Additionally, though motivators could be in place at a place of work, other factors could render employees not to take cognisance of these motivators yet other employees could

take long to be motivated. This may be because some employees by nature feel neglected or may be disrupted by other personal issues. Further, Lee and Lawrence (1991) echoed that, human needs fall into many categories and can vary according to the stage of development and total life situation. These needs and motives could assume varying degrees of importance to each person, creating some sort of hierarchy, but this hierarchy may be itself variable from person to person, from situation to situation, and from one time period to the other.

Therefore, though motivation may be viewed as a tool to ensuring that personnel work effectively, there may be need to investigate other factors within and outside the work environment that could affect an employee's performance. An employee could have his personal needs addressed at work, but if he has a number of unresolved problem at home, it may be difficult for such an employee to perform effectively at work. On the other hand, since a number of needs such as safety and esteem are required for an employee to be motivated to carry out his task effectively, it may be difficult to identify all individual needs accordingly in the organisation. Further, those employees that feel demotivated may indirectly or directly affect those that may be motivated. The negative attitude of the demotivated employee could cause the motivated employees to feel over-worked and this could lead them to not putting in their best. The overall result of such actions is poor performance which may lead to less care for equipment and subsequently low productivity resulting from equipment breakdown.

3.3.2 Critical Review of Training Theories

Though training could be termed as a process of teaching, or developing in oneself skill and knowledge that relate to specific useful competencies, employees may not utilise these learnt skills due to various factors such as attitude and their relationship with superiors and how commitment management may be towards employee's welfare. Wood and Bandura (1989:361) pointed out that, the quality that makes a learning organisation is the courage and commitment of managers to be able to learn together.

Though leaning through training could be an important aspect of an organisation's development, management is expected to lead this process and give responsibilities to employees with the freedom to make own decisions. Further, employees could be well trained, but if management does not give them enough authority to make

decisions, the contribution of training to the company productivity may not exist. Confirming this idea, Swieringa and Wierdsma (1992:361) explained that, a learning organisation is based on a philosophy in which its members consider themselves and each other as adults: as people who have the will and the courage to take on responsibility for their own functioning in relation to the other person, and who expect the same from the other person.

In summary, if training is not flexible and not empowering in nature, it may lead to rigid, standardised, and less flexible ways of managing the trainees and their concerns. This situation may make the learners less creative as they may only focus on what they have learnt in resolving problems and not any other practical way.

3.3.3 Critical Review of Quality Theories

Quality entails fitness for purpose, however, if quality requirements are not correctly defined, the desired quality may not be attained. The other issue could be that, though quality standards may be accurately defined, the personnel tasked with these standards may not comply with the set standards due to such factors as production push where management puts too much emphasis on production with less attention to quality. As such, for quality implementation to be effective, there is need for clarity in defining quality and a management buy-in. Additionally, Price and Shanks (2005:88) stressed that, the confusion in information quality frameworks mainly results from a lack of theoretical basis for deriving and defining quality dimensions and measures.

Although this study agrees with Reeves and Bednar (1994:419) who argued that the quality of any product or output is defined by considering the nature of that product, it may also be noted that, quality may not be defined independent of a quality evaluators (Carr, Gibson and Robinson, 2001:1240). Therefore, in situation like underground, in addition to the OEMs specifications of equipment and parts, the prevailing underground conditions must be considered in defining quality of replacement parts or equipment.

With regard to equipment spare parts, management may be required to define the quality measurements and show leadership in managing quality by providing the necessary tools and benchmarks. There is need for a quality evaluation system to be put in place to offer checks and balances. On the other hand, it may be difficult to

define the criteria to be used in defining quality and thereafter, identify or formulating measurements. This may be because certain items may be difficult to test. In terms of mining equipment, the quality of components such as drill rig drifters could be difficult to determine as on commissioning, they may be found to be fit for purpose, but prematurely fail in service due to the harsh underground conditions, maintenance or operational practices. Therefore, it may be formally impossible to test the predictions of certain theories under most epistemologies.

Finally, it may be noted that the quality of parts may not be the only bottom-line to getting good or bad performance from parts or systems, other aspects such as usage and environmental factors may be considered. The quality of work or maintenance practices could be another aspect which may equally affect the performance of equipment. To determine the quality of maintenance performed by maintenance personnel, LCM maintenance department examined the quality of maintenance practices through equipment performance audits and Planned Task Observations carried out by supervisors while the subordinates were carrying out their work.

3.3.4 Critical Review of Production Theory

The production theory determines the input required in order to produce a certain amount output. This theory concentrates more on the output and the unit cost of production. Therefore, production theory may not directly investigate the factors that could affect the factors of production such as the effect certain independent variables may have on the reliability of equipment.

Further, Robert (2016) concluded that, the production theory has been charged with excessive simplification as it assumes that there are no changes in the rest of the activities while individual firms and industries are making the adjustments described in the theory; it neglects changes in the technique of production. Further, the production theory is not based on analysing equipment failure causes, but based on factor contribution to productivity. Therefore, this theory may not be entirely used to determine the cause of equipment breakdowns.

3.3.5 Critical Review of Predetermined Maintenance

Predetermined maintenance could be scheduled in hours, days, months or could be annual and certain equipment may be maintained based on specific millage/distance covered.

However, predetermined periods though in most cases is aided by the use of approved formula, it may still be difficult to determine the exact period of maintenance, more especially where equipment such as underground drill rigs could be affected by factors such as attitude, underground environmental conditions, maintenance practices, resource constraints and Supply Chain factors. Further, despite predetermined maintenance directing its efforts on preventing assets from breaking down by performing maintenance regularly, unpredicted breakdowns could still occur if the variables that cause stochastic deterioration of equipment components and systems are not identified and mitigated .

Though Murthy et al (2004) indicated that the Weibull was commonly used in statistical analysis due to its flexibility and ability to deal with small sample size in order to evaluate lifetime of system components, other factors such employees' attitude, maintenance practices, environmental conditions and Supply Chain factors could cause the parts or systems to fail before the projected maintenance or replacement time. Therefore, it may be significant to consider these factors when determining the maintenance intervals.

Further, the Naval Sea Systems (1988) explained that although numerous ways have been proposed for determining the correct intervals of preventive maintenance tasks, none may be practicable, unless the in-service age-reliability characteristics of the system or equipment affected by the desired task are known.

The suggested illustration below shows one way of determining the maintenance interval:

$$T = -\emptyset \log_e (2A-1)$$

Where:

T is the task periodicity

\emptyset is the no-task M

A is the desired/expected availability

Illustration:

- (i) No-task MTBF = - 50 hours (an estimate)
- (ii) Desired/expected availability = .9
- (iii) Task periodicity (T) = $-50 \log_e [(2 \times .95) - 1] = -50 \log_e .$
- (iv) 5 hours

In the above calculation, MTBF stands for Mean Time Before Failure, the average time from one failure to the other and T is the projected time interval.

Source: Naval Sea Systems, 1988.

Though the intervals derived from this formula may give an estimate of the maintenance period, the maintenance point may be influenced by other factors such as environmental conditions, maintenance characteristics as well as the quality and Supply Chain factors. The effect of these factors could cause the equipment to fail before the predetermined maintenance or replacement time.

3.3.6 Critical Review of Reliability Centered Maintenance

The RCM philosophy as seen in the earlier sections, employs Preventive Maintenance, Predictive Maintenance, Real-time Monitoring, Run-to-Failure which is also known as reactive maintenance and finally, Proactive Maintenance techniques in an integrated mode to increase the probability that a piece of equipment or component may function as required over its design life cycle with minimum maintenance and reliability. Figure 3.15 diagrammatically illustrates this principle. The aim of RCM philosophy is to provide the specified function of the equipment, with the necessary reliability and availability at the lowest cost possible. Further, RCM may require that maintenance decisions be founded on maintenance requirements supported by comprehensive technical and economic validation. Additionally, it may provide direction into the desired and more economical way of carrying out maintenance on a specific equipment, component or system. This could be made possible by providing maintenance strategies that may be aligned with the functionality of these components, systems or equipment. However, RCM may be challenging to employ as it involves stages that may require intensive training and expensive equipment to

implement. The other factor could be that a pool of qualified and experienced personnel may be required to run with the day to day activities of RCM.

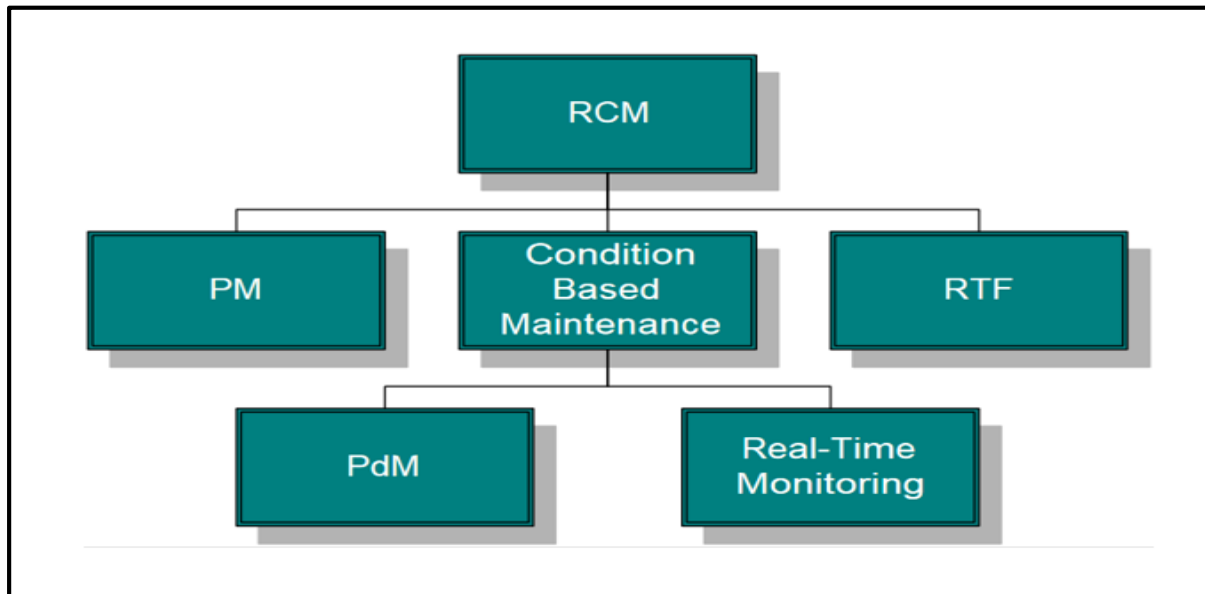


Figure 3.15: Elements of RCM

Source: Howard (1978)

Further, it has been estimated by Mohammed (2012:2) that more than 60 percent of all RCM programs initiated fail to be successfully implemented and that any of the other 40 percent that may be completed are performed superficially, making their true value only marginal. To support his findings, Mohammed further streamlined some challenges of RCM and explained them as follows:

- i. RCM programs are likely to result in failure because they do not incorporate the correct mix of knowledge and organisational buy-in from all applicable in-house stakeholders.

Therefore, consensus buy-in may be required from maintenance, engineering, operational personnel and this team may also include craft personnel because they are very insightful and eventually they may be representatives of the RCM program once it is completed.

- ii. RCM may create unnecessary and costly administrative problems by creating unnecessary administrative teams to support the RCM process, such as RCM steering groups, focus groups and other committees.
- iii. RCM may not be a PM reduction program, rather, it is viewed as a reliability program.

- iv. The likelihood of misunderstanding hidden failures and redundancy could be high. Additionally, it may be difficult to understand how to handle hidden failures and redundancy, how to find them, and what can distinguish them from a run-to-failure component. In light of this, one of the major challenges could be how to analyse an entire system that may be hidden, such as an emergency safety system and how to handle hidden failures in hidden systems.

In summary, the objective of RCM could be to maintain the inherent reliability of the equipment design, however, it may be worth noting that changes in inherent reliability could be the sphere of design rather than maintenance. On the other hand maintenance may only achieve and maintain the level of reliability for equipment, which may be provided for by design.

3.3.7 Critical Review of Total Productive Maintenance

From the literature review, Total Productive Maintenance may be summarised as an organisational system that incorporates all members of the organisation in ensuring that the equipment is efficiently maintained. This may involve all levels of the organisation such as technicians, engineers, equipment operators and managers. This effort is aimed at improving product quality and productivity, eliminating frequent breakdowns and rework leading to a dependable structure which may maximise worker morale and subsequently, increased job satisfaction.

However, though TPM may present the above advantages, using personnel who may not have formal professional qualifications in maintenance related tasks could be harmful to both the equipment and personnel. Further, other challenges that organisations could encounter may include inadequate knowledge of TPM, lack of leadership and management support, organisational culture, excess inventory, and inadequate training, all of which may require time and money to address.

Further, Bhadury (2000:240) explained that, total productive maintenance is an innovative approach to maintenance that optimises equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through the involvement of the entire workforce. However, though the entire workforce may work towards eliminating breakdowns of equipment, there is a high possibility of only

identifying the faults and overlooking the actual factors that lead to failure of equipment components and systems.

Additionally, Bullinger and Menral (2002:3955) stated that, if an organisation emphasises teamwork, as in the case of those who adopt TPM, the remuneration structure should promote cooperation rather than undermine it. Further, a wider variety of remuneration schemes, which may take into consideration factors, other than rank, experience and length-of-service could be used in modern, innovative organisations. These may require company funding. Additionally, Bullinger and Menral (2002:3955) and Eti, Ogaji and Probert (2006:211) commented that, some organisations may use pay-for-skill programmes to develop multi-skilled employees, pay-for-performance, promote goal-sharing programmes, and provide bonuses that could be linked to group performance. However, Eti et al (2006:211) argued that, offering the “right” rewards alone is unlikely to produce sustained empowerment and the power of such methods to maintain commitment could decline with use. He concludes by saying that, ‘with such kind of incentives, today’s privileges may become tomorrow’s rights and that involvement and autonomy are the main motivations that could activate the human mind and drive human effort’. Therefore, pulling of employees together to conduct equipment maintenance may pose a challenge of determining the employees’ pay scale and if not managed properly, this could create demotivation among the employees.

In summary, though TPM could be centred on solving maintenance problems by involving all members of the organisation in equipment maintenance, developing this system could be costly and may require pulling employees from their routine tasks into training to understand the concepts of TPM. Further, the system may pose a danger to those employees who may not have adequate formal technical training to work on high technology machines such as drill rig.

3.3.8 Critical Review of Risk Based Maintenance (RBM)

Though Faisal and Haddan (2003:561) maintained that maintenance planning based on risk analysis can minimise the probability of system failure and its consequences and that it may help management in making correct decisions concerning investment in maintenance or related field, risk based maintenance may require multi-disciplined and highly skilled personnel with a high level of commitment. Further, lack of skills,

knowledge and experience could lead to serious equipment failure which may lead to high correction cost and in some cases injury to personnel.

Risk Based Maintenance may be likened to condition based maintenance as it monitors the performance of the equipment and also utilises such methods as Non-destructive testing (NDT) to identify defects. To this regard, risk based maintenance may concentrate on observing component or system deterioration pattern and pay less attention to identifying factors that cause deterioration of these parts and systems. Finally, from its definition, RBM could be viewed as a complicated system to implement and if not properly managed, it may increase equipment downtime due to regular and prolonged inspections.

3.3.9 Critical Review of Condition Based Maintenance

In condition based maintenance, the equipment is monitored for signs of failure or deterioration in performance through non-invasive measurements, visual inspections, performance data and planned examinations.

However, fatigue or uniform wear failure may not be detected with condition based maintenance measurements in situations where condition sensors may not be present. This may occur in certain harsh operating conditions such as the underground environment. Unexpected catastrophic failure of components could occur before the predetermined date of replacement or repair. The unpredicted failure may be as a result of stochastic wear of poor quality parts or wear accelerated due to exposure of equipment to adverse environmental conditions such as water and dust.

Further, apart from the replacement point being difficult to determine, replacing a component too soon or too late could have negative implications on the business. Removing a part too early could be costly and removing it too late could cause catastrophic failure of the equipment resulting in high recovery cost and loss of productivity due to unplanned downtime. Such random failure could introduce unpredictable maintenance situations which may interfere with planned maintenance schedules.

Though condition based maintenance may emphasise the monitoring of failure indicators of equipment components and parts, it may not highlight or address the cause of failure of these components and systems. This maintenance practice tend to

put more emphasis on monitoring the component as opposed to determining the cause of failure or factors behind the deterioration of a component or system.

Even if CBM may be a good tool for ensuring that the equipment or system continues operating effectively, timing could be a challenge as failure may not always be predicted, for example, the propagation of a crack on a piece of steel may not always take a gradual root, other factors within the operating system could increase or retard the propagation. Further, in being critical about CBM, Holmberg et al. (2009) claimed that, CBM system is difficult because the deterioration process could be stochastic. Hence, difficult to predict the failure point.

In summary, the time taken for inspections and monitoring of parts could outweigh productivity benefits in that more time could be spent on these inspections. Tying up of maintenance manpower to these inspections could equally deviate attention from other maintenance activities and distort planned maintenance schedules. The attitude of maintenance personnel could be another factor, if the detected faults are not reported and mitigated in time, unexpected failure could occur resulting into equipment breakdown and consequently loss of productivity.

Additionally, though a number of writers from the literature review commented that condition based maintenance has received increasing attention in the literature over the past years, Keizer et al (2017:405) on the contrary argues that the application of condition based maintenance in practice lags behind.

3.3.10 Critical Review of Corrective Maintenance

From the literature review, corrective maintenance may be summarised as a maintenance task implemented to identify, isolate, and correct a fault so that the failed equipment part, component or system is restored to an operational state. Further, it may be termed as a reactive kind of maintenance which may only take place after a fault has been identified.

Neelamkavil (2010:305) viewed corrective maintenance or run-to-failure model as a process or activity that is required to overcome a failure that has occurred or is in the process of occurring. Further, it constitutes repair, restoration or replacement of components, or other things to restore the system to its original state as it was in its new condition.

However, corrective maintenance may not accurately forecast the point at which failure may occur. Therefore, maintenance may be carried out immediately the fault is identified or deferred depending on the nature of the identified fault. This kind of maintenance could result into serious breakdown of equipment since some component failure could lead to collateral failure if the identified is not addressed in time. Predicting failure of a deteriorating part such as drill rig drifter parts could be difficult as the wear rate of such parts may be accelerated by environmental conditions as well as operator practices.

The period of deferring an observed failure or impending failure may not be accurately defined as equipment could fail before the predetermined time of repair or replacement due to operating conditions and other technical factors such as quality or genuineness of spare parts. Such component or system failure may cause collateral damage and reduced reliability reflected in downtime. It may equally take a longer time to restore the equipment back to its operating state as the breakdown may occur unexpectedly when the maintenance personnel may not be adequately prepared to address the breakdown. Therefore, it may be appropriate to say that corrective maintenance may tend to neglect the component or system by allowing them to run to failure. The focus may appear to be on replacement of the failed item rather than preventing failure.

In summary, condition based maintenance may be termed as a hybrid form, in which some, but not all uncertainty is taken away. Additionally, degradation usually remains an uncertain process, so that the exact time that maintenance may be needed remain unknown and failure of a single component from this kind of maintenance could create further breakdowns through collateral damage.

3.3.11 Critical Review of Breakdown Maintenance

In reference to the earlier sections, breakdown maintenance may be referred to as that kind of maintenance where repairs or replacement of a piece of equipment or system is carried out after a machine has failed. This kind of maintenance may not be appropriate for equipment such as drill rigs as letting components fail before replacement could result into serious equipment breakdown, however, it may apply on low cost, less replacement time items.

In summary, the study was anchored more on Deming's theory, in particular the Deming Wheel (or P-D-C-A Cycle). The cycle starts with identifying the problem in order to develop an action plan for development. The second stage is the implementation stage where the action plan is put into effect. Then comes the checking stage where the implemented action is checked against plan and the final stage is to institutionalise the improvement plan. This theory guided the study in identifying factors that led to the numerous drill rig breakdowns at LCM and to develop a framework that could be used to identify breakdown causes in order to implement necessary maintenance activities before the actual breakdown occurs. This was obtained through analysing the responses given through questionnaires and the key informants.

The study also applied two components of Deming's four elements, the knowledge of variation which implies that one goal of quality is to reduce variation because if managers do not understand variation, the extent of variation in their operation could increase. The second element is that of theory of knowledge which states that, there is no knowledge without theory and that theory requires predictions and not explanation. To identify and understand the factors that led to drill rig breakdowns at LCM, the study reviewed various theories for direction and this helped in outlining the conceptual framework. The idea of which theories to review was generated from the literature review.

However, other theories such as the Ishikawa theory assisted in building up on Deming's theory. Ishikawa presented a framework (for identifying causes) that aids in identifying causes of various problems, therefore, this theory helped in giving the study a guideline on how to identify the cause of the drill rig breakdowns at LCM. This was done through questionnaires, document review and interviews with key informants.

3.4 Conceptual Framework.

A conceptual framework in this study was developed and regarded as an interconnected set of ideas (theories) collected from the literature review and ideas developed from the study. It served as the foundation for understanding the causal or correlational designs of interconnections across events, ideas, observations, concepts, knowledge, interpretations and other components of experience. Further, Svinicki (2004:5) stated that everyone has a conceptual framework about how reality

works and allows him or her to make predictions about how A is related to B and what would happen when the two intersect. This allows us to make choices about our behaviour on the basis of what we think those relationships are.

The conceptual framework in the study further provided a reference for the formulation of the research questions as well as direction for the research design and the accompanying fieldwork. It also gave a strong structure for the organisation of the content of the study and allowed the clear identification of limitations of the study as well as the potential opportunities for future studies. Therefore, the ideas and concepts that were used to understand the study problem are shown in Figure 3.16:

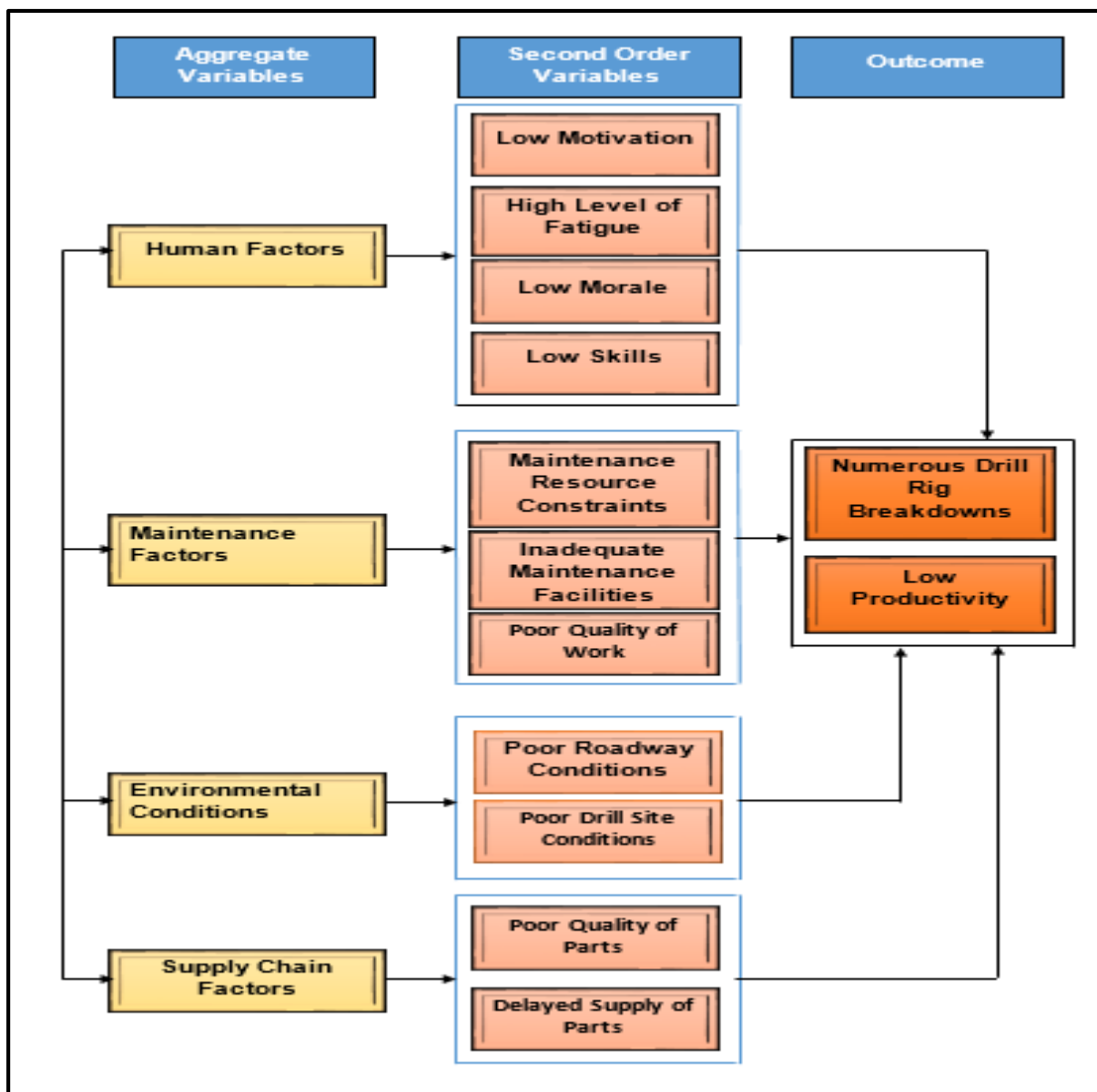


Figure 3.16: Conceptual Framework

Source: Author, 2019

3.5 Operationalisation of the Concepts

This section discusses the operationalisation of the concepts in the context of the study and how the study aimed at understanding and/or explaining the problem.

3.5.1 Human Factors

Drill rigs are operated and maintained by human beings, therefore, the study found it necessary to investigate how human related factors could influence or contribute to the numerous drill rig breakdowns at the mine.

Drill rig operators are tasked with the day to day operation of the drill rig and their skills, competence, selection and conduct could have a positive or negative impact on the operation or performance of the machine. This equally applies to the maintenance personnel who maintain and repair the drill rigs.

In a situation where employees are not motivated at a place of work, workers may not carry out their work effectively and care for the equipment they work with.

It was also important to understand the recruitment or selection process at the mine to determine how the recruitment process of the maintenance personnel and drill rig operators was carried out. This was done to assess how recruitment influences the performance of employees and how performance could in turn affective the performance of equipment. This was done through interviews with the Human Resources Manager and other key informants.

Training and development is another areas within the human factor circles which was equally investigated as poor training could result into poor work performance. This was done through interviews with key informants as well as through questionnaires.

3.5.2 Environmental Factors

From the literature review, it was noted that underground conditions if not maintained to acceptable standard may negatively affect the performance of equipment. Water and roadways if not properly managed could impact negatively on the performance of underground equipment. Further through literature review, it was noted that one of the biggest changes in running underground equipment was the severity of the mining conditions which may have a two-pronged effect: one, the life of the components or

machine systems is significantly reduced, causing components to fail prematurely and secondly, the loss of efficiency and ultimately productivity, which drives up the cost per ton of the operation.

Therefore, as seen from the explanations above, underground environmental conditions could contribute to drill rig breakdowns if the conditions are not adequately managed.

3.5.3 Maintenance Factors

It was noted from the literature review that the guiding principle of maintenance is the regular and systematic application of engineering knowledge and maintenance attention to equipment and facilities to ensure their proper functionality and to reduce the rate of deterioration. In addition to dedicated engineering, maintenance encompasses regular examination, inspection, lubrication, testing and adjustments of equipment with prior knowledge of equipment failure. It also provides a framework for all planned maintenance activity, including the generation of planned work orders to correct potential problems identified through inspection. Therefore, the result of such actions proactive rather than reactive, hence, optimising equipment performance and life and avoiding or minimising equipment breakdowns.

For maintenance to be effective, there is need for the maintenance department to have adequate training and skills, maintenance tools which may include physical maintenance tools as well as software. Maintenance infrastructure such as workshops and wash bays are equally important. Further, to ensure that the maintenance parts are of the acceptable standard, parts must be procured from the OEM or approved suppliers and all parts must be examined before being accepted for use. The storage and transportation of parts is another aspect that must be considered to ensure the parts maintain their quality throughout until they are finally installed on the equipment.

To carry out such activities, personnel with special skills and competency in the field of maintenance are required. Equipment such as a drill rig is a high technology machine and may require trained and competent personnel to repair and maintain it, otherwise if the maintenance personnel do not possess the right training and skills, they may not be able to execute maintenance activities appropriately. Therefore,

equipment maintained by such personnel may not perform as expected and this could lead to a number of unplanned downtime of equipment and high repair cost.

Further, looking at the maintenance practices in aviation industry as indicated from the literature review, there is need for an organisation to develop a maintenance culture that is based on precision and taking into account the consequence of failure. Responsibility and accountability have equally been found to be critical in maintenance as well as analysing failure causes and their implication.

3.5.4 Supply Chain Factors

Supply Chain is responsible for quality of maintenance replacement parts as it is a section of the mine tasked with the procurement of maintenance parts. Further, the Supply Chain could be viewed as a sequence of processes and flows whose objective is to meet final customer requirements. This study therefore, looked at Supply Chain from a process view and considered Supply Chain as the process of strategically managing the procurement, inspection and storage of parts and distribution to end-users. As such, the study found it necessary to investigate the Supply Chain related factors as these could have a major impact on equipment performance if not properly managed.

In summary, the interaction of the above factors if not managed properly could result into poor management of drill rigs and subsequently resulting into frequent equipment breakdown.

3.6 Conclusion

The theoretical and conceptual frameworks helped to determine and explain the path the study took and to ensure that the study was grounded firmly into theoretical constructs. Additionally, the study was underpinned on Deming's theory which centres on problem identification and mitigation as well as the principle of profound knowledge of quality management. As such, the theory was chosen to guide the study as the study involved identifying the factors that led to the numerous drill rigs breakdowns at LCM and thereafter develop a framework that may be used to identify drill rig breakdown causes.

Finally, the conceptual framework was developed with overall objective of making the study findings more meaningful, acceptable to the theoretical constructs in the field of study and ensuring generalisability. Chapter three sets out the platform for the next chapter, the methodology which is a systematic way of studying how to investigate a problem in a more scientific way through various techniques.

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 Introduction

The chapter discusses the research methodology and highlights the philosophical worldview assumptions adopted in the study and proceeds to discuss the research design, the target population, sample size, sampling procedure, data collection techniques, the pilot study, validity, credibility, reliability, ethical considerations and the conclusion of the chapter.

The research methods helped in finding ways of identifying the factors that caused drill rig breakdowns at LCM by providing such approaches as interviews, document review, questionnaires and observations for collecting data and the use of data analysis methodologies to arrive at the root cause. To determine the method to be used, the study. Additionally, the methodology assisted in structuring procedures used to investigate what was believed to be known, as well as to analyse what was known and the rationales behind these procedures.

The interpretation and how these philosophical assumptions were related to the study are discussed below:

4.2 Philosophical Assumptions

Weber (2003:5) indicated that, philosophical assumptions are broad, general ideas about the world, form the basis of the most influential perspectives, assumptions and even biases in the research. Additionally, Gable (2014:86) states that philosophical assumptions deal with the foundational assumptions and preconditions for the existence of science. These presuppositions are categorised in two main groups a: ontological assumptions which define the objects of knowledge, and epistemological assumptions which define the conditions for knowledge).

Further, Slife and Williams (1995:10) commented that to give direction to a study, the research should be directed by some philosophical idea in line with the research problem and continued by saying that, although philosophical ideas remain largely hidden in research, they still influence the practice of research and need to be

identified, Therefore, the study reviewed some philosophical assumptions to determine those that could help give focus to the study and among these were epistemology, ontology, phenomenology and Axiology.

4.2.1 Ontology

The study defined ontology as understanding reality and Burkhard and Smith (1991:61) defined Ontology as a branch of philosophy which is a science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality. Further, an ontology could also be viewed as a description (like a formal specification of a program) of the concepts and relationships that may exist for an agent or an organisation of agents, therefore, from the ontological assumption point of view, the study was able to make definitive and exhaustive classification of entities in all spheres of the study area such as identifying the factors that led to the numerous drill rig breakdowns at LCM through tool such as interviews, questionnaires, document review and observations. From the ontological perspective, it was certain that breakdowns were real and existed at the mine. Further, the mine management had a concern that the numerous drill rig breakdowns among other factors contributed to the low productivity at the LCM. Additionally, the themes drawn up in the data analysis were drawn from the ontological perspective as respondents and other parties involved in the study had the perception of the factors that led to the numerous breakdown of drill rigs at the mine and this was obtained from responses drawn from respondents.

4.2.2 Epistemology

The study defined epistemology as acceptable knowledge and According to Lehrer (1990:163), epistemology is one of the core areas of philosophy and it is concerned with the nature, sources and limits of knowledge.

In this Study, the epistemological assumption was laid down on the assumption that only authenticated literature based on the study topic was considered for use and/or reviewing and that the sources and views that were not from the study were acknowledged by citation. The equipment performance data was drawn from the mine monthly reports which were provided by the engineering department and reviewed by senior management. This information was considered authentic because it was

reviewed and signed off by senior management and later sent to the mine directors who made informed decisions from this information. The mine employee register used as a sampling frame was an authenticated document maintained by the Human Resources Department and updated on a weekly basis. This was the document equally used to effect employee's monthly payments.

The target population consisted of employees of the mine and who were attached or had the knowledge of the problem being investigated. Epistemologically, respondents were able to interpret what they believed could be the factors that led to the numerous drill rig breakdowns at the mine.

4.2.3 Phenomenology

The study viewed phenomenology as an inquiry coming from philosophy and psychology in which the researcher describes the lived experiences of individuals about a phenomenon as described by participants. This description culminates in the essence of the experiences for those who have experienced the phenomenon.

Further, Gallagher (2012:126) defined phenomenology as the study of human experience and of the ways things present themselves to us in and through such experience and that it is a study of structures of consciousness as experienced from the first-person point of view. Therefore, the study target population was made up of the drill rig operators and maintenance personnel and those employees of LCM who either worked or had some expert knowledge of the maintenance or operation of the drill rigs at the mine. These people worked in the environment where the equipment under study operated.

4.2.4 Axiology

Axiology from the study was termed as a branch of philosophy dealing with overarching values and Chopra (2005:2) referred to axiology as a branch of philosophy that studies judgments about values including both ethics and aesthetics.

It was therefore, necessary to make the values known in the study and to report values and biases as well as the value-laden nature of information gathered from all respondents and documents as well as observations.

The study therefore, followed all the provisions and regulations stipulated by the management of Lubambe Copper Mine. All the study assistants were taken through the mine inductions and reference checks were conducted, permission was sought from all the personnel who were asked to participate in the study and no one was coerced to participate in the study.

4.2.5 Methodology

The study explained methodology as the methods used in the process of research. Whereas, Myers (2009:260) defined research methods as a strategy of enquiry, which moves from the underlying assumptions to research design, and data collection.

The study used questionnaires, interviews, observation and document review to collect data and this data was both qualitative and quantitative in nature and was analysed by the use of NVivo and SPSS packages. The study therefore, used multimethod approach to analyse the data.

4.3 Research Design

A research design may be defined as the researcher's general for answering the research question or testing the research hypothesis. However, it is important to determine the philosophical worldview on which to anchor the study design as they assist in identifying the methods and procedures which should guide the study.

There are several philosophical worldviews that researchers bring to the study. The common philosophical worldviews are post-positivism; constructivism, transformative, and pragmatism. The philosophical worldview that underpins this study is pragmatism because it is related to the multi-methods approach which the study was based on.

4.3.1 Positivism Worldview

The positivism worldview reflects the need to identify and assess the causes that influence the outcome. Crosswell (2014:8) commented that, positivists hold a deterministic philosophy in which causes, termed as probability, determines effects or outcomes, implying the problem studied by postpositivists reflect the need to identify and assess the causes that influence outcomes, such as those found in experiments.

The study took a positivism approach of cause and effect process in investigating the causes of drill rig breakdowns at LCM. This was made possible through responses obtained from questionnaires and interviews. Documents were equally reviewed in order to identify the factors that were perceived to be causing breakdowns of drill rigs. Further, the information from the failure trends charts helped in determining the most recurring type of breakdowns. This information was then used to assess the possible causes of such failures and this was by interviewing the key informants and responses from questionnaires.

4.3.2 Constructivism Worldview

Creswell (2014:10) defines constructivism as a worldview approach that believes that, individuals seek understanding of the world in which they live and work. Individuals develop subjective meanings of their experiences—meanings directed toward certain objects or things. To get a broader understanding of the problem being investigated, the study targeted respondents from LCM and only those who were involved or had the understanding of the drill rig operations and the environment they operated from. This group was targeted as it could give responses based on their experience with the equipment being investigated. Further, from the constructivism point of view, management investigated factors that were responsible for not meeting the set production target and identified the numerous drill rig breakdowns at the mine as one major factor.

4.3.3 Transformative Worldview

This philosophical worldview focuses on the needs of groups and individuals in society that are marginalised or disenfranchised. It places central importance on the study of lives and experiences of diverse groups that are traditionally marginalised. Further, Mertens (2010:802) stated that the transformative worldview focuses on the needs of groups and individuals in society that are marginalised or disenfranchised.

This philosophical worldview did not apply significantly to the study in determining the factors that led to drill rig breakdowns at LCM as the study did not focus on the marginalised group, but finding the cause of the numerous drill rig breakdowns at the mine.

4.3.4 Pragmatic Worldview

The study defined pragmatic worldview as a philosophy that utilises different types of methods to solve a problem and is not restricted to a single method approach. This worldview directed the study into using a multi-methods approach. Creswell and Plano Clark (2007:273) explained that the distinction between mixed methods and multi-methods approached is that mixed methods combines qualitative and quantitative methods, whereas, multi-methods uses two qualitative methods. Additionally, Morse (2003:189) stated that, multi-methods approach involves qualitative and quantitative schemes that are comparatively complete on their own and then used together to form necessary components to answer a specific sub question and the results of the study triangulated to form a comprehensive whole.

The use of multi-methods approach was meant to increase the chances of getting at least one method that was appropriate for individual participants. For data collection, the data was collected through questionnaires, interviews, document review and observation and analysed separately with the results of each data set working as a form of triangulation.

4.4. Target Population

The study considered a target population as a collection of individuals from departments that were involved with the operation and maintenance of drill rigs at Lubambe Copper Mine and these were the main focus of a scientific query.

The target population comprised 201 Lubambe Copper Mine employees from Engineering department and Mining department. Further, key informants were drawn from Engineering, Mining, Process Plant, Supply Chain and Human Resources department. These departments were selected as they were either directly or indirectly involved with the activities of drill rigs at LCM. However, other department such as Security and Social Responsibility were left out due to their restricted knowledge on the study.

4.4.1 Sample Size

A sample size of 137 respondents was drawn from a population of 207 Lubambe Copper Mine employees. The sample size was calculated at 95% confidence level and 0.05 or 5% precision level using the formula below:

Sample Size Formula:

The following is the formula and workout that was used to calculate the sample size.

$$(i) \quad n = \frac{N}{1 + N(e)^2} \quad (\text{Source: Adapted from Yamane, 1967:886})$$

Where: **n** = is the sample size; **N** = is the population size; and **e** = is the level of precision.

$$(ii) \quad \text{Therefore: } N = 207; \text{ and } e = 0.05$$

$$(iii) \quad \text{Then: } n = \frac{207}{1 + 207(0.05)^2} = \frac{207}{1 + 0.5175} = \frac{207}{1.5175} = 136.4$$

Giving the sample size (n) equals to 137.

According to the formula used, the sample size of 137 respondents was large enough to be representative of the target population and a valid generalisation could be drawn from this sample size.

The sample size was further sub divided into departments (stratified) and the percentage allocated was dependant on how close the department was to the activities of drill rig operation and maintenance. Table 4.1 shows the stratums:

Table 4.1: Breakdown of Sample Size per Department

Department	Sample Size	%
Engineering Maintenance	51	37.2
Mining	79	57.7
Process Plant	7	5.1
Total	137	100
Key Informants	35	100
Total	172	100

Source: Author (2018)

4.4.2 Section Criteria

The selection criteria of respondents from the sampling frame was as follows:

4.4.2.1 Engineering Maintenance

In the study, the engineering maintenance personnel formed an important role in the selected sample as they were directly involved with the maintenance and repair of drill rigs at Lubambe Copper Mine. They were familiar with the environment drill rigs operated from and formed a close relationship with the drill rig operators who reported all faults noted on the machine to the engineering personnel.

A random sample of fifty one (51) engineering personnel was administered from the mine register which was used as the sampling frame because it is reliable and valid, exhaustive, and it allowed for tracing of respondents.

The respondents were selected using a simple random technique from the mine register and this approach was adopted to ensure each respondent had an equal chance of being included into the required sample. Simple random selection was achieved by using an Excel Radom Number Selector. This was done by entering the names of employs into excel sheet cells and the system was able to pick one cell at a

time. The name from the picked cell was entered into a separate sheet which finally formed a selected sample.

4.4.2.2 Mining Department

A total of seventy nine (79) mining personnel were selected through random sampling from the mine employee register, this register is exhaustive and valid and made tracing of respondents easy. Mining personnel were picked because they were responsible for the operation of the drill rigs and this gave them a better understanding of the behaviour of the machine and an understanding of the operating environment.

The respondents were selected using a simple random technique using a number random sector through the use of an excel program and the approach was adopted to ensure each respondent had an equal chance of being included into the required sample.

4.4.2.3 Process Plant

A total of seven (7) Process Plant personnel were selected through random sampling from the mine employee register, this register is exhaustive and valid and made tracing of respondents easy. The process plant personnel were picked because they were part of the mining operation and were believed to understand the operation of the underground equipment.

The respondents were selected using a simple random technique using a number random sector through the use of an excel program and the approach was adopted to avoid bias in selecting respondents.

4.4.3 Key Informants

The study considered key informants as those senior employees who had expert knowledge of the equipment and environment being studied. Mumtaz and David (2014:133) defined key informant as those people who understand what may be going on in the field being investigated. It involves getting information from such personnel as professionals who have first-hand information and knowledge about the subject. Further, these experts with their particular knowledge and understanding can provide insight on the nature of the problem and may give recommendations for the solution.

To be consistent in conducting interviews, an interview guide was developed and used for the selected key informants (appendix 5). Marshal (1996:92), commented that the use of key informants is a qualitative technique which has been used widely and successfully in several sectors of social science investigation. Further, he indicated that the main advantage of using this technique relates to the quality of data obtained in a relatively short period of time and that the selected key informants understand and have the expert knowledge of the area being investigated.

A total of thirty five (35) Key Informants were selected by using the purposive sampling technique. This group was interviewed so as to get expert views of management and the mine consultants on the causes and factors that they felt could have led to the numerous drill rig breakdowns at LCM. This group comprised senior professionals at the mine.

Further, Robson (2005:6) advises that purposive sampling technique allows the researcher to use his judgment to select cases that best enable the researcher to answer the research question and to meet the research objective.

4.4.3.1 Key Informants from Engineering Department

A total of fourteen (14) engineering personnel were selected through a purposive sampling. These respondents were picked for interviews due to their expert knowledge on the equipment and environment under study.

The engineering department was responsible for maintaining the equipment on the mine, therefore, they were expected to have a clear understanding of the performance of drill rigs and the conditions the equipment operated in. Further, these informants were equally involved in finding solutions to the numerous drill rig breakdowns experienced at the mine.

4.4.3.2 Key Informants from Mining Department

A total of fifteen (15) mining personnel were selected through a purposive sampling. These respondents were picked for interviews due to their expert knowledge on the equipment under study.

The mining department was responsible for operating the equipment on the mine and were familiar with the environment the equipment operated in. Therefore, this gave an

opportunity for the study to exclusively interview this group as their closeness to the equipment and environment could give them a better chance to respond to the study questions in detail.

4.4.3.3 Key Informants from Process Plant Department

A purposive sampling of two (2) Process Plant personnel was made considering that the managers from the Process plant attended management meetings where equipment performance was discussed. Further, these key informants were included in the sample frame as they fell under the mine production process stream. Since the Process Plant received ore from underground for processing, the managers from this department were meant to have adequate knowledge of the mining activities which included the operation of drill rigs. In confirming the relationship between mining and the Process Plant, Xiaowei (2012:1) explained that a typical mine consists of two parts of operation, namely mining and mineral processing.

4.4.3.4 Key Informants from Supply Chain Department

A total two (2) Supply personnel were selected through a purposive sampling as this department was responsible for purchasing and storage of maintenance parts and other materials.

In reference to the above, Ruben and Lauri (2000:169) defined Supply Chain as the network of organisations that is involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer. In support of this definition, the Supply Chain at the mine ensured that the mine acquired all the services and materials required on time, of high quality and at an economical price to ensure the mine operated efficiently without run-outs or acquiring poor standard parts that could fail prematurely when put to use. This involvement made certain Supply Chain personnel such as the Supply Chain Manager to have an understanding of the operations of drill rigs at the mine.

4.4.3.5 Key Informants from Human Resources Department

A total of two (2) Human Resources personnel were selected as they were responsible for dealing with human resource and industrial relation matters which included engaging, training and development of the mine personnel.

Additionally, Parameswari and Yugandha (2015:2) commented that human resource management involves conducting job analyses, planning personnel needs, recruiting the right people for the job, orienting and training, managing wages and salaries, providing benefits and incentives, evaluating performance, resolving disputes, and communicating with all employees at all levels. Since the drill rigs were managed by the mine employees, the study found it imperative to understand the welfare of the employees tasked with the operation and maintenance of drill rigs and this was done by getting expert views from the Human Resources Department. Further, all forms of complaints, grievances, training needs, promotion and other related activities of drill rig operators and maintenance personnel were channelled through the Human Resources Department.

4.5 Data Collection Techniques

The research instruments used in the study were drawn from a multi-methods approach which included personal interviews, questionnaires, document review and observations. The data collected was both primary and secondary, the primary data was collected through interviewing selected respondents and questionnaires were equally used to collect data from respondents. Secondary data was collected from the mine equipment records and periodical mine performance reports such as monthly reports and human resources reports.

Qualitative data consisted of information obtained from answers that were gathered through interviews and the questionnaires. The analysis of the qualitative data (words, text or behaviours) typically followed the path of aggregating it into categories or themes of information and presenting the diversity of ideas collated during data collection.

By using a multi-methods approach, the study gained an in breadth and depth of understanding and corroboration, while offsetting the weaknesses inherent in using each approach by itself.

The study also found out that one of the most important characteristics of conducting multi-methods research is the possibility of triangulation, i.e., the use of several means (methods and data sources) to examine the same phenomenon. Triangulation allows one to identify aspects of a phenomenon more accurately by approaching it from different vantage points using different methods and techniques.

The tools used to collect the data for analysis were the questionnaires, personal interviews and document review:

4.5.1 Questionnaires

The study reflected a questionnaire as a predefined set of questions in a predetermined order that is used to provide data that may be analysed to identify patterns and relationships within the answers to the study problem. Additionally, Ahmad (2012:4) defined a questionnaire as a set of questions on a topic or group of topics designed to be answered by the respondent. Further, a questionnaire may be viewed as a tool used to pose the questions that the researcher would want respondents to answer.

The questionnaires were self-administrated, thus, the respondent answered on their own, however, in certain situations where respondents were restricted due to literacy levels, assistance was provided by the study assistants.

The questionnaire was developed from the main objective of the study, which was to investigate the factors that led to drill rig breakdowns at LCM and out of the findings, develop a framework which could be used to identify potential causes of drill rig breakdowns. Further, the contents of the research questions were used to frame-up questions in the questionnaires which were both open ended and closed. The open ended questions gave an opportunity to the respondents to give further details to the problem under study.

4.5.2 Personal Interviews

An interview may be termed as a conversation for gathering information. Additionally, Gubrium and Holstein (2001:7) claimed that face-to-face interviews are suitable when the target population can communicate through face-to-face conversations better than they may communicate through writing or phone conversations. In this study,

interviews were conducted on a face-to-face basis and questions were open-ended with all responses documented in detailed transcription. However, Kvale (1996:129) warned that, though the qualitative research interview may seek to describe the meanings of central themes in the life world of the subjects, the main task in interviewing is to understand the meaning of what the interviewees say.

In addition, McNamara (1999:281) explained that, interviews are particularly useful for getting the story behind a participant's experiences. He further indicated that the reviewer can pursue in-depth information around the topic and that interviews can be useful as follow-up to certain respondents. Therefore, in interviewing the key respondents, there was an opportunity of getting in-depth answers due to the face-to-face intervention which allowed for further questioning where clarity was required. There was a further advantage in interviews as certain respondents could be approached more than once where more information or clarity was required.

The data collected consisted of views on human related factors, the nature environmental conditions, maintenance practices factors and Supply Chain related factors. These variables were targeted as they formed the area surrounding the drill rig activities and viewed as variables that could form the basis for answering the research questions.

4.5.3 Document Reviews

A document may be defined as a written text. The study therefore, considered the document review process as a channel for providing a systematic procedure for identifying, analysing, and deriving useful information from the existing documents at the mine. Documents such as equipment performance reports, production performance review reports, employee appraisals, failure analysis reports and condition monitoring reports were reviewed. The advantage of these reports is that they were specific to the study needs and were readily available at the mine site. In addition, the merit of the document review was that it facilitated validity checks and triangulation through comparing various kinds of reports and trend analysis which showed the behaviour of drill rig breakdowns.

4.6 Data Analysis Techniques

The study defined data as raw facts, therefore, data analysis was considered as the process of examining, transforming and moulding the data for the purpose of determining useful information, forming conclusions and supporting decision making from the conclusions made.

For accuracy and consistency in analysing the data, the analysis was done by the use of a computer. The computer software that was used is Statistical Package for the Social Sciences (SPSS) and NVivo. The advantages of SPSS are that it is user friendly, has enough space for a long range of numbers, and mathematical manipulation can easily be dealt with through its own in-built functions and it is the most suitable instrument to generate descriptive statistical data. Data presentation was done by frequency tables, figures and bar charts. The Chi-Square from SPSS software was used to determine relationships within the data as well as determination of the p value the Z-Test was carried out to test the hypothesis and also used to validate the Chi-Square results.

Qualitative data analysis was done by using the inductive process of building from the data to broad themes to a generalized model or theory (Punch, 2005). The study began by gathering detailed information from participants and then formed this information into categories or themes. These themes were developed into broad patterns, theories, or generalizations that were then compared with personal experiences or with existing literature on the topic. The NVivo package was to analyse unstructured and semi-unstructured data like interviews. Further, transcripts from qualitative survey questions and interviews with key informants were uploaded and coded in NVivo.

The selection process for key informants was through purposive sampling where the selection criteria was based on expert knowledge of the key informant in the area under study, this was made possible by selecting those senior personnel who worked close with the operating personnel. Further, the senior personnel from the maintenance department were selected as they had the expert knowledge of maintaining and repairing of drill rigs. The other important factor is that most of the selected key informants attended production review meetings where the mine performance was discussed. In these meetings, production bottlenecks were identified and mitigation action plans developed. Therefore, issued of equipment breakdowns

were discussed in these meetings and mitigation action plans determined by the same management team.

Interviews were conducted for the key informants guided by a documented interview guide. The interview guide was developed to maintain consistence in asking questions and contained questions that aimed at answering the research questions. Ethical considerations were observed when engaging with the key informants, no informant was forced or coerced to participate and all mine guidelines were followed as determined by the mine.

In validating the responses from the key informants, the knowledge of the interviewer was critical, the interviewer (the one carrying out the study) applied psychological phenomological reduction in that he had to weigh the responses given against his technical experience in the field of study. Zahavi (2003:54) indicated that, when applying psychological phenomological reduction in validating qualitative responses, the participants are focused on the description of their experiences, whereas the researcher focuses on the way in which the objects are manifested to the subject's internal consciousness. The other method used in the study to validate the data obtained from the key informants was through observing and assessing the frequency of appearance of certain objects or statements on the topic under study. As such, Gurwitsch (1966:713) commented that syntheses of identification is another criterion for the validation and verification of data from a phenomenological investigation which has to do with the way in which consciousness creates syntheses of identification through multiple appearances of the same object and establishes acts for meaning fulfilment.

Further, the participants were encouraged to give feedback if they required any change or addition to the statement they made earlier and Colaizzi (1978:353) explains that, it is common in Social and Human science to recommend the use of participant feedback as a way of validating results.

Finally, the data was presented through tables and the most interesting findings relating to the study were noted.

4.7.1 Pilot Study

The questionnaire for the study was developed from the main objective of the study, which was to investigate the factors that led to drill rig breakdowns at LCM and out of these findings, develop a framework which could be used to identify potential causes of drill rig breakdowns. Further, the contents of the research questions were used to frame-up questions in the questionnaires which were both open ended and closed. The open ended questions gave the respondents the freedom to express their views further. However, despite having developed the questionnaire, the study had to test this instrument in order to discover problems prior to the main study so that corrective action to improve the tool could be taken before issuing the questionnaire to the main respondents at LCM.

The pre-testing of the questionnaire was conducted from a different mine, Chibuluma Copper Mine located in Kalulushi on the Copperbelt province of Zambia. Chibuluma Mine has similar operations and equipment with the mine under study. A separate mine was used to test the questionnaire in order to avoid the main study respondents answering the same questionnaire more than once, a situation that could cause monotony to the respondents who may give rushed and inaccurate responses in the final questionnaire. The other reason was not to dilute the responses by allowing respondents predetermining the answers when it came to the main data collection time.

A total of thirty (30) copies were issued to respondents and twenty five (25) were completed and submitted. This is shown in table 4.2.

Table 4.2: Pilot Study Questionnaire Response Rate

Department	Issued	Returned	Percentage
Engineering	10	10	100
Mining	15	15	100
Process Plant	5	00	00
Total	30	25	83.3

Source: Author, 2019

4.7.2 Pilot Study Data Analysis

Responses from the questionnaire enabled the study to adjust some sections of the questionnaire and other questions were totally changed. The data from the questionnaire were analysed using bar and line graphs to determine the pattern of responses.

The result of the data presented in Table 4.3 shows that, out of twenty five (25 respondents), 76% (19 respondents) stated that there were numerous drill rig breakdowns at the mine and 4% (1 respondent) argued that the rate of drill rig breakdowns at the mine was not high. The other 20% (5 respondents) did not complete the questionnaires.

Table 4.3: Frequency of Drill Rig Breakdowns

Do you think there are numerous drill rig breakdowns at the mine?

NO	YES	NO RESPONSE
1	19	5
4%	76%	20%

Source: Field Data

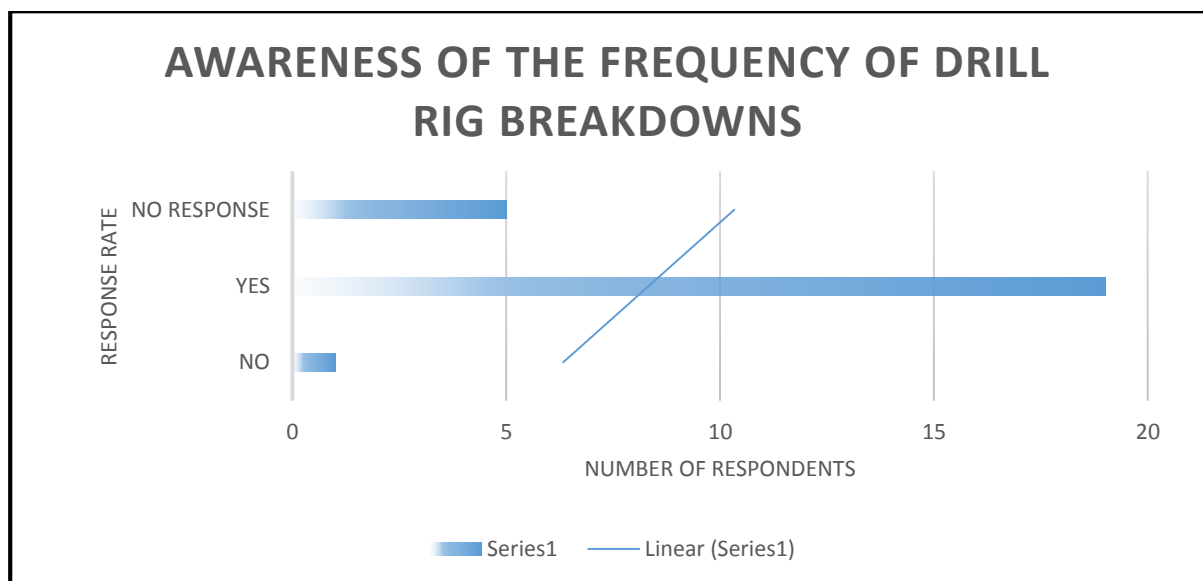


Figure 4.1: Frequency of Drill Rig Breakdowns

Source: Author, 2019

The first objective examined whether the human related factors contributed to the numerous drill rig breakdowns at the mine. Therefore, the results of the data presented in Table 4.4 indicate that, out of twenty five (25 respondents), 72% (18 respondents) stated that the human related factors contributed to the numerous drill rig breakdowns at the mine and 8% (2 respondents) said that the human related factors did not contribute to the drill rig breakdowns at the mine, whereas 20% (5 respondents) did not respond to the questionnaires.

Table 4.4: Human Factors

Do you think you think human factors contribute to the numerous drill rig breakdowns at the mine?

NO	YES	NO RESPONSE
2	18	5
8%	72%	20%

Source: Field Data

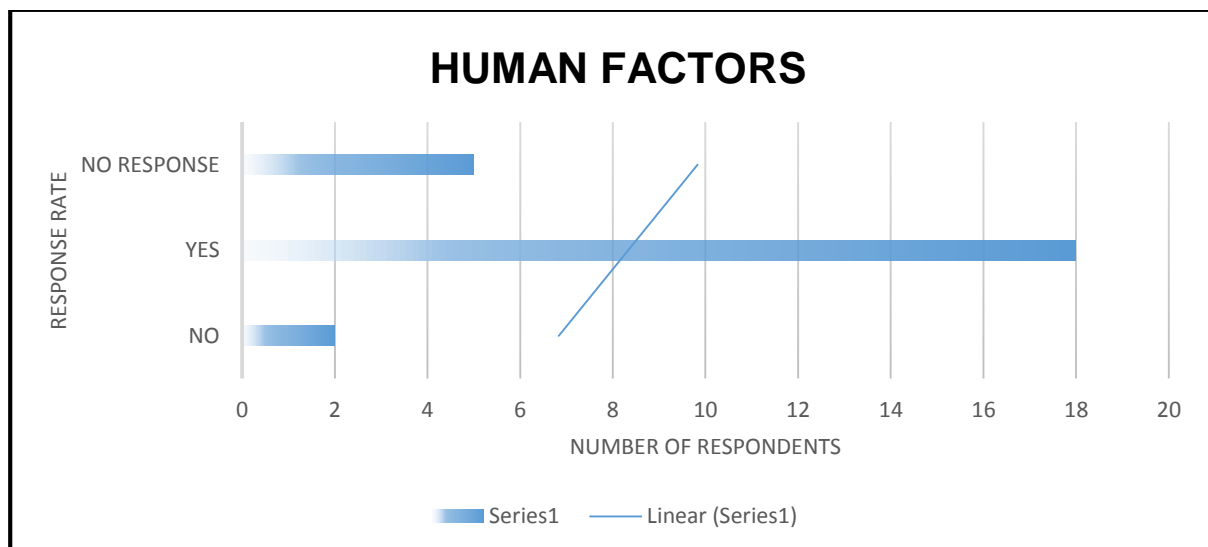


Figure 4.2: Human Factors

Source: Author, 2019

The second objective assessed environmental conditions and the results of the data in Table 4.5 shows that out of twenty five (25 respondents), 52% (13 respondents)

stated that the environmental conditions contributed to the numerous drill rig breakdowns at the mine and 28% (7 respondents) indicated that environmental conditions did not contribute to the numerous drill rig breakdowns experienced at the mine. Yet 20% (5 respondents) did not respond to the questionnaires.

Table 4.5: Environmental Factors

Do the environmental conditions contribute to the numerous drill rig breakdowns?

NO	YES	NO RESPONSE
7	13	5
28%	52%	20%

Source: Field Data

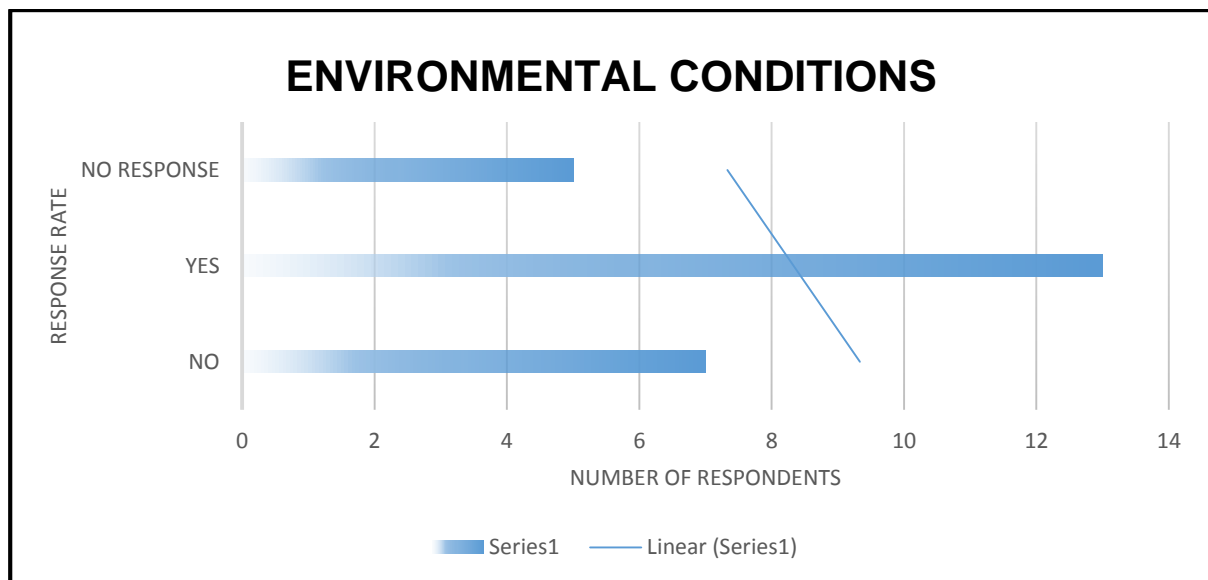


Figure 4.3: Environmental Conditions

Source: Author, 2019

The third objective was to investigate whether maintenance factors contributed to the numerous drill rig breakdowns at the mine. The results of the data shown in Table 4.6 indicate that out of twenty five (25 respondents), 48% (12 respondents) said the maintenance factors contributed to the drill rig breakdowns at the mine and 32% (8 respondents) showed that the maintenance factors did not contribute to the numerous

drill rig breakdowns at the mine. The other 20% (5 respondents) did not respond to the questionnaires.

Table 4.6: Maintenance Factors

Do the maintenance factors contribute to the numerous drill rig breakdowns?

NO	YES	NO RESPONSE
8	12	5
32%	48%	20%

Source: Field Data

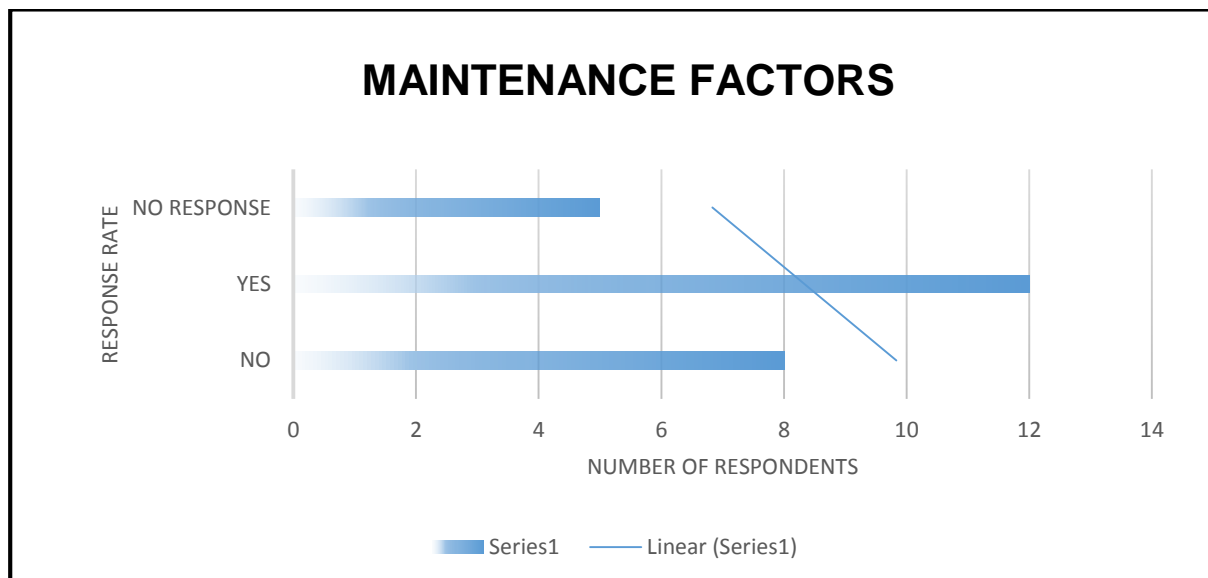


Figure 4.4: Maintenance Factors

Source: Author, 2019

Finally, the fourth objective determined whether the Supply Chain factors and quality of replacement parts contributed to the numerous drill rig breakdowns at the mine. The results of the data in Table 4.7 shows that out of twenty five (25 respondents), 56% (14 respondents) indicated that Supply Chain factors and the quality of replacement parts did not contribute to the numerous drill rig breakdowns. However, 24% (6 respondents) indicated that the Supply Chain factors and the quality of replacement parts contribute to the numerous drill rig breakdowns at the mine. The other 20% (5 respondents) did not respond to the questionnaires.

Table 4.7: Supply Chain Factors

Do Supply Chain factors contribute to the numerous drill rig breakdowns at the mine?

	NO	YES	NO RESPONSE
	14	6	5
	56%	24%	20%

Source: Field Data

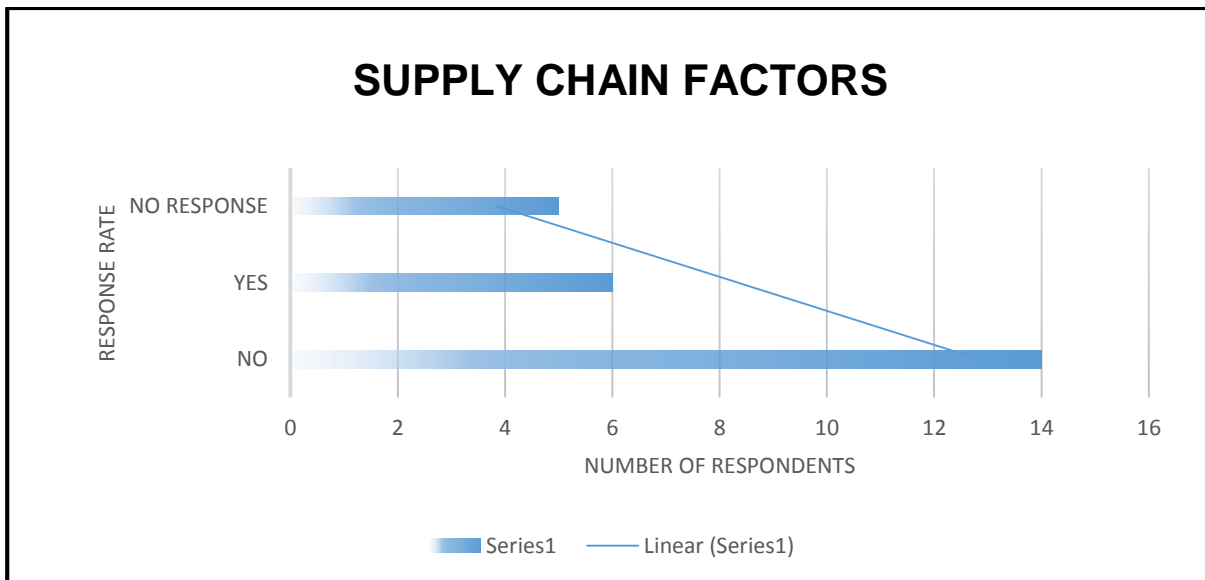


Figure 4.5 Supply Chain Factors

Source: Author, 2019

The summary of the responses to the four objective were as shown from the results of the data presented in Table 4.8. From the general perspective, 72% (18 respondents) indicated that human related factors contributed to the numerous drill rig breakdowns, 52% (13 respondents) argued that environmental factors contributed to the numerous drill rig breakdowns at the mine. Further, 48% (12 respondents) indicated that maintenance factors contributed to the numerous drill rig breakdowns and 24% (6 respondents) stated that Supply Chain factors contributed to the numerous drill rig breakdowns at the mine.

Table 4.8: Factor Contribution

Human factors	Environmental Conditions	Maintenance Factors	Supply Chain Factors
18	13	12	6
72%	52%	48%	24%

Source: Field Data

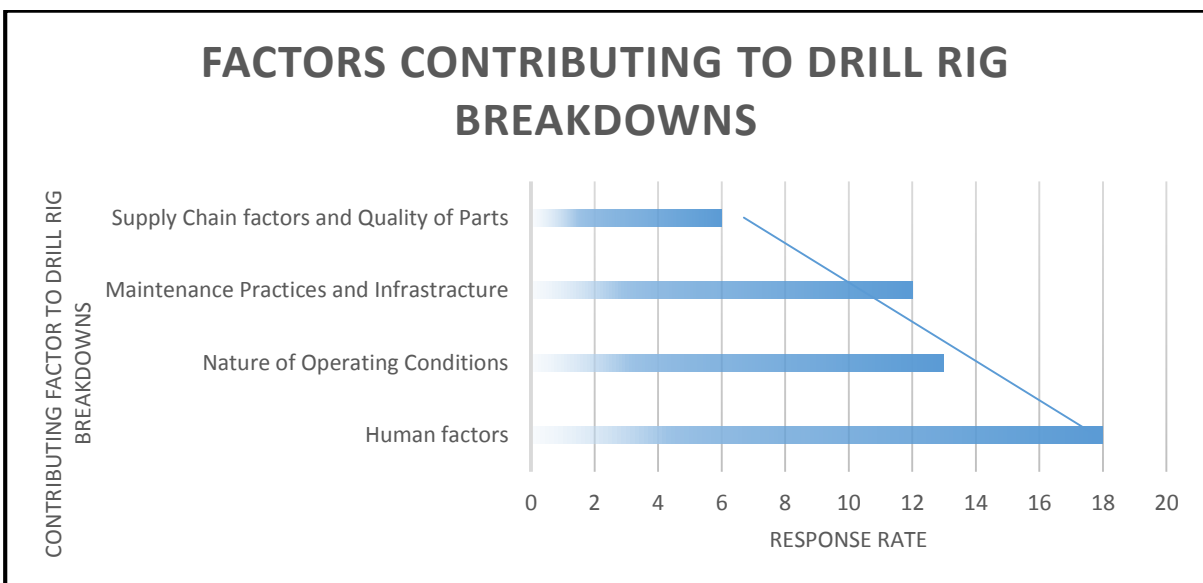


Figure 6: Factor Contribution

Source: Author, 2019

The weighted mean score of the distribution is calculated from the data in table 4.9.

Table 4.9: Mean of Factor Contribution

	Human Factors	Environmental Conditions	Maintenance Factors	Supply Chain Factors
Responses%	72	52	48	24
	4	3	2	1

Source: Field Data

$$(i) \quad \bar{X}_w = \frac{\sum x_i w_i}{\sum x_i}$$

Where:

$$(ii) \quad \bar{X}_w = \text{Weighted mean}$$

$$(iii) \quad \bar{X}_w = \frac{(72 \times 4) + (52 \times 3) + (48 \times 2) + (24 \times 1)}{72 + 52 + 48 + 24}$$

$$(iv) \quad \bar{X}_w = \frac{288 + 156 + 96 + 24}{196}$$

$$(v) \quad \bar{X}_w = \frac{564}{196}$$

$$(vi) \quad \bar{X}_w = 2.9$$

Therefore, what came out prominently as the major cause of drill breakdowns at LCM was the human factor.

In summary, the pilot study conducted at Chibuluma Mine reviewed that the human related factors were the major contributing factors to the numerous drill rig breakdowns experienced at the mine. The main areas highlighted were lack of motivation which was expressed in negative attitude, lack of proper training and development, lack of promotion and poor communication in that the superiors did not pay particular attention to employees' needs. Other factors in order of severity were environmental conditions, maintenance factors and Supply Chain factors.

4.7.3 Pilot Study Conclusion

The pilot study enabled the study to adjust the research instrument and to improve the efficiency of the same instrument in terms of validity and reliability. This test also enabled the study to understand the extent to which the questions could be answered and whether the goals and objectives could be reached. All anomalies observed were therefore noted and corrected.

4.7.4 Observations from the Pilot Study

The following is an extract of the process notes taken from the pilot study observations, and indicating issues picked before and during the interaction with the various respondents;

i. Observations - 1

The average completion time for a questionnaire – The time limit per session was set for a day initially, due to practical implications for the practice where the intervention programme was applied and the busy schedules of the respondents, the study found out that the time limit allocated was too short, and an assessment of all respondents reviewed that at least 2 days was adequate to complete the questionnaire effectively.

ii. Observation - 2

Terminologies used – Some respondents found certain terminologies difficult to understand. These were explained to the respondents by the study assistants. On the other hand, some terminologies were replaced with those that the respondents could comprehend easily.

iii. Observation - 3

Fear and anxiety – some respondents did not feel comfortable in the initial stage of the conversation as they believed that the questionnaire was meant to assess their performance. The study assistants took time to explain the reason for the questionnaire, emphasising that the document was not an assessment sheet for their performance, but a tool to assist in gathering information for a study which was independent of their work performance.

iv. Observation - 4

Time to issues questionnaires – issuing of questionnaire copies to drill rig operators from production areas caused the respondents not to adequately concentrate on the document as they appeared to pay more attention to their operations. This was because the operators were given targets to accomplish within a specific shift (time period). Drill rig operators were, therefore, engaged after production hours while they were waiting for buses and some arrangement were equally made to meet others at home during their day off.

v. Observation - 5

Language and culture- language could be seen as a means through which cultural norms and values are communicated. There was thus, need to incorporate different local languages to some employees who had difficulties in understanding English which was the official language at the mine. This situation only involved two drill rig

operators from a total number of respondents engaged. However, this did not inhibit communication as the assistants could understand and speak the local language.

Observation - 6

It was also observed that employees from the Process Plant had limited knowledge of the activities relating to drill rigs and this led to the Process Plant personnel being ruled out from the sample. This step was taken in order to avoid diluting the data with responses that could be given for convenience sake and not directed at the study topic. To maintain the sample size, the sample size had to be adjusted in such a way that the number of respondents from mining department was increase to take up the number of respondents taken from the Process Plant list. The number of respondents from the mining department was increased as this was the department directly involved with the operation of the drill rigs and had a better understanding of the machine and the environment.

In summary, the pilot study was important to the study for both the practical application of the study as well as for assessing the questionnaire. Further, it helped in testing whether the study instrument were asking the intended questions, whether the format was comprehensible and whether the selected validated tools were appropriate for the target population. Lastly, the pilot study assisted in testing the data collection process, the time taken to complete questionnaire, and the respondents' willingness to participate in the study.

After reviewing the responses and results of the pilot study, the questionnaire was adjusted as well as the sample size which was stratified according to the mine departments. Table 4.9 shows the adjusted sample size per department.

Table 4.10: Adjusted Breakdown of Sample Size Per Department

Department	Adjusted Sample Size	%
Engineering Maintenance	52	38.0
Mining	85	62.0
Process Plant	00	00
Total	137	100
Key Informants	35	100
Total	172	100

Source: Author (2018)

After all the adjustments were made, the questionnaire was issued to the intended respondents at LCM.

Further, in executing the study, other issues that formed part of the study integrity were also taken care of and among others, these included:

4.8 Validity and Reliability

To ensure consistence and to avoid bias within the study, issues of validity and reliability were observed. Thatcher (2010:125) indicated that validity is the extent to which any measuring instrument measures what it is intended to measure and reliability explained by Neuman (2011:56) is dependability or consistency of the research instruments, it suggests that the same thing is repeated or recurs under identical or similar conditions. Cacioppo and Petty (1982:116) claimed that for researchers to know that the scores represent the characteristic intended, they conduct research using the measures to confirm that these scores make sense based on their understanding of the construct being measured.

4.8.1 Validity

The study followed construct validity as it is concerned with the extent to which a research instrument (or tool) measures the intended construct. Further, Mislevy (2007:67) hinted that, of all the different types of validity that exist, construct validity is

seen as the most important form and that construct validity forms the basis for any other type of validity.

Construct validity was achieved in the study through conducting a pilot study where the questionnaires were tested on a different mine before being issued to the main respondents at LCM. This was carried out to ensure credibility and accuracy of the tool, further, the Z-Test in the study was used to validate the Chi-Square results.

4.8.2 Reliability

Fraenkel and Wallen (2003) and McMillan and Schumacher (2001) explained that a test is seen as being reliable when it can be used by a number of different researchers under stable conditions, with consistent results and the results not varying. Reliability reflects consistency and replicability over time.

Therefore, to maintain consistency, the study used instruments that have already been used and tested and these instruments were drawn from the literature review and among others included questionnaires and interviews. Questionnaires were used to collect data from the selected respondents and interviews were conducted with the key informants who had expert knowledge on the subject under study.

4.9 Ethical Considerations

Ethics is a branch of philosophy that deals with the conduct of people and guides the norms or standards of behaviour of people and relationships with each other. Further, Akaranga and Ongong'a (2013:8) indicate the ethics refer to an "ethos" or "way of life", social norms for conduct that distinguishes between acceptable and unacceptable behaviour". Additionally, Fouka and Mantzorou (2011:3) say that, researchers are professionals, hence, research ethics as a branch of applied ethics has well established rules and guidelines that define their conduct.

In terms of ethics, research ethical rules were considered; all members of the study group were mindful of the reaction from the population selected as it was composed of people of different academic backgrounds and gender. Additionally, respondents were assured that the study was not about investing employee's performance, but merely to obtain views of the respondents on what they thought were the causes of drill rig breakdowns at LCM and this information was for academic purposes only.

In summary, the study was conducted in a moral and responsible way with high honesty; both when it came to how to use methodology in the 'right' way and how all parties in the study were treated. The purpose and benefits of the study were explained to the respondents, as well as their rights and protection before the questionnaire was issued.

4.9.1 Veracity

Veracity may be termed as the principle of truth telling, and it is grounded in respect for persons and the concept of autonomy. Further, Geri and Judith (2002:63) stresses that researchers should tell the truth and pass on information in a comprehensive and objective way.

Further, in order for a person to make fully rational choices, he or she must have the information relevant to his or her decision. Moreover, this information must be as clear and understandable as possible. Truth telling is violated in at least two ways. The first is by the act of lying, or the deliberate exchange of erroneous information. However, the principle of veracity is also violated by omission, the deliberate withholding of all or portions of the truth. Finally, the principle of veracity can be violated by the deliberate cloaking of information in jargon or language that fails to convey information in a way that can be understood by the recipient or that intentionally misleads the recipient.

The study was initiated from full knowledge premise that the drill rig breakdowns at the mine were high and that the cause and factors leading to breakdown of equipment were not fully identified. This information was generated from equipment failure reports as well as production reports produced by the mine. Additionally, the mine management expressed concern that one factor affecting production was the numerous drill rig breakdowns at the mine (Lubambe Project Talon Report, 2016:60).

Additionally, the reason for conducting the study was clearly indicated on the questionnaire and this was meant to give the respondents confidence in their participation and proof that the study was not an investigation of their performance or to deceive them in any other way.

4.9.2 Privacy

Privacy may be defined as the control over the extent, timing, and circumstances of sharing oneself (physically, behaviourally, or intellectually) with others.

To ensure privacy of respondent in this study, unanimity of all respondents was strictly considered and this gave the respondents the confidence to participate in the study. Before commencing any form of interview, the respondents were assured that all the information given would be considered or treated secretly and not to be shared with any individual unless with permission of the respondent. To avoid a feeling of intimidation, all women were interviewed in an open space to give them freedom and assurance that they were safe and not under intimidation.

4.9.3 Confidentiality

Confidentiality in this study was defined as the treatment of information that an individual has disclosed in a relationship of trust and with the expectation that it would not be divulged to others without permission in ways that are inconsistent with the understanding of the original disclosure. Additionally, Oliver (2003:4) indicated that, confidentiality is commonly viewed as akin to the principle of privacy. On the other hand, Lee (1993:191) says, not sticking to confidentiality in research may lead to people reacting in different ways ranging from embarrassment to violence.

Therefore, in conducting this study, no information from any respondent was disclosed to a third party without concert and permission of the respondent. Further, the interviewer concentrated or asked questions relating to the study and did not go into asking personal questions to the respondent.

4.9.4 Fidelity

The study considered fidelity as the act of keeping promises (being faithful) and avoiding negligence with information. Further, Carol (2003:315) defined fidelity as the extent to which delivery of an intervention adheres to the proto-col or program model originally developed. As such, all the promises were kept by word of mouth on timing of various activity schedules, meetings, and other functions. This action encouraged the respondents to be part of the study.

4.9.5 Informed Concert

The study ensured that no participant was forced or coerced to participate in the study, each participant was introduced to the study, and thus, giving reasons for the study and its depth and the individuals were asked whether they were interested in participating or not. Participation for all respondents was voluntary.

4.9.6 Transparency

Throughout the study openness was maintained, no information was hidden and all activities of the study members were known to all participants including Lubambe Copper Mine management.

4.10 Conclusion

The philosophical assumptions that are brought to the study are epistemological, ontological, axiology and methodological. Further, the worldview underpinning the study is constructivism which believes that individuals seek understanding of the world they live in and work. This view was appropriate for the study as the problem being investigated was within an organisation and the respondents involved were employees of the same organisation and were familiar with the equipment under study. Additionally, a multi-methods approach was employed for collecting data.

Further, the study followed the laid down rules for selecting the sample and sampling procedures. In use were research instruments that relate to the multi-methods research approach. As such, a pilot study was conducted to pre-test the research instruments. Validity and reliability are essential to a research study. Therefore, validity and reliability issues were considered and laid down procedures adhered to. As far as ethical considerations are concerned, the study ensured that there was a balance between protecting respondents and the quest for knowledge. The ethical issues that were adhered to are veracity, confidentiality, privacy, fidelity, transparency and informed concert.

Chapter four established the research methodology of the study and followed by chapter five which covers data analysis and presentation.

CHAPTER FIVE

DATA ANALYSIS, PRESENTATION AND RESULTS

5.1 Introduction

This chapter starts by presenting the response rate of the questionnaires issued and further highlights the general information which consists of the position the respondent held at LCM, the years an individual had worked in the company and the years worked in the industry. The shift an employee worked at the time of data collection was also noted and this was to ensure that respondents in all shifts were covered as the mine operated three shifts of 8 hours per day. Further, the chapter reports the frequency of respondents' views on whether LCM was experiencing numerous drill rig breakdowns and assesses the major causes of drill rig breakdowns. Additionally, the effect of human factors on drill rig breakdowns at LCM was examined and this goes further to examine the state of employee motivation, drill rig operator training, adequacy of the number of drill rig operators and the use of drill rigs at the mine. Maintenance factors are studied looking at the adequacy of drill rig workshop facilities. The chapter proceeds to examine environmental factors which include the condition of worksites and finally, the impact of Supply Chain factors on drill rig breakdowns at LCM was surveyed.

The chapter further proceeds to discuss responses of the key informants on the objectives of the study and ends with a summary. Chapter six is then introduced and discusses the results of the study gives meaning and describes the importance of the findings.

The data was analysed in order to transform, remodel and revise the data with a view to reach a conclusion of the study. Additionally, Lee et al (2017:267) explained that data are collected in raw format and can be difficult to understand. Therefore, there is need to summarise, process and analyse the data collected. Analysis of data was done with the help NVivo, which was used to code the data and SPSS from which the Chi-square was used to determine the significance of the results obtained, the 'p' value and the chi-square value. The Z-Test was conducted to ascertain the validity of the results obtained from the Chi-square.

5.2 Response Rate

As a way of gathering data from different stratum, two separate questionnaires were developed, namely, engineering questionnaire (appendix 6) and mining questionnaire (appendix 7). Further an interview guide was prepared for the key informants. The distribution of the copies of questionnaires and the response rate are shown in Table 5.1. The key informants were picked due to their expert knowledge in the operation of the equipment under study. Additionally, the interview guide was used to maintain consistence in asking questions and this made noting of similarities and differences in responses practical and easy.

Table 5.1: Response Rate

Department	Issued	Completed	Variance	Percentage Completed
Engineering Maintenance	52	50	2	96.1
Mining	85	84	1	95.0
Process Plant	00	00	00	00
Total	137	134	3	97.8
Key Informants	35	35	0	100

Source: Author, 2019

5.3 General Information

General information consists of the data that was meant to understand the involvement of the respondent in the operation and maintenance of drill rigs at Lubambe Copper Mine as well as the knowledge of the trend of drill rig breakdowns. As such, this information consists of the position of the respondent, length of service at Lubambe Copper Mine, length of service in the mining industry and the shift a respondent worked.

5.3.1 Positions in the Organisation

Table 5.2 represents the category of respondents and their respective roles in the organisation. The letters GES stands for General Engineering Supervisor and the position is at the same level in the organisation hierarchy as the Mine Captain.

Table 5.2: Positions in the Organisation

Position	Frequency	Percentage
Superintendent	5	3.7
Mine Captain and GES	8	6.0
Engineer	8	6.0
Shift Boss and Foremen	23	17.2
Drill Operator and Maintenance	52	38.8
Drill Rig Assistant and Planner	16	11.9
Helper	22	16.4
Total	134	100.0

Source: Filed Data

From the data presented in Table 5.2, 3.7% (5 respondents) were superintendents, 6.0% (8 respondents) were mine captains and GES, 6.0% (23 respondents) were shift bosses and Foremen, 38.8% (52 respondents) were drill rig operators and maintenance personnel, 11.9% (16 respondents) worked as drill rig assistants and Planners and 64.4%(22 respondents) were helpers.

5.3.2 Years Worked at Lubambe Copper Mine

Table 5.3 shows the average number of years respondents had worked at Lubambe Copper Mine. This was mainly to affirm that the respondent was familiar with the equipment at LCM.

Table 5.3: Years of Service at Lubambe Copper Mine

	Frequency	Percent
1 to 5	44	32.8
5 to 10	42	31.3
above 10	48	35.8
Total	134	100.0

Source: Filed Data

The data from Table 5.3 show the service in years of respondents at Lubambe Mine. Further, the data in the Table shows that of the 134 respondents, 32.8% (44 respondents) had a service of 1 to 5 years, 31.3% (42 respondents) had worked between 5 and 10 years and 35.8% (48 respondents) were above 10 years in service. This shows that the data were collected from employees who had worked at Lubambe Copper Mine for different lengths of time. Both new and older employees participated in the study, indicating a fair representation of the different employee categories based on the number of years they had worked at the mine.

5.3.3 Years Worked in the Mining Industry

Table 5.4 shows the years the respondent had worked in the mining industry at the point of data collection.

Table 5.4: Years of Service

	Frequency	Percent
1 to 5	58	43.3
5 to 10	40	29.9
above 10	36	26.9
Total	134	100.0

Source: Filed Data

Similarly, the data in Table 5.4 show a fair representation of respondents by years of experience in the mining industry. Additionally, the data show that 43.3% (58 respondents) had worked in the mining industry for a period of 1 to 5 years, 29.9% (40 respondents) had worked for a period of 5 to 10 years and 26.9% (10 respondents) had worked for over 10 years. The essence of this data collection was to ensure that the responses were collected from a balanced pool of respondents.

5.3.4: Shift Worked by Employee

Table 5.5 shows the shift respondent worked. This was meant to ensure that all shifts were covered as the mine operated three shifts of eight hours per day namely, day shift, afternoon shift and night shift.

Table 5.5: Work shifts

	Frequency	Percent
Night Shift	19	14.2
Day Shift	115	85.8
Total	134	100.0

Source: Filed Data

As seen from the data in Table 3.5, out of 134 respondents, 14.2% (19 respondents) worked nightshift, while 85.8% (115 respondents) worked dayshift. It may also be noted that some employees were not fixed to one shift, but rotate between the three shifts.

The data is skewed as most of the respondents in the supervisory and maintenance roles only worked dayshift and that planned maintenance work was only carried out during the day. Therefore, the majority of the maintenance personnel were assigned to dayshift.

5.3.5: Drill Rig Breakdown Frequency

In this study, it was important to get the general views of the respondents on the frequency of breakdowns. This was to affirm the ontological assumption of the study that the frequency of breakdown of drill rig at Lubambe Copper Mine was high.

Table 5.6: Breakdown Frequency (cross tabulation)

Do you think drill rigs have a lot of breakdowns?

			NO	YES	TOTAL
Employment category	Supervision	Count	12	32	44
		Expected Count	11.2	32.8	44.0
Operatives		Count	22	68	90
		Expected Count	22.8	67.2	90.0
Total		Count	34	100	134
		Expected Count	34.0	100.0	134.0

Source: Filed Data

Table: 5.7: Breakdown Frequency - Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact (2-sided)	Sig. (1- sided)	Exact Sig. (1- sided)
Pearson Chi-Square	.125 ^a	1	0.724			
Continuity Correction ^b	0.020	1	0.887			
Likelihood Ratio	0.124	1	0.725			
Fisher's Exact Test				0.833		0.439
Linear-by-Linear Association	0.124	1	0.725			
N of Valid Cases	134					

a. 0 cell (0.0%) have expected count less than 5. The minimum expected count is 11.16.

b. Computed only for a 2x2 table

The data in Table 5.6 show that out of 134 respondents, 74.6% (100 respondents) commented that the frequency of drill rig breakdowns at Lubambe Copper Mine was high and only 25.4% (34) did not think that the frequency of drill breakdowns was high.

Further, it was important to check whether the views of the respondents were not influenced by the respondent's position. As such, the data in Table 5.6 below show the cross tabulation between the frequency of drill rig breakdown and respondent's position at Lubambe Copper Mine. From the results obtained, there is no difference in responses between supervisors and operatives and the Chi-Square results indicate ($\chi^2 (1, N = 134) = 0.125, p = 0.724$). This shows that Lubambe Copper Mine was experiencing a high frequency of drill rig breakdown. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Drill rigs had a lot of breakdowns at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: Drill rigs did not have a lot of breakdowns at LCM.

- **Significance Level** $\alpha = 0.01$

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{0.125} = 0.353$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.724$

- **Conclusion**

Since $p\text{-value} = 0.724 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that there is no difference in the opinion held by supervision and operatives at LCM on the frequency of break downs of drilling rig. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

5.3.6: Major Causes of Drill Rig Breakdowns

The specific possible causes of drill rigs breakdowns identified by respondents are; 1) Dust, 2) Water, 3) Temperature, 4) Abuse, 5) Poor maintenance, 6) Quality of parts,

7) Human errors, and 8) Lack of motivation of operators. The data in Figure 5.8 shows the frequency of responses towards these factors.

Table: 5.8: Major Causes of Drill Rig Breakdowns at LCM

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Dust	6	4.5	5.0	5.0
	Water	6	4.5	5.0	10.1
	Temperature	5	3.7	4.2	14.3
	Abuse	19	14.2	16.0	30.3
	Poor Maintenance	29	21.6	24.4	54.6
	Quality of parts	7	5.2	5.9	60.5
	Human errors	4	3.0	3.4	63.9
	Lack of motivation for operators	43	32.1	36.1	100.0
	Total	119	88.8	100.0	
Missing	System	15	11.2		
	Total	134	100.0		

Source: Field data

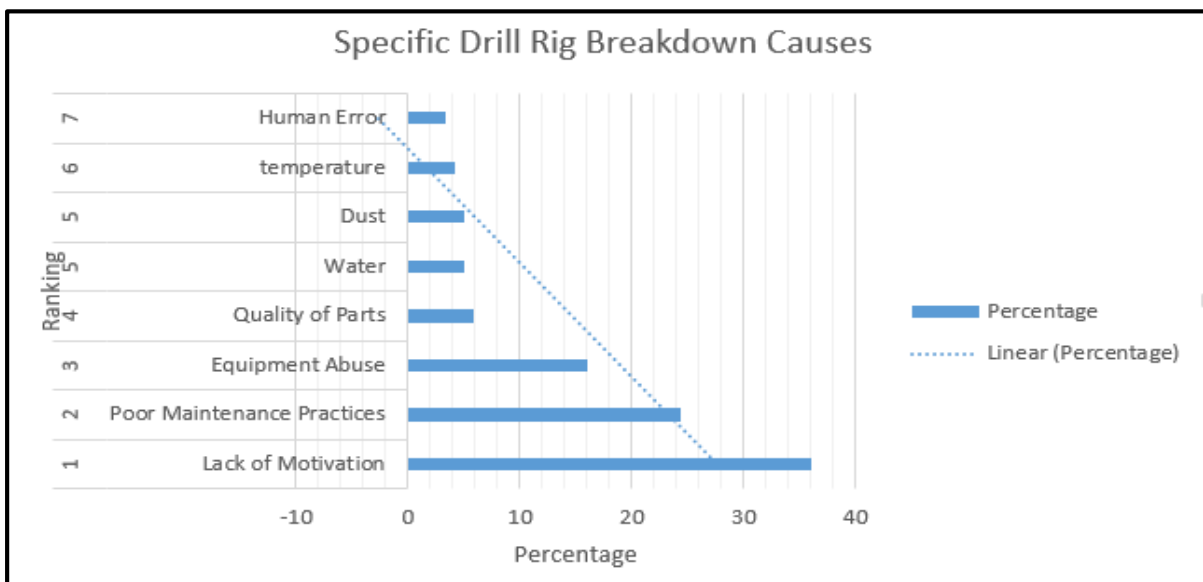


Figure 5.1: Specific Drill Rig Breakdown Causes

Source: Author, 2019

The data in Table 5.9 show that lack of motivation for operators is the single highest contributor to drill rig breakdown as indicated by 36.1% of the respondents. This is

followed by poor maintenance (24.4%) and abuse (16%). Other factors contributing to drill rig breakdowns are the quality of parts (5.9%), dust (5.0%), water (5.0%), temperature (4.2%) and Human error (3.4%). Further, the data in Figure 5.1 shows graphically average distribution of the specific factors as indicated by respondents.

5.4: Human Factor Causes of Breakdowns

In this study, human factors are termed as those elements that may affect an employee (positively or negatively) in interacting with the work environment. Therefore, the study focused on determining whether human factors could contribute to the numerous drill rig breakdowns at LCM. Human factors are therefore, concerned with applying what is known about human behaviour, abilities, limitations, and other characteristics to the design of systems, tasks/activities, environments, and equipment/technologies. The ACT Training (1998:1) states that, human factor is about persons in their existence and working conditions; about their relationship with equipment, with procedures and with the environment about them as well as their relationships with other human beings.

Table 5.9: Human Factors Causes of Breakdowns – Cross tabulation.

Do you think human factors contribute to drill rig breakdowns at Lubambe Mine?

			YES	NO	TOTAL
Employment Category	Supervision	Count	30	25	55
		Expected Count	25.8	29.2	55.0
	Operatives	Count	31	48	79.0
		Expected Count	35.2	43.8	79.0
Total		Count	60	74	134
		Expected Count	60.0	74.0	134.0

Source: Field Data

Table 5.10: Human Factor Causing Breakdowns - Chi-Square Tests

	Value	df	Asymptotic Significance(2- Sided)	Exact Sig (2-Sided)	Exact Sig (1- Sided)
Pearson Chi-Square	2.670 ^a	1	0.102		
<i>Continuity Correction^b</i>	2.070	1	0.150		
Likelihood Ratio	2.665	1	0.103		
Fisher's Exact Test				0.121	0.075
Linear-by-Linear Association	2.647	1	0.104		
N of Valid Cases	134				

- a. 0 Cells (0%) have expected count less than 5. The minimum expected count is 17.82
- b. Computed only for a 2x2 Table

The data in Table 5.9 show that out of 134 responses, 55.2% (74 respondents) attributed the high frequency of breakdown to human related factors. The other factors which are not human related accounted for the remaining 44.8% (60 respondents). From the results obtained, there was no difference in responses between managers and operatives and the Chi-Square results indicate ($\chi^2(1, N = 134) = 2.67, p = .102$). This shows that both supervisors and operatives believe that human related factors were the main causes of drill rig breakdowns. Further, to enhance the Chi-Square test, the Z-test analysis was carried out so as to confirm the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Human related factors were the main cause of drill rig breakdown at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: Human related factors were not the main cause of drill rig breakdown at LCM.

- **Significance Level** $\alpha = 0.01$
- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{2.670} = 1.634 \text{ (Z score is the same as square root of Pearson Chi-Square)}$$

$$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.102$$

- **Conclusion**

Since $p\text{-value} = 0.102 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that Human factors are the major cause of drill rig breakdown at LCM. Therefore, the Z-Test static verifies the results obtained from the Chi-Square test.

5.4.1 Employee Motivation (both maintenance and mining personnel)

At Lubambe Copper Mine, lack of motivation among operators and maintenance personnel has been highlighted as the single most important cause of drill rig breakdowns. Table 5.11 shows the nature of responses from questionnaires.

Table 5.11: Employee Motivation – Cross Tabulation

Do you think both maintenance and operating personnel are adequately motivated?

			NO	YES	TOTAL
Employment category	Supervision	Count	26	18	44
		Expected Count	31.2	12.8	44.0
	Operatives	Count	69	21	90
		Expected Count	63.8	26.2	90.0
Total		Count	95	39	134
		Expected Count	95.0	39.0	134.0

Source: Filed Data

Table 5.12: Employee Motivation – Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1- sided)
Pearson Chi-Square	4.424 ^a	1	0.035		
Continuity Correction ^b	3.613	1	0.057		
Likelihood Ratio	4.303	1	0.038		
Fisher's Exact Test				0.044	0.030
Linear-by-Linear Association	4.391	1	0.036		
N of Valid Cases	134				

- a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.81
- b. Computed only for 2x2 table

The data in Table 5.11 show that out of the 134 respondents, 70.9% (95 respondents) indicated that drill rig operators and maintenance personnel were not adequately motivated. The remaining 29.1% felt that the operators and maintenance personnel were adequately motivated. From the results obtained, these responses were reliant on the position that the respondent hold in the organisation and the Chi-Square results ($\chi^2(1, N = 134) = 4.42, p = .035$) show that more operatives indicate that there is lack of motivation (76.7%), compared to managers (59.1%). This indicates that operatives are more likely to consider lack of motivation as a major cause of drill rig breakdown than those respondents in management positions. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Both maintenance and operating personnel were adequately motivated

$H_a: \pi_1 - \pi_2 \neq 0$: Both maintenance and operating personnel were not adequately motivated

- **Significance Level** $\alpha = 0.01$

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{4.424} = 2.103$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.035$

- **Conclusion**

Since $p\text{-value} = 0.035 < 0.05 = \alpha$, we reject the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that lack of motivation is the cause of breakdown of drill rig at LCM. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

In support of the above findings, drill rig operators highlighted a number of problems that indicated lack of motivation as the leading cause of drill rig breakdowns. First, working in acting roles without confirmation for long periods. Most of the drill rig operators indicated that they were demotivated because they had been working as acting drill rig operators for longer periods (exceeding 2 years) without being confirmed in these roles. To support this assertion, one respondent said that:

'I have been in the acting role for over 2 year and I do not get any form of acting allowance. Further, I have escalated this condition to management for consideration, but no action has been taken to address the situation.'

Additionally, operators felt that the non-existence of performance bonus at Lubambe Copper Mine, which is a common practice in the Zambian mining industry, was contributing to low motivation among operators. Another respondent explained that: 'There is no form of performance bonus scheme that could motivate us to work hard and on the other hand our salaries are lower compared with our counterparts in other mines, this is discouraging.'

5.4.2: Operator Training

Operator training was cited as one factor that could contribute to the drill rig breakdown at LCM. Table 5.13 shows responses to the adequacy of drill operator training.

Table 5:13: Operator Training – Cross Tabulation

Do you think the training given to drill rig operators is adequate?

			NO	YES	TOTAL
Employment category	Supervision	Count	19	25	44
		Expected	15.4	28.6	44.0
Total	Operatives	Count			
		Count	28	62	90
		Expected	31.6	58.4	90.0
		Count			
Total		Count	47	87	134
		Expected	47.0	87.0	134.0
		Count			

Source: Field Data

Table 5:14: Operator Training – Chi-Square Test

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2- sided)	Exact Sig. (1-sided)	Sig.
Pearson Chi-Square	1.891 ^a	1	0.169			
Continuity Correction ^b	1.398	1	0.237			
Likelihood Ratio	1.865	1	0.172			
Fisher's Exact Test				0.182	0.119	
Linear-by-Linear Association	1.877	1	0.171			
N of Valid Cases	134					

- a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 15.43.
- b. Computed only for a 2x2 table

The data in Table 5.13 show that out of 134 respondents, 66.9% (87 respondents) indicated that training given to drill rig operators was adequate and the other 35.1% (47 respondents) believed that the training given to drill rig operators was not adequate. Responses from the supervisory side indicates that, 56.8% of the respondents believed that the training given to drill rig operators was adequate and 43.2% believed that the training was not adequate. The training evaluation and certification of the operators was based on safety topics and not on the machine operation. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results indicate ($\chi^2(1, N = 134) = 1.891, p = .169$) stating that all respondents believed that operators had adequate training. Further, to enhance the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: The training given to drill rig operators at LCM was adequate.

$H_a: \pi_1 - \pi_2 \neq 0$: The training given to drill rig operators at LCM was not adequate.

- **Significance Level $\alpha = 0.01$**

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{1.891} = 1.375$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.169$

- **Conclusion**

Since $p\text{-value} = 0.00169 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that operators at LCM have adequate training on rig operation. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Though the majority of respondents indicated that the training for drill rig operators was adequate, a number of critical issues were raised regarding the quality, coverage and duration of the training. The drill rig operators indicated that the training lacked the technical aspects of diagnosing and repairing minor problems, but only focused on drilling, safety and basic machine operating procedures. They said if they had the basic technical Knowledge of the machine, they could proactively report potential breakdowns to the maintenance personnel before a breakdown occurred and that downtime could be minimised by being specific in reporting the nature of breakdown to the technicians on duty. To support this view, one respondent stated that:

‘it will be better if the company can start giving us some technical training on the drill rigs, this will help us to understand the machine and reduce breakdowns, Sandvik [Drill rig OEM] can be approached to organise short courses, otherwise our training is not complete.’

Another respondent hinted that:

‘It is going to be better if our training includes a bit of technical training and simple tool given to us. This will enable us to work on simple problems such as changing hoses and tightening bolts and nuts.’

Further, the respondents highlighted a number of important aspects that bordered on the quality of training such as the inadequate number and quality of trainers, and inappropriate training methods. To this effect, one respondent explained that:

‘the mine trainers are few and do not have formal training in teaching methodology, further, the operator practical training is carried out in simulators without proceeding to the actual underground environment, so when we are allocated machines, it becomes very difficult to adapt and we end up damaging the machines where disciplinary action is mate for the damage caused.’

Further, one of the senior drill rig operator trainers claimed that:

‘Some of the drill rig operators do not pass through the training school, separate and secrete arrangements with their superiors are made underground and these are the operators who probably work in acting roles without being confirmed for several years. The training school on the other hand does not have a firm program or modules for training drill rig operators and this makes the training to be random with a likelihood of omitting critical phases of the program. In addition, the trainers do not undergo formal teaching methodology courses to enhance their teaching skills, the trainers are only picked from operating departments as promotion on the basis of hard work.’

The other drill rig operator trainer specified that:

‘The training for drill rig operators is adequate, however, trained operators are given other roles and their roles are taken up by inexperienced operators recommended by senior supervisors. These operators are not trained by the training school, but by their trained and experienced colleagues who have been given other roles other than what they are trained for. These operators create a lot of damage to the equipment, hence, the high frequent of drill rig breakdown. To enhance the drill rig operator’s skills, basic technical training is required for both the trainees and trainers, this will help the operators in identifying potential breakdowns and resolving minor breakdowns. This can reduce equipment downtime and improve productivity. The number of trainers is not adequate and this is why onsite underground practical drilling training is not conducted’.

5.4.3: Adequacy of Operators

The staffing level of drill rig operators was yet another factor that could contribute to the numerous drill rig breakdowns at LCM and the data in table 5.15 show the views from respondents on the adequacy of drill rig operators at LCM.

Table 5.15: Adequacy of the Number of Operators – Cross Tabulation

Does the mine have enough drill rig operators?

			No	Yes	Total
Employment category	Supervision	Count	16	28	44
		Expected Count	17.7	26.3	44.0
	Operatives	Count	38	52	90
		Expected Count	36.3	53.7	90.0
Total	Count		54	80	134
	Expected Count		54.0	80.0	134.0

Source: Filed Data

Table 5.16: Adequacy of the Number of Operators – Chi-Square Test

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2- sided)	Exact Sig. (1- sided)
Pearson Chi-Square	.422 ^a	1	0.516		
Continuity Correction ^b	0.213	1	0.644		
Likelihood Ratio	0.424	1	0.515		
Fisher's Exact Test				0.576	0.323
Linear-by-Linear Association	0.418	1	0.518		
N of Valid Cases	134				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 17.73.

b. Computed only for a 2x2 table

The inadequacy of the number of operators was equally acknowledged as one of contributing factors to drill rig breakdown at LCM. This was despite 59.7% of the respondents stating that they considered the number of drill rig operators at the mine to be adequate. The data in Table 5.15 show that out of 134 respondents, 59.7% (80 respondents) indicated that the mine had adequate operators while 40.3% (54 respondents) stated that the mine did not have adequate drill rig operators. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results specify ($\chi^2(1, N = 134) = 1.891, p = .169$) indicating that all respondents believed that the number of drill rig operators at the mine was adequate. Further, to enhance the Chi-Square test, the Z-test analysis was conducted so as to verify the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: LCM had enough drill rig operators.

$H_a: \pi_1 - \pi_2 \neq 0$: LCM did not have enough drill rig operators.

- **Significance Level** $\alpha = 0.01$

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{0.422} = 0.649$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.516$

- **Conclusion**

Since $p\text{-value} = 0.516 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that there was an adequate number of operators at the mine. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

This analysis is supported by respondent's views where a number of respondents raised important issues regarding the drill rig operators. Further, there were allegations that most of the operators were not adequately trained to operate drill rigs.

The staffing levels of qualified operators was not adequate though the inclusion of unqualified operators made it appear as if the number was adequate. This limitation in the number of qualified and competent operators posed a lot of pressure on the experienced operators who had to carry out extra work that the inexperienced operators may not do. The use of untrained operators could be a cause of the numerous breakdowns at the mine. One respondent reported that:

'We work extra hours because we are few and the machines are many, the other operators are not trained and we always carry out tasks they are supposed to do. In turn you find that the level of absenteeism of the experienced operators is high and this is because we are overworked.'

Another respondent claimed that:

'The assigning of one operator to a machine per shift is stressful as the machine has several levers to manipulate. As such, we have to come out of the machine to arrange and install drill rods in order for the machine to pick. One operator is not enough per shift to carry out all the drilling operations required.'

Yet one of the respondents among those who claimed that the number of drill rig operators at the mine was adequate argued that:

'The number of drill rig operators is enough, except there is no systematic planning by our supervisors. The mine planning department provides drilling schedules according to the number of machines and planned work-hours, but these plans are changed by our supervisors underground. This stresses the operators and result into operators not reporting for work and giving various false excuses for their absenteeism.'

5.4.4: Use of Drill Rigs

The use of drill rigs for other purposes other than those originally intended was one of the factors that could lead to the high frequency of drill rig breakdowns at LCM, therefore, it was important to examine this factor. The data in Table 17 show whether drill rigs at LCM were used for the right purpose.

Table 5.17: Use of Drill Rigs

			No	Yes	Total
Employment category	Supervision	Count	3	41	44
		Expected Count	5.9	38.1	44.0
	Operatives	Count	15	75	90
		Expected Count	12.1	77.9	90.0
Total		Count	18	116	134
		Expected Count	18.0	116.0	134.0

Source: Field Data

Table 5.18: Use of Drill Rigs – Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1sided)
Pearson Chi-Square	2.465 ^a	1	0.116		
Continuity Correction ^b	1.691	1	0.193		
Likelihood Ratio	2.730	1	0.099		
Fisher's Exact Test				0.177	0.093
Linear-by-Linear Association	2.447	1	0.118		
N of Valid Cases	134				

Are drill rigs used for the right purpose?

- a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.91.
- b. Computed only for a 2x2 table.

The data in Table 5.17 show that out of the 134 responses 86.6% (116 respondents) believed that the drill rigs were used for the intended (design) purpose. Whereas 13.4% (18 respondents) believed that drill rigs at LCM were not used for the correct purpose. From the results obtained, the responses are not dependant on the position

that the respondent held in the organisation and the Chi-Square results show ($\chi^2(1, N=134) = 2.47, p = .116$) indicating that all respondents believed that the drill rigs were used for the intended purpose at Lubambe Mine. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Drill rigs were used for the right purpose at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: Drill rigs were not used for the right purpose at LCM.

- **Significance Level $\alpha = 0.01$**

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{2.465} = 1.570$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.116$

- **Conclusion**

Since $p\text{-value} = 0.116 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that drill rigs were used for the correct purpose. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Some of the respondent's arguments can be supported by the above analysis. A number of respondents argued that the drill rigs were not used for the right purpose and among the respondents who said the drill rigs were not used for the correct purpose one indicated that:

'drill rigs are not used correctly, the face rigs, the DD321 are used for supporting ground and this operation causes the boom parts to break because this machine is not designed for support, but face drilling. We are supposed to use the DS420 Bolter

or the DS311 Roof Bolter which are meant for support. These two machines are available at the mine but not used.'

On the other hand, a respondent from those said the drill rig were used for the right purpose specified that:

'The drill rigs at LCM are used correctly, but what causes the numerous damage to the machine is the fall of ground from the mining faces due to weak ground'.

5.5: Maintenance Factors

Maintenance factors were also considered to be one of the causes of drill rig breakdown at LCM. Therefore, the data in Table 5.19 show respondent's views on whether maintenance factors contributed to drill rig breakdown at LCM.

Table 5.19: Maintenance Factors

Do maintenance factors contribute to drill rig breakdowns at LCM?

			NO	YES	TOTAL
Employment category	Supervision	Count	19	25	44
		Expected	17.1	26.9	44.0
	Operatives	Count	33	57	90
Expected		34.9	55.1	90.0	
Count					
Total	Count	52	82	134	
	Expected	52.0	82.0	134.0	
	Count				

Source: Field Data

Table 5.20: Maintenance Factors - Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2sided)	Exact (1sided)	Sig.
Pearson Chi-Square	.528 ^a	1	0.467			
Continuity Correction ^b	0.290	1	0.591			
Likelihood Ratio	0.525	1	0.469			
Fisher's Exact Test				0.572	0.294	
Linear-by-Linear Association	0.524	1	0.469			
N of Valid Cases	134					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 17.07.

b. Computed only for a 2x2 table

As seen from the data in Table 5.19, 61.2% (82 respondents) stated that the maintenance factors did not contribute to drill rig breakdown at LCM, while 38.8% (52 respondents) believed that the maintenance factors contributed to drill rig breakdown. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results indicate ($\chi^2(1, N = 134) = 0.528, p = .467$) signifying that all respondents believed that the maintenance factors contribute to drill rig breakdown at LCM. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Maintenance factors contributed to drill rig breakdowns at LCM

$H_a: \pi_1 - \pi_2 \neq 0$: Maintenance factors did not contribute to drill rig breakdowns at LCM

- **Significance Level** $\alpha = 0.01$

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{0.528} = 0.726$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.467$

- **Conclusion**

Since $p\text{-value} = 0.467 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that maintenance factors contribute to breakdown of drill rigs at LCM. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Among the respondents who said that the maintenance factors contributed to drill rig breakdown, one stated that:

‘Lubambe Copper Mine maintenance department has no effective Enterprise Resource Maintenance system for planning and scheduling of work. This creates a situation of random scheduling which leads to distortion of the maintenance schedules. This position causes more breakdowns as some machines may not be serviced according to the OEM intervals and certain major components could be run beyond the life cycle causing sudden failure.’

The other respondent stated that:

‘The non-availability of workshops underground is a major problem for the organisation. The maintenance of equipment is not carried out to OEM standards because the workshop space is not available. Usually the surface workshop is congested with broken down machines and leaving no space for planned preventive maintenance. This condition equally contributes to the numerous drill rig breakdowns experienced on drill rigs at the mine.’

On the other hand, one of the respondents from those who specified that the maintenance factors did not contribute to drill rig breakdown commented that:

‘The infrastructure is adequate, however, the workshop is always crowded with broken-down equipment. If the rate of equipment breakdown is minimised, there will be a lot of workshop space available for planned preventive maintenance. If this condition is corrected, then the maintenance personnel will be able to carry out their work

according to the OEM recommendations, hence, minimising equipment breakdown and improving productivity.’

5.5.1: Adequacy of Drill Rig Workshop Facilities

The inadequacy of workshop facilities was been considered as a factor that could lead to drill rig breakdowns at LCM and the data in Table 5.21 give respondent’s views on whether the mine had adequate maintenance facilities or not.

Table 5.21: Adequacy of Drill Rig Workshop Facilities

Are the workshop facilities for maintaining drill rigs adequate?

			NO	YES	TOTAL
Employment category	Supervision	Count	16	28	44
		Expected	12.5	31.5	44.0
	Operatives	Count	22	68	90
		Expected	25.5	64.5	90.0
Total		Count	38	96	134
		Expected	38.0	96.0	134.0

Source: Field Data

Table 5.22: Adequacy of Drill Rig Workshop Facilities - Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2- sided)	Exact Sig. (1- sided)
Pearson Chi-Square	2.067 ^a	1	0.151		
Continuity Correction ^b	1.521	1	0.217		
Likelihood Ratio	2.020	1	0.155		
Fisher's Exact Test				0.159	0.109
Linear-by-Linear Association	2.051	1	0.152		
N of Valid Cases	134				

The data in Table 5.21 show that out of 134 respondents, 71.6% (96 respondents) indicated that the drill rig workshop facilities were adequate and on the other hand, 28.4% of the respondents believed that the drill rig workshop facilities were not adequate. From the results acquired, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results indicate ($\chi^2(1, N = 134) = 2.067, p = 0.151$) signifying that all respondents believed that the drill rigs workshop facilities were adequate. Further, to enhance the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: The workshop facilities for maintaining drill rigs were adequate at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: The workshop facilities for maintaining drill rigs were not adequate at LCM.

- **Significance Level** $\alpha = 0.01$
- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{2.067} = 1.437$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.151$

- **Conclusion**

Since $p\text{-value} = 0.151 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that the amount of drilling rig workshop facilities are adequate at LCM. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Some of the expressions given by the respondents over the adequacy of the drill rig workshop facilities are as follows:

Among those respondents who indicated that the facilities were adequate, one said that:

‘The surface workshop is big and it has refuelling and oil filling facilities, I have not seen machines lined up for refuelling.’

Further, one respondent among those who said the facilities were not adequate argued that:

‘The facilities are not enough though the workshop may be big. We do don’t have testing equipment such as dynamometers for testing major components such as engines and transmissions. This is why at times when we buy components they fail prematurely, it’s because we only rely on the supplier’s test certificate which could be a mere paper exercise and not portray the actual condition of the component’.

The other respondent alleged that:

‘The facilities are not adequate because there is no workshop underground. The machines operate from underground and because we do not have workshop facilities underground, we are meant to drive or toll machines to surface and this is a cause of further damage to machines. The idea of always moving machines from underground to surface also causes failure of the machine drive train and further, it is also costly driving machines all the way to surface as we burn fuel for nothing.’

5.6: Environmental Conditions

Environmental conditions were equally identified as one factor that could contribute to drill rig breakdowns at LCM. The data in Table 5.8 show how respondents perceived environmental conditions in relation to drill rig breakdowns at LCM.

Table 5.23: Environmental Conditions

Do underground environmental conditions contribute to drill rig breakdowns?

			NO	YES	TOTAL
Employment category	Supervision	Count	23	21	44
		Expected	25.0	19.0	44.0
	Operatives	Count	53	37	90
		Expected	51.0	39.0	90.0
Total		Count	76	58	134
		Expected	76.0	58.0	134.0

Source: Field Data

Table 5.23: Environmental Conditions- Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2- sided)	Exact Sig. (1- sided)
Pearson Chi-Square	.527 ^a	1	0.468		
Continuity Correction ^b	0.292	1	0.589		
Likelihood Ratio	0.525	1	0.469		
Fisher's Exact Test				0.578	0.294
Linear-by- Linear Association	0.523	1	0.470		
N of Valid Cases	134				

- 0 cells (0.0%) have expected count less than 5. The minimum expected count is 19.04.
- Computed only for a 2x2 table

The data presented in Table 5.23, show that out of 134 respondents, 43.2% (58 respondents) indicated that the underground environmental conditions contributed to the numerous drill rig breakdowns whereas 56.7% (76 respondents) believed that environmental conditions did not contribute to the numerous drill rig breakdowns. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results show ($\chi^2(1, N = 134) = 2.066, p = 0.151$) stating that all respondents believed that environmental conditions were one of the contributing factors to the major breakdowns of drill rigs. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Environmental factors caused drill rig breakdowns at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: Environmental factors did not cause drill rig breakdowns at LCM.

- **Significance Level** $\alpha = 0.01$

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{0.527} = 0.725$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.468$

- **Conclusion**

Since $p\text{-value} = 0.468 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that environmental conditions cause breakdown of drill rig at LCM. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Some of the expressions given by the respondents on environmental conditions in relation to drill rig breakdowns were:

One of the respondents from those who said that the underground worksite conditions did not contribute to the numerous drill rig breakdowns said:

‘The underground temperature at the mine is not high compared with other mines, Lubambe Copper Mine is not deep enough to start experiencing high temperature that could affect the performance of machines.’

Further, a respondent from those who believed that environmental conditions contributed to the numerous drill rig breakdown said:

‘The rate of failure of equipment drive train components is very high compared with other mines I have worked for. At Lubambe Copper Mine the roadways are rough and all the worksites are rough and full of water. These conditions affect the life cycle of equipment parts both electrical and mechanical.’

5.6.1: Underground Drill Site

Conditions of drill sites have the potential to cause equipment breakdown, therefore, drill site conditions were considered as one of the causes which could contribute to the numerous drill rig breakdowns at LCM.

Table 5.25: Underground Environmental Factors – Chi-Square Test

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Dusty	76	56.7	95.0	95.0
	Water	2	1.5	2.5	97.5
	Temperature	2	1.5	2.5	100.0
	Total	80	59.7	100.0	
Missing	System	54	40.3		
Total		134	100.0		

Source: Filed Data

The data in Table 5.25 show that out of 134 respondents, 95.0% (76 respondents) said that the drill site conditions were dusty, 2.5% said the drill site conditions were water logged and 2.5% said the temperature was high in drill site areas.

5.7: Supply Chain

Since materials used for the maintenance and repair of drill rigs were purchased through the Supply Chain department, Supply Chain factors were considered as one factor that could contribute to drill breakdowns at LCM. The data in Table 5.26 show how respondents viewed Supply Chain factors in relation to drill rig breakdown at LCM.

Table 5.26: Supply Chain Factors

Do Supply Chain factors contribute to the numerous drill rig breakdowns at LCM?

			No	Yes	TOTAL
Employment category	Supervision	Count	11	33	44
		Expected	13.8	30.2	44.0
Total	Operatives	Count	31	59	90
		Expected	28.2	61.8	90.0
	Count	42	92	134	
	Expected	42.0	92.0	134.0	
		Count			

Source: Field Data

Table 5.27: Supply Chain Factors – Chi-Square Test

	Value	df	Asymptotic Significance (2-sided)	Exact (2-sided)	Sig. Exact (1- sided)	Sig. Exact (1- sided)
Pearson Square	Chi- a	1.225	1	0.268		
Continuity Correction ^b		0.825	1	0.364		
Likelihood Ratio		1.253	1	0.263		
Fisher's Test	Exact				0	0.182
					.	
					3	
					2	
					4	
Linear-by-Linear Association		1.216	1	0.270		
Linear-by-Linear Association		134				

Supply Chain factors were been considered as factors that could contribute to the numerous drill rig breakdowns experienced at LCM despite 68.7% of the respondent stating that Supply Chain factors did not contribute to the numerous drill rig breakdowns at the mine. From the data presented in Table 5.26, out of 134 respondents, 68.7% (92 respondents) stated that Supply Chain factors did not contribute to the numerous drill rig breakdowns at the mine while a further 31.3% (42 respondents) believed that Supply Chain factors contributed to the numerous drill rig breakdowns at the mine. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results indicate ($\chi^2(1, N = 134) = 1.225, p = 0.268$) stating that all respondents believed that Supply Chain factors contributed to the numerous drill rig breakdowns at the mine. Further, to enhance the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Supply Chain factors at LCM caused drill rig breakdowns.

$H_a: \pi_1 - \pi_2 \neq 0$: Supply Chain factors at LCM did not cause drill rig breakdowns.

- **Significance Level** $\alpha = 0.01$
- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{1.225} = 1.106$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.268$

- **Conclusion**

Since $p\text{-value} = 0.268 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that Supply Chain factors contributed to breakdown of drill rig at LCM. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Expressions given by the respondents on Supply Chain factors in relation to drill rig breakdown at LCM include among others:

One of those who said that Supply Chain factors contributed to drill rig breakdown at the mine said:

‘Most of the parts that the mine orders are from the OEM and the quality is good as they go through quality assurance before delivery and each time these parts are delivered to the mine, test certificate is issued by the supplier or contractor.’

On the contrary, a respondent from those who believed that the quality of parts used on drill rigs was not good said:

‘The quality of parts can be questionable and I don’t think it’s good. Components are refurbished outside the mine and the mine does not know the condition of the internal parts used on these components. Though test certificates could be issued, these can merely be papers. One time we opened a refurbished axle for a TH540 dump truck refurbished by one of the mine approved contractors, old bearings were found inside the axle. The quality could only be trusted if these components are refurbished at the mine.’

5.7.1: Storage of Parts

Storage of parts is related to quality of parts in that if good quality parts are not properly stored, their quality can be compromised, therefore, the storage of parts was considered as one of the factors that could contribute to the numerous drill rig breakdowns at LCM. The data in Table 5.28 show the level of response from questionnaires on the storage of maintenance parts.

Table 5.28: Storage of Parts

			NO	YES	TOTAL
Employment category	Supervision	Count	7	37	44
		Expected	6.9	37.1	44.0
Total	Operatives	Count	14	76	90
		Expected	14.1	75.9	90.0
		Count	21	113	134
		Expected	21.0	113.0	134.0

Source: Field Data

Table 5.29: Storage of Spare Parts – Chi-Square Test

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.003 ^a	1	0.958		
Continuity Correction ^b	0.000	1	1.000		
Likelihood Ratio	0.003	1	0.958		
Fisher's Exact Test				1.000	0.571
Linear-by-Linear Association	0.003	1	0.958		
Linear-by-Linear Association	134				

The data obtained from Table 5.28 show that out of 134 respondents, 84.3% (113 respondents) indicated that the storage of parts used on drill rigs was good and a further 15.7% (21 respondents) believed that the storage of parts used on drill rigs at LCM was not good. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results indicate ($\chi^2(1, N = 134) = 0.003, p = 0.958$) showing that all respondents believed that the storage of parts used for maintaining and repairing drill rigs were good. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Storage of parts caused drill rig breakdowns at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: Storage of parts did not cause drill rig breakdowns at LCM.

- **Significance Level** $\alpha = 0.01$

- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{0.003} = 0.05$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.958$

- **Conclusion**

Since $p\text{-value} = 0.958 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that storage of parts could cause breakdown of drill rig. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Further, some of the comments given by the respondents on the storage of parts used on drill rigs in relation to drill rig breakdowns were:

Among respondents who indicated that the storage of parts used for maintaining and repairing drill rigs was good said:

‘The parts are properly stored in cabins and others are covered in plastic in the mine store to avoid water and dust.’

On the other hand, a respondent among those who stated that the storage of parts used on drill rigs was not of good quality said:

‘The parts could be stored well in the mine store, but when they go to satellite stores, they are not kept properly because the cabinets are not adequate and further, the underground storage facilities are usually exposed to water and dust, therefore, it may not be right to say the storage of parts used on drill rigs is good.’

5.7.2: Contamination of Oil and Fuel Dispensing Facilities

Contamination of fuel and oils was equally observed as one factor that could contribute to the numerous drill rig breakdowns at LCL as fuels and oils are sensitive to contamination.

Table 5.30: Contamination of Oil and Fuel Dispensing Facilities

			NO	YES	TOTAL
Employment category	Supervision	Count	12	32	44
		Expected Count	8.9	35.1	44.0
	Operatives	Count	15	75	90
		Expected Count	18.1	71.9	90.0
Total	Count		27	107	134
	Expected Count		27.0	107.0	134.0

Source: Filed Data

Table 5.31: Contamination of Oil and Fuel Dispensing Facilities Chi-Square Tests
Are the fuel and oil dispensing facilities adequately secured against contamination?

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2- sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.066 ^a	1	0.151		
Continuity Correction ^b	1.460	1	0.227		
Likelihood Ratio	1.996	1	0.158		
Fisher's Exact Test				0.172	0.115
Linear-by-Linear Association	2.051	1	0.152		
N of Valid Cases	134				

- a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.87.
- b. Computed only for a 2x2 table

The data in Table 5.30 show that out of 134 respondents, 79.8% (107 respondents) believed that the oil and fuel dispensing facilities were adequately secured from contamination, whereas 20.1% (27 respondents) said that the oil and fuel dispensing facilities were not adequately secured against contamination. From the results obtained, these responses were not dependant on the position that the respondent held in the organisation and the Chi-Square results shows ($\chi^2(1, N = 134) = 2.066, p = 0.151$) indicating that all respondents believed that the oil and fuel dispensing facilities were adequately secured against contamination. Further, to augment the Chi-Square test, the Z-test analysis was conducted so as to validate the results obtained.

Z- Test Analysis

- **Hypotheses**

$H_0: \pi_1 - \pi_2 = 0$: Contamination of oil and fuel dispensing facilities caused drill rig breakdowns at LCM.

$H_a: \pi_1 - \pi_2 \neq 0$: Contamination of oil and fuel dispensing facilities did not cause drill rig breakdowns at LCM.

- **Significance Level** $\alpha = 0.01$
- **Rejection Region**

Reject the null hypothesis if $p\text{-value} \leq 0.05$.

- **Test Statistic**

From the relationship of Z-Test is equal to the square root of the Chi-Square static, the Z-Test static can be calculated as:

$Z = \sqrt{\text{Pearson Chi-Square}} = \sqrt{2.066} = 1.437$ (Z score is the same as square root of Pearson Chi-Square)

$p\text{-value} = \text{Asymp. Sig. (2-tailed)} = 0.151$

- **Conclusion**

Since $p\text{-value} = 0.151 > 0.05 = \alpha$, we accept the null hypothesis.

Therefore, at the level $\alpha = 0.01$ level of significance, there is enough evidence to conclude that contamination of oil facilities could contribute to breakdown of drill rig at LCM. Therefore, the Z-Test static confirms with the results obtained from the Chi-Square test.

Comments given by the respondents on the state of the oil and fuel dispensing facilities at LCM included:

A respondent among those who said the oil and fuel dispensing facilities were secured against contamination said:

'The dispensing facilities on the mine are adequately secured against contamination as the Wigget system is used for decanting oils and fuels into vehicle tanks and these prevent contamination.'

A respondent from those who maintained that the oil and fuel dispensing facilities were contaminated said:

'Not all oil and fuel dispensing facilities are secured against contamination, oil is taken underground to worksites in open containers. Some of these containers are dirty and in certain instances not adequately dried after washing. Therefore, they contain some water which is a form of contamination to oil and fuel. The bulk oil and fuel tankers that

take fuel and oil to drill rig sites underground are not clean and we do not know when they were last flushed to remove slug and water from the tanks.’

5.8 Thematic Analysis

This section discusses the views that were brought forward regarding the study topic. The discussion centred on what the key informants felt were the causes of the numerous drill rig breakdowns at LCM.

To be consistent in conducting interviews, an interview guide was developed and used for the selected key informants. Marshal (1996:92) commented that the use of key informants is a qualitative technique which has been used widely and successfully in several sectors of social science investigation. Further, he indicated that the main advantage of using this technique relates to the quality of data obtained in a relatively short period of time and that the selected key informants understand and have the expert knowledge of the area being investigated. The key informants selected in this study were those employees from management level who understand the operation of the equipment under study and attended production and management meetings where equipment performance was discussed.

5.8.1 Key Informants

A total of 35 key informants were selected and interviewed. Table 5.1 shows the key informants by employment category.

Table 5.32: key Informants

Item	Designation	Number
1	Mine manager	1
2	Safety Manager	1
3	Supply Manager	1
4	Human Resources Manager	1
5	Process Plant Manager	1
6	Underground Manager	2
7	Mine Superintendent	3
8	Training Superintendent	1
9	Contracts Superintendent	1
10	Road maintenance Superintendent	1
11	Engineering Superintendent	4
12	Supply Superintendent	1
13	Projects Engineer	1
14	Dewatering Engineer	1
15	Maintenance Planner	1
16	General Engineering Supervisor (GES)	4
17	Engineering Training Coordinator	1

18	Maintenance Planning Engineer	1
19	Mine Planning Engineer	1
20	Blasting Engineer	1
21	Chief Surveyor	1
22	Ventilation Engineer	1
23	Mining Consultant	3
24	Engineering Consultant	1
	Total	35

Source: Field Data

The key informants in Table 5.1 were purposively selected on the bases of their expert knowledge on the study topic.

Further, the responses given by the key informants in relation to the study objective and research questions have been summarised in tables (appendix 9).

5.8.1.1 Human Factors

The data in Table 5.33 show the views of the key informants on whether human factors contributed to the numerous drill rig breakdowns experienced at the mine.

Table 5.33: Human Factors

Do Human Factors Contribute to Breakdowns of Drill Rigs?	Not Human Related	Human Related
	4	31
	11.4%	88.6%

Source: Field Data

Additionally, the data in Table 5.33 show that out of 35 key informants 88.6% (31 key informants) believed that the drill rig breakdowns at the mine were caused by human factors and a further 11.4% (4 key informants) indicated that the human factors contributed to the numerous drill rig breakdowns.

The major areas of concern highlighted were:

- i. The employees were demotivated as there was no extra financial incentive to appreciate their performance.
- ii. The training given to the drill rig operators was not adequate and the selection procedure was bias.

- iii. The employees felt management did not consider their plea to management in several areas of their operations such adjusting their condition of service.
- iv. The drill rig operators were equally not motivated in that they did not see any room for career development.
- v. The drill rig operators were fatigued at work as most of them worked prolonged hours due to carrying out duo roles and assisting operators who did not have adequate drilling skills.
- vi. It was equally noted that most of the drill rig operators worked in acting roles for extended periods of time and this dampened their moral.

5.8.1.2 Maintenance Factors

Maintenance factors were equally perceived as one of the causes of drill rig frequent drill rig breakdowns experienced at the mine and Table 5.34 show the nature of responses from the key informants.

Table 5.34: Maintenance Factors

Do maintenance factors contribute to breakdowns of drill rigs?	Not Related to Maintenance Factors	Related to Maintenance Factors
	11	24
	31.4%	68.6%

Source: Field Data

Further, the data in Table 5.34 indicate that out of 35 key informants, 68.6% (24 key informants) commented that maintenance factors contributed to the numerous drill rig breakdowns at LCM while 31.4% (11key informants) said that the drill rig breakdowns were caused by factors other than maintenance related factors.

The main areas stressed by the key informants as contributing to the drill rig breakdowns at the mine were:

- i. Maintenance was not carried out as per the OEM standards as the maintenance personnel were usually attached to resolving breakdowns of

equipment in production areas and forfeiting maintenance of equipment that was due for service.

- ii. The mine did not have an appropriate maintenance software package that could assist in flagging maintenance points and storing various maintenance information such as equipment history, breakdown analysis by major component failure, maintenance unit cost calculation and projections and reconciliation of maintenance compliance to name a few.
- iii. The mine did not have adequate physical infrastructure, for example, the mine had only one workshop located on surface for carrying out all maintenance work including component change out and rehabilitation of equipment.
- iv. The maintenance personnel did not have adequate equipment for testing equipment parts and components and this led to parts being fitted on the machine without confirming their integrity. Reliance was on the test certificate issued by the supplier. In an event of a premature failure of a component, failure analysis was carried out (appendix 5) and if the fault was related to the manufacturer of contractor and the component was within the warranty period, a warranty claim was launched (appendix 6).

5.8.1.3 Environmental Factors

From the literature review, environmental factors were equally considered as one of the causes of drill rig breakdowns in a mine. Therefore, this item was considered in the study and Table 5.35 show how the key informants responded to the question of whether environmental factors contributed to the breakdowns at LCM.

Table 5.35: Environmental Factors

Do environmental factors Contribute to Breakdowns of Drill Rigs?	Not related to Environmental conditions	Related to environmental conditions
	8	27
	22.9%	77.1%

Source: Field Data

The comments by the key informants are supported by the data in Table 3.35 which show that out of 35 key informants, 77.1% (27 key informants) felt that environmental conditions contributed to the drill rig breakdowns experienced at the mine. On the other hand, 22.9% (8 key informants) argued that environmental factors did not contribute to the drill rig breakdowns at the mine.

In relation to environmental factors, the following areas were highlighted by the key informants:

- i. The roadways and work site conditions were waterlogged and rough for smooth operation of equipment.
- ii. The mine design in most areas was not good, some areas were too steep for the equipment to negotiate. This created damage to drive units of equipment.
- iii. Some areas were not adequately ventilated, a condition that led to high temperature in these working areas. This condition had a duo effect, the first on was on the health of employees and the second one was the damage to equipment components such as engines.

5.8.1.4 Supply Chain Factors

Supply Chain factors have also been identified as one area that can contribute to breakdowns of equipment, therefore, the study investigated the impact of environmental factors on the performance of drill rigs and the data in Table 5.36 show the frequency of responses from key informants.

Table 5.36: Supply Chain Factors

Do Supply Chain factors Contribute to Breakdowns of Drill Rigs?	Not related to Supply Chain	Related to Supply Chain
	13	22
	37.1%	62.9%

Source: Field Data

Further, the data in Table 5.36 point out that out of 35 key informants, 62.9% (22 key informants) explained that Supply Chain factors contributed to drill rig breakdowns at LCM and the other 37.1% (13 key informants) stated that Supply Chain factors did not contribute to the drill rig breakdowns experienced at LCM.

The major issues identified and discussed by key informants in relation to Supply Chain factors and their influence on drill rig reliability included:

- i. The storage of maintenance parts more especially the bigger components was not good, they were exposed to moisture and dust.
- ii. The transportation of maintenance parts from stores to the workshop was in open vehicles and this exposed the parts to contamination.
- iii. The Supply department did not have a quality assurance section to test or check the items received. They equally depended on the test certificate provided by the supplier and performance information from the user department.

5.9 Conclusion

This section has evaluated the data using analytical and statistical tools to discover essential information that has been used to arise at the conclusion. The Chi-Square from SPSS software was used to determine relationships within the data and the Z-Test was carried out to test the hypothesis. The data from key informants was also uploaded and coded using NVivo. This data was analysed and presented through tables.

CHAPTER SIX

DISCUSSION OF RESULTS

6.1 Introduction

The purpose of the chapter is to interpret, give meaning and describe the significance of the findings in light of what was already known about the study and to explain any new understanding or insights that may emerge as a result of undertaking the study. This is where the study reports the findings based upon the methodology applied to gather the information.

Further, the discussion of finding enabled the study to have deeper knowledge about abstract principle of the findings, to have an understanding of the findings and the reasons behind their existence and finally it gave guidance in the study in line with the work carried out. Trigueros (2018:10), commented that, in the discussion chapter, the researcher begins to answer the research questions and the general research objective illustrating the main observations.

The results and findings of the study are discussed in this chapter and outline the following specific research objectives:

- i. To determine the influence of human related factors on drill rig breakdowns.
- ii. To ascertain the impact of underground environmental conditions on drill rig breakdowns.
- iii. To establish the effect of maintenance related factors on drill rig breakdowns.
- iv. To find out whether Supply Chain factors contribute to drill rig breakdowns.

The following sections discuss the results of the data analysis in relation to the research objectives.

6.2 How Human Factors Led to Increase in Drill Rig Breakdowns.

The results of this study show that motivation, fatigue and training and development are among the human related factors that cause drill rig breakdown at LCM. According to the results of the study, 70.9% (95 respondents) believed that the drill rig operators

and maintenance personnel were not motivated whereas 29.1% (39 respondents) felt that both drill rig operators and maintenance personnel were adequately motivated. 66.9% (87 respondents) indicated that the drill rig operator training was adequate and 35.1% (47 respondents) commented that the drill rig operators training was not adequate. Additionally, 69.7% (80 respondents) suggested that the number of drill rig operators was adequate whereas 40.3% (54 respondents) indicated that the number of drill operators was not adequate.

Further, the study reviewed that operators worked in acting roles without being confirmed for longer periods exceeding the company recommended period. This situation had a negative impact on the motivation of the operators and led to operators not caring for the equipment they were tasked to operate.

Carrying out duo roles, that of drill rig operator and supervising the inexperienced operators was demotivating to the experienced operators as this meant working long hours, additionally, they were not paid for supervising the inexperienced operators.

The maintenance personnel worked long hours attending to breakdowns of drill rigs and had little time of rest. Further, they were affected by constant failure of major components. Some of these failures were as a result of using substandard contractors to repair specialised components which needed the use of special equipment and testing before commissioning. The continuous replacement of these components made the maintenance personnel work extra hours without enough rest.

The high rate of drill rig breakdown pulled the maintenance personnel away from carrying out planned maintenance, a situation which created more breakdowns. Due to the increased number of breakdowns and the need for carrying out planned maintenance, the staffing levels were not adequate to cover both activities. Additionally, this condition led to fatigue of the maintenance personnel. Further, this situation had a negative impact on their performance, as such, concentration on the job became low with some employees resorting to absenteeism and claiming to be sick. Figure 6.1 diagrammatically illustrates the results of managing and not managing fatigue.

On the other hand, maintenance personnel indicated that they were demotivated as they were not entitled to any form of bonus scheme for the job they carried out. Further, they worked in difficult underground environmental conditions and at the same time working long hours without being recognised through some form of a financial incentive unlike their counterparts in other mines who they claimed were eligible to such financial incentives.

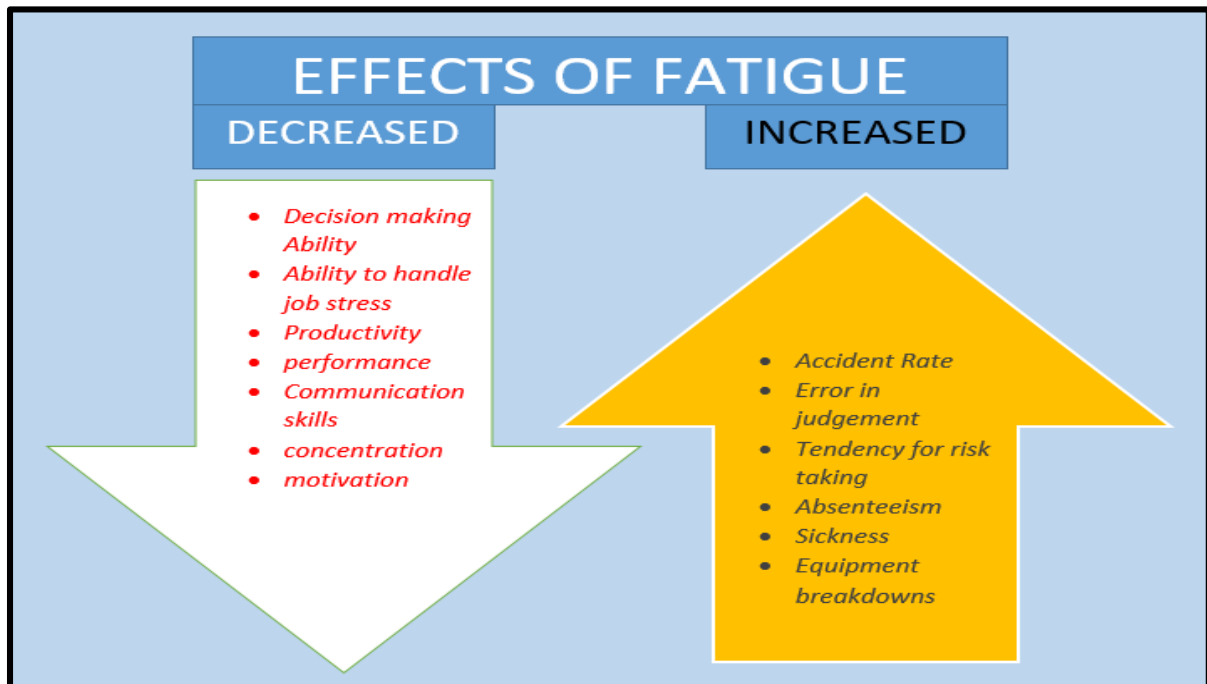


Figure 6.1: Impact of Fatigue on Employees **Source:** Author, 2019 (adopted from Lubambe Coppermine Mine Safety Awareness Sheet, 2018)

Figure 6.1 show that when an employee carries out his task under the condition of fatigue, such an employee is prone to accidents, develops poor judgement, resorts to absenteeism and pretending to be sick. On the other, conditions of controlled fatigue lead an employee to have good decision making ability, effective communication and concentrates on the job. This can motivate the employee to care for the equipment assigned to him.

In support of the data presented from this study, Pink (2011) explained that, throughout time, tangible rewards have been the most common way to motivate employees to perform. He further indicated that, it is important for managers to learn and understand what actually motivates employees and to respect those drives for the benefit of the

organisation. Further, Kerr (1975:769) claimed that pricing of performance leads to higher performance and productivity. Therefore, if personnel involved with the operation and maintenance of drill rigs are motivated through financial rewards, their performance could increase and subsequently improve productivity. Additionally, Sen (1977:317) commented that, a tangible reward that can crowd out intrinsic motivation is money. In the same vein, the drill operators who were in acting roles wanted confirmation in those roles and to be remunerated according to the company pay scale of drill rig operators. The maintenance personnel wanted recognition in form of money as an incentive for the harsh conditions they work in.

On the other hand, working long hours for both drill rig operators and maintenance personnel can cause fatigue which may result in lack of concentration on the job. Finally, the results of the study carried out by Mohammad (2011:149) concluded that human factors play an important role in the operation of the mine in supporting equipment maintenance practices. Additionally, the study found out that inadequate or inappropriate training programs for drill rig operators affected the motivation of operators and the end result was increased equipment breakdown due to vices such as negligence. The study also discovered that, unreliable equipment (numerous breakdowns) equally negatively impacted the motivation of drill rig operators who want to work, but hindered by the frequent equipment breakdown. The operators tended to lose confidence in the equipment and cared less for the machine.

Therefore, it was found out that it was important for management to understand and mitigate the actual causes of demotivation rather than looking at motivation in general in dealing with the causes that led to frequent drill rig breakdowns at LCM.

6.3 How Maintenance Factors Led to Increase in Drill Rig Breakdowns.

The results of this study show that non-availability and inadequacy of maintenance resources and non-adherence to OEM standards were some of the factors which contributed to drill rig breakdowns at LCM.

The inadequate number of maintenance personnel was equally highlighted through qualitative interviews by the key informants as a contributing factor to the numerous

drill rig breakdowns experienced at LCM. The maintenance personnel were continuously being assigned to breakdowns at the expense of preventive maintenance activities. This suggests that the mine did not have adequate human resource to undertake both preventive and breakdown maintenance. Further, the location of the workshop away from the worksites meant that the mine needed to have adequate transport and communication facilities. However, these facilities were not adequate. The obtained p value of 0.467 indicates that the responses given were not dependant on the position that the respondent held in the organisation. Therefore, the responses were not biased.

In terms of workshop facilities, out of 134 respondents, 28.4% (38 respondents) commented that the drill rig workshop facilities were not adequate to facilitate maintenance work as recommended by the OEM. While 71.6% (96 respondents) contended that the drill rig workshop facilities were adequate for maintaining and repairing drill rigs at the mine.

Most of the key informants indicated that the infrastructure was not adequate as there was only one workshop located on surface and that this condition made it difficult for the maintenance personnel to attend to breakdowns underground. Such a situation called for the machine to be tolled to surface or a person had to go to surface to collect equipment or tools. This was tedious and time consuming.

Further, the planning and scheduling of equipment was difficult due to the non-availability of an online enterprise maintenance system to assist in planning and scheduling of preventive maintenance work. Additionally, the mine had over ninety pieces of underground equipment which required to be maintained at specified intervals as per the OEM recommendations. However, these standards were not met due to lack of time as the maintenance personnel were in most cases attending to breakdowns. Further, out of the thirty five (35) key informants interviewed, 68.6% (20 key informants) explained that the maintenance practices were not followed and that the maintenance infrastructure was not adequate, while 31.4% (11 key informants) stated that the maintenance practices conformed to the OEM standards and that the infrastructure was adequate.

Additionally, if the maintenance system is not adequate, it may be difficult to develop a culture on which maintenance may be anchored. It is importance to develop a culture of accuracy where failure is avoided through precision, responsibility through the development of chapters in maintenance, combining maintenance with safety, emphasis on consequences, appropriate inspections, the use of approved check sheets and avoiding depending on memory, continuous training and following change in technology and giving feedback to occurrences.

Unger and Conway (1994:140) argued that, over the years, significant progress has been made in maintaining mining equipment from the worksite, however, this has been challenging due to the complexity of underground environmental conditions and safety of both personnel and equipment. Further, the study conducted by Mkemai (2011:149) stated that there are three types of workshops at Tulawaka Mine in Tanzania, the mine at which he conducted his study. The first workshop repaired development vehicles (drill rigs, scaling machines, concrete trucks, trucks, etc.). The second maintained LHDs, scaling machines and big boulder trucks. The third dealt with maintenance trucks, mining trucks, fire trucks and busses. Maintenance services from major services to small repairs, bearing and brake changing, transmission and motor changing were carried out in workshop two. The repair work included boom repair, bucket repair and equipment structural repair. This gave the maintenance personnel the flexibility to carry out planned maintenance and component replacement in line with the OEM schedules as they had adequate workshop space and storage facilities both underground and on surface.

Further, the study has discovered that maintenance infrastructure could go beyond the physical maintenance resources such as workshops to intangible infrastructure such as maintenance software which can support planning and scheduling of maintenance work. Inadequate enterprise resource planning systems can negatively affect planning and scheduling of equipment as a result of irregular maintenance intervals. Without such tools, accurate planning and scheduling of equipment for maintenance could be difficult and this can lead to equipment not being maintained as per the OEM recommendations.

6.4 How Environmental factors Influenced Drill Rig Breakdowns

Factors associated with environmental conditions in the drill rigs operation could be collectively termed as operating conditions. In this study, the operating conditions relate to the status of the roadways and worksites. Lack of proper maintenance of and mine design have been cited as one of the contributing factors to drill rig breakdowns at LCM and further, the results of this study show that 43.2% (58 respondents) attributed the drill rig breakdowns to the rough underground operating conditions, while 56.7% (76 respondents) believed that the worksite and roadway conditions did not contribute to the numerous drill rig breakdowns experienced at the mine. Some respondents also explained that, the steepness of the roadways made the driving conditions difficult leading to increased drill rig breakdowns. Additionally, poor ventilation in worksites created the high operating temperature which affected the operation of the equipment. As such, 95.0% (76 respondents) associated the drill rig breakdowns to dust, 2.5% (2 respondents) attributed the drill rig breakdowns to water within the operating sections and the other 2.5% (2 respondents) assumed that underground temperature contributed to the numerous drill rig breakdowns at LCM. Further, out of thirty five (35 key informants), 82.9% (29 key informants) indicated that the underground conditions contributed to the numerous drill rig breakdowns at the mine. However, 17.1% (6 key informants) stated that the underground operating conditions did not contribute to drill rig breakdowns at the mine. In general terms, the p value of 0.151 indicate that, the responses provided were not dependent on the position that the respondent held at the mine.

In support of the findings of this study, Hall (1997) sited that, in the mining industry, equipment such as underground mobile equipment is affected by various environmental conditions under which the equipment operates. These conditions include varying temperature, restricted access, poor lighting and ventilation. Additionally, Onwe and Abraham (2015:15) explained that the underground conditions are hot and noisy and that there is always a likelihood of fires and the possibility of ground fall and in addition, harmful gases and dust generated from drill rigs while drilling. Therefore, management of these conditions is imperative for the safely and healthy of employees and to keep the machines in good operating order.

It may therefore, be concluded that, the rough underground roadways are as a result of not having a committed roadway crew to maintain the roads and further, the study found out that the worksite areas were rough and waterlogged due to inappropriate mine design.

Finally, mitigating these basic factors can improve both the roadway and worksite conditions, hence, reducing equipment breakdowns.

6.5 How Supply Chain Factors Influenced Drill Rig Breakdowns

Supply Chain factors at LCM have also been identified as one factor contributing to the numerous drill rig breakdowns. The areas highlighted include, inventory management, quality management and procurement systems. A number of respondents explained that, the existing inventory management system at the mine was prone to stock-outs of key replacement parts. Stock outs arose from the long lead time and inappropriate reorder. Such stock-out lead to occasional use of alternative and refurbished parts which did not last as expected on the machine. Further, from the results of this study, 31.3% (42 respondents) alleged that Supply Chain factors and contributed to the frequent drill rig breakdown at LCM. This was attributed to the absence of a quality management system in the receiving and storage process. The quality of replacement parts was only judged based on the supplier's test certificates and how the part performed while in service. Further, the respondents alluded the numerous drill rig breakdowns to the use of wrong specifications in the procurement and inventory management process and this resulted in procuring wrong parts.

To the contrary, 68.7% (92 respondents) argued that Supply Chain factors did not contribute to the frequent drill rig breakdowns experienced at the mine. Further, storage of replacement parts was examined and the results of the investigation indicated that, out of 134 respondents, 84% (113 respondents) claimed the storage of replacement parts at LCM was good. Whereas 15.7% (21 respondents) alleged that the storage of parts at LCM was not good and caused certain major equipment components to fail prematurely while in service due to prolonged exposure to heat, moisture and dust before installation.

These results can be supported by the conclusion of the study conducted by Alberto (2012) where he stated that, companies have been looking at various ways of managing maintenance activities through successful warehouse operations. He further indicated that, the scope of warehouse operations in terms of size, location and type/number of equipment dictates whether the maintenance plan has its own in-house maintenance service or depends more on outsourced contracting. Regardless of the source of repair, two responsibilities of warehouse maintenance are to be achieved: safe and reliable operations of material handling equipment and maintenance of warehouse facilities, grounds, utilities, plumbing, heating, air conditioning, fire protection, security system and so on.

Though procuring and providing maintenance replacement parts to the maintenance personnel can be one of the most important function of the Supply Chain department, the study has found out that, it is important to have an inspection section within Supply Chain to inspect (accept/reject) the procured parts before releasing them to the end user. Additionally, it has also been noted from the study that though the quality of maintenance replacement parts can be good, the quality of these parts is likely to be reduced or distorted through transportation from supply to breakdown areas.

6.6: Conclusion

The chapter discussed, interpreted and described the significance of the findings in light of what was already known about the study problem investigated and explained new understanding or insights that emerged as a result of studying the problem. The findings from the data collected related to the research questions that were framed to guide the study. Additionally, the chapter analysed how human related factors, maintenance factors, environmental factors and Supply Chain factors contributed to the numerous drill rig breakdowns at the LCM. This chapter introduces chapter seven, the research findings which presents the data that formed the basis for investigation and the findings of the study based upon the methodology applied to gather information.

CHAPTER SEVEN

DISCUSSION OF THE FINDINGS

7.1 Introduction

This chapter presents the data that has been given meaning by the various forms of analyses that formed the basis of investigation and the findings of the study were based upon the methodology applied to collect information.

7.2 Findings

The main objective of the study was to identify the cause of the numerous drill rig breakdowns at Lubambe Copper Mine and thereafter, develop a framework that could be used to identify these causes. As such responses from the selected respondents helped in arriving at the study conclusion.

Therefore, the results of the study show that there were numerous related and unrelated causes that led to the numerous drill rig breakdowns at LCM. Further, based on the results from the study, these causes were broadly classified as human factors, environmental factors, maintenance factors and Supply Chain factors.

7.2.1 Human Factor

The study focused on determining how the relationship between the employees and the systems with which they interacted with could contribute to the numerous drill rig breakdowns. This was considered because human factors are concerned with application of what is known about human behaviour, abilities, limitations, and other characteristics to the design of systems, tasks/activities, environments, and equipment/technologies.

Further, the International Ergonomics Association (2010) defines human factor as the scientific discipline concerned with the understanding of interactions among humans and other components of a system, and the occupation that applies theory, principles, data, and other approaches to design in order to enhance human well-being and overall system performance.

While studies relating to human factors in the mining industry (Whiteley, 2002:68, Gagné and Deci, 2005:331; Callow, 2006:826; Arca and Prado, 2008:247) seem to agree with the prominent features of this study, other issues have been identified from the study which are different from the previous studies. The issues at LCM which affected employee performance include, employees acting in roles without confirmation, employee fatigue arising from carrying out duo roles, inappropriate drill rig operator training and development, low staffing levels and the use of inexperienced operators.

7.2.1.1 Motivation

One of the key human related factors which was identified as a cause of drill rig breakdowns at LCM is lack of motivation among drill rig operators and maintenance personnel. Broussard, Gredler and Garrison (2004:106), broadly defined motivation as the attribute that moves human beings to do or not to do something and Guay et al (2010:712) summarises motivation as the reason underlying behaviour.

Additionally, when employees are not motivated at a workplace, they tend to find ways of not reporting for work through such means as unexplained and repeated sick leave, this situation may be coupled with low levels of involvement or commitment to work. Repeated mistakes, negative behaviour and bad attitudes arise from demotivated employees.

Low levels of motivation was cited as the leading cause of drill rig breakdowns at Lubambe Copper Mine. The results of this study shows that most operator were demotivated by some human resource management practices which they deemed unfair. The respondents indicate that workers were subjected to working as drill rig operators on an acting capacity without being confirmed in these roles within the stipulated time. Such practices caused employees to feel that they were not recognised for their work and being deprived of opportunities for advancement and career growth. According to Herzberg (1976:53), recognition, advancement and growth are motivators in a work place which can lead to improved employee efficiency and job performance and further, Lussier (2005:12) advises that each time employee's performance is not up to the required level or above, management needs to determine which performance factor needs to be improved and improve it.

Other factors identified and linking to low motivation related to pay and the non-availability of a performance-based incentive schemes such as production bonus. Production bonuses were a common practice in rewarding employees in the mining industry. Herzberg (1976:53) classifies pay related issues as dissatisfiers whose absence can lead to job dissatisfaction. Arising from continued studies on motivation, Shadare et al (2009:10) stated that motivation increases the willingness of the workers to perform, thus increasing effectiveness of the organisation.

Since production bonuses were widely used in the mining industry, employees that did not receive such incentives could development a feeling of inequity regarding their compensation.

Therefore, when job performance is low as a result of lack of motivation, employees may neglect their equipment, a condition that can lead to high frequency of equipment breakdown. This finding is similar to a study conducted by Callow (2006:821) at a mine in South Africa where he suggested that low motivation leads to reduced equipment operator efficiency.

7.2.1.2 Fatigue

Most concepts of fatigue hinge on the understanding that energy exhaustion is the major cause of fatigue and the common understanding is that, fatigue is caused by the exhaustion of bodily and/or mental resources from carrying out work and is the direct result of doing work (Cameron 1973:713). Further, when the worker's concentration is low due to fatigue, the chances of inappropriate use of equipment are high and could lead to high equipment breakdown frequency.

Fatigue was cited as another cause leading to breakdowns of drill rigs at LCM. The results of this study show that a number of drill rig operators worked long hours due to the inadequate number of drill rig operators. Additionally, if one of the operators was sick then the one on shift was asked to work double shift to cover up the operator who did not turn up for work. As a result, the operators got fatigued and failed to concentrate on their work. This condition could lead to increased number of accidents and operator absenteeism, a condition that may further reduces the number of drill rig operators.

Further, the results of the study show that the mine had a large number of inexperienced operators who did not complete their tasks within the stipulated time

frame. Therefore, experienced operators were made to do extra work to cover for the lost time emanating from the use of inexperienced operators. As such, the experienced operators worked extended hours with inadequate rest periods. On the other hand, the inexperienced operators equally got exhausted due to repeated work in trying to correct the drilling mistakes. In addition, some experienced operators carried out duo roles, they worked as drill rig operators as well as supervising inexperienced drill rig operators. This made the experienced operators to rush in performing their duties.

This finding can be supported by the results from the study conducted by Cameron (2007:720) who concluded that problems of fatigue in industry can be overcome by the application of human factors philosophies to the full range of human factor problems in industry, and by the application of appropriate work-rest cycles for several kinds of work.

On the other hand, Rabinbach (1990:3) stated that, the relation between fatigue and energy depletion gives rise to the extensive assumption that fatigue is as a result of direct effect of long continuous periods of work. Further, Cutsen et al (2017:1), explained that mental fatigue is a psychological state caused by protracted periods of demanding cognitive activity and that it has been suggested that mental fatigue can affect physical performance.

7.2.1.3 Operator Training and Development

The other factor cited as a cause of the numerous drill rig breakdowns at LCM is the nature of operator training and development program. The results of this study show that, despite the training for the drill rig operators being regarded as adequate, there are nevertheless some important aspects of training that were neglected. The scope of the operators' training did not cover most of the functionalities of the machine and this made operators to have difficulties in their early stages of operating the machine as they managed some machine operations through trial and error methods. The drill rig training program was more focussed on the safety aspect of the machine rather than the primary operation of the equipment and the actual drilling process. This indicates that most operators lacked basic technical knowledge which could help them identify faults or failure indicators. Further, no training audits were undertaken to assess the effectiveness of the training in actual job performance of the operators.

The quality of training was also low as the mine did not have specialised trainers. Additionally, the number of the available trainers was not adequate, a condition which made trainers rush through the training programme. As such, the poor quality of training can lead to low motivation and reduced job performance among operators. In line with the above narration, Kuhn (2012) said, research has shown that training and motivation have a positive impact on performance of employees and that when job performance is low as a result of lack of motivation caused by inappropriate training, employees wrongfully operate their equipment. This condition may lead to high frequency of breakdown. This finding is similar to the results of the study conducted by Haskel and Hawkes (2003) who commented that higher qualifications for both equipment operators and maintenance personnel are necessary for the efficient management of equipment and on the other hand, Mohammad (2011:149) argued that training of operating and maintenance personnel is key to reducing equipment breakdowns through proper identification and resolution of equipment faults. Figure 7.1 shows how human factors were perceived to have contributed to the numerous drill rig breakdowns at LCM.

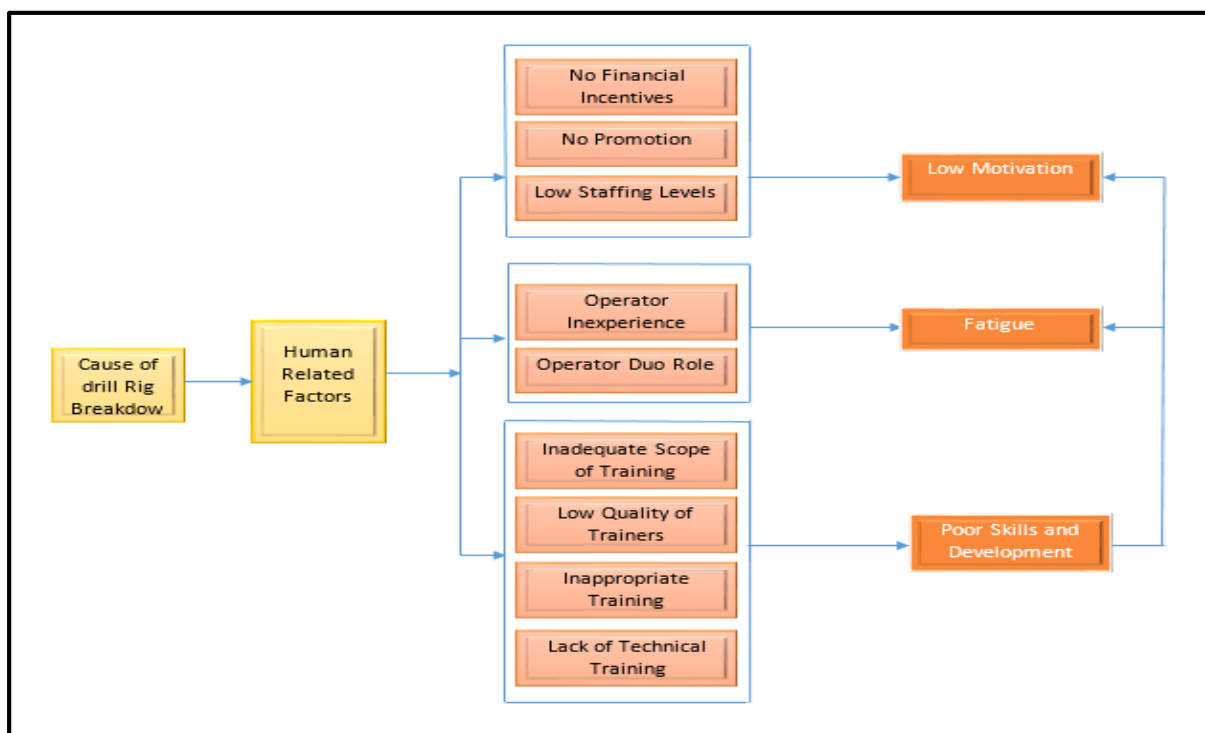


Figure 7.1: Human Factors Causes of Drill Rig Breakdowns **Source:** Author, 2019

From this section, it has been noted that human factors can contribute to the numerous breakdowns of drill rigs at LCM. Human factors influence the performance of drill rig

operators through different behaviours such as satisfaction or dissatisfaction exhibited by employees in responding or reacting to equipment they are deployed to work on. To further stress the findings of this study, Habtoor (2016:460) remarked that, human factors have a great influence on quality improvement practices as well as organisational performance and that human factors indirectly and significantly influence organisational performance.

7.2.2 Environmental Factors

Underground environmental conditions have been cited from the study results as one of the causes of drill rig breakdowns at Lubambe Copper Mine. Shu et al (2015:236) stated that underground mines are one of the most challenging environments for operators and their equipment. He however, ascertained that, aside from the environment in which machines operate, almost all of these factors can be managed and improved to lower breakdowns and consequently, cost per ton.

In this study, operating conditions are considered as the nature of underground work site in which equipment and personnel work. Therefore, the hush underground conditions if not corrected to meet the legal requirement could lead to equipment breakdown. Water and dust affect both electrical and mechanical components of the machine, thereby reducing the life span of these components. Further, heat if not controlled is yet another factor that can affect equipment parts and disable the machine. In support of this, Hall (1997) contended that, in the mining industry, specialised equipment, more especially mobile equipment is affected by various environmental factors under which the equipment operate.

The study results show that the causes of drill rig breakdowns relating to the operating environment were attributed to the state of the roadways and worksites. Roadways included the routes that the drill rigs travelled on to and from their allocated worksites. Therefore, their condition had the potential to increase the frequency of equipment breakdown. The factors that were identified from the results of the study regarding the state of the roads included being steep, water logged and having a rough terrain. Road steepness was a mine design issue while the roughness of the road terrain and being water logged were caused by lack of maintenance. In steep slopes, drill rig operators faced difficulties in negotiate the incline, and this struggle led to severe damage to the

machine drive system. This problem was compounded when the road terrain was rough and water logged.

Similarly, rough terrains and collection of large amounts of water in the main operating areas were one of the major contributors to machine breakdowns in the worksites. Additionally, the high temperatures in the worksites led to increase in the frequency of drill rig breakdown. Poor ventilation is believed to cause high temperature in underground work places. This condition causes overheating of drill rig engines which results in failure of such components. Reeds (2019:3) stressed the importance of guidelines for ventilation design. These guidelines he said include recommended airway velocities, minimum volumes of air for a split, and the optimum amounts of intake air that should reach the worksite. Therefore, a ventilation system can be adequate in reducing temperature if recommended guidelines are followed.

These findings can be supported by Thornburg (2016) who indicated that, operating a drill rig in harsh environmental conditions can cause frequent breakdown of machines and associated subsystems. Barabady and Kumar (2008:647) implied that the performance of mining machines does not only depend on the reliability of the equipment, but also the environmental conditions where the equipment operate. Further, Sahu (2015:237) commented that proper design and maintenance of the roadways plays a significant role in reducing the breakdown frequency of equipment and thereby increasing production and productivity in a mine. The results of the study are further supported by the results of the study conducted by Ray and Euler (2017:651) which concluded that, environmental conditions such as temperature are required to be maintained within acceptable parameters in the mine working environment to minimise stress on equipment and personnel. Figure 7.2 shows how environmental factors were alleged to cause equipment breakdown at LCM.

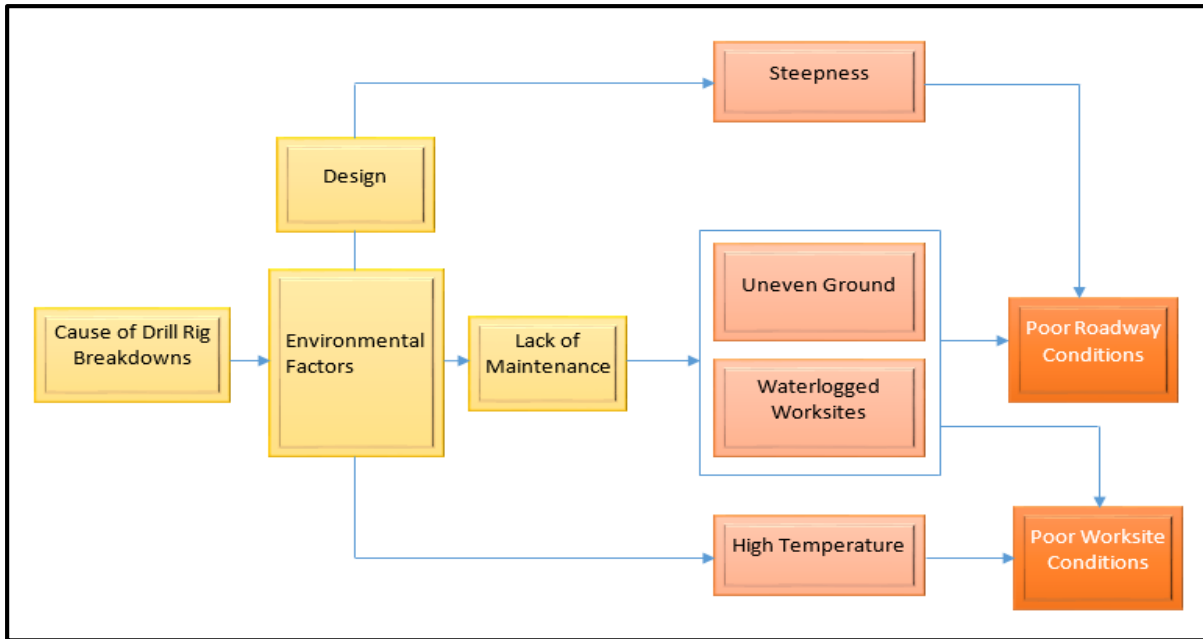


Figure 7.2: Operating Conditions

Source: Author, 2019

In summary, the results of the data analysed indicate that environmental conditions contributed to equipment breakdowns at the mine. Further, the National Research Council (2002:28) stated that underground environmental conditions are a challenge for underground mines and that it is necessary to control levels of such elements as temperature and pollutants both of which have a negative impact on the health of personnel and equipment.

7.2.3 Maintenance Factors

A number of writers on maintenance theories maintain that maintenance consists of two main components, preventive and corrective maintenance. Additionally, Li et al (2015:220) comments that maintenance practices can be put into two major groups, namely Preventive Maintenance and Corrective Maintenance.

In this study, maintenance practices were considered as a set of activities developed to ensure proper running of equipment. This further meant ensuring that technical involvement was taken at the right opportunities with the right scope and in accordance with good technical systems and legal requirements, in order to avoid loss of functionality or reduction of efficiency and. As such, should any of these occur, ensure that they were reverted to good operating conditions at the quickest possible delay, all at an optimised total cost and within the confines of safe working practices.

Though from the results of the study, maintenance factors were not cited as the major cause of drill rig breakdown at the mine, the results of this study indicate that the number of maintenance personnel was not adequate and this resulted into some maintenance schedules being postponed or omitted all together. Further, the maintenance section did not have a reliability section for analysing equipment failures and making recommendation on the failure mode. This task was carried out by the maintenance technicians and engineers, however, this task was usually rushed with wrong results or not done altogether as the technicians and engineers were usually busy attending to breakdowns to ensure equipment was repaired in time for production. Additionally, Niklin (2013:93) indicated that failure causes of production systems need to be identified for effective solutions and root-cause failure analysis is used to identify the failure causes.

Inadequate maintenance practices can lead to high frequency of breakdown as the maintenance conducted on the machine may not be adequate enough to prevent breakdowns of the equipment. This finding is similar to the results of the study conducted by Barabady and Kumar (2008:647) which concluded that, the performance of mining machines depends on such aspects as the reliability of the equipment used, the operating environment, the maintenance efficiency, the operation process and the technical expertise of the miners. Further it is important to develop a culture of accuracy where maintenance may be improved and sustained through precision, responsibility through the development of chapters in maintenance, combining maintenance with safety, emphasis on consequences, appropriate inspections, the use of approved check sheets and avoiding depending on memory, continuous training and following change in technology, failure analysis of failed parts and giving feedback to occurrences.

Additionally, the maintenance personnel did not have adequate transport to get to breakdown sites in time and had to walk to attend to the broken down equipment. The facilities in which the maintenance activities were designated to be undertaken were also inadequate. The mine only had one maintenance workshop which was located away from the drill rig operating areas. This workshop was located on surface and either drill rigs or replacement parts had to be moved across some distances to where maintenance was to be carried out. The size of the workshop was also small for most

comprehensive maintenance operations such as component change out which required more time and space. The non-availability of a maintenance program (Enterprise Recourse Planning) made it difficult for the maintenance personnel to plan and schedule work. Therefore, the tracking of the life circle of equipment and components was through Excel spread sheets which had neither maintenance triggers nor automatic check sheets generation capabilities. Figure 7.3 shows how maintenance factors contributed to drill rig breakdown at LCM.

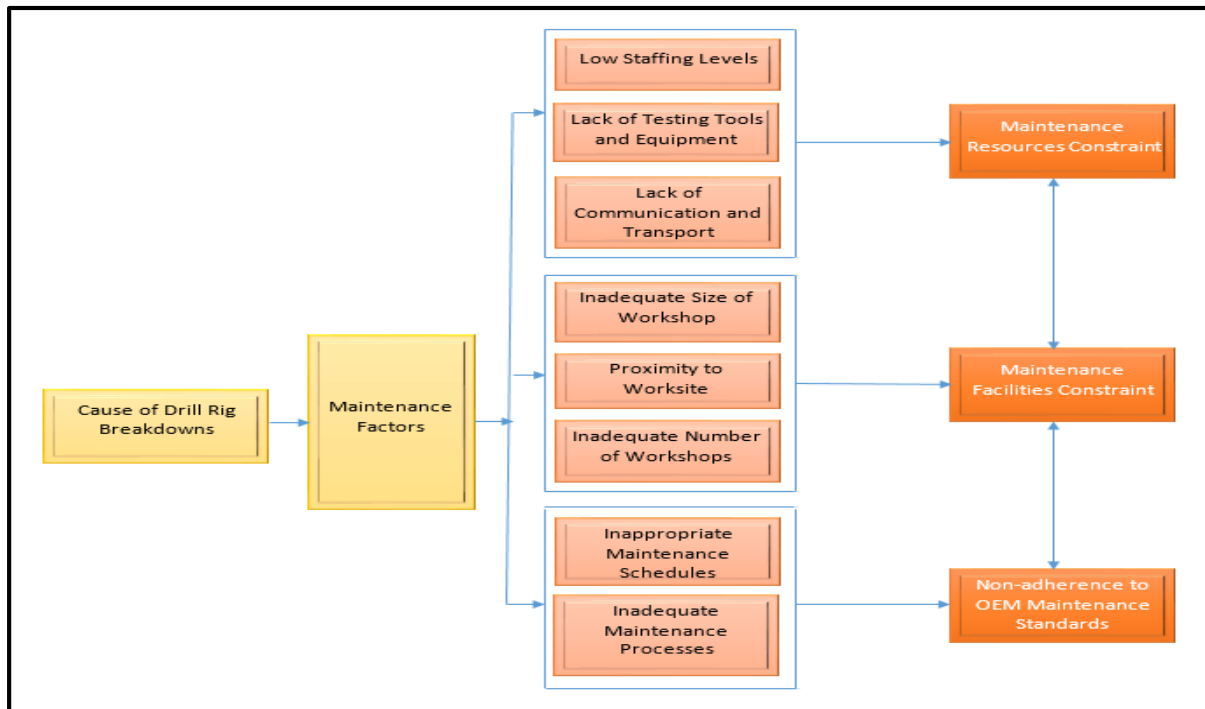


Figure 7.3: Maintenance Practices and Infrastructure **Source:** Author, 2019

In summary, this section has indicated that the maintenance factors contributed to the numerous drill rig breakdowns experienced at LCM. The mine maintenance personnel did not carry out certain functions in line with the OEM recommendation as they did not have facilities such maintenance programs, testing equipment, special tools for specialised tasks and the physical infrastructure (workshop) was not adequate to facilitate tasks such as component change out which was recommended by the OEM. The non-adherence to the OEM standards led to performing substandard maintenance work which resulted into equipment failing to perform as intended. To support this observation, Bevilacqua and Braglia (2000:71) explained that there is need to have proper maintenance strategies to monitor, manage and optimise equipment utilisation and eventually maximising productivity. Further, they stated that maintenance

managers are expected to adopt the best maintenance practices from several maintenance strategies and finally Parida et al (2015:2) hinted that maintenance strategies provide important support for heavy and capital intensive industries by keeping the productivity performance of plants and machines in a reliable and safe condition.

7.2.4 Supply Chain Factors

Supply Chain is linked to the quality of parts since it is responsible for the procurement of parts for the mine. Supply Chain is a classification of (decision making and execution) methods and (material, information and money) flows that aim to achieve optimal customer requirements and takes place within and between different Supply Chain phases. The Supply Chain not only include the manufacturer and its suppliers, but also (depending on the logistics flows) transporters, warehouses, retailers, and consumers themselves. It includes, but is not restricted to, new product development, marketing, operations, distribution, finance, and customer service (Chopra and Meindl, 2001).

Though from the results of the study, Supply Chain did not significantly contribute to the drill rig breakdowns at Lubambe Copper Mine, respondents advanced significant observations on Supply Chain. The supply department had an online material issuing and monitoring system to ensure quick and accurate provision of materials to user department, however, in some cases the items took long to be issued because of the user department delays in submitting requests (raising of requisitions in the system) and in certain situations, part numbers did not match the item required. Further, the system did not trigger the reorder level and this contributed to stock outs of major maintenance parts. Additionally, the supply department did not have a quality assurance section and depended on supplier's test certificates and visual inspection by user departments to ascertain the integrity of received components or parts.

In addition, the mine has adequate storage facilities for the small and medium items, however, bigger items are stored in open space subjected to water and dust. Though the store yards for storing bigger components may be adequately fenced, they are not provided with roofing or band walls to prevent moisture and dust.

The results of this study are in line with the conclusion made by Paz and Leigh, (1994:47) who established that the shortage of supplies directly or indirectly affect

productivity and tend to make maintenance scheduling a dynamic and challenging process. Poor or inadequate maintenance scheduling leads to frequent equipment breakdowns. Additionally, Vliegen (2009) and Kumar et al (2000) indicated that, the performance of a spare parts supply chain with respect to maintenance processes is generally measured by numerous performance indicators such as, total predictable number of backorders, the percentage of part requests which can be met immediately (fill-rate) and the waiting time for an arbitrary request for a part. The delay in the supply of maintenance parts resulted into extended downtime and the over use of certain parts beyond the operating life cycle, a situation which led to unexpected failure of components.

7.2.4.1 Quality of Spare Parts

Quality has been defined differently by various writers. Although the term quality is quite widely used by practitioners and academics, there is no generally agreed definition of it since different definitions of quality are appropriate under different circumstances (Seawright and Young, 1996:107; Russell and Miles, 1998:13; Sebastianelli and Tamimi, 2002:442).

Although the results of the study indicate that the quality of parts did not have a major impact on equipment breakdown at Lubambe Copper Mine, some respondents expressed important views on the quality of parts used on drill rigs. The factors that were identified as having an effect on the quality of replacement parts relate to procurement, storage and compliance to EOM installation standards.

In procurement, the failure to conform to EOM product specifications and the sourcing of substitute parts can affect the quality of replacement parts. During delivery of parts, the absence of testing equipment used for inspecting parts on receipt can also lead to accepting and subsequent using substandard replacement parts. The maintenance personnel only visually inspected replacement parts that were delivered to stores because there was no equipment available on the mine site for testing the quality of parts or components. All major parts delivered to stores were accepted on the basis of the contractor's test certificates, therefore, in an event of premature failure, the mine only claimed compensation through warranty if a component failed within the warranty period (appendix 9). The quality of refurbished components by the local contractors was not up to the OEM standard. Most of the contractors did not have testing

equipment. On the other hand, the mine did not have a quality assurance department to verify the quality of the refurbished part. This condition resulted into accepting and storing parts which did not meet the correct specifications. The use of such parts on equipment led to premature failure hence, increasing the frequency of machine breakdown.

The storage and transportation of parts can also affect quality. Though the storage facilities were available in stores, the number of closed cabinets for storing sensitive items such as bearings was not adequate. Additionally, some big and heavy components were kept outside, exposed to dust and water. Other parts were stored in areas which were difficult to access and this led to damaging the parts during handling. Further, parts were delivered from stores to underground in open vehicles, thus, leaving these items exposed to contamination from water or dust. In some instances, these parts got damaged while in transit either to the workshop or underground. Some replacement parts which were subjected to moisture and dust did not complete the life cycle when put into operation and this contributed to the poor quality of parts used on machines.

Compliance with OEM installation standards is also important in safeguarding the quality of replacement parts. If the parts used on drill rigs do not conform to the OEM standards, the performance of such parts may not perform as expected and this situation may result into a high rate of equipment breakdown. Similarly, the conditions in which maintenance is carried out can affect the quality of maintenance parts.

The results of this study therefore, are supported by the findings from the study conducted by Fourie (2009:275) in South Africa which found out that, to improve the reliability of equipment and reduce breakdowns, the quality of maintenance and maintenance parts is key. In mechanised mining, inappropriate maintenance practices emanating from the use of substandard replacement parts and incorrect installation procedures may result into reduced machine efficiency (availability, utilisation, productivity, and quality) which can subsequently endanger the success of the mining operation (Fourie 2009:275). Another study conducted by Al-Chalabi (2014:306) established that there is need to improve quality of critical components in order to reduce down time of drill rigs. Figure 7.4 shows how supply factors can lead to machine breakdown.

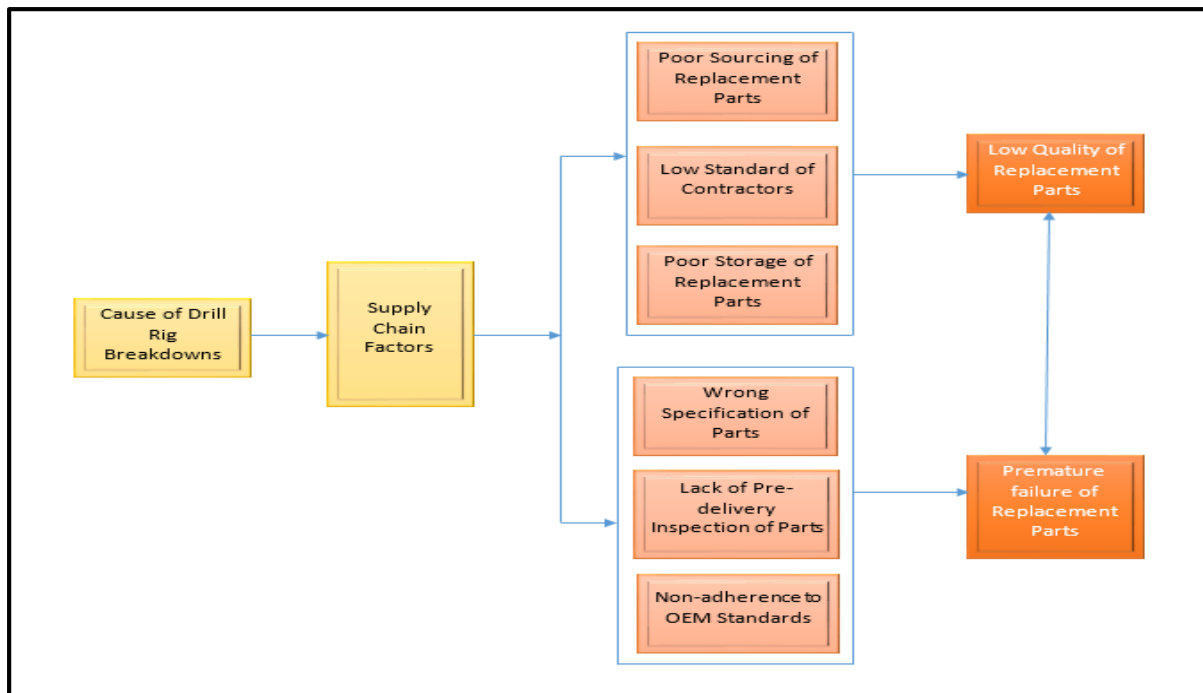


Figure 7.4: Supply Chain and Quality factors

Source: Author, 2019

In summary, this section has indicated that Supply Chain factors can affect the performance of equipment leading to numerous equipment breakdown. It has further been noted that the mine did not have tools for testing the items delivered to the mine by suppliers a condition which led to accepting replacement parts of inferior standard. Additionally, the inadequate storage facilities resulted into exposing parts to moisture and dust.

The result of the study carried out by Carr and Paarson (1999:497) indicated that Supplier quality management is a set of activities in most cases initiated by the management to improve organisational performance. They further commented that such activities include measuring and tracking the cost of supplier quality, using performance based score cards to measure supplier performance, conducting supplier audits and establishing effective communication channels with suppliers among many more, with an aim of achieving customer satisfaction. Further, Paul et al (2008:238) concluded that measuring supplier performance is an important means of modifying managerial behaviour, and aligning the relationship with the strategic and operational goals of the buyer firm. In emphasising the importance of conformance to standards, Kaplan and Norton (1992:71) advises that it is important to alert and educate the suppliers on the importance of observing dimensions of performance and to direct improvement activities by identifying deviations from standards.

The section also notes that supplier selection is critical as certain suppliers may not meet the required or acceptable OEM standards requirements. Parts supplied by such suppliers may fail prematurely increasing the number of equipment breakdown and resulting into reduced productivity.

7.3 Framework for Identifying Drill Rig Breakdowns

The study began by identifying the broad spectrum of the problem and then further narrowed down to different study variables. This was made possible by first studying the literature review and later finding the gap in the literature. Therefore, a framework for identifying the potential causes of drill rig breakdowns at LCM was developed by linking the gaps identified in the literature review to the variables identified in the study through questionnaires, interviews, document review, and observations and from the various theories studied.

Tariq (2015:4) claimed that science is founded on several different pillars that combine to offer the methods of reasoning, logic, and ethics to conduct a study. As such, based on the research methods, the basis of all research is scientific reasoning. Additionally, science is grounded on experiments, and it involves variables to conduct any experiment and find out the results. The variables, therefore, play a significant role in a research study than the experiment itself. Further, the variables chosen must be related to the theoretical framework supporting the study and that variable must be used in a controlled way, it is not only about measuring it, but can be manipulated according to different research criteria.

The proposed framework for identifying drill rig breakdown is driven from the investigation of the variables that are believed to cause drill rig breakdowns at LCM. This framework may assist management in finding solutions to minimise the frequent drill rig breakdowns and in line with this theory, Zait (2016:117) commented that exploratory researches tend to identify clues and tries to obtain a better picture of the study variables and their relationships. Further, she explains that, variables identified in studies can lead to new explorations and theories. As such this study proposes a framework that could help the mine decision maker identify potential causes of drill rig breakdowns and make proactive strategies to prevent breakdowns. Figure 7.5 presents a network diagram of the framework.

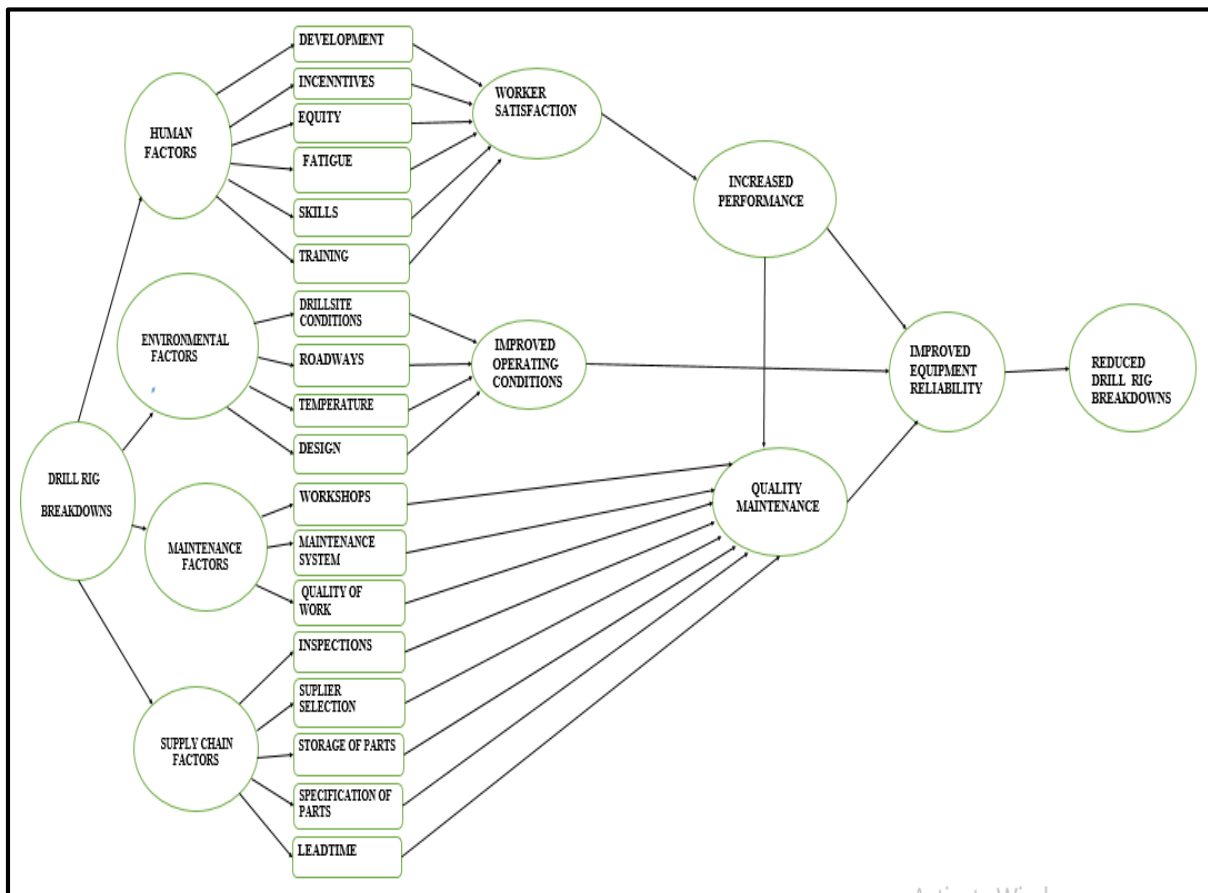


Figure 7.5: Drill Rig Breakdown Framework

Source: Author, 2019

7.3.1 Operationalisation of the Framework

The proposed drill rig breakdown framework follows the main dimensions of the analytical framework, addressing the human factor, environmental factors, maintenance factors and Supply Chain factors which may be referred to as the aggregate variables. This is further followed by identifying the second order variables and describing how they affect the aggregate variables. Thereafter, proposing measures or strategies to mitigate their impact which could subsequently lead to reduced drill breakdowns.

7.3.1.1 Human Factors

Human factor related causes have been identified in the study as the major dynamics contributing to the frequent drill rig breakdowns at the mine. The major areas highlighted within the human factor comprise employ training and development, the issue of incentives, equity within the work place, skills and workplace fatigue. As such, addressing these concerns could help reduce the impact of the human factor on drill rig breakdowns.

Most of the drill rig operators are assigned acting roles without being confirmed within the stipulated time. This action demotivates the operators and develop an attitude of not caring for the equipment they are assigned to work with. However, this condition can be alleviated by ensuring that each acting role is acknowledged by human resources personnel and documented with the acting period and allowances clearly defined. Further, the training department should formulate a training request form that the requesting department should complete and signed by senior officials and thereafter, the document may be sent to the Human Resources Department for final approval, filling and follow-up. This will create transparency and instil confidence in the operators.

Further, incorporating an incentive scheme into the annual budget and reviewing it each year could motivate both the drill rig operators and maintenance personnel. This could equally be coupled with a benchmarking process which may be conducted within the Zambian mines to compare the conditions of employment. The results of such benchmarking audits could be given to management before the final approval of the budget for consideration. This may help management adjust the incentives in line with other mines within the country as the underground conditions are similar in most Zambian mines.

The training of drill rig operators needs to be revised so that the programme encompasses all aspects that are required for accurate and effective drilling. This should include selecting the drill rig operators on merit and avoid favouritism or other backhand methods. To enhance the skills of the drill rig operators, performance audits should be conducted on drill rig operators after completing their training in order to identify and address the gaps in performance. Additionally, the issue of fatigue for the drill rig operators can be alleviated by carrying out a job analysis to arrive at the optimal number of qualified and competent operators. This action could equally relieve the experienced operators from carrying out more than one role and availing them ample time to rest.

Addressing the above issues adequately could lead to worker satisfaction and subsequently increased performance. However, this requires concerted effort from all levels of management.

7.3.1.2 Environmental Factors

Environmental factors have also been cited as one aspect which contributes to the numerous drill rig breakdowns experienced at LCM. Improving the condition of roadways by introducing a maintenance team to maintain the roads could reduce machine breakdowns associated with equipment components such as the drivetrain. To ensure effectiveness, the road maintenance team have its own management and not to operate under the production section. This is to avoid divided attention where production could take preference and side-line the road maintenance task. Running dewatering pipes through raise boreholes (drilled holes) away from the decline (roadway) could equally minimise damage to the roadways because no water could run along the decline in an event of a pipe burst. This initiative could also keep the pipes away from damage from mobile equipment. Where possible, drilling of drain holes in operating areas should be encouraged as this could help drain the stagnant water from operating areas. Water contributes to premature failure of tyres, axles and electrical components or systems among others.

The mine design is one aspect which must be looked at by the mining department. The incline of roadways must be observed to ensure that steep inclines are avoided as these pose a great challenge to mobile equipment. Ventilation into working areas must be adequate to ensure that temperatures are within acceptable limits as stipulated by the Mine Safety Department. This is for the safety and health of both equipment and personnel.

Once the operating conditions are improved, the damage to equipment could be minimised resulting into equipment increased effective operating time and further leading to improved productivity. This condition could also give the maintenance personnel time to plan and carry out planned preventive maintenance with less interruptions to the plan.

7.3.1.3 Maintenance Factors

Maintenance factors have also been identified as one aspect that can contribute to the numerous drill rig breakdowns at LCM. These factors arise as a result of a scarcity of workshop infrastructure, inappropriate maintenance systems, poor quality of maintenance and maintenance parts. However, these aspects can be mitigated

through purchasing a maintenance system which supports both planning and scheduling of work. There are a number of such enterprise resource planning tools such as DELTA or PRONTO systems which are widely used by several mining companies within the country.

Further, there is also need for the mine to construct at least one underground workshop for carrying out drill rig maintenance and repair work. This move could free the surface workshop for other machines and major component replacements tasks. It is important to fit the workshop with facilities such as testing equipment (e.g. dynamometers), oil and diesel dispensing facilities, battery charging units, air compressors for inflating tyres and an overhead crane to name a few.

Additionally, to minimise the mean time to repair, the maintenance personnel should be provided with recovery vehicles fitted with shelves for carrying tools and other forms of equipment such as chain blocks and slings. The purchase of testing equipment could equally minimise the frequency of rework by testing all components before installation. This should allow the maintenance personnel to reject parts that may not meet the OEM minimum standards and prevent unplanned downtime arising from premature failure of components.

On the other hand, to ensure effective labour utilisation, a job analysis/design should be conducted to ensure that the correct number of personnel is made available to the department to cater for both breakdowns and planned preventive maintenance work.

The availability of the above requirement could lead to effectiveness in maintenance of drill rigs and subsequently leading to improved equipment reliability.

7.3.1.4 Supply Chain Factors

Supply Chain is yet another area that contributes to the numerous drill rig breakdowns at the mine and the major issues identified in the study are storage of parts, lack of an inspection system, extended lead-time, supplier selection and inadequacies in specification of parts to be procured. However, mitigating these issue could help in reducing drill rig breakdowns at the mine.

The Supply Chain department can improve the storage of replacement parts by providing shelter for bigger items kept outside and improving transportation facilities for parts in transit from stores to the end-user.

Inspection of procured maintenance replacement parts should be enhanced through the use of correct measuring and testing equipment. It is therefore important to introduce a separate inspection or reliability section within the Supply Chain department to inspect and approve or disapprove the received items. This initiative could support the maintenance department in that the parts used on equipment could be of a required quality. There is also need to ensure that suppliers of critical items are selected on merit and this can be facilitated by carrying out vendor audits for physical structures, skills and competency.

Before ordering any item, specifications must be fully reviewed by the end users and the parts catalogue must equally be audited at specified interval by the maintenance personnel to ensure that all the specifications carried in the parts catalogue conform to the OEM specifications.

The other item that leads to the maintenance personnel either prolong the use of a component on a machine or use alternative parts is the long lead-time of certain parts. The Supply Chain department needs an enterprise resource system that is capable of flagging the minimum level of parts carried in stores. The other way to achieve this shortfall is for the maintenance personnel to provide the Supply Chain department with parts requirement projection information to help in timing the procurement of such parts.

Finally, the use of the proposed framework can generate worker satisfaction, improved environmental conditions and improved quality of maintenance, all of which if planned and executed accordingly could lead to improved equipment reliability and subsequently reduced number of drill rig breakdowns.

7.4 Conclusion

The chapter investigated the findings from the data presented. The results of this study show that there were numerous related and unrelated factors that led to breakdown of

drill rigs at the mine. Based on the results from the study, these factors were broadly classified as human factors, environmental factors, maintenance factors and Supply Chain factors and from an investigation of these factors, a framework for identifying drill rig breakdowns has been proposed. Further, the chapter sets out a platform for chapter eight, the conclusion and recommendations which includes the practical and the theoretical recommendation as well as the study limitations and areas of further studies.

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATIONS

8.1 Introduction

The main aim of this chapter is to present the conclusions drawn from the results of the analysis of the questionnaires, interviews and then make research limitations, implications and recommendations for further research. Phillips and Pugh (1994: 59-60), pointed out that in general terms, the final chapter discusses why and in what way the theory one starts with may be different from the final result obtained from the research work.

8.2 Conclusion

The main objective of this study was to explore the causes of drill rig breakdowns at Lubambe Copper Mine and thereafter develop a framework for identifying the potential causes of breakdowns. Therefore, the study sought to investigate and evaluate how human factors, maintenance factors, environmental factors and Supply Chain factors contributed to drill rig breakdowns at Lubambe Copper Mine.

The most important finding to emerge from this study is that, human factors contributed significantly to the numerous drill rig breakdown at LCM. The elements of human factor that contributed to these breakdowns at the mine included lack of motivation, high levels of fatigue among operators and maintenance personnel, and the low skill levels of operators arising from inappropriate training and development program implemented at the mine.

The low motivation among operators and maintenance personnel is attributed to certain poor human resource management practices at Lubambe Copper Mine. The other cause of low motivation is the use of employees without confirming them in their acting roles. This finding answers the gaps that are in literature such as the reason why drill rig operators have low motivation at work. Further, another cause of low motivation was identified as the alleged absence of a financial incentive (production bonus) scheme at the mine. Since production bonuses are common in the mining industry, operators consider the reward system as inequitable. Additionally, the low

staffing levels of operators and maintenance personnel entails that the employees work extended hours without much rest.

Finally, though Bruno and Raymond (2010) established causes of drill rig breakdowns among others as hose burst, overheating, shank adapter breaking, drilling rods getting stuck in holes, rod breaking, drill rod breakage, poor flushing, low percussion and rotation pressure, drill chain breakage and truck removal and breakage. This study has found out that aspects such as low motivation can result into negligence leading to equipment failure.

Further, the other aspect coming out prominently as a contributing factor to the numerous drill rig breakdowns at LCM is the environmental factor. Lack of maintenance of the roadways and worksites as well as inappropriate mine design contributed significantly to the drill rig breakdowns experienced at the mine. The operating areas were waterlogged with rough terrains. Additionally, certain sections of the roadways were steep making it difficult for the drill rigs to negotiate the incline. Other areas of the mine were hot as the air flow was low and this condition led to drill rig engines overheating and subsequently failing. Further, this finding answers the gaps that are in literature such as whether environmental factors contributed to the numerous drill rig breakdowns at Lubambe Copper Mine.

With reference to the literature review, though Barabady and Kumar (2008) indicated that the performance of mining machines depends on the reliability of the equipment used, the operating environment, the maintenance efficiency, the operation process and the technical expertise of the miners, this study has found out that lack of roadway maintenance and inappropriate mine design can lead to drill rig breakdowns.

The other factors identified as a causes of drill rig breakdowns in this study relate to equipment maintenance. The aspects that were identified in this area included, the non-availability and inadequacy of maintenance resources as well as non-adherence to OEM standards. This resulted from the non-availability of an Enter Price Resource Planning system, lack of test equipment for verifying the integrity of replacement parts before they are fitted on the machine, having only one workshop on surface and having none underground. Other issues included, lack of transport for the maintenance personnel and the low staffing levels. The impact of these factors is that maintenance is not carried out according to the OEM recommendations.

Though Haskel and Hawkes (2003) concluded that higher qualifications and skills for both equipment operators and maintenance personnel are necessary for the efficient management of underground equipment, this study has discovered that intangible maintenance infrastructure such as automated planning and scheduling network tools are necessary for accurate and effective maintenance of equipment and their absence or inadequacy can result into poor equipment maintenance and subsequently contributing to equipment breakdown at the mine.

The other factor coming out prominently from this study as a contributing factor to drill rig breakdowns at LCM, though not a major contributing factor, is Supply Chain. The first item is inventory management, stock outs of most key replacement parts arose as the supply system did not have a minimum level flagging software to alert the buyer when the stock level was approaching minimum. This condition lead the maintenance personnel to use alternative spares while waiting for the original parts. The alternative parts did not last as expected on the equipment and their failure contributed to the numerous drill rig breakdowns experienced at the mine. As there were no reference checks on the suppliers and other contractors, the procurement process ended up selecting suppliers and contractors who could not meet their delivery obligations and the parts supplied did not meet the OEM specifications.

Additionally, the OEM specifications were not adhered to in certain instances and this led to purchasing of wrong parts which either failed to fit where intended or broke down after installation. The absence of quality assurance checks on receipt of items in stores indicated that the quality of incoming spare parts was not guaranteed. As such, the quality of replacement parts received was determined through supplier's test certificates and how well the part performed while in service. Finally, the conditions of the storage space for parts was unsuitable and inadequate. The Supply section had no proper shelter, leaving some large components exposed to water and dust. Further, storage facilities in certain areas were not easily accessible, leading to possible damage when retrieving the components.

8.3 Recommendations

This study was based on a detailed analysis of Lubambe Copper Mine in search of the causes of drill rig breakdown based on the operational practices in the mine and using

theoretical analysis. Therefore, the findings of the study have implications for both theory and practice.

8.3.1 Practical Recommendations

The practical recommendations relate to how Lubambe Copper Mine management can address the identified causes of drill rig breakdowns. This study has shown how job-related attitudes exhibited by employees can cause breakdown of machines that employees use. It has therefore, highlighted on the importance of creating a conducive working environment for employees tasked with operating sensitive and expensive equipment in the organisation. As such, rather than just caring so much about the high value equipment such as drill rigs, management needs to be sensitive to the needs of employees as well.

This study therefore, recommends that management at Lubambe Copper Mine should develop measures to monitor and reduce the feelings of inequity perceived by employees in their compensation schemes. Specifically, employees have been demotivated by the absence of a production-based bonus, which has been alleged to have been implemented even by some contractors doing similar work at Lubambe Copper Mine. Such a system can cause employees to care more about the reliability of the equipment, while at the same time increasing their earnings. Similarly, promoting drill rig operators in their substantive roles in good time can instill a sense of ownership towards the equipment and career progression.

The identified causes of fatigue at Lubambe Copper Mine were low staffing levels, and the assigning of more than one role to the experienced drill rig operators. Such problems arise in the organisation when job analysis has not been properly undertaken and can lead to high employee fatigue which ultimately result in low motivation among employees. Therefore, management must ensure that the right quantity and quality of drill rig operators is determined and engaged to avoid employees working extra hours and carrying out of duo roles. This can be achieved by a Job analysis of the drill rig operator role which may help to properly design the job. Further, job analysis can help to determine the overall required staffing levels, skills and competences of the operators and description of separation roles. Additionally, the skills and competences of drill rig operators can be further developed by improving the quality of trainers and the training program.

Inadequate staffing levels were also identified as one of the causes of poor maintenance practices at Lubambe Copper Mine. In the same way, this arose from lack of proper job design. Hence, there is need to extend the job analysis, training and development to all employees associated with drill rig operations. Whereas, the roadway conditions can be improved by introducing a roadway maintenance team and improving the mine design.

Finally, to further assist the mine management in mitigating drill rig breakdowns at the mine, the study has developed a framework which can be used to identify potential drill rig breakdowns before the actual breakdown occurs. Therefore, if well implemented, the framework can assist reduce the number of breakdowns at the mine and as such, increase productivity. However, for the framework to be effective, the mine must develop a maintenance culture which should be based on precision, responsibility through the development of chapters in maintenance where individual maintenance personnel are responsible for a specific part or parts of the machine during maintenance, combining maintenance with safety, emphasis on consequences of breakdowns, appropriate inspections through competent and qualified supervisors, the use of approved check sheets and avoiding dependency on memory, continuous training and following change in technology, failure analysis of failed parts and getting feedback from equipment operators on the health of the machine they are assigned to. Lastly, the maintenance personnel should have the right qualifications for the job, must be competent and should be assessed regularly to ascertain the level of competence.

8.3.2 Theoretical Recommendations

The theoretical recommendations of this study arise from the limitations that the study faced, their implications and hence suggestions of areas for future study. Though through the search of literature, other areas of interest arose, however, these areas were not handled conclusively in this study, hence, the recommendation for further studies. Further, arising from the results of the study, a framework for identifying potential causes of drill rig breakdowns at LCM has been proposed and recommended to add value to the existing body of knowledge.

8.4 Limitations

Although this study considers the causes of drill rig breakdowns, it falls short of analysing the financial implication of the breakdowns. Therefore, future studies should consider empirically analysing the impact of drill rig breakdowns on the total cost to the company.

The other limitation of this study relates to the focus on one firm, Lubambe Copper Mine in the industry. This choice of the study design was motivated by the desire to explore and have a deeper understanding of the factors that led to high frequency of drill rig breakdown at the mine. The findings of this study may therefore, not be generalisable to other organisations.

8.5 Areas of Further Research

Most studies on human behavior forecast on how employee behavior affects organisational performance in general. This study therefore, contributes to the knowledge about how employee behavior can negatively affect productivity through increased breakdowns of the equipment that they use. In this regard, there is need to carry out more empirical studies to test how employee behaviors and attitudes, such as motivation and fatigue, affect reliability of equipment in an organisation.

Though the mine design was identified as one of the factors contributing to drill breakdowns at LCM, the study did not analyse how the mine design may be improved to reduce the impact on mobile equipment reliability more especially drill rigs. Therefore, further studies should be conducted to empirically analyse how the mine design can be addressed to minimise stress on equipment.

Additionally, the gaps identified in this study can be used as journal manuscripts for further literature review to readers and researchers who may be pursuing a similar study.

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APPENDICES

APPENDIX 1
ASSET SPECIFICATIONS

ASSET SPECIFICATION

Scope

This specification defines the minimum requirements for supply of mobile equipment to be based at the Lubambe Copper Mine in Zambia (“equipment”)

Equipment

Class	
Make	
Model	

Category	
Capacity	

Standards

Unless a specific exemption is provided in writing by the organizing the equipment shall, as a minimum, meet or exceed the requirements of each of the following standard

- The site build specification
- Specific requirements for the item of equipment
- Country mining Act: Guide to mining regulations 1973 (under review)
- Applicable ISO standard

Drawings

Unless a specific exemption is provided in writing by the organizing the equipment shall, as a minimum, meet or exceed the requirements of each of the following Drawings

- N?A
-

Operational parameters

Unless a specific exemption is provided in writing by the organizing the equipment shall, as a minimum, meet or exceed the requirements of each of the following parameters

Parameters	Settings
Application	Underground mobile equipment
Operating envelop (decline & lateral)	5.1 m wide x 5.0 m high
Operating envelope (ore drives)	5.1 m wide x 5.0 m high
Operating gradients	(9°) 1:7
Operating radius (minimum)	15m
Maximum speed limit underground	20 km / hr.
Road type	Compacted road base and development mullock
Temperature – dry bulb	To 30°C
Temperature – wet bulb	37°C (relative humidity 88.5%)
Process water salinity	3000 mg / L TDS (process effluent)
Ground water salinity	Approx. 200 mg / L TDS (“Drinking water”)
Ground water PH	6.5-8.5
Ventilation requirements	0.5m ³ /s/ rated kw Mr. 902(2) (f)
Loose bilk density for design	1.56 tonnes / m ³

Identification

A compliance plate shall be securely installed in a prominent position recording the serial number, tare weight, gross weight and the maximum safe axle load for the machine

The organization’s unique alpha numeric identification (“asset number”) shall be fixed to the left – hand side, right – hand side, rear and front of the machine to be clearly visible from any position. Asset number shall be profile cut stainless steel and 100 mm high /.

Standard service fluids

The company has in place a supply agreement for the following standard servicing fluids at the site

Description	Supplier	Specification
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Oil – Engine	Shell	Rimula R3 X 15w-40 CH-4/228.3
Oil – Hydraulic	Shell	Tellus S2 M 100
Oil – Transmission	Shell	Spirax S4 CX 30
Oil – Differences	Shell	Spirax S2 A 85W-140
Oil – Final Drives	Shell	Spirax S2 A 85W-140
Oil – Rock Drill	Shell	Air Tool Oil S2 A 320
Coolant – Engine	Shell / Spectra	Mono ethylene Glyco based (MEG) coolant. (NAP – Fee)
Crease	Shell	Gadus S3 V460D

The supplier shall advise the organizing if any of the standards servicing Fluids are not suitable for the equipment and suggest an alternative specification. The supplier shall fill the equipment with an initial fill of all fluids compatible with the standard servicing fluids.

Serviceing Fluids System

Oil System

- A remote dip stick shall be fitted to enable checking of the engine oil from ground level
- A sight glass or similar shall be fitted to enable checking of transmission and hydraulic oils from ground level
- Wiggins dry break fittings shall be installed in a convenient central position to enable fluids evacuation and fill from ground level using the following connection

Connection	Supplier	Type - Size
Engine Oil	Wiggins	79326ASSY0N2
Hydric Oil	Wiggins	79326A6008-12
Transmission Oil	Wiggins	79326/P-1880
Coolant	Wiggins	N/A
Bulk Grease	Lincoln	SKFSGH-50

Grease Systems

- Equipment shall be fitted with the following grease systems.

Description	Coverage	Drill - DEV	Drill - LH	Loader Truck	Utility Vehicle	Tool Carrier	Light Vehicle & Ancillary
Auto Grease – Hydraulic	Machine			X			
Auto Grease – Electric	Carrier				X	X	
Auto Grease – Electric	Boom / Scissor				X		
Auto Grease – Electric	Boom / Attach		X				
20 Kg Drum , Air Pump & Reel (20m)	Machine	X	X				
Fully Manual							X

- Ancillary equipment includes dozer, grader, roller etc. Auto greaser systems shall be set up to enable centralized greasing of the machine with sufficient capacity for 13 hours continuous operation.
- Auto greaser systems shall enable centralized greasing of the machine in isolation of the auto greaser.

Testing & Sampling

Clearing labeled and conveniently located test points shall be provided for testing hydraulic pressures (e.g., system pressure, charge pressure)

- Clearly labeled and conveniently located sampling points shall be provided for:
 - engine oil
 - hydraulic oil, and
 - Transmission oil.
- Sample points shall be pressurized, require the engine running for a sample to be taken and deliver representative fluid samples with consistent sampling practices.

Housing & Piping

- All housing & piping shall be clamped using non-abrasive clamps/ mounts to prevent chafing

- Housing & piping that pass through a bulkhead shall be protected from wear by rubber grommets or have a positive connection on either side of the bulkhead.
- Where possible all hoses shall be routed so that in the event of a burst or leaking hose, flammable liquid cannot contact a hot surface,
- Those hoses that cannot be routed away from hot surfaces shall be shielded so that in the event of a burst or leaking hose, flammable liquid cannot contact a hot surface
- All discharge or breather pipes shall be extended below the machine frame and directed away from any hot surfaces.

Diesel Fuel

The Specification for diesel fuel used at the Site is as follows:

Supplier	Oryx
Specification	Low Sulphur Diesel
Sulphur Content	< 50 ppm
ISO Cleanliness Rating	22/20/ 17
Other	-

Carrier

Reflective Tape Requirements

- Yellow reflective tape along both sides to indicate the length & height,
- White reflective tape cross the front to indicate the width & height, and
- Red reflective tape across the back to indicate the width & height

Reflective Tape Application

- Minimum width of 50 mm and in compliance with United Nations E/ECE/Trans/ 505/R 104 or the US Federal specification ASTM D4956-07,
- Applied in a straight line with the least number of interferences e.g. indicators lights, door handles and other obstacles, and
- Cut 25 mm shorter than desired length so that the reflective tape ends short of the panel, rounded along the edge to prevent lifting away from the panel.

Labeling - In addition to any standard OEM labeling the following actions / warnings shall be clearly labeled:

Actions in the event of fire,

- Warnings at pinch points,
- Warnings at hot areas,
- Warnings at other hazards,
- Warning at all accumulators to safely release pressure before commencing work,
- Warning on any spring applied brake chamber that a spring is under compression,
- Warnings on any other sources of stored energy

Additional Safety Equipment

- A first aid kit shall be fitted inside the cabin.
- 2 x rubber or urethane wheel chocks shall be mounted on the front of the Equipment
- A physical articulation lock shall be fitted to articulated equipment to prevent articulation when people are working in the articulation area.
- An implement lock shall be fitted to lock any implement in the raised position.
- A hydraulic accumulator shall be fitted to the hydraulic system pilot circuit of loaders to allow the bucket to be lowered in the event of engine failure.
- A hydraulic accumulator shall be fitted to the hydraulic system pilot circuit of loaders to allow the bucket to be lowered in the event of engine failure.

Operator cabin

Equipment shall be fitted with the following cabins:

DESCRIPTION	Drill - Dev	Drill - LH	loader	truck	Utility vehicle	Light vehicle	Tool carrier	ancillary
Enclosed cabin	x	x	x	x	x		x	x
Open canopy								
Standard cabin						x		

Enclosed cabins shall be Air conditioned using R 134A gas,

- Positive pressure inside cab
- Sound suppressed to <85dba,
- Fitted with two means of egress
- Fitted with windscreen washer / wiper

- Fitted with internal light (LED)
- Fitted with fire resistance materials (upholstery, / insulation etc.) and
- Fitted with securely fastened sign “NO unrestrained loads to be carried in this cabin

Open canopy shall be

- ROPS/ FOPS Certified
- Fitted with an operator door (other than drills), and
- Fitted with a cooling fan

Standard cabins shall be OEM cabin provide for a road licensable LV's

Equipment Access

General compliance:

- Hand rail/ grip & foot holes shall allow adequate support for the operator and three-point contact when accessing the machine and checking / topping up fluids levels.
- Steps, rugs, ladders and walkways shall be non-slip surfaces and shall minimize rock and soil retention.
- All handrails / grab rails shall be painted a light green color to aid in identification of the handrails / grab rails in situations of poor or diminished visibility.
- Walkways shall be designed to eliminate trip or slip hazards i.e. exposed hinges.
- Hinged engine covers / bonnets shall open to a stable position and fitted with locks to prevent accidental closure.
- Covers / bonnets over 10 kg shall be easily removable and fitted with suitable lifting devices or gas struts.
- Guards shall be fitted on all rotating components to prevent contact with personnel during normal operating tasks
- All areas of equipment requiring regular maintenance shall be within safe reach of personnel standing on permanent platforms, floors or walkways.
- Fold down safety rails shall be fitted for access to and working on top of bonnet covers.
- Lifting points shall be clearly identified

Controls / Warning Devices

Controls and warning devices shall be clearly labelled in English and positioned within easy reach of the operator. Each item of Equipment shall be fitted with:

- An audible horn / hooter,

- An audible reversing alarm B60 Series shall sound automatically when reverse gear is selected, and
- Reverse lights shall operate automatically when reverse gear is selected
-

Gauges /System Indicators

Dash instrumentation shall include as a minimum:

- Tacho rpm,
- Engine hour meter,
- Fuel level and oil pressure gauges
- Transmission temperature and pressure gauges
- Engine temperature and pressure gauges
- Cooling water temperature gauge
- Coolant level monitor, and
- Voltmeter

Gauges and system indicators shall:

- Be labelled in English and positioned within clear view of the operator, and
- Show maximum, minimum and operational ranges of all equipment systems,

Engine

Requirements

- Diesel fueled and liquid cooled,
- Meet or exceed Tier II USA Federal Standards for diesel engine emissions,
- Meet noise attenuation to, ≤ 85 db A
- Operation efficiently on the diesel fuel specification set out under diesel fuel , and
- Operation efficiently in the conditions set out under operational parameters

Emissions

Diesel emissions measured without an exhaust treatment device at torque stall condition

Shall not exceed (MR913 (a)):

- 1000 ppm oxides of nitrogen (NOX) 0.1 Per centum by volume

- 2000ppm carbon monoxide (CO) 0.2 per centum by volume

The exhaust system shall be designed to ensure exhaust emissions do not enter the Operator/ passenger compartment and shall be filtered with a purifier sized to the engine

Management System

An engine management system shall monitor the critical performance measures of the engine and provide audible and visual warning of engine faults with engine shutdown in the event of a critical fault .

Critical faults shall include low oil pressure , high coolant temperature and low level with engine shutdown occurring after the operator has been provided with a 6 second warning alarm

An “energized to run fuel shutdown system that is linked to the fire suppression and engine man agent systems shall automatically surface temperatures

The exhaust system shall be designed to ensure that in the event of a burst , leak or otherwise,

flammable liquid cannot contact surface that exceeds a temperature of 200 degrees Celsius.

A ceramic coated steel fire wall shall be fitted to segregate the transmission / converter area

An engine to run fuel shutdown system that is linked to the fire suppression and engine

From the hot engine parts. Exhaust and engine components that require heat shielding alarm.

Shall be coated with a ceramic material

The use of porous insulation materials that retain hydrocarbons / flammable liquid is not acceptable a sheat shielding

Air Induction

The air cleaner shall be a cyclonic dry element type with a mechanical restriction indicator rated for the engine requirements under the conditions set out in the operational Parameters . Double hose clamps shall be fitted to all resilient air hose connections.

Fuel Systems

The fuel system shall be fully sealed and fitted with:

- A water trap
- A filtration system to a minimum 5 microns, and
- An automatic failsafe fuel shut off solenoid mounted on the pickup hose from the fuel tank, interlocked with the ignition and requiring power to run

Fuels tanks shall be:

- Of steel Construction,
- Sized for a minimum on board fuel capacity of 13 hours continuous operation,
- Fitted with non-leaking caps that are effective regardless of inclination , and
- Fitted with a Wiggins dry break quick fill connector and breather as the only means of adding fuel

Fuel hose shall be:

- Fuel compatible
- Steel braided
- Fire resistant,
- Anti-static,
- Corrosion resistant,
- Routed in a manner that provides protection from hot surfaces (i.e. exhaust pipes)
- Protected by an Aeroquip (or equivalent) fire resistant sock.

Cooling System

The cooling system shall be adequate to maintain the design engine temperature specified by the manufacturer under the conditions set out under operations Parameters

Cooling fans, belts and drive systems shall be adequately guarded to prevent injury.

Radiators shall be:

- Corrosion resist
- Fitted with a radiator cap that allows pressures to be manually released prior to removal
- Fitted with a sight glass or similar as an alternate method of checking the coolant level, and
- Fitted with an overflow pipe, extended towards the ground.

Hydraulic Systems

General

The hydraulic system shall be designed so that any hydraulically operated implement (e.g. booms or drilling systems) cannot move in an uncontrolled manner if there is a loss of hydraulic supply pressure.

The hydraulic system shall be fitted with both pressure and return filtration with return Filtration of < 15 micron

Hose and Piping

- Hydraulic hoses shall be fire resistant or fitted with a fire- resistant wrap.
- All hosing and piping shall be clamped using non-abrasive clamps/ mounts to prevent chaffing.
- Hosing and piping that pass through a bulkhead shall be protected from wear by rubber grommets or have a positive connections on either side of the bulkhead.
- All hosing and piping shall be routed so as not a cross over electrical wiring and provide maximum physical protection to the hose or pipe.
- Where possible all hoses shall be routed so that in the event of a burst or leaking hose flammable liquid cannot contact a hot surface.
- Those hoses that cannot be routed away from the hot surface shall be shielded so that in the event of a burst or leaking hose, flammable liquid cannot contact a hot surface.
- All discharge or breather pipes shall be extended below the machine frame and directed away from any hot surfaces.
- Hydraulic hose inside cabins must be suitably covered to prevent hot oil spraying on the operator in the event of hose failure.

Drive Line

General

The drive train shall be 4 x4 with full time all-wheel drive lockable front hubs.

The procedure for disengaging the drive train for towing shall be addressed in the supplier's maintenance manual.

Underground equipment shall be locked in four-wheel with the gear change isolated to limit the maximum speed.

Automatic transmissions shall be fitted with an interlock that only allows the engine to start when the transmission lever is in neutral or park.

Brakes

General

The Equipment shall be fitted with a service braking system and an emergency / park braking

system that are fully compliant with the most current version of legislation applicable to the site

The procedure for disengaging the brakes for towing shall be addressed in the maintenance manual.

Each braking system shall bring the machine to a controlled stop when travelling in a loaded

Condition at maximum rated operating speed down the maximum gradient on the normal decline roadway. The braking systems shall be capable of independent testing by the operator.

Braking system pressures shall be monitored by separate pressure gauges and brake disc wear shall be measured by indicators on individual packs.

Service Brakes

Service brakes shall be dual circuit, fully hydraulic, fully enclosed, wet disc and failsafe.

An Indicator light or similar shall be located on the board of the operator's cabin to warn of brakes drag or low release pressure.

Park/ Emergency Brakes

The park/ emergency brakes shall be:

- Able to hold the machine under 110% of the maximum rated load on the maximum positive and negative gradients,
- Applied by a 'push to apply' switch located within easy reach of the operator
- Applied through a neutral braking system within 3 seconds of selecting neutral gear,
- Automatically engaged when the engine is stopped

The park / emergency brakes shall be automatically engaged under the following circumstances

- Brake charging pressure low
- Hydraulic oil tank level low
- Brake oil tank level low
- Transmission clutch pressure low, and
- Cabin door open / not latched

Retarder:

Trucks and UV's shall be fitted with a retarder device that is automatically applied in the event of an engine over-speed event .

Retardation systems in order of preference are:

- Hydraulic - fitted into the converter / transmission or rear wheels,

- Engine Exhaust - internal engine, not a butterfly valve in the exhaust pipe,
- Telma - electric retarder assembly in the rear tail shaft

Tyres and Rims

Rims

The equipment shall be fitted with specified rims marked with a unique identification number to be provided by the Organisation.

Tyres

The equipment shall be delivered with fitted tyres that are compatible with the Operational Parameters

Spare Tyres and Rim Assembly

The equipment shall be delivered with one (1) x spare tyre and rim assembly.

Electrical System

Voltage

The low voltage electrical system shall be 24 volts

Standard

Low voltage electrical systems shall be installed to Austrian Standard AS4242 or a recognised standard equivalent to AS4242.

Isolation

A four- pole isolator that isolates the battery power (Main Isolator) and shuts down the engine when in the open position shall be;

- Colored red,
- Location and function clearly labelled in the permanent corrosion resistant material,
- Accessible from ground level without lifting an engine cover or bonnet,
- Located as close as practicable to the batteries and AFFF activation point, and
- Lockable in the open (off) position using a standard isolation lock.

A four - pole isolator installed in the starting circuit (Start Isolator) to prevent the machine starting when the main isolator is in the closed (on) position shall be:

- Colored yellow,
- Location and function clearly labelled in permanent corrosion resistant material,
- Accessible from ground level without lifting and engine cover or bonnet,

- Positioned in the engine compartment, and
- Lockable in the open (off) position using a standard isolation lock.

Emergency Stops

A fail - safe emergency stop button that stops the machine and shuts down the engine shall be:

- Colored red,
- Location and function clearly labelled in permanent corrosion resistant material,
- Fitted at the operator's control panel and adjacent to the AFFF activation point,
- Latched either electrically or mechanically such that shut down can only be reversed by a deliberate action.

Batteries

Equipment shall be equipped with 2 x gel type batteries as a minimum.

The batteries shall be housed in a compartment that provides protection for the batteries with adequate clearance between the battery and any cover. Insulating material shall be provided on the underside of any cover that is over battery terminals.

Battery leads shall be:

- Double insulated as a minimum,
- Fitted with a fusible link in the main positive battery lead,
- Fitted with a circuit breaker on the alternator charge lead, and
- Fitted with terminal boots to provide protection at +ve and - ve battery terminals

Cables connected directly to battery terminals and / or battery isolators shall be run in separate conduits or otherwise suitably protected from wear and damage.

Jump Starting

A jump start receptacle shall be fitted with voltage and polarity clearly labelled in permanent resistant material. Type: Caterpillar

Alternator

The alternator shall be of a sufficient size to reflect the actual electrical load on the machine.

Circuit Breakers

Enclosures shall minimise the exposure of manual circuit breakers to dust and moisture.

Junction Boxes

Conduits and junction boxes for low voltage cables / harnesses shall be water tight and rated to IP66 as a minimum as preferably constructed from stainless steel.

Electrical Plugs

Electrical plugs shall be filled with Ensto non-flammable electrical grease.

Electrical Wiring

Electrical wiring shall be:

- Of heavy duty construction,
- Positioned so as not to be exposed to physical damage,
- Positioned away from hot surfaces and corrosion substances,
- Routed separately to hydraulic hoses and AFF hoses
- Secured by suitable cable fixing and fastening points that protect against damage,
- Protected by suitable flame resistant mechanical protection (i.e. double insulated using suitable conduit or heat shrink) throughout the length of the run other than a short section of cable close to connectors that may have insulation exposed for identification purposes. this short section and the associated connectors shall be covered in non-flammable Densil tape or similar when the machine is in service,
- Protected by rubber grommets where cables are required to pass through bulkheads,
- Protected by flexible boots at bulk head terminations,
- Protected by flexible boots at any connections (i.e. starter motor, alternator, circuit breakers) with terminals covered by OEM covers or non -flammable Densil tape,
- Protected by a covering that is adequately secured at any termination (i.e. Partition wall),
- Clamped or secured to provide triple insulation - securing double insulated cable to steel work with cables ties is acceptable where the steel work is provided specifically for the purpose.

Lights

Equipment shall be fitted with the following LED lights suitably protected against rockfall and side wall damage:

Description	Color	Drill-Dev	Drill-LH	Loader	Truck	Utility vehicle	Light vehicle	Tool Carrier	Ancillary
Driving lights	White	X	X	X	X	X	X	X	X

Working Lights (adjustable)	White	X	X	X	X	X	X	X	X
Reversing Lights	White	X	X	X	X	X	X	X	X
Parking Lights	White	X	X	X	X	X	X	X	X
Brake Lights	Red	X	X	X	X	X	X	X	X
Indicator Lights	Amber			X	X	X	X	X	X
Operator Position lamps (near side)	Green			X	X	X		X	
Operator Position lamps (off side)	Red			X	X	X		X	
Side Lights	Amber			X	X	X	X	X	X
Rotating Beacons	Amber	X	X	X		X	X	X	X
Emoting Beacon	Red			X					
Explosive Beacon	Blue					X			

Reversing lights shall come on automatically when reverse gear is selected and shall be fitted with a manual override switch to allow the reversing lights to be switched off.

Fire Control

Fire Risk Assessments

- The Equipment Supplier shall conduct a fire assessment on the equipment in accordance with Australian standard AS5062 or a recognised standard equivalent to AS5062 to determine both the requirements for fixed fire protection and identify opportunities for further fire prevention or reduction risks after implementation of the fire protection systems, other things identify the location, size and number of nozzles applicable for the equipment, and
- The fire risk assessment shall amongst
- The Equipment Suppliers shall provide the organisation with a copy of the fire risk assessment and compliance certificates as part of the commissioning process.

AFFF System

- The suppliers shall install a SANDVIK ECLIPSE FOAMAFF system compliant to AS5062 or a recognised standard equivalent to AS5062 with automatic detection that covers all critical of the machine in accordance with the relevant fire risk assessment,

- The AFFF system reservoir shall comply with AS1210 or a recognised equivalent to AS1210 and shall be marked and certified accordingly.
- A pressure gauge or similar that is accessible from ground level shall be fitted as a method of checking the charge status of the AFFF system.
- A fire sensor tube shall be positioned appropriately to ensure that the AFFF system activities in the event of the fire,
- The AFFF system shall include continuous pressure monitoring and automatic engine shut down that is activated after a 6 second warning when system pressure drops to below a pre-determined pressure setting.
- The AFFF system shall include automatic shutdown of the high voltage (550v) supply to the Equipment when the AFFF system is activated automatically or manually.
- Two manual activation points shall be fitted with one located in the operator cab and the other accessible from the ground adjacent to the battery isolator, and
- Wiring for the AFFF system shall be segregated from other electrical and flammable liquid lines.

Portable Fire Extinguishers

Two (2) portable 9kg powder fire extinguishers shall be securely installed on quick release brackets on either side of the equipment in the following locations.

- Close to the entrance to the cab, to enable unrestricted access and visual inspection,
- Close to the AFFF manual activation point and accessible from the ground level.

Electrical – High Voltage (Drills)

Voltage

The 550 volt electrical system shall be 3 phase and 50 Hz and limited to 250 Amp current draw

Standards

High voltage electrical systems for development and production drills shall be installed to Australian Standards AS3000 or a recognised standard equivalent to AS3000.

Trailing Cable

Trailing cable shall be flexible, copper screened (individual core/phase screening) rubber insulated and sheathed: $3x[AA]mm^2 + 1x[BB]mm^2 + 2x[CC]mm^2$

- Phase core = [AA], Earth Core = [BB] & Pilot Core = [CC]

The trailing cable shall be [xxx] mm diameter and 100-150 m long

The trailing cable plug shall be a Victor 250 amp 1100 Volt restrained plug.

The trailing cable shall be able to wind and out by a cable reel under machine power.

A dummy receptacle shall be fitted to the rear of the machine in a suitable protected to securely lock the cable plug in a position that prevent use, using a standard isolation lock.

Junction Boxes

All electrical junction boxes shall be [blue] and clearly labelled with 'Danger' [1000] V' and reflective danger tape. The boxes must also be enclosed, lockable and mechanically guarded.

Testing

The electrical system shall be designed where possible to allow from an external display (i.e. ECM).

Where testing is required, contact points shall be shrouded and openings that allow live testing shall be of a size sufficient only to allow access for a test probe.

Interlock

Pilot isolation shall be interlocked to the carrier ignition to cut out the high voltage power supply when the ignition switch is in the on position or when the diesel engine is running.

Hour Meter (Drills)

In addition to the engine hour meter, hour meters shall be fitted and clearly marked to allow individual readings to be taken for each.

- Power pack
- Percussion source , and
- Compressor

Equipment under Remote Control

Equipment that can be controlled under remote control shall be equipped for remote

- Activation of the emergency stops
- Activation of the fire suppression system
- Restart of the engine after activation of fire suppression system, and
- Switching on/ off for reversing lights

Automation and Data Capture

The equipment suppliers shall provide details capture (payload, productivity, machine systems) for the equipment.

TOWING, LIGHTING AND JACKING

Towing points at the front and rear of the machine shall be clearly identified by high visibility paint and marked with the design load capacity. Towing points shall enable the machine to tow other vehicles of similar size or to be towed itself in the event of malfunction or retrieval.

Lifting points shall be clearly identified by high visibility paint and marked with the design load capacity. Lifting points shall enable the machine to be safely lifted.

Jacking points shall be clearly identified by high visibility paint. Jacking points shall enable the machine to be safely jacked up for tyre changing or other maintenance functions.

Communication

Equipment shall be fitted with a Motorola or Kenwood two way radio.

A suitable 12 volt power supply shall be installed in the cabin for radio communication.

Paint / Color

Standard OEM Color to a paint specification that will not deteriorate within 5 years of commissioning under the listed in the operational parameters

Organisation Livery

Equipment decals shall comply with corporate livery requirements provided by the organisation.

Parts Support

The equipment supplier shall provide an accurate listing of parts and materials in an electronic format that can be uploaded directly into the site's Computerised Maintenance Management System (CMMS) and inventory control system.

The equipment supplier shall provide an accurate listing of parts and materials to be held by the equipment supplier in a local store and the expected lead time on delivery for non-stock items.

OEM Manual

The equipment supplier shall provide the following OEM manuals:

- 2 x sets of service/ part manuals in electric format
- 2 x sets of service/ part manual in hard copy format
- 2 x full sets of laminated schematic drawings, and
- 2 sets of operator's manuals.

Documentation

The equipment supplier shall provide the following Documentation:

- Commissioning report
- Statutory approval
- Fire risk assessment
- Emissions testing process with results for engine supplied.
- Compliance certificates
- Templates of the window glass profile, and
- Commissioning certificates

Maintenance Schedule

The Equipment Supplier shall provide a maintenance schedule setting out the OEM recommendation preventive maintenance tasks and associated frequencies for the equipment.

Warranty

The machine shall be covered by a standard factory warranty unless otherwise agreed between the organisation and the supplier.

Commissioning

The equipment supplier shall commission the equipment for operational use including but not limited to the following:

- Wash and details the equipment,
- Repair any damage
- Touch up paint damage
- Replace damaged stickers / decals
- Equipment service including bolt tensions
- Commission engine in accordance with OEM requirements
- Diesel emissions test certificate and report
- Service brake test certificate and report
- Emergency brake test certificate and report
- Fit for purpose confirmation of mechanical / electrical control devices
- Fit for purpose confirmation of mechanical / electrical instrumentation

- Fit for purpose confirmation of equipment safety devices
- Fit for purpose confirmation of personnel protection devices
- Approval and testing required by Statutory Authorities
- Delivery of all OEM Manuals, Documentation and Schedule to the Organisation.

Training

The supplier shall provide the following equipment training to the organisation at the site after commissioning and before hand over.

- 40 hours onsite training for the organisation’s operators spread over 5 days nominally at 8 hours per day,
- 40 hours onsite training for the organisation’s maintenance spread over 5 days nominally at 8 hours per day.

Hand Over

Written confirmation of pending equipment hand over shall signify the suppliers’ advice to the Company that commissioning and Training is complete. Written acceptance of Equipment Hand Over shall signify the companies’ acceptance of the Equipment as commissioned unless otherwise noted.

Special Requirements

Machine Specific Requirements are included in the invitation to tender.

Operator

Full Name	
Project Role	
Full Name	
Project Role	

Signature	
Date	

Peer Review

Approval

Full Name	
Project Role	

Signature	
Signature	
Date	

Created by: Galatia, D (2017)

APPENDIX 2
TRAINING REPORT ON BASIC ELECTRO –
HYDRAULIC COURSE FOR LUBAMBE
EMPLOYEES

SANDVICK MINING AND ROCK TECHNOLOGY TRAINING DEPARTMENT
TRAINING REPORT ON BASIC ELECTRO – HYDRAULIC COURSE FOR
LUBAMBE MINE FROM 5TH JUNE – 9TH JUNE 2017

REPORT

Prepared By: Chomba Nkaka

Date 24th June, 2017

To: Philemon Kamina

MTCE Planner/Engineering Training Coordinator

Lubambe Copper Mine

INTRODUCTION

TRAINING REPORT ON BASIC ELECTRO HYDRAULIC COURSE

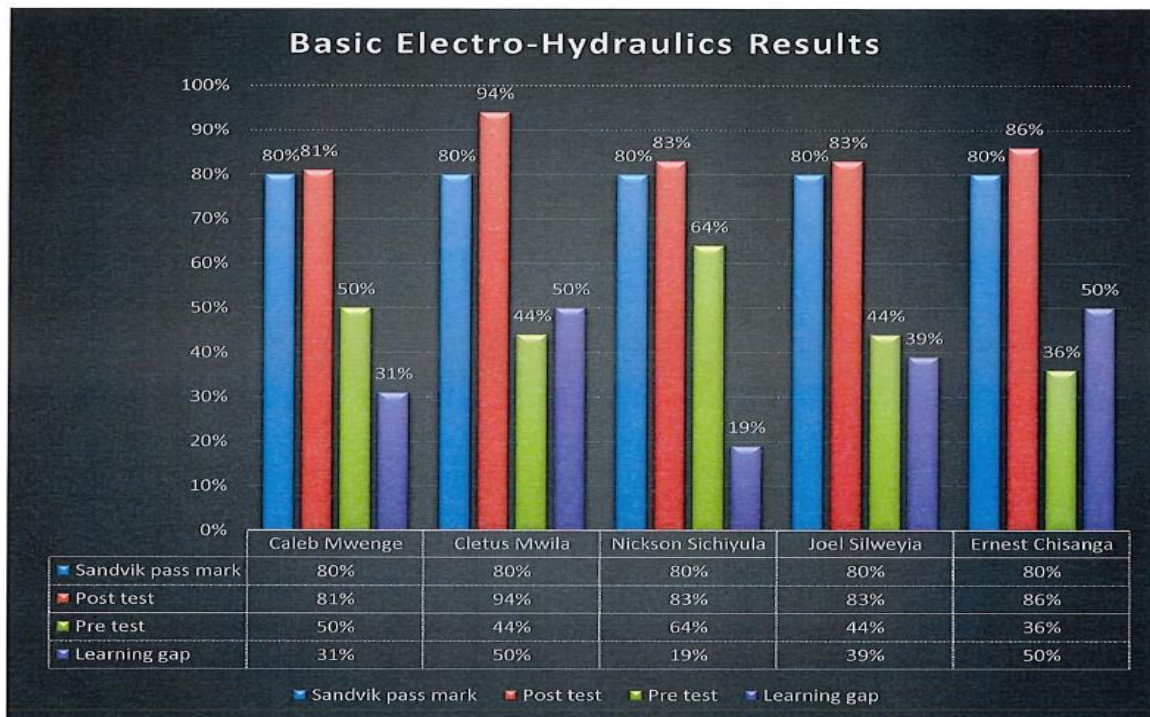
The above mentioned training was conducted to five Lubambe Mine Technicians. The training was conducted from 29th may – 2nd June 2017 at, Sandvik Technical training academy in Kitwe

COURSE MAP: BASIC ELECTRO – HYDRAULIC COURSE

ACTIVITY	DAY
Pre test Theories	Day One
<ul style="list-style-type: none"> - Behc Induction - Behc Safety Instructions - Hazards Identification And Risk Assessments - Lock Out And Tag In Procedure - Correct Use Of PPE And Tools 	
INTRODUCTION TO HYDRAULICS	Day Two
<ul style="list-style-type: none"> - Hydraulic Maintenance - Hydraulic Properties - Advantages And Disadvantages Of Hydraulics - Hydraulics Components - Hydraulic Symbols - Hydraulic Circuits 	

INTRODUCTION TO BASIC ELECTRICAL	Day Three
<ul style="list-style-type: none"> - Electrical Maintenance - Dc And Ac Circuits - Electrical Components - Electrical Symbols - Electrical Circuits 	
PRACTICALS	Day Four
<ul style="list-style-type: none"> - Designing of hydraulic circuits on BEHC simulator - Designing of electrical circuit on BEHC simulator 	
<ul style="list-style-type: none"> - Designing of combination circuits of hydraulic and electrical circuits on BEHC simulator - Troubleshooting on designed circuits on BEHC simulator 	Day Five
Post Test	

Before and after training a test was given to the Trainees in order to measure the knowledge they had before and after training. The results came out as shown in the graph below.



Note: Sandvik pass mark is 80%

All the trainees got below Sandvik pass mark of 80% and above in their pretests

After all the trainees managed to pass their posttest as they got 80% and above.

Cletus Mwila was the most outstanding Trainee with 94%.

Observation

It was a challenge to some technicians to identify electrical and hydraulic symbols, hence reading of electrical and hydraulic circuits was a problem

All the participants who attended the training participated very well in class, and during the practical's (circuit designing and troubleshoots)

Learners co-operated very well in both time management and behavior conduct, during the training period

Recommendations

Management should ensure to arrange machines specific courses, in order to help their Technician to fully understand how to read different circuit on different machines

Management should provide relevant schematic (circuits) diagrams to Technicians and they should be always encouraged to use them (electrical Hydraulic Circuits) when doing their troubleshooting.

Conclusion

When Technicians are trained and fully understand systems on deferent machines, it will be helpful for the company as it will reduce on breakdowns time.

All participants managed to get more than the Sandvik passing mark of 80% in the post-test

Assessment log books has been given to each Trainee for you (management) to assess them, and they should submit to Sandvik after six weeks, therefore, as management help them in this process.

Capable certificates will be given to those who will meet the assessment requirement, after receiving the assessments log books.

Below is a list of the Technicians particulars, pre-test results

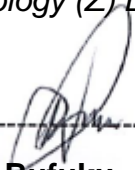
NAME	SURNAME	ID NUMBER	PRE TEST	POST TEST	LEARNING GAP	REMARKS
Caleb	Mwenge	285778/64/1	50%	81%	31%	Passed Post Test
Cletus	Mwila	189835/63/1	44%	94%	50%	Passed Post Test
Nickson	Sichvula	239098/64/1	64%	83%	19%	Passed Post Test
Joel	Silweyia	238047/65/1	44%	83%	39%	Passed Post Test
Ernest	Chisanga	399496/67/1	36%	86%	50%	Passed Post Test

We look forward for more business with you

For and on behalf of Sandvik Mining and Rock Technology (Z) LTD



Chomba Nkaka
Technician trainer – Central Africa



Nixon Bufuku
Training Supervisor – Central Africa

APPENDIX 3
COMPONENT FAILURE INVESTIGATION
REPORT

COMPONENT FAILURE INVESTIGATION REPORT

Failure event	AXIE failure- front & rear. Large amount of bearing metal at 142 Hours
---------------	--

Date	12/10/2018
------	------------

Context
<p>LCM has a plan in place for the replacement of a significant number of over hours machine components, during the process a number of low hour failure of Sandvik rebuild components was experienced. Sandvik was not willing to repair them under warranty. LCM has implemented a magnetic plug inspection process as part of the maintenance system, a number of low hours axles had plug ratings of 4/5, and this raised concerns about the standard of rebuilds. LCM had one of the axles removed from DT13(142Hrs) and a strip down failure analysis was conducted at Sandvik in Kitwe facility, the following report summarized those findings</p>

Purpose
- Identify root cause for the premature axle failure

Component Identification

Description	Kessler D106
--------------------	--------------

Manufacturer	Kessler	Part Number	56210427
Model	D106	Serial Number	560666
Manufacturer's Markings		Supplier's Markings	

Status At Installation	<input type="checkbox"/> New	<input type="checkbox"/> Rebuilt	<input type="checkbox"/> Transfer
------------------------	------------------------------	----------------------------------	-----------------------------------

Component History

Remove From Asset By	Sandvik	Meter Reading At Removal	
Date Failure		Date Removed	

Component Supplied By	Sandvik	Purchase Date	
Component Warranty Period	1000Hrs	Component Warranty Expire Date	
Failure Within Component Warranty	Yes		

Component Installed By	LCM/Sandvik	Meter Reading At Installation	13,479 Hrs
Date Installed	11/12/2018	Installation Warranty Period	1,000 Hrs
Failure Within Installation Warranty	Yes	Installation Warranty Expire	

Time In Service (Months)	Target		Actual		Variance	
Time In Service (SMU)	Target	10000	Actual	142	Variance	9858

OPERATING HISTORY

Kessler axle Serial Number 560666 was removed from DT14 due to excessive brake wear. Axle hours: 7853 – Dated /2018

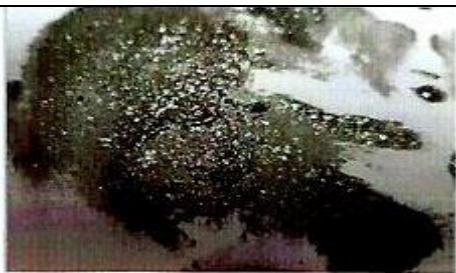
Maintenance History

Kessler axle Serial Number 560666 was removed from DT14 due to excessive brake wear.
 Axle hours: 7853 – Dated /2018
 Rebuilt by Sandvik Kitwe
 Fitted to the front position of DT13 on 12/11/2018
 Magnetic plug inspection identified rating 4/5 metal contamination 142 hours from fitment

Oil Sample History

Not enough operation hours to trigger sampling first sample due at 500 operating hours

“As Failed” Images



Metal found on Magnetic Plugs



Metal found on Magnetic Plugs

“As Failed” Inspection Results

Metal found on final drive Magnetic Plugs. Ratings 4/5

Component Cleaning

“Clean Component” Images



Spindle Retaining Nut
Loose



Bearing Wear



Sun gear Thrust Washer
Damage



Bearing Wear



Bearing Wear



Brake Seal Installing
Damage



Brake Seal With Silastic
Sealing



Bearing Cone Prior to
remove of Cage



Bearing Cup Wear



Bearing Cone with Rollers Removed



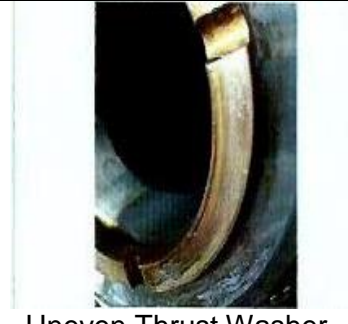
Spindle Wear / Metal Contamination



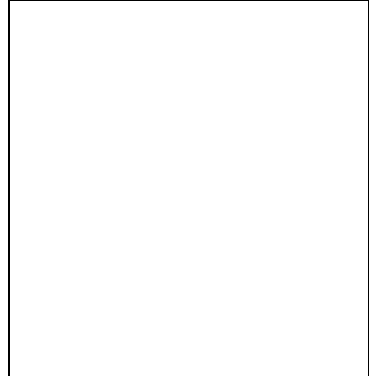
Assembly Damage to Brake Cooling seal



Bearing Wear



Uneven Thrust Washer wear



“Clean Component” Inspection Results

Sun gear thrust washers badly worn and damaged ,
Inner and outer wheel bearings in advance stage of failure ,
Brake cooking seal has evidence of incorrect installation, hummer damage to the seal carrier
Use of sealant to prevent the brake cooling leaking, this was covering the seal tension spring and would prevent the seal working correctly

Dimension Analysis

No Destructive Testing

Chemical / Metallurgical

Failure Mechanism

Bearing Wear Leading to failure

Failure Mode

Buckling	
Corrosion	
Creep	
Fatigue	

Impact	
Rupture	
Fracture	

Wear	Yes
Yielding	
Thermal Shock	

Immediate Cause(S)

Bearing with 7853 hours not replaced during the rebuild,
 Poor work practices used during the assembly process

Contributing Factors

Not rebuilt to the OEM specification ,
 OEM assumed that LCM wanted “Cheap rebuilds” and true rebuild costs were not provided to the customer,
 Sandvik has provided site maintenance service to LCM for some 5years, manganic plug information was not fed back to LCM
 Suspect OEM built components to exceed the minimum warranty and not the full life advised by Sandvik ,
 Comment by workshop manager that the Kessler bearings were expensive to replace
 Sandvik workshop manager advised he was not aware of the running cost(\$Hr)
 implication of not achieving components life

Warranty Consideration – Component

Warranty Consideration Installation

Corrective Actions

1	TBA by Sandvik
2	
3	
5	

Monitoring Requirements

Type Of Monitoring	Frequency	Period
Oil sampling	500hr	Life of machine
Magnetic plug inspection	125hr/weekly	Life of machine
Visual inspection	Daily	Life of machine

Supporting Information**Investigation Team****Team Leader Declaration**

Team Role	Name	System Role	Experience
LCM investigation			
LCM investigation Leader			
OEM representertive			

This component failure investigation report is an accurate report of the investigation and the findings arising out of the investigation

Full Name

Signature

System Role

Date

Peer Review

Full Name

Signature

System Role

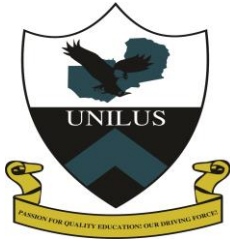
Date

APPENDIX 4
DRILL RIG COMPONENT REPLACEMENT
SCHEDULE

Drill Rigs Component Replacement Schedule

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
DL321 MAJOR COMPONENT												
Cumulative Hours												
Engine	1,037	4,175	1,609	1,983	8,528	2,643	639	5,676	231	5,115	3,818	3,121
Transmission	5,214	1,724	1,609	3,264	2,073	2,643	639	1,682	1,839	148	4,700	1,308
Torque Converter	7,971	437	1,609	3,264	5,020	2,643	639	5,685	1,602	148	314	1,308
Front Axle	1,379	86	1,609	1,347	3,335	2,643	639	1,508	21,252	1,217	6,226	268
Rear Axle	709	4,007	1,609	11,135	2,513	2,643	639	1,658	0	21,196	6,226	268
Front Differential	1,379	86	1,609	1,347	3,335	2,643	639	1,508	2,294	1,217	6,226	268
Rear Differential	709	4,007	1,609	11,135	2,513	2,643	639	1,658	0	21,196	6,226	268
Steering Cylinder - Left	3,250	8,280	1,609	11,135	10,898	2,643	639	2,623	640	2,814	18,036	1,308
Steering Cylinder - Right	25,543	31,328	1,609	399	10,898	2,643	639	1,105	1,393	12,447	18,036	1,308
Lift Cylinder - Left	8,208	6,576	1,609	174	10,898	2,643	639	17,470	2,835	9,086	5,311	13,842
Lift Cylinder - Right	6,806	8,348	1,609	2,359	10,898	2,643	639	2,604	2,835	9,086	3,268	13,842
Centre Mountings (Pillow Block)	10,443	11,987	1,609	7,062	10,898	2,643	639	15,101	21,252	10,768	18,036	268
Brake Assy - Front	1,379	86	1,609	1,347	3,335	2,643	639	1,508	21,252	1,217	6,226	268
Brake Assy - Rear	709	4,007	1,609	11,135	2,513	2,643	639	1,658	0	21,196	6,226	268
Radiator			1,609			2,416	639					

APPENDIX 5
INTERVIEW GUIDE FOR KEY
INFORMANTS



UNIVERSITY
OF
LUSAKA

INTERVIEW GUIDE FOR THE KEY INFORMANTS

Date.....

SCHOOL OF POST GRADUATE STUDIES.

ANALYSIS OF FACTORS THAT CAUSE DRILL RIG BREAKDOWNS:

A Case of Lubambe Copper Mine

Dear Key Informant,

The purpose of this questionnaire is to provide feedback relating to the cause and factors that cause frequent drill rig breakdowns at the mine. This is designed to help the author gather information for analysis to complete his PhD study.

Gathering data from you as a person who operates, maintains or has the knowledge of drill rig activities at the mine is a vital part of this process. Please fill in all parts of this questionnaire and note that the information provided by you in this questionnaire is **STRICTLY CONFIDENTIAL** and will be used for the purposes of this study only. It will not be used in a manner which would allow identification of your individual responses.

FOR KEY INFORMANTS

Indicate the position held by Key informant.....

- i. Do you know the underground drill rigs?

1	Yes	
2	No	
3	Don't now	

- ii. Do you have any idea of their operation?

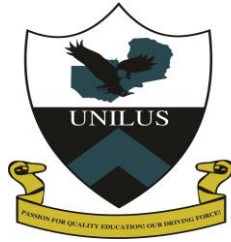
1	Yes	
2	No	
3	Don't now	

Specify:

- iii. Do you think the drill rig operators have adequate training and development? Specify:
- iv. Do you think the maintenance personnel are adequately trained and developed? Specify:
- v. Do you think both the drill rig operators and maintenance personnel are adequately motivated? Specify:
- vi. Do you think the underground environmental conditions contribute to drill rig breakdowns? Specify:
- vii. What is your opinion on the condition (quality) of parts used on drill rigs?
- viii. Do you think drill rigs are used for the right purpose? Specify:
- ix. What do you think could be done to minimize drill rig breakdowns?

Thank you for your time and Cooperation.

APPENDIX 6
QUESTIONNAIRE FOR MAINTENANCE
PERSONNEL



UNIVERSITY
OF
LUSAKA

PHD THESIS QUESTIONNAIRE

Questionnaire Number :

Code: ENG001

Date:

SCHOOL OF POST GRADUATE STUDIES

ANALYSIS OF FACTORS THAT CAUSE DRILL RIG BREAKDOWNS:

A Case of Lubambe Copper Mine

Dear Respondent,

The purpose of this questionnaire is to provide feedback relating to the cause and factors that cause frequent drill rig breakdowns at the mine. This is designed to help the author gather information for analysis to complete his PhD study.

Gathering data from you as a person who operates, maintains or has the knowledge of drill rig activities at the mine is a vital part of this process. Please fill in all parts of this questionnaire and note that the information provided by you in this questionnaire is **STRICTLY CONFIDENTIAL** and will be used for the purposes of this study only. It will not be used in a manner which would allow identification of your individual responses.

for
official
use

SECTION A: BACKGROUND INFORMATION

Tick (✓) the appropriate box or boxes as you answer the following questions:

1. What is your role in relation to drill rig maintenance and repair?

Maintenance Foreman	Maintenance Planner	Maintenance Technician	Parts Coordinator

Helper	Others

2. How long have you been with the mine?

1 to 5 years	
5 to 10 years	
Above 10 years	

3. How long have you been in this role?

1 to 5 years	
5 to 10 years	
Above 10 years	

4. What does your role involve with regard to drill rigs?

.....
.....
.....
.....

Specify

5. What shift are you normally associated with?

Day Shift	
Night Shift	

SECTION B: HUMAN FACTORS

6. Do you think the maintenance personnel are adequately motivated?

Yes	
No	

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.....
.....
.....

Specify

7. Do you think the maintenance get enough rest?

Yes	
No	

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.....
.....

.....S
Specify

8. Do the maintenance personnel have adequate skills to maintain the drills?

Yes	
No	

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.....
.....

Specify

9. Do the maintenance personnel have the necessary skills to maintain drill rigs?

Yes	
No	

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.....
.....

Specify

10. Is the number of maintenance personnel adequate to maintain and repair broken down drill rigs?

Yes	
No	

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.....
.....

Specify

SECTION C: MAINTENANCE FACTORS

11. What type of maintenance is carried out on drill rigs?

Planned maintenance	
Condition Based maintenance	
Predetermined Maintenance	
Breakdown Maintenance	

.....
.....
.....

Specify

12. Do the maintenance personnel repair the drill rigs according to the OEM standards?

Yes	
No	

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.....

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.....
Specify

13. Does the maintenance department have a specific maintenance program?

Yes	
No	

.....
.....
Specify

14. Do you think the time allocated to drill rigs for maintenance is adequate?

Yes	
No	

.....
.....
Specify

15. Do you think the maintenance personnel have the right tools and equipment to carry out maintenance on these machines?

Yes	
No	

.....
.....
Specify

16. How often do you experience breakdowns of drill rigs in a shift?

Every 1 to 3 hours	
3 to 5 hours	
5 to 8 hours	
8 to 10 hours	
10 to 12 hours	
None	

.....
.....
Specify

17. Do the maintenance personnel have the right testing equipment to determine the quality of procured or refurbished components?

Yes	
No	

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.....
.....

Specify

18. What do you think are the major factors contributing to the frequent breakdowns of drill rigs?

Dust	
Water	
Temperature	
Abuse	
Poor maintenance	
Age of Equipment	
Production Demands	
Quality of Spare Parts	
Human Error	

.....
.....
.....

Specify

19. Do the maintenance personnel have adequate maintenance infrastructure?

Yes	
No	

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.....
.....

Specify

SECTION D: ENVIRONMENTAL FACTORS

20. Do the underground conditions contribute to the high rate of drill rig breakdowns?

Yes	
No	

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.....
.....

Specify

21. What do you think is the state of the underground roadways and work sites?

Water logged	
Slippery	
Uneven Terrain	
Steep	
High Temperature	

.....
.....
.....

Specify

22. Do you think the drill rigs are used for the purpose intended for?

Yes	
No	

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.....
.....

Specify

23. How do the underground conditions contribute to the frequent drill rig breakdowns?

.....
.....
.....

Specify

SECTION E: SUPPLY CHAIN FACTORS

24. Do you think the spare parts procured by supply are of acceptable quality?

Yes	
No	

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.....
.....

Specify

25. Do you think the spare parts storage facility are of an acceptable standard?

Yes	
No	

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.....
.....
Specify

26. Are refurbished components repaired to OEM standards?

Yes	
No	

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.....
.....
Specify

27. Does the Supply Department provide spare parts in time?

Yes	
No	

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.....
.....
Specify

28. Does the storage of maintenance replacement parts conform the OEM recommendations?

Yes	
No	

.....
.....
.....
Specify

29. Are the oil and fuel dispensing facilities adequately secured from contamination?

Yes	
No	

.....
.....
.....
Specify

30. Does the supply department have equipment for testing the quality of procured or refurbished components?

Yes	
No	

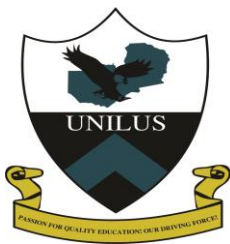
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Specify

Note: If you have further comments to make on this questionnaire, you may still use a separate piece of paper/s to present your comments.

Thank you for your time and Cooperation.

APPENDIX 7
QUESTIONNAIRE FOR MINING PERSONNEL



**UNIVERSITY
OF
LUSAKA**

PHD THESIS QUESTIONNAIRE

Questionnaire Number :

Code: MIN001

Date:

SCHOOL OF POST GRADUATE STUDIES

ANALYSIS OF FACTORS THAT CAUSE DRILL RIG BREAKDOWNS:

A Case of Lubambe Copper Mine

Dear Respondent,

The purpose of this questionnaire is to provide feedback relating to the cause and factors that cause frequent drill rig breakdowns at the mine. This is designed to help the author gather information for analysis to complete his PhD study.

Gathering data from you as a person who operates, maintains or has the knowledge of drill rig activities at the mine is a vital part of this process. Please fill in all parts of this questionnaire and note that the information provided by you in this questionnaire is **STRICTLY CONFIDENTIAL** and will be used for the purposes of this study only. It will not be used in a manner which would allow identification of your individual responses.

for
official
use

SECTION A: BACKGROUND INFORMATION

Tick (✓) the appropriate box or boxes as you answer the following questions:

1. What is your role in the organization?

Mine Captain	Shift Boss	Drill Operator	Drill Rig Assistant

Helpers	Other

2. How long have you been with the mine?

1 to 5 years	
5 to 10 years	
Above 10 years	

3. How long have you been in this role?

1 to 5 years	
5 to 10 years	
Above 10 years	

4. What does your role involve?

.....
.....
.....
.....
.....
.....
.....

5. What shift are you normally associated with?

Day Shift	
Night Shift	

6. Do you think drill rigs have a lot of breakdowns?

Yes	
No	

7. If your answer to 6 above is Yes. What do you think is the major cause of breakdowns?

Dust	
Water	
Temperature	
Abuse	
Poor maintenance	
Age of Equipment	
Production Demands	
Quality of Spare Parts	
Human Error	
Lack of motivation for operators	

.....
.....
.....
.....
specify

8. How often do you think drill rigs breakdown in a shift drill rigs in a shift?

Every 1 to 3 hours	
3 to 5 hours	
5 to 8 hours	
8 to 10 hours	
10 to 12 hours	
None	

SECTION B: HUMAN FACTORS

9. Do you think the drill rig operators are adequately motivated?

Yes	
No	

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.....
.....
Specify

10. Do you think the drill rig operator Training is adequate?

Yes	
No	

.....
.....
.....
Specify

11. Do you think the drill rig operators have adequate skills to operate drill rigs?

Yes	
No	

.....
.....
.....
Specify

12. Do you think Drill rig operators are given enough time to rest?

Yes	
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No	
----	--

13. Do you think the number of drill operators is adequate?

Yes	
No	

.....
.....
.....

Specify

SECTION C: MAINTENANCE FACTORS

14. Do you think the maintenance personnel have the right skills to maintain drill rigs?

Yes	
No	

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.....
.....
.....

Specify

15. Do think the time allocated for drill rig maintenance is adequate?

Yes	
No	

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.....
.....
.....

Specify

16. Do you think the drill rigs are adequately maintained?

Yes	
No	

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.....
.....
.....

Specify

17. Do you think the mine has adequate infrastructure to maintain the drill rigs effectively?

Yes	
No	

.....
.....
.....
.....

Specify

SECTION D: ENVIRONMENTAL CONDITIONS

18. Do you think the drill rigs are used for the right purpose?

Yes	
No	

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.....
.....

Specify

19. Do you think the operating conditions underground contribute to the frequent breakdowns of drill rigs at the mine?

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.....
.....

Specify

20. What do think is the state of the underground work site conation where the drill rigs operate?

Dusty	
Muddy	
Hot	
Uneven Ground	
Poor Visibility	
Weak Rock Structure	

.....
.....
.....
.....

Specify

SECTION E: SUPPLY CHAIN FACTORS

21. Do you think the supply department procure quality maintenance parts for use on drill rigs?

Yes	
No	

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.....

Specify

22. Do you think the Supply department has adequate storage capacity for drill rigs maintenance parts?

Yes	
No	

.....
.....
.....

Specify

23. Are the fuel and oil dispensing facilities adequately secured against contamination?

Yes	
No	

.....
.....
.....

Specify

24. Are the maintenance parts delivered to stores from suppliers and contractor adequately inspected to ensure quality?

Yes	
No	

.....
.....
.....

Specify

25. Do you think the condition of spare parts storage facilities is good?

Yes	
No	

.....
.....
.....

Specify

Note: If you have further comments to make on this questionnaire, you can still use a separate piece of paper/s to present your comments.

Thank you for your time and Cooperation.



Human Factors

Question	Respondent	Response	Theme	Comments
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Do human related factors contribute to drill rig breakdowns	Mine Manager	The senior maintenance personnel do not discipline their subordinates for poor performance. They do not care where the equipment is running of not. The rate of absenteeism for the drill rig personnel is high.	Human related factors	There could be no interest in work which may indicate lack of motivation.
Do human related factors contribute to drill rig breakdowns	Supply Manager	The human factors may not be responsible for the breakdown of equipment. The underground conditions are responsible for breakdowns.	Nature of underground conditions	
Do human related factors contribute to drill rig breakdowns	Human Resources Manager	The managers have failed to promote the operators in acting roles despite several reminders from the human resources department. The operators may not perform as expected in these roles as they may not be remunerated according to the roles they perform.	Human related factors	Could be lack of motivation due to management lack of care for the drill rig operators.
Do human related factors contribute to drill rig breakdowns	Underground Manager 1	The frequency of absenteeism among operators was high and most of them had a negative attitude towards	Human related factors	The issues presented relate to human factors

work. They equally complained of the non-availability of incentive bonuses. The maintenance personnel are casual in approaching work. They do not look at the urgency of the job. Further, they take long time to respond to breakdowns.

<p>Do human related factors contribute to drill rig breakdowns</p>	<p>Manager 2</p>	<p>Maintenance personnel respond to breakdowns at their own time and at times may approach a broken down machine without tools. Nothing seems to bother them.</p>	<p>Human related factors</p>	<p>Could be an indication of lack of motivation</p>
<p>Do human related factors contribute to drill rig breakdowns</p>	<p>Process Plant Manager</p>	<p>The drill rig operators lack the interest in their work. They may observe a potential breakdown, but may not report to the maintenance personnel until it develops into a major breakdown</p>	<p>Human related factors</p>	<p>Could be an expression of lack of motivation</p>
<p>Do human related factors contribute to drill rig breakdowns</p>	<p>Mine Superintendent 1</p>	<p>The machines are old and this demotivates both the maintenance personnel and drill rig operators.</p>	<p>Human related factors</p>	<p>The numerous breakdowns experienced from old machines could</p>

				demotivate the workers
Do human related factors contribute to drill rig breakdowns	Mine Superintendent 2	The maintenance personnel are too ambitious, they always want to be given incentives for the work they form. Since they do not have such incentive they do not pay particular attention to the performance of the equipment, hence the numerous breakdowns.	Human related factors	The need for incentives could result into equipment breakdowns.
Do human related factors contribute to drill rig breakdowns	Mine Superintendent 3	The drill rig operators normally don't want to report potential breakdowns as they would prefer the machine to breakdown so that they could rest	Human related factors	This could happen due to fatigue of employees
Do human related factors contribute to drill rig breakdowns	Training Superintendent	The maintenance personnel do not listen to complaints from the operators and operators continue using the machine out of frustration and the end result is the breakdown of the machine.	Human related factors	Could be caused due to low morale of operators using an unreliable machine
Do human related factors contribute to drill rig breakdowns	Contracts Superintendent	The frequent breakdowns are caused due to the poor quality of procured parts and substandard repair work of major components	Quality related factors	Could relate the frequent breakdowns of drill rigs to poor quality of replacement parts

Do human related factors contribute to drill rig breakdowns	Underground Road Maintenance Superintendent	The breakdowns of equipment are not caused by human related factors, but the rough underground conditions.	Nature of underground conditions	Could be attributed to harsh underground conditions.
Do human related factors contribute to drill rig breakdowns	Engineering Superintendent 1	Mining personnel are lazy to report potential breakdowns and the end result is usually catastrophic failure.	Human related factors	Could be due to lack of interest in work.
Do human related factors contribute to drill rig breakdowns	Engineering Superintendent 3	Both drill rig operators and maintenance personnel tend to ask for extra incentives while the mine is not producing the required amount of ore. Lack of these incentives create an environment where the employees have less care for machines.	Human related factors	The employees could feel they are not adequately incentivised.
Do human related factors contribute to drill rig breakdowns	Engineering Superintendent 4	The drill rig operators are overused and would prefer to damage the machine so that they could rest.	Human related factors	This could be driven from fatigue of employees.
Do human related factors contribute to drill rig breakdowns	Supply Superintendent	Maintenance personnel are demotivated as they are not given any extra incentive for working in harsh conditions. At times breakdowns	Human related factors	Could be as a result of low motivation for maintenance personnel due to lack

		occur from drill sites and the maintenance personnel have to work from such dangerous sites. This demotivates them and do not pay particular attention to preventive maintenance.		of financial incentives.
Do human related factors contribute to drill rig breakdowns	Dewatering Engineer	The maintenance personnel work on old machines that fail frequently. The frequent failures do not give the maintenance personnel enough time to rest. Therefore, they do not carry out maintenance work as per the OEM recommendations as they are always rushing through breakdowns.	Human related factors	This could arise from fatigue of the maintenance personnel
Do human related factors contribute to drill rig breakdowns	Maintenance Planning Engineer	The frequent drill rig breakdowns make the maintenance personnel tired and due to this condition, they tend to take short-cuts in their work. This results in breakdowns of equipment	Human related factor	Could be as a result of fatigue arising from the frequent breakdowns of drill rigs.
Do human related factors contribute to drill rig breakdowns	General Engineering Supervisor 1	The drill rig operators usually absentee themselves from work due to fatigue. This is	Human related factors	Related to fatigue.

		because they carry out more than one role due to the fact that the staffing levels are low. Those who remain working are overworked and do not take care of the machine as they rush their work so that they could knock off to have some rest.		
Do human related factors contribute to drill rig breakdowns	General Engineering Supervisor 2	The staffing levels of the maintenance personnel are low and this makes them work extra hours. This makes the maintenance personnel not to follow correct procedures when working on the equipment. This results in unnecessary breakdowns of equipment.	Human related factors	This could be as a result of not having enough time to rest and concentrate on planned maintenance
Do human related factors contribute to drill rig breakdowns	General Engineering Supervisor 3	Human factors seem not to be the major cause of breakdowns. The equipment is old and need replacing	Age of equipment	The old age of drill rigs could be the major cause of breakdowns.

Do human related factors contribute to drill rig breakdowns	General Engineering Supervisor 4	The mine does not care about the affairs of the people who work in difficult conditions. Therefore, employees are demoralised and use the equipment carelessly resulting in breakdowns.	Human related factors	Could be as a result of low employee morale.
Do human related factors contribute to drill rig breakdowns	Engineering Training Coordinator	The major cause of drill rig breakdowns is not as a result of human factors, but lack of technical training of the drill rig operators. They do not understand some signs of equipment breakdowns until an actual breakdown occurs.	Inadequate operator training	The major cause of breakdowns could be ascribed to lack of technical training for the drill rig operators.
Do human related factors contribute to drill rig breakdowns	Maintenance Planning Engineer	The drill rig operators are overworked as they carry out duo roles due to the low staffing levels. Therefore, they work under fatigue and bound to cause equipment damage.	Human related factors	The frequent drill rig breakdowns could be as a result of drill rig operator's fatigue.
Do human related factors contribute to drill rig breakdowns	Mine Planning Engineer	The number of operators is low and this makes them carry out extra roles. The operators may say the staffing levels are	Human related factors	Fatigue could be one factor that leads to drill rig breakdowns.

		adequate simply because they would like to work over time to make extra money. However, due to fatigue their concentration on work is reduced and this leads to equipment damage.		
Do human related factors contribute to drill rig breakdowns	Blasting Engineer	Operators are overworked due to low staffing levels and corruption where inexperienced operators are used and putting more pressure on the experienced operators.	Human factor related.	These breakdowns could be attributed to fatigue of operators.
Do human related factors contribute to drill rig breakdowns	Chief Surveyor	The drill rig operators have no confidence in management as most of them work in acting roles without being confirmed. Some acted for as long as 5 years. This demoralised the operators and made them less effective at work and the result was damage to equipment.	Human related factors	Lack of motivation could be associated with the numerous drill rig breakdowns.
Do human related factors contribute to drill rig breakdowns	Ventilation Engineer	The underground conditions are tough and the drill rig operators need some form of a financial incentive to work harder and look after the	Human related factors	Lack of motivation could be sited as one of the factors leading to drill rig breakdowns.

		<p>machines well. This does not apply at the mine. If the operator does not look after his machine well, then the machine is prone to unnecessary breakdowns.</p>		
Do human related factors contribute to drill rig breakdowns	Mining Consultant 1	The drill rig operators cause equipment breakdown because they hide potential faults so that they could finish drilling and knock off.	Human related factors	This could be as a result of fatigue or negligence.
Do human related factors contribute to drill rig breakdowns	Mining Consultant 2	The operators do not care for the machines; they pass the equipment in water and rough ground. They always complain of not having extra incentives for the work they are involved with.	Human factor related	Cause of breakdowns could be attributed to lack of motivation.
Do human related factors contribute to drill rig breakdowns	Mining Consultant 3	Almost all drill rig operators are in acting roles and feel management does not care about their affairs. They do not put in all the best in their work and they end up using machines without following the set procedures. This creates unnecessary breakdowns of equipment.	Human related factors	Lack of motivation due to working in roles they are not remunerated accordingly could result to breakdown of equipment.

Do human related factors contribute to drill rig breakdowns	Mining Consultant 1	Human factors do not cause drill rig breakdowns. The equipment is old and prone to breakdowns.	Age of drill rigs	The cause of the frequent drill rig breakdowns could be attributed to the old age of machines.
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Source: Field Data

Maintenance Factors

Question	Respondent	Response	Theme	Comments
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mine Manager	The maintenance personnel have the skills to maintain the equipment. All they need is urgency in responding to breakdowns. Infrastructure is adequate for them to carry out their tasks.	Human factor related.	Attitude could contribute to the numerous drill rig breakdowns.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Safety Manager	The frequent breakdowns pull the maintenance personnel from carrying out planned maintenance and this is worsened by the non-availability of workshops underground.	Related to maintenance practices and infrastructure.	The non-availability of underground workshops could be cited as a contributing factor to poor

				maintenance practices.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Supply Manager	Maintenance personnel do not follow the OEM standards practices because of the numerous breakdowns at the mine. They rush through work to attend to breakdowns, one from the other. Additionally, their workshop has no special testing tools to verify the integrity of the repaired or procured parts. This situation results in premature failure of the procured parts	Related to maintenance practices and infrastructure.	Lack of testing equipment and non-adherence to OEM standards has been cited as one factor that could lead to drill rig breakdowns.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Human Resources Manager	The maintenance personnel have the skills and undergo extra OEM training. Therefore, their maintenance practices may not contribute to breakdowns of drill rig at the mine. However, the infrastructure is not adequate. Their maintenance program cannot support such a large fleet of equipment.	Infrastructure related factor.	Breakdowns of drill rigs could be attributed to lack of maintenance infrastructure .
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Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Underground Manager 1	The maintenance personnel do not follow the OEM maintenance practices due to production pressure. Further, the	Related to maintenance practices and infrastructure	The frequent drill rig breakdowns could be attributed to the non-adherence to OEM standards and
--	-----------------------	--	---	---

mine has only one workshop on surface which creates congestion when there are two or three broken down equipment in the workshop.

inadequate workshop space.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?

Underground Manager 2

The infrastructure is adequate and the maintenance personnel have the skills to maintain the machines. Additionally they follow the OEM standards. The underground conditions are bad.

Underground operating conditions

Attributes the frequent drill rig breakdowns to the rough underground operating conditions.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?

Process Plant Manager

The maintenance personnel spend their time moving up and down looking for tools and parts as they do not

Related to maintenance practices and infrastructure

Lack of underground workshops could be cited as a contributing factor to poor

have a workshop or satellite store underground. This situation takes most of their time and trade off planned maintenance which is critical to the reliability of the equipment.

<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>Mine Superintendent 1</p>	<p>The maintenance practices are not properly followed as a result of production pressure where the equipment is always required to be in production at all times. Some procedures are skipped to avoid incurring extra downtime. If the breakdowns are controlled, the</p>	<p>Related to maintenance practices and infrastructure</p>	<p>Highlights production pressure as a cause of not following the correct maintenance practices</p>
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infrastructure
 should be
 adequate.

<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>Mine Superintendent 2</p>	<p>The lack of underground workshops makes the maintenance personnel take a longer time to repair equipment. In some cases they have to go to surface to get the parts or tools. This process may cover the whole shift. Hence neglecting planned maintenance.</p>	<p>Related to maintenance practices and infrastructure</p>	<p>Lack of workshop facilities underground could be cited as one of the contributing factors to drill rig breakdowns.</p>
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Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mine Superintendent 3	The maintenance practices are not followed. The maintenance personnel spend more time resolving problems and have little time for planned maintenance which could help reduce breakdowns if properly followed. The mine has only one workshop which is not enough.	Related to maintenance practices and infrastructure	Maintenance time is not enough due to the numerous equipment breakdowns.
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Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Training Superintendent	The maintenance practices are good as the maintenance personnel follow the manuals of the OEM in carrying out maintenance	Infrastructure related factors	Lack of infrastructure could be sited as one of the factors contributing to the frequent drill rig breakdowns.
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and they follow the check sheets when maintaining the equipment. What makes it appear like the infrastructure is not adequate, is the high rate of breakdowns to attended to in the workshop

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?

Contracts Superintendent

The maintenance personnel have good maintenance practices and the infrastructure is adequate. But because the underground condition where the machines operate from are rough, the machines breakdown frequently. The continuous drill rig breakdowns

Related to underground operating conditions.

Operating conditions could be cited as one of the causes of drill rig breakdowns.

make the maintenance skip some maintenance procedures. The workshop can handle about eight machines at a time and this must be enough if the breakdowns of drill rigs are controlled.

<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>Underground Road Maintenance Superintendent</p>	<p>The number of maintenance personnel is not adequate and this makes it difficult to follow the correct maintenance practices. The non-availability of the workshop underground makes it difficult for the maintenance personnel to work. At times they work from muddy places</p>	<p>Related to maintenance practices and infrastructure</p>	<p>Non-availability of underground workshop could make it difficult for the maintenance personnel to work according to the OEM standards.</p>
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		which affect the performance of the installed parts.		
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Superintendent 1	The maintenance practices are followed though the infrastructure in terms of maintenance programs is not adequate. The current system cannot flag maintenance intervals and provide warning for late maintenance.	Related to maintenance practices and infrastructure	Could attribute the frequent drill rig breakdowns to inadequacy of maintenance planning and scheduling tools.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Superintendent 2	The zeal to follow the OEM maintenance practices is there for the maintenance personnel. However, the inadequacy of both physical structure and software prohibits the maintenance personnel to work to OEM standards.	Related to maintenance practices and infrastructure	Infrastructure to support good maintenance practices may not be adequate.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Superintendent 3	The maintenance practices are hindered by lack of correct tools, inadequate planning system and the inadequate workshop space. Planned maintenance and major component replacement are carried out in the same workshop. These two activities are supposed to be separated, but the main constraint is that there is only one workshop available on site.	Related to maintenance practices and infrastructure	Workshop space cited as one of the contributing factors to drill rig breakdowns.
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Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Superintendent 4	The maintenance practices are good and the infrastructure is adequate. The only problem is that the maintenance personnel are overwhelmed with the numerous breakdowns that are caused due to wrong use of the equipment. Face rigs for example are	Wrong use of machine.	Wrong use of equipment could cited as one of the causes of drill rig breakdowns.
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		used for support. This causes the front part of the machine to fail as it is not designed for this operation.		
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Supply Superintendent	The parts from suppliers are not tested before being used to determine their integrity. This is a bad practice in itself. Not having testing equipment to carry out such tests is a lack of infrastructure. Therefore, the two put together contribute to the premature failure of the new components, hence the numerous breakdowns.	Related to maintenance practices and infrastructure	Lack of test equipment could lead to not following the acceptable maintenance practices of receiving maintenance and replacement parts.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Projects Engineer	The maintenance practices are good and the infrastructure is adequate for the maintenance personnel to carry out their work effectively. However, the distance travelled by the machines from underground to surface for maintenance is long and the	Related to inadequate infrastructure.	The frequent drill rig breakdowns could be attributed to inadequate infrastructure

		bad roadway conditions affect the major components of the machine such as the drivetrain. This results into equipment breakdowns.		
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Dewatering Engineer	The non-availability of underground workshops makes it very difficult for the maintenance personnel to follow the right maintenance practices.	Related to maintenance practices and infrastructure	Inadequacy of workshop facilities underground could hinder good maintenance practices.
	Maintenance Planning Engineer	The correct maintenance practices are not followed due to lack of infrastructure. The current maintenance program does not support planning and scheduling of work.	Related to maintenance practices and infrastructure	Planning and scheduling may not be adequately implemented due to lack of maintenance infrastructure
	General Engineering Supervisor 1	The maintenance practices are affected by the lack of good maintenance facilities such as an effective maintenance program	Related to maintenance practices and infrastructure	Could attribute the ineffective maintenance practice to lack of maintenance infrastructure

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	General Engineering Supervisor 2	The maintenance practices are affected by the non-availability of an effective Enterprise Resource Planning system to direct maintenance. Most of the inputs and outputs are manual, making it difficult to track the equipment performance and maintenance schedules.	Related to maintenance practices and infrastructure	The maintenance program may not be adequate to support maintenance planning and scheduling.
	General Engineering Supervisor 3	The idea of carrying out planned maintenance in the same workshop with major component replacement is not ideal. The two activities should be separated. The concentration usually is on component replacement and maintenance is neglected.	Related to maintenance practices and infrastructure	Inadequacy of workshop space could affect maintenance practices.

<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>General Engineering Supervisor 4</p>	<p>The maintenance planners do not have adequate planning and scheduling skills. This results into wrong scheduling of machines for maintenance with some totally missing maintenance. This results into breakdowns as some replacement parts may work over and above their operating cycle.</p>	<p>Related to maintenance practices and infrastructure</p>	<p>Lack of planning skills could be identified as one of the factors contributing to the frequent drill rig breakdowns.</p>
<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>Engineering Training Coordinator</p>	<p>The maintenance section has planners carrying out the work of both planning and scheduling. This leaves the system without checks as planning needs to check how the work is scheduled and closed out. This makes it difficult to schedule machines for maintenance if there are many broken down machines in the workshop as it becomes 'first come first save'</p>	<p>Related to maintenance practices and infrastructure</p>	<p>Lack of human resources could contribute to the numerous drill rig breakdowns.</p>

		which distorts planned maintenance. This results into unnecessary breakdowns.		
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Maintenance Planning Engineer	The planners and maintenance personnel have the necessary skills. However, the maintenance program available for planning is not adequate looking at the high number of machines to be maintained. A planning tool that incorporates both planning and prompting maintenance dates would be more ideal	Related to maintenance practices and infrastructure	Planning and scheduling tools may not be adequate.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mine Planning Engineer	The maintenance personnel should have a workshop underground for carrying out planned maintenance and minor breakdowns. This will improve maintenance planning and provide enough working space for major component	Related to maintenance practices and infrastructure	Inadequate workshop space could be identified as a constraint hindering good maintenance practices. Hence, the numerous drill rig breakdowns

		replacement on surface.		
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Blasting Engineer	The only way to reduce the numerous breakdowns of drill rigs at the mine is to introduce underground workshops to cater for minor breakdowns and maintenance.	Related to maintenance practices and infrastructure	Inadequate workshop space could be identified as a constraint hindering good maintenance practices
	Chief Surveyor	The roadway and work site conditions must be improved in order to reduce breakdowns of drill rigs. The maintenance practices are compromised due to the maintenance personnel consistently attending to breakdowns other than concentrating on planned maintenance.	Related to maintenance practices and infrastructure	Rough underground conditions could contribute to the numerous drill rig breakdowns, and this robs the maintenance personnel of the time to carry out adequate planned maintenance on equipment. .
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Ventilation Engineer	Once the operating conditions are improved, the equipment breakdowns will be reduced. The maintenance practices are good and the infrastructure is available.	Not related to maintenance practices and infrastructure	Cited poor environmental conditions as contributors to drill rig breakdowns.

<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>Mining Consultant 1</p>	<p>The water in operating areas and high temperature affect the performance of equipment. If these are corrected, the current maintenance infrastructure could be available to handle the equipment fleet.</p>	<p>Related to underground operating conditions</p>	<p>Underground operating conditions could be cited a one of the factors responsible for drill rig breakdowns.</p>
<p>Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?</p>	<p>Mining Consultant 2</p>	<p>Underground workshops are required to minimise the drill rig breakdowns. Drill rigs are not meant to be driven a longer distance. A combination of poor roadways and rough work site conditions contribute to breakdowns of drill rigs. The maintenance personnel have good maintenance practices and the infrastructure is adequate. The numerous breakdowns deprive the maintenance personnel of time to adequately plan and maintain</p>	<p>Related to harsh underground operating conditions.</p>	<p>Underground environmental conditions could be cited as one of the contributing factors to drill rig breakdowns.</p>

		the drill rigs according to the OEM standards.		
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mining Consultant 3	The operator training must include basic maintenance for the operators to proactively detect potential breakdowns and resolve those within their capability and report major ones to maintenance personnel before a breakdown occurs. Otherwise the maintenance practices on the mine are good and the infrastructure is adequate.	Related to operator training	Could attribute the frequent drill rig breakdowns to lack of technical skills for drill rig operators to proactively detect potential equipment faults.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Consultant 1	The maintenance system used does not support planned maintenance. Due to this the planning and scheduling of drill rigs is not effective. This condition leads to fatigue failure of some components due to prolonged use.	Related to maintenance practices and infrastructure	Maintenance planning system could be cited as a deterrent to good maintenance practices. Hence, the frequent drill rig breakdowns

Source: Field data

Environmental Factors

Question	Respondent	Response	Theme	Comments
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Mine Manager	The roadways and operating areas are in a bad state. The worksites are usually under water and this is mainly because of the rampant power trip-outs causing dewatering pumps to stop running.	Operating conditions contribute to drill rig breakdowns.	Roadways and worksite conditions could be cited as contributing factors to drill rig breakdowns.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Safety Manager	The operating conditions may not be so bad. The drill rig operator skills are below the acceptable standards	Related to drill rig operator skills.	Inadequate drill rig operator's skills could be cited as one of the contributing factors to drill rig breakdowns.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Supply Manager	The rate of failure of the drill rig parts indicate that the operating conditions are not good. Further, most of the parts that fail prematurely are brought to supply full of mud and water.	Operating conditions contribute to drill rig breakdowns.	Mud and water found in failed parts could be the cause of failure, hence operating conditions could be one of the contributing factors to drill rig breakdowns.

<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>Human Resources Manager</p>	<p>The operating conditions are in a poor state. Operators complain of being disciplined for breaking machines. However, when further investigations are carried out, it is often found out that, the machines are affected by the harsh conditions underground.</p>	<p>Operating conditions contribute to drill rig breakdowns.</p>	<p>The harsh equipment operating condition could contribute to the frequent drill rig breakdowns.</p>
<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>Underground Manager 1</p>	<p>The underground conditions are poor and affect the operation of drill rigs.</p>	<p>Operating conditions contribute to drill rig breakdowns.</p>	<p>Underground conditions contribute to the frequent drill rig breakdowns.</p>
<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>Underground Manager 2</p>	<p>The operating conditions are not very bad, however, some of these breakdowns are caused due to using machines for purposes they are not designed.</p>	<p>Wrong use of equipment.</p>	<p>Wrong use of machines could be cited as one of the causes of drill rig breakdowns.</p>

Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Process Plant Manager	The underground operating conditions are in a bad state due to poor design of mining. This needs to be improved. The mine does not have drain hole to keep the water away from the worksite areas.	Operating conditions contribute to drill rig breakdowns.	Poor mine design could be identified as a factor that contributes to drill rig breakdowns.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Mine Superintendent 1	Drill rigs are meant to work in harsh conditions. Therefore, the underground conditions cannot be considered as bad for drill rig operations. Drill rig operator competency should be assessed	Drill rig operator skills	Lack of drill rig operator skills could result into drill rig breakdowns.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Mine Superintendent 2	Though the operating conditions are one of the major contributors to drill rig breakdowns, operator practices may be a leading factor in creating breakdowns.	Operating conditions contribute to drill rig breakdowns.	Operator's practices identified as one major cause of drill rig breakdowns.

<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>Mine Superintendent 3</p>	<p>Drill rigs are supposed to work in the harsh underground conditions without difficulties. What contributes to the numerous drill rig breakdowns is that the maintenance personnel do not have adequate maintenance facilities.</p>	<p>Inadequate maintenance facilities</p>	<p>The lack of maintenance facilities could be cited as one of the contributing factors to drill rig breakdowns.</p>
	<p>Training Superintendent</p>	<p>Underground conditions are rough and contribute to drill rig breakdowns. Most areas are rough and waterlogged.</p>	<p>Operating conditions contribute to drill rig breakdowns.</p>	<p>Water and rough ground conditions could contribute to component failure. Hence, the frequent drill rig breakdowns</p>
<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>Contracts Superintendent</p>	<p>The high number of warranty claims rejected due to parts being found with mud inside indicate that the underground operating conditions are in a bad state and contribute to premature failure of equipment parts.</p>	<p>Operating conditions contribute to drill rig breakdowns.</p>	<p>The nature of component failure could indicate that the nature of the underground conditions contribute to the frequent drill rig breakdowns.</p>

Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Underground Road Maintenance Superintendent	The underground conditions are not as bad. The operators are not motivated and do not take care of the equipment.	Related to human factors.	Low motivation of drill rig operators could be cited as one of the causes of drill rig breakdowns.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Engineering Superintendent 1	The roadway and worksite conditions are bad and this can be seen from the frequent failure of equipment drivetrain.	Operating conditions contribute to drill rig breakdowns	The nature of the equipment operating conditions could be associated with the frequent failure of the equipment drivetrain.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Engineering Superintendent 2	The water usually found in failed machine axles indicate that the operating conditions where drill rigs operate are not good and contribute to failure of equipment axles.	Operating conditions contribute to drill rig breakdowns	Failure of axles could be attributed to bad worksite conditions. Hence, this condition could contribute to the numerous drill rig breakdowns.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Engineering Superintendent 3	Most of the electrical short circuits on drill rigs are caused by ingress of muddy water into electrical components. This indicates that the	Operating conditions contribute to drill rig breakdowns	Muddy water into electrical components could result into failure of such parts. Hence, the high number of drill rig breakdowns.

		conditions from which the drill rigs operate are not good and contribute to equipment breakdowns.		
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Engineering Superintendent 4	The frequency of center section failure is high and this is caused by the machine running over uneven ground.	Operating conditions contribute to drill rig breakdowns	Uneven ground could be associated with failure of the drill rig center section.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Supply Superintendent	The tyres of drill rigs fail prematurely due to running in water most of the time.	Operating conditions contribute to drill rig breakdowns	The high frequency of drill rig tyre failure could be associated with water in work places.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Projects Engineer	Most of the failed components have been found with muddy water inside.	Operating conditions contribute to drill rig breakdowns	Failure of most major components could be attributed to muddy water.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Dewatering Engineer	The construction of water dams along the decline (main underground roadways) cause the roads to flood when there is a pump failure or maintenance work on pumps. When	Operating conditions contribute to drill rig breakdowns	Poor design of dewatering dams contributes to damaging of roadways which in turn affect the equipment drivetrain and tyres.

the water runs along the roadway, it creates pot holes and water settles in these holes. Such conditions contribute to failure of equipment drive components as well as tyres.

<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>Maintenance Planning Engineer</p>	<p>The rate of drivetrain section of the drill rigs is high and this is due to the uneven ground.</p>	<p>Operating conditions contribute to drill rig breakdowns</p>	<p>Uneven ground could be cited as one of the contributing factors to failure of equipment drivetrain. This contributes to the numerous drill rig breakdowns.</p>
<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>General Engineering Supervisor 1</p>	<p>The ground in some drill site areas is weak and while drilling, rocks fall off and damage the front part (boom) of the machine.</p>	<p>Operating conditions contribute to drill rig breakdowns</p>	<p>Weak ground conditions could contribute to the machine boom damage through rock falls.</p>
<p>Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?</p>	<p>General Engineering Supervisor 2</p>	<p>The operating conditions are not too bad. The mining faces are not adequately cleaned before commencing drilling and this causes rocks</p>	<p>Poor house keeping</p>	<p>Poor housekeeping of the mining face could be noted as one factor causing rocks to fall from the mining face onto the</p>

		to fall from the face and damage the boom and the feed hoses.		machine boom causing damage to the equipment.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	General Engineering Supervisor 3	Belly plates usually get damaged due to the machines running over protruding ground. The extent of this is damage to the equipment oil sump.	Operating conditions contribute to drill rig breakdowns	Rough ground could be cited as the cause of equipment oil sump damage. This results into equipment breakdown.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	General Engineering Supervisor 4	The major failure mode of drill rig tyres is sidewall cut. This arises due to rough conditions.	Operating conditions contribute to drill rig breakdowns	Rough side walls could damage equipment tyres.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Engineering Training Coordinator	The drill site areas are hot and the air flow is low. This causes the equipment to use the same circulating air. This causes the equipment engine to overheat and subsequently fail.	Operating conditions contribute to drill rig breakdowns	High temperature could be cited as a contributing factors to failure of drill rig engines.
Do equipment Operating Conditions Contribute to Breakdowns	Maintenance Planning Engineer	The frequency of damaged tyres is high indicating rough operating conditions.	Operating conditions contribute to drill rig breakdowns	Rough surfaces could cause premature failure of equipment tyres

of Drill Rigs?				
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Mine Planning Engineer	The underground conditions are not bad. The operator's practices are responsible for the numerous drill rig breakdowns.	Related to human factors.	Operator practices could contribute to the frequent drill rig breakdowns
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Blasting Engineer	The operating conditions are not so bad. Some drill rigs are used for wrong purposes	Related to wrong use of equipment	Drill rigs could be applied wrongly outside the design specifications.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Ventilation Engineer	In drill site areas, the flow of air is low and this causes the areas to be hot. This is because of the inadequate ventilation raises (ventilation tunnels)	Operating conditions contribute to drill rig breakdowns	Poor ventilation could affect the machine performance and eventually resulting into equipment failure.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Mining Consultant 1	There are no drainages along the work areas and roadways. This causes water build up in these places and affect the equipment.	Operating conditions contribute to drill rig breakdowns	Water could affect most of the equipment parts leading into equipment failure.
Do equipment Operating Conditions Contribute to	Mining Consultant 2	In some areas, the ground is in layers and breaks off while drilling. These rocks	Operating conditions contribute to drill rig breakdowns	Geological formation could be cited as one factor leading to

Breakdowns of Drill Rigs?		fall onto the front part of the machine causing damage.		equipment damage.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Mining Consultant 3	In certain drill site areas, drill rods tend to jam while drilling leading to rod breakage or damage to the drifter.	Operating conditions contribute to drill rig breakdowns	Ground conditions could cause stuck rod and subsequent failure of drifters.
Do equipment Operating Conditions Contribute to Breakdowns of Drill Rigs?	Engineering Consultant 1	Most of the drill rig tyres fail due to steel penetrations.	Related to housekeeping	Housekeeping could be identified as one of the contributing factor to drill rig premature tyre failure.

Source: Author 2019

Table 5.37: Environmental Factors

Do environmental factors Contribute to Breakdowns of Drill Rigs?	Not related to Environmental conditions	Related to environmental conditions
	8	27
	22.9%	77.1%

Source: Field Data

Supply Chain Factors

Question	Respondent	Response	Theme	Comments
Do Supply Chain related factors and quality of replacement parts Contribute to	Mine Manager	Supply Chain factors and quality of parts do contribute to equipment breakdowns on the mine. Most of the	Supply Chain related factors and quality	Use of substandard contractors to repair equipment components could be cited as one of the

<p>Breakdowns of Drill Rigs?</p>	<p>contractors who repair components do not have quality infrastructure and tools to work on complicated components.</p>	<p>causes of premature failure of components.</p>	
<p>Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?</p>	<p>Safety Manager</p>	<p>The mine does not know the conditions of spare parts used when contractors assemble components. Second hand parts are used at times and this results into premature of these components.</p>	<p>Supply Chain related factors and quality</p> <p>Quality of repaired components could be identified as one of the causes of premature failure of components.</p>
<p>Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?</p>	<p>Supply Manager</p>	<p>Supply chain related factors and quality may not contribute to drill rig breakdowns. The major cause of drill rig breakdowns is the way parts are handled by the maintenance personnel after drawing them from stores. The parts are not covered when being taken to breakdown sites.</p>	<p>Related to handling of parts</p> <p>Poor handling of parts compromise quality and subsequently result in premature failure of parts when fitted on equipment.</p>

Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?	Human Resources Manager	Supply Chain related factors and quality are not a contributing factor to breakdowns of drill rigs. The old age of equipment contributes more to these failures.	Related to old age of equipment	Old equipment could be prone to frequent breakdowns.
Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?	Underground Manager 1	Supply Chain factors and quality are responsible for the numerous drill rig breakdowns. There is no stores for keeping parts underground, therefore, parts are exposed to dust and moisture.	Supply Chain related factors and quality	Lack of storage facilities could affect the quality of parts and lead into premature failure of these parts.
Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?	Underground Manager 2	The parts are not tested upon delivery at stores. Only visual inspection is carried out.	Supply Chain related factors and quality	Lack of testing equipment result into accepting inferior parts that may not work as desired when fitted on equipment.
Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?	Process Plant Manager	Supply Chain usually goes for cheaper sources of maintenance parts without taking into consideration	Supply Chain related factors and quality	Cheaper parts may not be of good quality. Therefore, substandard parts could breakdown before their

parts Contribute to Breakdowns of Drill Rigs?		the quality of parts. This on several occasions has led to premature failure of parts.		intended maturity period
Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?	Mine Superintendent 1	The conditions in which the parts are replaced underground are not good. Water and dust affect the life cycle of these parts.	Related to operating conditions	Underground conditions could be sited as contributing factors to drill rig breakdowns.
Do Supply Chain related factors and quality of replacement parts Contribute to Breakdowns of Drill Rigs?	Mine Superintendent 2	Lack of proper storage facilities underground contributes to the deteriorating of quality of the maintenance parts as parts are exposed to moisture and dust.	Supply Chain related factors and quality	Lack of storage facilities could attribute to poor quality of replacement parts reducing the lifespan of the parts
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Training Superintendent	Lack of testing equipment at stores allows poor quality parts to be accepted onto the mine site and used on drill rigs.	Supply Chain related factors and quality	Non-availability of testing equipment could result into accepting inferior parts that may not be fit for purpose.
Do maintenance practices and	Contracts Superintendent	The quality of parts is good. However, parts are mishandled in transit to	Related to handling of parts to breakdown sites	Handling of parts by maintenance personnel to breakdown

Infrastructure contribute to breakdowns of drill rigs?	breakdown sites which are associated with moisture and dust.		sites could result into damage of parts rendering them ineffective.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Underground Road Maintenance Superintendent	The machines are old and even if good parts are used, they will still be affected by the general old parts.	Related to the old age of equipment The numerous drill rig breakdowns could be attributed to the old age of machines.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Superintendent 1	The replacement parts installed on equipment are not tested since there is no testing equipment at stores or at the maintenance workshop. This conditions is not good and other parts fail immediately after installations.	Supply Chain related factors and quality Lack of testing equipment could render the mine accepting inferior equipment parts.
	Engineering Superintendent 2	Supply have no specific part numbers for ordering maintenance parts, there are various part numbers which becomes difficult to order the original part that may be fit for purpose.	Supply Chain related factors and quality Wrong or inadequate specification of maintenance parts when ordering could result into ordering wrong parts that may not perform as intended when fitted on a machine.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Superintendent 3	The storage of big items such as axles and cylinders at stores is not good. These parts are kept outside without shelter in direct sunlight. Heat affects internal seals and once such a component is put into service, the seals fail within a short time.	Supply Chain related factors and quality	When certain equipment parts are exposed to water, heat and dust, their reliability is reduced and could not perform as intended when put in service.
	Engineering Superintendent 4	The contractors given major components to repair do not use recommended parts, but use alternative parts that may not withstand the harsh underground conditions.	Supply Chain related factors and quality	To make extra profit, contractors who repair major components for the mine may use cheaper and inferior parts on components repaired. These components may fail prematurely when in service.
	Supply Superintendent	The quality of parts is good. However, the equipment on which these parts are used is old.	Related to old age of machines	Old equipment could be prone to breakdowns.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Projects Engineer	Though the quality may be good, the harsh underground conditions affects the performance of parts.	Related to underground operating conditions	Drill rig breakdowns could be attributed to the harsh underground conditions.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Dewatering Engineer	A mixture of uncontrolled water and mud affects the equipment.	Related to underground operating conditions	The harsh underground operating conditions could contribute to the numerous drill rig breakdowns.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Maintenance Planning Engineer	Due to technological advancement, it has become difficult to tell which parts is original and which one is not. Therefore, advanced testing equipment is required to keep up with this phenomenon. Unfortunately the mine does not have such equipment and ends up procuring substandard parts that look original.	Supply Chain related factors and quality	Lack of testing equipment could result into procuring substandard replacement parts that may not be fit for the intended purpose.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	General Engineering Supervisor 1	The major parts are not stored properly at supply. They are kept in open spaces.	Supply Chain related factors and quality	Poor storage of parts could contribute to the early failure of replacement parts when

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	General Engineering Supervisor 2	The use of substandard contractors to repair major components contributes to premature of parts. Supply select contractors on the basis of price and not quality.	Supply Chain related factors and quality	put into service. Poor quality of parts procured on the basis of low price may contribute to the numerous drill rig breakdowns.
	General Engineering Supervisor 3	Underground conditions are so rough that even if new and quality parts are used, they do not take long in service.	Related to underground conditions	The rough underground conditions could be cited as a contributing factor to equipment breakdowns.
	General Engineering Supervisor 4	The non-availability of a reliability section makes it difficult to identify poor quality parts. The maintenance personnel only pick parts from supply and install them on machines. It is not easy to identify a 'copyright' part by merely looking at it.	Supply Chain related factors and quality	Lack of specialised inspection of procured parts could lead into accepting poor quality parts that could not perform as expected.
	Engineering Training Coordinator	The contractors that repair components do not have special tools	Supply Chain related factors and quality	Components not repaired to the OEM specifications may not work as intended

		and equipment to work on components that require precision setting of parts.		when fitted onto the machine.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Maintenance Planning Engineer	Supply needs to put up satellite stores with good storage facilities underground. Currently there are no standard stores underground except substandard ones run by operating personnel.	Supply Chain related factors and quality	Parts not stored properly could not perform as expected if put into use.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mine Planning Engineer	Storage of goods must be improved to maintain the quality of parts. Currently parts like hydraulic cylinders are kept in open spaces.	Supply Chain related factors and quality	Parts not stored properly could not perform as expected if put into use.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Blasting Engineer	The quality of parts used on drill rigs is good. However, the machines are used for operations they are not designed for.	Related to wrong application of the machine	Wrong application of the machine could lead to damage of the equipment parts leading to the machine breaking down.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Chief Surveyor	The water in work places affect the performance of equipment parts. Quality and storage of	Related to operating conditions	Uncontrolled water in work places cited as a contributing factor to

		parts is fairly good.		equipment breakdowns.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Ventilation Engineer	The quality of parts is not bad, the heat underground contributes to failure of sensitive parts such as engines.	Related to underground operating conditions	Harsh equipment operating conditions could lead to breakdown of equipment parts.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mining Consultant 1	The confusion in part numbers of replacement parts leads supply to ordering inferior parts.	Supply Chain related factors and quality	Using wrong part numbers for ordering replacement parts could result into receiving substandard parts that may not last long in service or may out rightly fail to fit.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mining Consultant 2	The storage facilities are not adequate such that the bigger components are kept outside in the open. This affects the quality of replacement parts.	Supply Chain related factors and quality	Poor storage of parts could be cited as a contributing factor to premature failure of replacement parts.
Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Mining Consultant 3	The quality of procured replacement parts is not good and this is due to buying from cheaper sources and neglecting quality.	Supply Chain related factors and quality	Cheaper parts may not be of good quality, therefore, if such parts are used on equipment, they may fail before their predetermined life cycle.

Do maintenance practices and Infrastructure contribute to breakdowns of drill rigs?	Engineering Consultant 1	Contractors who repair components use old parts because the assembling of these components is not witnessed by the mine personnel.	Supply Chain related factors and quality	Lack of inspection of repaired parts could result into receiving components repaired with old internal parts. Such components may not perform as expected.
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Source: Field Data

APPENDIX 9
WARRANTY CLAIM

WARRANTY OF CLAIM

		DATE	CLAIM NO.
Affiliate Or Distributor: Stores To Identify Suppler		Address:	COUNTRY: Zambia
Customer's Name: Lubambe Mine		Address :	COUNTRY : Zambia
Machine Model : TH54	Date Service	Machine Serial No. Site Fleet ID:DT05	Engine Hours. 128Hrs
Failed Component: Engine	Component Model No. DETROIT	Component Serial No. No. 06R1050735	Engine Serial No. 06R1050735
Date Sold	Date In Service:	Date Failure: 03-08-2018	Operation Hours: 128Hrs
Type Of Mine, Construction Work, Etc. Underground Mine			
Description of the damage , exact location of the damage, special conditions and other facts involved, measures, remedy			

QTY	INSTALLED PART NUMBER	REMOVED PART NUMBER/ SERIAL	CATALOGUE DESCRIPTION	PRICE EACH	TOTAL
	R23538451				
Photo Enclosed Action Requested: Issues Credit Replace Parts			For Factory Use	Total Parts	
One Failure On Each Claim, Use Type Writer, Submit Claim Within 30 Days From Damage, Airmail First Sheet And File One, Retain Parts Available For Inspection, A Photo Is Requested And May Eliminate Need Of Returning The Parts				Total Labour	
For Regional Use		<input type="checkbox"/> Claim Returned For Completion			

		Date:	By:
<input type="checkbox"/> Claim Forwarded For Factory		<input type="checkbox"/> Claim Accepted	<input type="checkbox"/> Claim Rejected
Date:	By:	Date:	By:
<input type="checkbox"/> Claim Accepted	<input type="checkbox"/> Claim Rejected	Date Of Credit	Amount
Date:	By:		Credit No.
Date Claim Received			Inv.

APPENDIX 10
APPROVAL LETTER FROM LUBAMBE
COPPER MINE



LUBAMBE COPPER MINE LIMITED

Shaft 2, Chimfunshi Road, Chililabombwe

PO Box 11215, Chingola, Zambia

Telephone: +260 212 325 800

+260 096 245 800

Fax: +260 212 310 055

To: Dyson Galatia

Mine No. 10062211

Designation: Engineering Manager

From: The General Manager

Lubambe Copper Mine

Date: 20th June 2016.

Dear Dyson,

**RE: WRITING OF AN ACADEMIC PAPER ON UNDERGROUND PRODUCTION
EQUIPMENT BREAKDOWNS AT LUBAMBE COPPER MINE.**

Following our discussion where you indicated that you have been writing a paper on the major causes of breakdown of underground production equipment at Lubambe Copper Mine and that you would like to further proceed with this paper for academic purposes through the University, I authorise you to carry on with your paper on academic basis.

However, it should be noted that all the data collected from the mine and used in this document shall be for academic reason only.

I further wish you all the best in this positive endeavour you have undertaken.

**JACQUES VAN DER BIJL
GENERAL MANAGER**

LUBAMBE COPPER MINE LIMITED

Company Registration Number: 37227

Directors: Ms C M Johnstone, Dr P C Kasolo, F A Uys, W G K Mutale, C Spollen

VAT No. 10090534-13



JOINT VENTURE

APPENDIX 11
LETTER OF ADMISSION TO THE DOCTOR
OF PHILOSOPHY DEGREE PROGRAM



UNIVERSITY
OF
LUSAKA

Plot No. 37413, off Alick Nkhata Road, Mass Media, P.O. Box 36711, Lusaka
Phone: +260 211 233407, 258409, Fax: +260 211 233409, E-mail: ictar@zamnet.zm, unilus@zamnet.zm

All correspondence should be addressed to the rector

Friday, February 24, 2017

Galatia Dyson
0967820176
5251 Coronation
Kalulushi
Copperbelt-Zambia

Dear Mr. Galatia ,

RE: ADMISSION IN THE DOCTOR OF PHILOSOPHY IN PROJECT MANAGEMENT DEGREE PROGRAMME – JANUARY 2017 INTAKE

On behalf of the University Senate, I am pleased to inform you that your application for the Doctor of Philosophy in Project Management programme at the University of Lusaka has been successful. The programme commences in January 2017. However there are a few steps to be followed to complete your registration as a DBA student:

Your Student number is **PHDPM17110311**.

You will be expected to present the original copies of your academic and professional certificates when you come for registration as well as the Research Methodology courses. **Meanwhile, begin reading around your area of research interest and prepare a maximum of between 1,000 to 1,500 word proposal which should be handed in to the Head of Department, Postgraduate Studies.** Please note that orientation will be conducted right after registration.

The school will provide you with details pertaining to the registration process in due course. See attached copy of tuition fees per semester. The terms and conditions are indicated thereon.

Please ensure that:

1. You complete the attached credit agreement form, which should be emailed back to accounts@ictar.ac.zm or accountant@ictar.ac.zm. You may contact the accounts office on Phone: +260 211 233407, 258409.
2. If you are an international student, visit the Zambia immigration website (www.zambiaimmigration.gov.zm) for more immigration information or download the study permit application form from the link on our website (www.unilus.ac.zm/International.aspx).
3. The coordinator of Postgraduate Studies is your contact person for all academic related queries. You may contact the coordinator via email at hodpostgraduate@ictar.ac.zm. All DBA/PhD students are required to attend the Research Methodology and Proposal Writing Series as given below, please refer to the attached programme for details:
 1. SERIES1: INTRODUCTION TO RESEARCH METHODS
 2. SERIES2: RESEARCH PROPOSAL WRITING
 3. SERIES3: QUALITATIVE RESEARCH METHODS
 4. SERIES4: QUANTITATIVE RESEARCH METHODS
 5. SERIES5.1: MANAGING THE RESEARCH PROCESS
 6. SERIES5.2: WRITING CIRCLE (COLLEGIAL NETWORKING + SUPPORT)

Yours Sincerely

Mr. Mwamba Chanda
DEPUTY REGISTRAR

cc. Dean, School of Postgraduate

Please kindly sign a copy of this letter and email a copy back if you are agreeable to the terms and conditions outlined above.

I.....accept the offer and conditions stated there in.

Signed:..... Date:

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