# UNIVERSITY OF MINES AND TECHNOLOGY, TARKWA

FACULTY OF INTEGRATED MANAGEMENT SCIENCE

DEPARTMENT OF MANAGEMENT STUDIES

A THESIS REPORT ENTITLED:

**A COMPARATIVE ANALYSIS BETWEEN "MEAN TIME BETWEEN FAILURE" AND "MAINTENANCE FREE OPERATING PERIOD" OF MILLS ASSET MANAGEMENT AT ANGLOGOLD ASHANTI IDUAPRIEM LIMITED**

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

BY:

**Ing. Osman Karim**

TARKWA, GHANA

SEPTEMBER 2022

**UNIVERSITY OF MINES AND TECHNOLOGY,**

**TARKWA**

FACULTY OF INTEGRATED MANAGEMENT SCIENCE

DEPARTMENT OF MANAGEMENT STUDIES

A THESIS REPORT ENTITLED:

# A COMPARATIVE ANALYSIS BETWEEN “MEAN TIME BETWEEN FAILURE” AND “MAINTENANCE FREE OPERATING PERIOD” OF MILLS ASSET MANAGEMENT AT ANGLOGOLD ASHANTI IDUAPRIEM LIMITED

BY:

**Ing. Osman Karim**

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

**THESIS SUPERVISORS:**

……………………………

**Dr Joseph Nyeadi**

……………………………

**Dr Akyene Tetteh**

TARKWA, GHANA

SEPTEMBER 2022

# DECLARATION

I declare that this thesis is my own work. It is being submitted in partial fulfilment of the requirements for the award of Master of Science Degree in Engineering Management in the University of Mines and Technology, Tarkwa. It has not been submitted for any degree or examination in any other university.

……………………………….

(Signature of Candidate)

……… day of ………….(Year)…………..

# ABSTRACT

This thesis is a comparative analysis between meantime between failure (MTBF) and maintenance free operating period (MFOP) of mills Asset Management at Anglogold Ashanti Iduapriem Limited. Management often consider such factors considered in their budgetary allocation. The work developed a methodology using the data on the Mills to determine the health status of the Mills and to conduct a comparative analysis between Maintenance Free Operating Period (MFOP) which is not popularly known in the Mining Industries with the popularly known and frequently used reliability metric Mean Time Between Failure (MTBF). The results indicates that the MTBF stoppage intervals were 0.1 to 0.3 weeks whiles that of MFOP ranges from 0.2 to 7.1 weeks. This indicates that the MFOP gives mining firms higher reliability of equipment as compare to MTBF. The result was affirmed by a mine site engineer who said "the existing maintenance metrics (MTBF) has not been able to help Iduapriem mine to holistically deal with its maintenance and breakdown challenges." This work exposes the inherent errors in MTBF applications and the benefits of applying MFOP, these errors have two significant implication from regulators perspective and competitive edge of the organisation.

# DEDICATION

I joyfully dedicate this work to the Almighty God for His endless blessings in all spheres of my Life. To my entire family for their support and encouragement, especially my dear wife, Zenabu Abubakar. My superiors at the work (AAIL) site, especially the Senior Manager, Ing. Isaac Boakye Aduenin, for their reputable support and encouragement. And to all my friends and lectures, especially Dr Akyene Tetteh, whose input and patience made this work a success.

# ACKNOWLEDGEMENTS

All praise is due to God Almighty, who has given me the Grace and strength to see the completion of this work. Unto Him, I give all the thanks.

I am particularly indebted in gratitude to my supervisors, Dr Joseph Nyeadi and Dr. Akyene Tetteh, for their guidance and support.

I wish to acknowledge most especially my Senior Manager for his encouragement and motivation and, most importantly, the opportunity to allow me to embark on this journey in the midst of my tight schedule.

My deepest gratitude goes out to my family for their encouragement and to all those whose contribution made this project a success but could not mention their names; I thank you, and may the good Lord bless you.

# TABLE OF CONTENTS

**Content** **Page**

**Declaration.................................................................................ii**

**ABSTRACT ..................................................................................iii**

**DEDICATION ..............................................................................iv**

**ACKNOWLEDGEMENTS.................................................................v**

**List of Abbreviations ....................................................................xi**

**CHAPTER 1 INTRODUCTION ........................................................ 1**

**1.1 Background to the Study** ........................................................ 1
**1.2 Statement of the Problem** ....................................................... 2
**1.3 Objectives of the Study**........................................................... 3
**1.4 Research Question** ................................................................. 4
**1.5 Significance of the Study** ........................................................ 4
**1.6 Organisation of the Research** ................................................... 5

**CHAPTER 2 LITERATURE REVIEW ...............................................6**

**2.0 Introduction** .......................................................................... 6
**2.1 Conceptual Review**.................................................................. 6
2.1.1 Objective of Maintenance ........................................................7
2.1.2 Maintenance Management and Asset Care...................................7
2.1.3 Types of Maintenance ..............................................................8
2.1.4 Preventive Maintenance............................................................8
2.1.5 Corrective Maintenance ..........................................................10
2.1.6 The Current State of the System's Assets...................................10
2.1.7 Minimum Life Cycle Costs........................................................10
2.1.8 The Best Long-Term Funding Strategy .......................................11
**2.2 Key Stages of Asset Management Lifecycle** ..................................11
2.2.1 Planning ..............................................................................11

2.2.2 Acquisition ........ 12
2.2.3 Operations and Maintenance ........ 13
2.2.4 Disposal ........ 14
**2.3 Asset Management Strategy ........ 14**
2.3.1 Challenges ........ 15
2.3.2 Mean Time Between Failure (MTBF) Related problems ........ 16
**2.4 Required Maintenance Modul in the Military field ........ 16**
**2.5 Theoretical Review ........ 17**
2.5.1 Theory of Bathtub Curve ........ 17
2.5.2 Pareto Theory ........ 19
**2.6 Empirical Review ........ 21**
**2.7 Chapter Summary ........ 26**

**CHAPTER 3 RESEARCH METHODOLOGY ........ 28**

**3.0 Introduction ........ 28**
**3.1 Research Approach ........ 28**
**3.2 Research Design ........ 29**
**3.3 Data Source ........ 30**
3.3.1 Data Gathering ........ 31
3.3.2 Data Collection ........ 31
3.3.3 Data Classification ........ 32
**3.4 Model Specification ........ 35**
3.4.1 Pareto Analysis ........ 37
3.4.2 Laplace Test ........ 37
3.4.3 Weibull Analysis ........ 38
3.4.4 Mean Time Between Failure (MTBF) ........ 38
3.6.5 Maintenance Free Operating Period (MFOP) ........ 39

**CHAPTER 4 RESULTS AND DISCUSSION ........ 44**

**4.0 Introduction ........ 44**
**4.1 Results ........ 44**

4.1.1 Pareto graph Analysis ........................................................................................44
**4.2 Discussions**........................................................................................49
4.2.1 Comparative Analysis of MTBF and MFOP for the Mills ..............................................49
**4.3 Industrial Evaluation and Validation of the Research** ...................................52

**CHAPTER 5 CONCLUSION, FINDINGS, AND RECOMMENDATION ...............54**

**5.0 Introduction...........................................................................54**

**5.1 Summary of Findings** ........................................................................54
**5.2 Recommendations** ..........................................................................56
**5.3 Implication** ..................................................................................57
**5.3 Future Research direction** ................................................................58
**5.4 Conclusison** .................................................................................59

**REFERENCES .............................................................................................60**

**INDEX ..........................................................................................65**

## List of Figures


| Figure | Title | Page |
|---|---|---|
| 2.1 | Optimization of Maintenance | 9 |
| 2.2 | Asset Management Lifecycle | 12 |
| 2.3 | The Bathtub Curve | 18 |
| 3.1 | Milling Plant flow chart | 36 |
| 4.1 | Study Design | 30 |
| 4.2 | Pareto Chart for Sag 1, 2019 | 45 |
| 4.3 | Pareto chart for Sag 2, 2019 | 46 |
| 4.4 | Pareto Chart for Sag 1, 2020 | 46 |
| 4.5 | Pareto Chart for Sag 2, 2020 | 47 |
| 4.6 | Weibull Chart for Sag 1 2019 4.7 Weibull Chart for Sag 2 2019 | 48 |
| 4.8 | Weibull Chart for Sag 1 2020 4.9 Weibull chart for Sag 2 2020 | 49 |
| 5.1 | Circuit 1 MFOP Representation | 56 |
| 5.2 | Circuit 2 MFOP representation | 57 |

## List of Tables


| Table | Title | Page |
|---|---|---|
| 3.1 | Number of Events Found in the Data | 35 |
| 3.2 | Failure Data Extracted from the Primary Source for Both Mills | 36 |
| 3.3 | Reliability Measures | 42 |
| 3.4 | Definition of Variables and Measurements | 43 |
| 4.1 | Laplace test for Sag 1 & 2 for 2019 & 2020 | 48 |
| 4.2 | MTBF Vrs. MFOP | 50 |
| 5.1 | Comparative Analysis of MFOP and MTBF | 56 |

## List of Abbreviations

MFOP.................................................Maintenance Free Operating Period

MTBF.................................................Mean Time Between Failures

AAIL..................................................AngloGold Ashanti Iduapriem Mine

AHM...................................................Asset Health Management

CIL ....................................................Carbon-In-Leach

MW.....................................................Mega Watt

RTF.....................................................Run-To-Failure

PDCA................................................. Plan, Do, Check, Act

OEM.................................................. Original Equipment Manufacture

PM..................................................... Preventive Maintenance

LCCA..................................................Life-Cycle Cost Analysis

LCC....................................................Life-Cycle Cost

AM......................................................Asset Management

CMMS................................................ Computerised Maintenance management system

EAM....................................................Enterprise Asset Management

SAG.....................................................Semi-Auto-Genius

SCADA.................................................Supervisory Control And Data acquisition

MS.......................................................Microsoft

SAP......................................................Systems Applications And Products

KPI.......................................................Key Performance Indicators

MRP.....................................................Maintenance Required Period

FFOP.................................................. Failure Free Operating Period

MTTF...................................................Meantime To Failure.

GTSF...................................................Green Tailing Storage Facility

CVR07.................................................Conveyor 07

# CHAPTER 1

# INTRODUCTION

## 1.1 Background to the Study

Industrial equipment maintenance is a vital yet underestimated business job, especially in manufacturing. The fundamental objective of such companies, as the name implies, is production, which unfortunately becomes the primary focus of the management body.

The traditional perspective of maintenance is responsible for repairing broken goods. Adopting such a restrictive maintenance perspective will be limited to the reactive obligation of repair operations or item replacement provoked by failures. This is an expensive venture for any management body (Andrew and Jardine, 2019). Equipment performance management includes but is not limited to maintenance management. Anon., (1985) defines maintenance as "any operations targeted at maintaining or returning an object to the physical state considered required for the performance of its manufacturing purpose."

Asset performance management, commonly known as physical asset management, encompasses various activities (Andrew and Jardine, 2019). Technical, planning, operation, performance evaluation, improvement, and disposal should be included in the asset life cycle (Murray et al., 1996). An asset is a resource having an economic value that an individual, business, or country owns or controls in the prospect of future profit. Assets are purchased or created to increase a company's worth or enhance its operations, and they are recorded on the balance sheet. Asset management ensures that assets are available and reliable to support corporate activities. This necessitates implementing an asset management system that facilitates asset planning, purchase, maintenance, and logistics. Across these activities, other support services such as information technology, financial, and legal services are necessary. Asset types include current, non-current, physical, intangible, operating, and non-operating assets. Asset health management

(AHM) is the study of managing the "health" of a single asset or a group of assets. This frequently includes procedures for determining asset health and time spent deciding what measures should be taken to manage the assets' health. This also involves a discussion about health at the end of life to guarantee that the investment is exploited to its maximum potential.

AngloGold Ashanti Iduapriem Mine Limited (AAIL) operates a Carbon-in-leach (CIL) plant at Tarkwa. The gold processing plant is made up of equipment such as a tower crane which aids in lifting carbons onto the tanks and subsequently into the tanks, and compressors that produce oxygen to support leaching. However, due to poor management, even recovery of Gold from milled material known as slurry will be at the lowest level, hence affecting production (Ndur et al., 2015). There is, therefore, the need to manage the performance of this equipment to support and increase production in AngloGold Ashanti – Iduapriem Mine.

## 1.2 Statement of the Problem

Plant and equipment, referred to as assets, are of high capital and require diligent and special tools to keep them operating satisfactorily. Owing to the cost of maintenance of these assets, Iduapriem mine has employed several methods to increase the equipment reliability to achieve the set plant availability target of the mine.

However, there are still problems such as increasing equipment unplanned breakdown resulting in frequent stoppages whiles operating. These stoppages cause significant challenges such as an increase in the wear rate of the Mill components, energy consumption due to high initial power that is 3X of the rated capacity (3.0X2.5MW = 7.5MW) required to start the Mill at idle state, whiles the Mill requires 2.5MW as the rated power consumption at operating state, these are as a result of Mill failures. The failures also causes settlement of materials in the pipelines and boxes due to abrupt stoppages of the Mill circuit without adequate flushing of the lines. These problems require a new strategy to keep the plant operating as intended and stop per plan, these stoppages impact negatively on the plant availabilities required, in the year 2020 under review, an actual average availability of 92.8% against an average budget availability of 94.8% resulting in negative average availability of 2.0%, whiles 2021 average actual availability was 94.0% against an average budget of 94.3% resulting in negative average 0.3%, this lower than budgeted is despite allowable downtime as a result of the strategy (MTBF) employed. Other problems are the frequency of Shut down maintenance to adopt for its Milling plants; owing to this, several managers have been trying many factors and strategies. As a result, shut down frequency changes have been based on individual feelings and thoughts. These changes have created uncertainty in the production target development over the years.

These problems make it significant to research and provide remediation to the problems since an improved reliable asset improves productivity and enhances the safety of the staff designated to maintain the Asset. Among the four main Milling plants in AngloGold Ashanti - Iduapriem, three are over-aged Assets, which contribute to the problems mentioned above; this research work, therefore, seeks to determine the reliability status of the Circuits and address the problems mentioned.

## 1.3 Objectives of the Study

The main purpose of this study is to look into the asset management and maintenance procedures used at AngloGold Ashanti's Iduapriem Mine. The specific objectives aer the following:

i. To assess the Plant Reliability state of the Milling circuits of AngloGold Ashanti-Iduapriem Mine (AAIL)
ii. To conduct a comparative analysis between Meantime Between Failure (MTBF) with Maintenance Free Operating Period (MFOP).

## 1.4 Research Question

i. What is the reliability status of the Mills to support production cost-effectively?
ii. Among the Maintenance Free Operating Period (MFOP) and Mean Time Between Failure (MTBF), which model is best suitable for the maintenance of Mills to achieve efficient operation?

## 1.5 Significance of the Study

Considering the contribution of the plant and equipment in the gold mining industry, AngloGold Ashanti Iduapriem mine, to be precise, several works have been carried out to ensure cost-effective management of the asset. In addition, the continuous improvement model method has been utilized consistently to enhance the performance of the asset for the aim of constant improvement, resulting in the plan, do, check, and act approach.

Other common continuous improvement methods, such as six sigma, lean, and total quality management, emphasize employee participation and teamwork, work to measure and systematize processes, and reduce variation, defects, and cycle times, and would be investigated to supplement the work already done at the AngloGold Ashanti Iduapriem mine.

Since the research findings could be used as a benchmark for improving the performance of the asset in other mines, other signs of this research could be implemented, should AngloGold Ashanti group implement the findings in other AngloGold Ashanti mines. Further significance of this research will help the management appreciate the role of maintenance of the asset and how a well-maintained asset contributes to the organization's cost management.

## 1.6 Organisation of the Research

The study will be divided into five chapters, focusing on a different major issue. Chapter one is essentially the study's introduction, and it covers the background of the study, statement of the problem, research aims, and objective, questions, among others.

Chapter two, the literature review, would consist of the management tools employed and manufacturer recommendations review; the Engineering management strategy would be elaborated in chapter three. Finally, results and discussion for the study will be covered in chapter four. Finally, chapter five will review the research objective, the summary of the findings, recommendations, and the future research direction.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Introduction

The affiliate scholarly literature and publications on maintenance strategies are reviewed in this chapter. Given the importance of effective and efficient assets to organizations, reviewing existing literature on the subject has become necessary. After analyzing the existing literature in this study area, the literature will be supported by the theories available, and the chapter will justify the need to conduct this research.

## 2.1 Conceptual Review

Understanding what asset management entails starts with comprehending the term asset in context (Petchrompo et al., 2019). Asset management is defined as an integrated activity to realise value from systems of assets. Asset management is described as "an organization's coordinated activity to realize value from assets." As a result, this is broader than physical assets, which represent a substantial target and focus for a more significant number of businesses (Ma et al., 2014). Various governmental and non-governmental groups have defined asset management in different ways.

According to (Petchrompo et al., 2019), asset management is a holistic approach involving all organizational departments to successfully manage existing and new assets and provide customer service. The goal is to maximize benefits, minimize risks, and deliver a suitable level of service to the company while maintaining a sustainable balance. Asset management is based on a specific fundamental according to (Ma et al., 2014). A maintenance strategy is required to achieve the optimum goals to maximise an asset's benefits and reduce its associated risk.

According to Alvarez et al. (2019), a maintenance strategy is a long-term plan that encompasses all areas of maintenance management and determines the yearly maintenance program's direction and detailed action plans for reaching the organization's desired future state. Strategic plans are long-term in character and address difficulties related to the organization's business objectives. A maintenance plan is an integrated strategy used by corporate management to stress the relevance of a certain piece of equipment that impacts various types of maintenance work (Márquez, 2007). The creation of a maintenance plan is based on corporate business objectives and explicit knowledge of the role of maintenance in corporate strategy (Abd et al., 2015). The maintenance objectives must be specified as direct input from the company (Márquez et al., 2009). If the basis for each piece of equipment is not correctly planned, a well-developed maintenance strategy will be ineffective.

### 2.1.1 Objective of Maintenance

The maintenance function's goal is to ensure that production has the best possible availability, usage, and efficiency. Several theories support the need for maintenance of fixed assets such as Mills

### 2.1.2 Maintenance Management and Asset Care

There is still a lot of misunderstanding in maintenance management about the terminologies used for different forms of maintenance, especially in the industrial sector, not just in Production and Operations Management but also in related literature. This can be a stumbling block to the definition of standard terminology, and it occurs because:

i. Incorrect conceptualization or dissemination of adopted labels for types of maintenance, which are local or particular habits, not necessarily in a suitable way or fully expressed or understood,
ii. Neologism, often derived from translations of foreign languages,
iii. Different authors' definitions of distinct names are based on unique contexts. Even if the vocabulary varies, the notion must be grasped. Careful standardization is necessary to provide a clear notion to assist the maintenance decision maker in selecting the best type for a piece, equipment, installation, or system (Flavio, 2017).

### 2.1.3 Types of Maintenance

Dealing with regular maintenance of assets, equipment, and property is an inescapable component of running a firm. Unfortunately, owing to natural wear and tear, frequently used equipment can occasionally malfunction, fail, or slow down. Still, you can make efforts to extend the life of your company's most important assets (Warren, 2020). The majority of maintenance falls into one of two categories preventive maintenance and corrective maintenance.

According to many sources, corrective Run-To-Failure (RTF) and preventive maintenance are fundamental maintenance techniques. Therefore, maintenance activities can be divided into two categories. Corrective maintenance can be done right away or deferred until a more convenient time for production capacity (Jantunen et at., 2019). On the other hand, preventive maintenance is divided into two types: condition-based maintenance, which can be done on a scheduled, continuous, or requested basis, and time-based schedule maintenance (Jantunen et at., 2019).

### 2.1.4 Preventive Maintenance

Tasks and maintenance plans are initiated ahead of time to avoid failures in preventive maintenance. Preventive maintenance (PM). A series of tasks performed at a frequency dictated by the passage of time, the amount of production, machine condition that either extend the life of an asset or detect that an asset had critical wear and is going to fail or break down constitute PM (Garg et al., 2006). Preventative maintenance involves taking the necessary safeguards and procedures before an accident or equipment breakdown. Regular business and equipment inspections, cleaning and lubricating key equipment, and keeping your company's grounds neat are all examples of preventive maintenance (Warren, 2020).

Preventive maintenance should only be done when the benefits outweigh the risks and expenses (Warren, 2020). Preventive maintenance can be categorized as either use-based or condition-based. One way to improve preventive maintenance schedule is to follow the PDCA model, Plan, do, check, act (PDCA) is a cycle that is used for problem-solving that includes planning, implementation, follow-up and evaluation, which according to Srivannaboon (2009) is a metod used for continual improve the process (Nylander, 2015)

Plan Examine recommended OEM recommendations, repair histories, criticality, and equipment usage patterns to establish a baseline for PM frequencies. If you want reliable outcomes, stick to your plan. To see if your plan is functioning, look at the failure data for each asset. If a purchase breaks down between maintenance, act or raise the frequency of PMs; if no failures are found between PMs, reduce the frequency (See Figure 2.1).

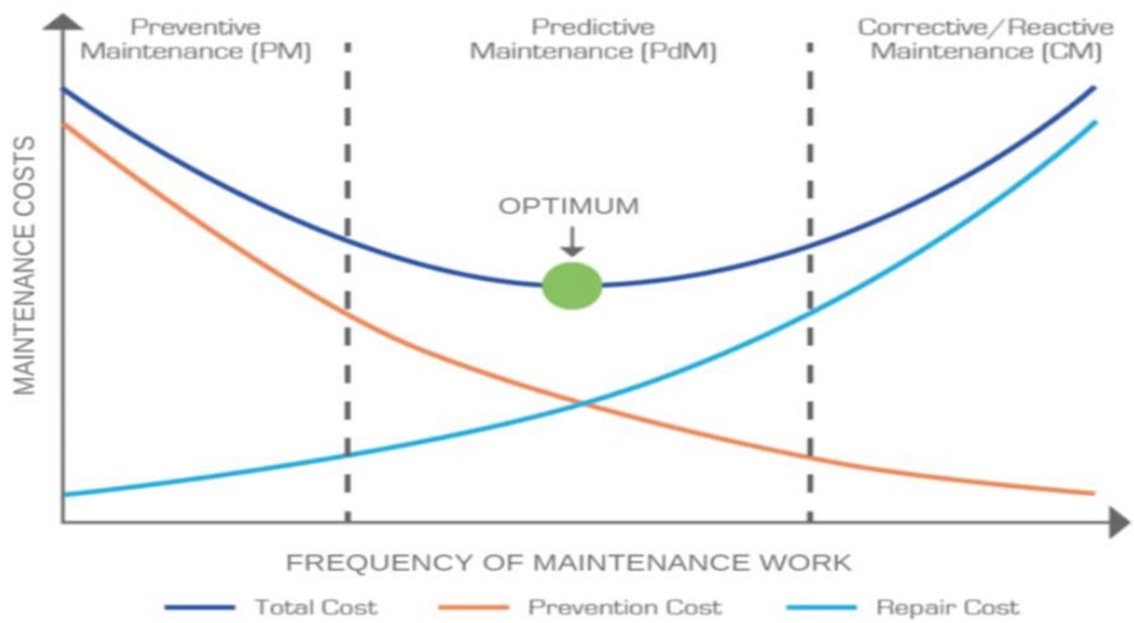


**Figure 2.1 Optimization of Maintenance**

Source: (Pandey et al., 2012)

### 2.1.5 Corrective Maintenance

Is done to return the equipment to working condition after breakdown or after perceived deficiences that are severe enough to cause a stop in production (Adolfsson et al., 2011). Corrective maintenance is the action taken to restore an item to its original working state after failure or deficiencies were discovered during preventative maintenance or otherwise. Corrective maintenance is a type of unscheduled maintenance that must be added to, integrated with, or replaced for previously scheduled work in most circumstances. Repair, often known as corrective maintenance, is an important aspect of overall maintenance (Modarres, 2006).

### 2.1.6 The Current State of the System's Assets

Utilities must have a thorough grasp of the present state of all existing assets before installing an asset management system. This is a starting point for continued monitoring, analysis, maintenance planning, and resource allocation.

### 2.1.7 Minimum Life Cycle Costs

The capital budget and operations and maintenance staff account for about 85 percent of a typical utility system's expenses. Therefore, asset management systems help determine the most cost-effective ways to provide the greatest or desired level of service over time. A life-cycle cost analysis (LCCA) examines the entire costs of an asset, product, or measure across time. It takes into account all costs, including initial expenses such as capital investment, procurement, and installation; future costs such as energy and maintenance, operating costs, capital replacement costs, and financing costs; and any resale, salvage, or disposal costs over the Asset's or product's lifetime. LCC is an economic assessment of an item, system or facility over its life, expressed in terms of equivalent cycle costing. It is used to compare various options by identifying and assessing economic impacts over the life of each option (Kshirsagar et al., 2010)

### 2.1.8 The Best Long-Term Funding Strategy

To establish an effective asset management program, you'll need a long-term funding strategy and sensible financial judgments. First, knowing the utility's total economic expenses and revenues is critical for proper financial forecasting. The financial forecast is then utilized to determine future planning and decisions that will improve operations and enable utilities to fulfill their revenue goals while reducing expenses. There are three types of asset funding techniques: conservative, which involves utilizing equity or a long-term bank loan to fund permanent assets; aggressive, which consists in using a short-term loan; and moderate, which combines both conservative and aggressive strategies (Kochhar, 1997).

## 2.2 Key Stages of Asset Management Lifecycle

### 2.2.1 Planning

The first stage of the asset life is planning. At this stage, asset needs are developed and validated. Next, existing assets must be assessed for their ability to satisfy service delivery requirements to determine asset requirements. Next, management strategies must be created to include and analyze the asset need. At all phases of the planning process, it is vital to ensure that continuous development adds value to the business. If the company implements effective planning and all stages of the asset management cycle, it will be able to:

i. Evaluating the current assets' sufficiency;
ii. Assuring that the resources required are available when they are needed;
iii. Identifying underperforming or surplus assets;
iv. Assuring that assets are well-maintained; and
v. Estimating asset provisioning alternatives as well as funds for asset acquisitions (See Figure 2.2).

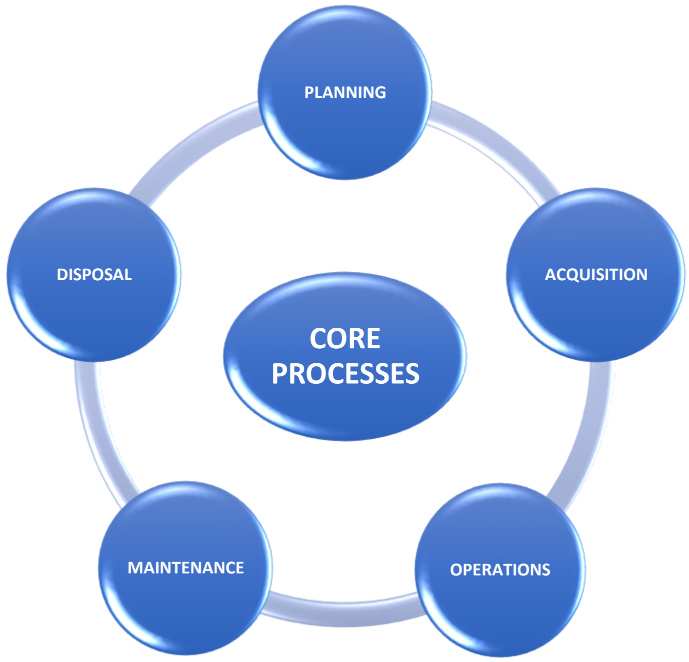


**Figure 2.2**

Source: Kiritsis (2010)

2.2.2 Acquisition

The second of four major stages in the asset management life cycle is acquisition. Asset acquisition, or the act of purchasing or taking over an asset to support an organization's growth, is an important aspect of asset management in any business. Acquisition begins once the best decision has been made on the best alternative after the cost and needs have been specified.

There are actions involved in purchasing an asset to ensure cost-effective acquisition; they include activities such as developing and procuring an asset; these activities must be used effectively to obtain an asset that is fit for purpose. The organization must first decide if the asset will be purchased or built indefinitely. Next, create a budget for asset acquisition, a purchase timeline, and a purchasing demand. A realistic budget and cash flow should be designated as inadequate funds; otherwise, project management may jeopardize the asset acquisition process. Once these requirements have been satisfied, a project team should monitor the process to ensure that all acquisition processes are completed to achieve service delivery and other organizational objectives (Gonzalez et al., 2016).

The "Bull whip effect," which implies a lack of synchronisation among supply chain elements, is used to underline the fit for purpose. Inventory and, in this case, assets accrue at various phases as supply patterns do not meet demand patterns, and shortages delay or arise at other stages. The bullwhip effect occurs when the demand order variabilities in the supply chain are amplified as they moved up the supply chain (Lee et al., 1997). The capital obtained to purchase another asset is referred to as acquisition finance. Acquisition finance enables customers to fulfill their current acquisition goals by providing quick funds that can be used to complete a transaction (Will, 2019). An asset management system may track the item over its full life cycle once it has been acquired and installed.

### 2.2.3 Operations and Maintenance

After the asset has been placed, the following stage is operation and maintenance, which is the most time-consuming part of the asset life cycle. This stage describes how the asset is used and managed and any necessary maintenance and repairs. During operation, an asset will be monitored and checked regularly for any performance issues that may arise unexpectedly. This is the point at which maintenance and repairs become more common. As an asset ages, wear and tear accumulate, necessitating regular maintenance to help extend the asset's life and value.

These demands upkeep, modifications, and updates to keep assets updated with an ever-changing workplace. Because all equipment is prone to failure, a mechanism must be in place to replace or repair any faulty units so that the production process may proceed. This function is called maintenance. Maintenance is one of the fastest-growing specialties (Coetzee, 1997). This is based on four main reasons;

i. Production equipment has become more sophisticated.,

ii. The requirement for a high rate of return on investment,
iii. The hefty maintenance costs and
iv. The maintenance function's complexity.

### 2.2.4 Disposal

Finally, after an asset has served its purpose, it is decommissioned and sold, reused, dumped, or recycled. Even if an object has no commercial value, it may need to be appropriately disposed of to avoid hurting the environment. Several accounting computations and entries must be completed when a capital asset or non-current asset is sold. First, because the asset is no longer managed, it must be removed from the accounting records. Most of the time, the asset will be sold for more or less than its carrying value, resulting in a profit or loss on sale that must be accounted for. Finally, the non-current asset registration must be updated to reflect the asset's disposition (Kaplan, 2020).

Even if an object has no commercial value, it may still need to be properly disposed of to avoid damaging the environment. This method might be deconstructing the asset piece by piece or erasing its data. If this type of asset is still required for operations, it will be replaced, and the asset life cycle will start over.

## 2.3 Asset Management Strategy

The Engineering Department's Asset management strategy is dedicated to establishing what the company intends to achieve from Asset management operations according to the timeframe. Asset management is a broad word, according to (Bellwether, 2015). It is a process that leads to the acquisition of assets and their use and disposal to maximise the assets' value and potential throughout their useful lives.

It also controls and maintains any costs and hazards related to the assets. It is not a product that can be purchased but rather a discipline that must be followed to preserve your possessions. Asset management is used in various fields; in this case, it is used in the mining industry to understand how physical assets are maintained and used for the company's advantage.

According to The Institute of Asset Management (2011), certain aspects, such as existing and future demand, should be considered in this plan; the existing and future AM capabilities of the organization, such as processes, information, systems, people, tools, and resources, as well as the condition and performance needs of the firm's assets; and how the organization intends to develop its future capabilities to a level of maturity necessary to deliver its organizational goals.

### 2.3.1 Challenges

Besides the safety of the asset and the people managing the Asset, there are five main challenges in achieving an effective asset management plan these are,

i. Choosing the right asset,
ii. reducing asset downtime,
iii. how to replace the asset,
iv. understanding asset cost and
v. taking a systematic approach.

For an AM strategy to live up to its expectations, (Wenzler, 2005) proposes four key challenges, which are:

i. The strategy should be in line with the values and goals of the stakeholders.
ii. Balancing dependability, safety, and financial factors.
iii. Taking advantage of performance-based rates; and
iv. Adapting to the punishment system based on production

### 2.3.2 Mean Time Between Failure (MTBF) Related problems

Problem 1: the key reason why MTBF fails to relate to the culture of maintenance and its practice is maintenance work orders are required to capture all maintenance activities; however, this is not the case in most maintenance practice environments.

Some maintenance fields in some companies have rules such as, "A work order will be written only if the equipment is down for more than one hour." Such a rule limits the outcome of the MTBF. In other maintenance fields, if work requires no resources, that will trigger the flow of work, in which case the work order is relevant, work orders are not created, and as a result, relevant history is captured to support MTBF. This is a practical observation in the field of this study.

Problem 2: Not every asset is loaded into the CMMS/EAM. This is a problem that makes writing an emergency work order impossible. It is impossible to track the reliability issue if not all assets to the component's level are tracked. If 20% of assets eat up 80% of resources, it will be important to identify that 20% and set them up in the CMMS/EAM.

## 2.4 Required Maintenance Modul in the Military field

Among security systems is defense equipment; no country can afford such equipment failure in the field of operations; however, owing to the global pressure on defense budgets, military forces need to sustain operational availability at a required level and have to reform maintenance policies (Ahmadi et al., 2009). Under this circumstance, one of the most significant issues to consider when deploying a weapon system might be optimizing lifetime operating costs by determining suitable maintenance intervals. Most defense standards, such as MIL-HDBK-217F, MIL-STD-1388, and MIL-STD-2173, utilize the mean time between failures (MTBF) for planning maintenance. However, MTBF cannot be used to model age-related failure mechanisms due to the exponential distribution's memoryless property, which does not include a time-variant despite its theoretical ease of use. Maintenance models based on MTBF admit that failure cannot be evaded and lead to corrective maintenance (Long et al., 2009). In military establishments, the penalty costs caused by corrective maintenance can greatly outweigh the preventive maintenance costs (Moon et al., 2012).

For example, a long preventive maintenance interval for saving $100 preventive maintenance could cause corrective maintenance, leading to a $100 million warship being non-operational. This could result in a military defeat that could cause casualties and deaths. A maintenance-free operating period (MFOP) can be defined as “a period of operation during which an item will be able to carry out all its assigned missions, without the operator being restricted in any way due to system faults or limitations, with the minimum of maintenance” (Kumar, 1999). MFOP survivability (MFOPS) refers to the probability that the item will survive for the duration of MFOP, as shown in Equation (1) (Kumar, 1999). This paper also demonstrates some empirical evidence to support the performance of the maintenance optimization model.

## 2.5 Theoretical Review

### 2.5.1 Theory of Bathtub Curve

The Bathtub curve theory was developed to track failure rates over product life cycles due to its form. For understandable reasons, the early failure, or "infant mortality," regime has been the focus of intense examination for many years. The weak or minimally functional population members fail at a decreasing rate during brief periods (Kosky et al,. 2021). The bathtub Curve describes three stages of asset life until the asset is finally disposed of and deconstructed from any organization's Asset registry. AngloGold Ashanti's maintenance procedures are based on these stages, as defined by (Ohring, 1995). The bathtub curve, named for its shape and shown in Figure 2.3, is perhaps the most famous graphical representation in the field of reliability. The resulting curve describes the behavior of engineering components and the lifetimes of human populations.

Early failure, sometimes known as "infant mortality," is the first stage of the curve. It has a lower failure rate. During this time, the population's weakest or least functional individuals fail. This curve segment is the foundation for the commonly used method of filtering out defective components and weak ones with a high risk of failure. Products must withstand some form of initial stressing in screening processes (e.g., burn-in at high temperature, application of electrical overstress, temperature cycling). In addition, particulates and contaminants frequently cause early failures during the manufacturing of IC chips. The intrinsic failure phase follows a long, reasonably flat section. In this location, failures happen randomly, and the failure rate is very stable. Because this is where a component spends most of its useful life, most reliability testing is done to determine h(t) values in this region.

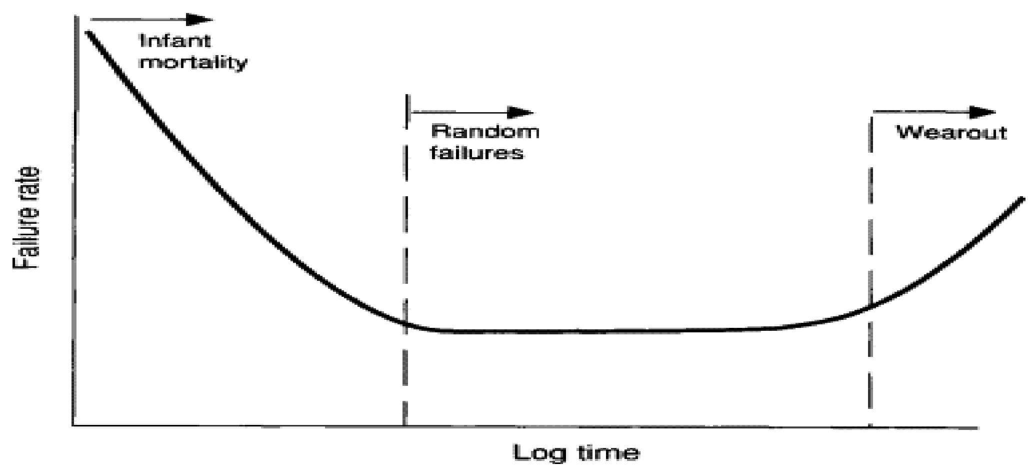


**Figure 2.3 The Bathtub Curve**

Source: Jiang (2013)

Finally, there's also the wear-out failure regime to consider. Because components degrade faster in this area, the failure rate rises. Extending the life of parts before they wear out is one of the most significant tasks in processing and manufacturing. In this direction, considerable progress has been made. Many gadgets do not fail outright but rather become obsolete due to design modifications and new technologies. Due to the cost involved in installing critical Assets like Mills, in the third stage of the bathtub Curve, the Asset is refurbished to restore it to the acceptable operating level.

### 2.5.2 Pareto Theory

The Pareto 80/20 Rule, also known as the Pareto principle or law, states that a small number of causes (20%) is responsible for a large percentage (80%) of the effect (Lipovetsky, S., 2009). The notion was named after Vilfredo Pareto, an Italian economist who noticed in 1895 that around 80% of Italy's land belonged to 20% of the population. (Pareto et al,. 2007). Other theories, such as power-law distribution and Zipf's law, assume that objects are not distributed most of the time evenly. Though the three theories suggest the same context, the Pareto rule has become synonymous with the 80/20 distribution (Figure 2.4).

Pareto Distribution Formula

The formula for calculating Pareto Distribution is as follows:

$$F(x) = 1 - (k/x) a \tag{2.1}$$

$X$ – random variable, $k$ – Lower bound on data, and $a$ – Shape parameter.

On a chart, the Pareto distribution is represented by a slowly declining tail, as shown below:

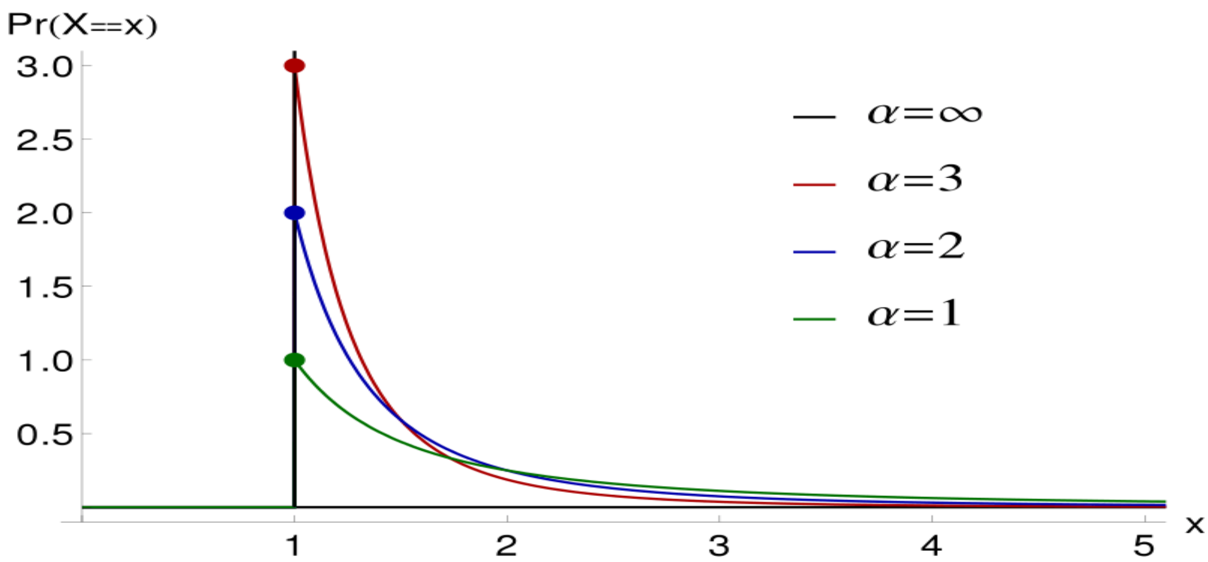


**Figure: 2.4 Pareto Distribution Formula**

Source: Cirillo (2013).

This principle, according to Pareto, might be applied anywhere. In practice, this concept says that 20% of your activities will account for 80% of your results. As a result, you can use this guideline to boost your productivity and meet your objectives in less time (Emi, 2018).

Laplace theory, when determining the data set after it has been correctly gathered and handled with a database, such as a Microsoft Excel file, the Laplace test is a suitable place to start. Vlok (2011) state that the Laplace test is an excellent place to start when determining the data set after accurately collecting and managing it with a database, such as a Microsoft Excel file. One approach for determining if discrete events in a process have a trend is to use the Laplace test (Pencer at el., 2006). The centroid test, also known as the Laplace test, compares the centroid of observed arrival times to the midpoint of the observation period. This metric approximates the standardized normal random variable (e.g., z-score).

$$\text{Laplace score} = [((\sum_{i}^{n} t_i) / n) - T / 2] \Big/ T\sqrt{1/12n} \tag{2.2}$$

Where $t_i$ is the time (e.g., number of days) from a given start point to the time of each event (e.g., failure), $n$ is the number of events (e.g., failures), $T$ is the time from the start point to the end of the observation period, and Note: If the last event occurs at the end of the observation period (i.e., $t_n = T$), then use n - 1 instead of n in all three places in the formula.

When a full-scale reliability program is not in place, the Laplace Test can be used to quantify trends of unwanted occurrences for each system element and any combination, (Pencer et al,. 2006). This assists management in identifying and prioritizing aspects that require further investigation (e.g., verification, a root cause) and possible remedial or corrective action as a proactive step. In addition, the Laplace test can and should be used to validate the constant failure rate (exponential) model when establishing the reliability of a repairable system. This is crucial because, in a repairable system, the variable of interest is not the system's lifetime as in classical dependability but the time between repeated failures of a single system.

## 2.6 Empirical Review

There has been a great demand to maintain assets mainly due to the high capital cost-efficiently. As a result, maintenance experts are working to establish efficient maintenance techniques. Maintaining engineering systems has been a considerable challenge since the industrial revolution. Despite this, significant progress has been made in the effectiveness and efficiency of maintenance. The multidisciplinary nature of organizational engineering maintenance and cost, complexity, and competitiveness are all barriers in this field. Complexity and competition play an even more significant part in today's increasingly technologically advanced businesses and the "global village" in which enterprises now find themselves. External considerations such as suppliers, as well as environmental and safety concerns, are added to this. This involves using effective PAM and ancillary maintenance procedures that will positively impact critical elements within an organization.

Shaalane (2012) researched improving asset care plans in mining: applying aviation maintenance developments. This thesis aims to compare the Maintenance Free Operating Period (MFOP), which is derived from aviation, with the traditional and widely used dependability metric Mean Time Between Failure (MTBF), which has revealed some inherent drawbacks in the field of maintenance throughout time. This is primarily due to MTBF's inherent acceptance of failure and the unscheduled maintenance that goes hand in hand. Furthermore, the MFOP concept has been successfully applied to a mining-specific case study; however, no other MFOP application to the mining industry has been discovered too far.

The research aims to see if the maintenance interval measure is effective. Maintenance Free Operating Period (MFOP) is more suited in physical assets, therefore overcoming the inherent flaws of the commonly used metric Mean Time Between Failure (MTBF) (MTBF). Anglo Platinum's case study effectively verified the MFOP principle and methodology. In addition, industry specialists provided feedback. More information could be collected by employing failure statistics and the MFOP principle of defining dependability in a different and opposing manner to MTBF, resulting in a more complete and accurate portrayal of the system studied. MFOP can therefore be used to define dependability targets that are more easily understood and less ambiguous. MFOP leads to organizational asset optimization rather than fostering a climate prone to mediocrity, as MTBF does. All of the research objectives were satisfied. Finally, the MTBF school of thinking was tested using the devised approach in a case study versus the MFOP school of thought. The null hypothesis (for the assessment of physical assets in the mining sector, Maintenance Free Operating Periods are not a more good dependability indicator) can thus be rejected, as it can be demonstrated that using the aviation-derived concept of Maintenance Free

Operating Period (MFOP) is a far more appropriate reliability metric in the assessment of physical assets.

Simoes at el., (2011) researched the topic literature review of maintenance performance measurement: A conceptual framework and directions for future research. The purpose of this research was to perform a thorough evaluation of the literature on a variety of aspects of current maintenance operations, measurements, and management. The performance metrics, measurement, and management of the many maintenance elements are the subject of this literature study. The purpose of this study is to shed some light on the key aspects and characteristics of efficient performance maintenance management approaches.

Maintenance has a broader viewpoint in today's open system manufacturing firms, according to Simoes at el., (2011). As a result, maintenance has shifted from a strictly defined operational perspective to an organizational strategy perspective in such businesses. Some scholars relate this tendency to adopting increasingly modern technology (Swanson, 1997), a greater focus on safety, and new environmental legislation. As a result, maintenance managers are being called upon to integrate and direct the maintenance efforts to meet organizational strategic goals efficiently and effectively (Maletic et al., 2014).

Maintenance expenses have risen due to the shifting organizational function of maintenance and the increasing complexity of production technology (Parida and Kumar, 2006). Maintenance expenditures are estimated to account for 25% of total operating costs in manufacturing companies (Cross, 1988a; Komonen, 2002). Maintenance expenses may exceed operational costs in several industries, such as petrochemicals, electricity, and mining (Parida and Kumar, 2006). As a result, maintenance performance measurements, measurement, and management should be given special attention, resulting in increased organizational efficiency and effectiveness.

Despite the various benefits of efficient performance measurement and management, as well as the fact that firms that employ integrated balanced performance management systems outperform those that do not (Parida and Kumar, 2006), studies have revealed that 70% of all system implementation initiatives fail (Bourne et al., 2005). Worse, just one-third of firms with strong maintenance management procedures tended to receive the full benefits of their maintenance management activities, according to Cholasuke et al., (2004), in a survey of manufacturing organizations. As a result, some scholars have advocated for more comprehensive and novel performance management approaches, such as the Balance Scorecard, and new organizational improvement instruments, such as the Balance Scorecard (Garg and Deshmukh, 2006).

The following are essential considerations, according to Parida and Kumar (2006), that warrant the deployment of a maintenance performance measurement process: calculating the value produced by maintenance, justification for investing, making changes to resource allocations, concerns about health, safety, and the environment, focus on knowledge management, adapting the operating and maintenance plan to new trends, and changes in organizational structure.

After additional content analysis of the selected articles, three major themes about maintenance performance metrics, measurement, and management emerged. These themes reflect potential study areas and are outlined; maintenance resources are used efficiently, support whole maintenance and information systems, measurement, measures, and human factor management. In this perspective, closed system manufacturing businesses viewed maintenance as a necessary evil or a cost of doing business. In contrast, open system manufacturing organizations viewed maintenance as a strategic competitive resource. Maintenance is considered an integrated, strategic organizational system in many manufacturing companies.

Manufacturing firms require a systematic, dynamic performance management method to measure, monitor, track, and continually improve the various areas of organizational performance from an implementation standpoint. This will help the company transition from reactive, preventive, and predictive to holistic/process-oriented, complete, and systematic. It is suggested that future systematic research efforts in maintenance performance and management are required to enhance theoretical constructs and support the use of more practical methods.

Parida and Kumar (2006) put forward these recommendations; integrate maintenance-related performance into the broader performance system of the organization, track and enhance the many components of the maintenance effort, create a maintenance performance management system and implement a maintenance performance measurement tool/process

Adolfsson (2011) research is based on a case study was conducted at SKF Gothenburg to investigate the "efficiency of Corrective Maintenance. As part of the Supply Chain Management master's degree, this master thesis was performed throughout the summer and fall of 2011. Corrective maintenance is conducted when a system or machine fails. Reestablish a successful operation. It includes repairing and replacing defective elements. Contrary to preventative maintenance, corrective maintenance cannot be scheduled (Blischke and Murthy 2005). This makes them more challenging to prepare and more expensive to execute.

According to Ohldin (2011), the information improved the more recent the orders were, but it was also difficult to use as a gauge. For example, there was merely a tiny mistake in some circumstances that did not require any extra information. As a result, it was unclear what percentage of orders required information, and the metric was too variable to be useful. It was thought that having a precise and crisp reporting structure was vital, but it would have worked better if the purpose had been more apparent. Instead, the reporting should be viewed as a requirement that must be completed before the order can be achieved.

He recommended goal formulation, resource planning, and communication were the three areas where the recommendations for the corrective maintenance department were divided. There are three suggestions for goal setting: encourage others to improve, set maintenance goals that are in sync with production goals, and create and visualize ways for the technicians to achieve their objectives. Besides, with resource planning, the following recommendations are given staffing should be planned following resource consumption, support the central maintenance unit with functional maintenance, and ongoing repairs need a shift change. Finally, with communication, the recommendations are to operators should be notified in advance of the technician's arrival, develop the existing communication escalation model and incorporate maintenance in the production steering meetings

He concluded that, in a word, the three aspects are equally vital and, if enhanced, would provide various advantages. There is no prioritization between them since they have diverse influences on the task and must be addressed accordingly.

## 2.7 Chapter Summary

Even though maintenance of physical Assets has been challenging, significant progress has been made in the effectiveness and efficiency of maintenance. Some of the challenges have been suppliers and environmental and safety concerns. This thesis aims to compare the Maintenance Free Operating Period (MFOP), which is derived from aviation, with the traditional and widely used dependability metric Mean Time Between Failure (MTBF), which has revealed some inherent drawbacks in the field of maintenance throughout time. This is primarily due to MTBF's inherent acceptance of failure and the unscheduled maintenance that goes hand in hand. Furthermore, the MFOP concept has been successfully applied to a mining-specific case study; however, no other MFOP application to the mining industry has been discovered too far.

The research established that Maintenance Free Operating Period (MFOP) is more suited for physical assets, therefore overcoming the inherent flaws of the commonly used metric

Mean Time Between Failure (MTBF). Anglo Platinum's case study effectively verified the MFOP principle and methodology. And also, MFOP can therefore be used to define dependability targets that are more easily understood and less ambiguous. the MTBF school of thinking was tested using the devised approach in a case study versus the MFOP school of thought. The null hypothesis (for the assessment of physical assets in the mining sector, Maintenance Free Operating Periods are not a better dependability indicator) can thus be rejected, as it can be demonstrated that using the aviation-derived concept of Maintenance Free Operating Period (MFOP) is a far more appropriate reliability metric in the assessment of physical assets.

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.0 Introduction

In order to achieve the objective set out in this research work, a research methodology will be applied to achieve the two objectives. Owing to the data being analysed, a quantitative research approach is adopted. The data sample is based on equipment failure, which impacts the processing of Gold-Bearing materials. There are four Mills involved in processing Gold in the Iduaprime Mine, and these are two Semi-auto genius (Sag) Mills and two Ball mills; the Sag Mills are considered the primary Mills, whiles the Ball Mills are secondary.

The data sampling is based on the shift system per daily production operation; each day consists of two systems, the day and night shift systems. Therefore, the data are the failures per hour of operation, which is why the quantitative approach is appropriate. There is only one instrument involved in the data collection and clarification; the Mine uses the SCADA system to track the failures used for the research work. The data is subsequently pulled into MS Excel for analysis. Finally, the data are analysed through the Pareto theory. Ethically, engagement with the Mine production team will be carried out to ensure the right data and the reason are achieved.

## 3.1 Research Approach

This work uses a quantitative research technique to critically analyze the physical asset management (PAM) of Iduapriem Mine, using data from a minimum of two years and hands-on data to support the history gained. Quantitative research is the process of gathering, analyzing, interpreting, and writing a study's findings. In contrast, qualitative research is a different approach to data collection, analysis, and report writing than typical quantitative methods (Creswell, 2007). The reason for utilizing a quantitative strategy is that it has fewer biases than a qualitative research approach.

### 3.2 Research Design

Quantitative research has dominated the area of study to provide meaning and knowledge. Quantitative research is centered on numeric data collecting and data analysis using mathematical models. Surveys and experimental procedures distinguish quantitative research from already established hypotheses (Ormrod, 2001). The following are the four major types of quantitative research designs: descriptive research design, correlational research design, causal-comparative/quasi-experimental research, and experimental research.

For this study, a descriptive research design was used to characterize the present status of an identified variable. Typically, the researcher does not begin with a hypothesis but rather develops one after gathering evidence. Then, the hypothesis is tested by analyzing and synthesizing the data. The descriptive research design allows the researcher to achieve the goal of describing something in detail. For example, the Physical Asset Management critical review of the Iduapriem mine would be carefully carried out using the descriptive design to obtain the detail of recommendations needed to achieve the goal of the research work given the data range.

The mining industry is increasingly becoming a high-cost venture with initial capital being extremely high; hence a piece of reliable equipment would be required to achieve higher utilization of the asset. Therefore, one of the aims is to establish the reliability of the main critical circuits of the Anglogold Ashanti Iduapriem Mine. Another aim is to further investigate between MFOP and MTBF and establish a matric that aims to eliminate equipment's potential and functional failures to the barest minimum; by extension, the lesser the maintenance, the lesser maintenance cost and loss of production cost. The cost of equipment failure is categorized into two elements, thus Cost of Production loss and Cost of maintenance (Restoration), Figure 3.1.

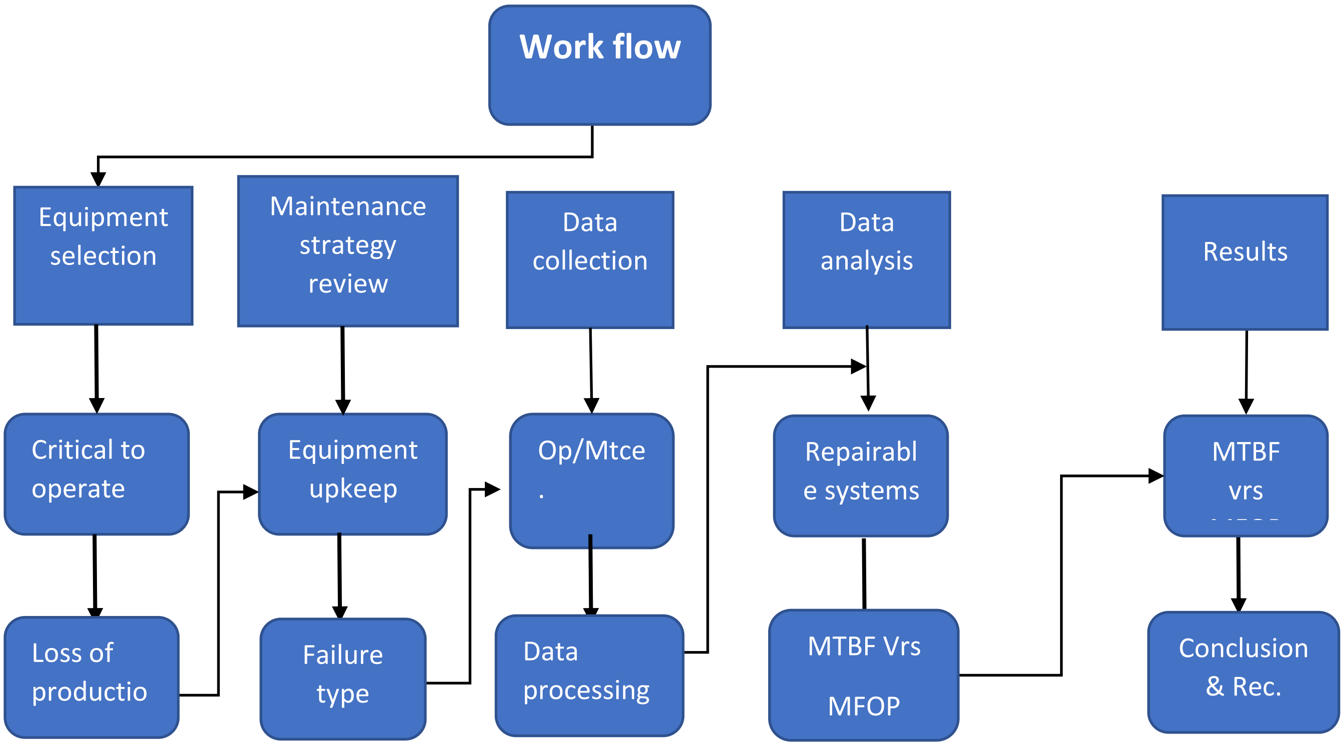


**Figure 3.1: Study Design**

Source: Author's Construct

## 3.3 Data Source

To critically analyse Iduapriem Mine's physical asset management, the study adopted a two-year time series of secondary data relating to the most critical asset of the mine. These were when the most recent and effective technology was employed to manage the Mills, which happens to be the most vital asset of the Mine. The data gathered for the study consider the daily, monthly, quarterly, and annual data with hands-on data relevant to the study.

### 3.3.1 Data Gathering

Failure data resulting from unplanned maintenance, such as corrective maintenance to breakdown maintenance data, is required; these failure data for the Mills were analyzed. For this work, two types of events are needed for the main data set (a) Event number one - Breakdown or unplanned maintenance and (b) Event number two - Planned maintenance. The data set contains additional events such as power downtimes. These are not considered because the power to the Mine is tapped from the National Grid, which is a whole asset regime that may require future similar work to ascertain the power reliability, etc.

### 3.3.2 Data Collection

Data collection gathers and analyses information from several sources to provide a comprehensive and accurate picture of a subject. Data collection allows a person or organization to answer pertinent questions, assess results, and forecast future probability and trends. (Emily, 2020). After identifying the Circuit or asset to be analyzed, data collection from the exact unit, system, or Circuit begins. Gathering and collecting data depend largely on the setup relating to data acquisition and the level of intelligence employed at where the system is installed or the operational area of the system. Where electronic devices such as sensors are installed to capture data from the operating equipment, important data can be captured.

A data historian can capture the data and store it for future usage, the period of data stored is dependent on the space available for data. Therefore, a period of data saving is essential to store data. Less advanced systems, such as whole systems applications and products (SAP), are used. The option will be to examine maintenance records for failures data for the asset or the facility being analyzed. Microsoft Excel is mainly used to analyze the data set to edit and manage to suit the research work; this is not to edit to be biased but edit to be in line with the result; excel allows reducing the extensive data into a Pareto chart.

Regardless of the study, precise data was required to ensure the research's integrity. The chance of mistakes was decreased by selecting an appropriate data-gathering instrument (existing, modified, or newly built) and clearly outlined instructions for its proper usage. Two crucial questions should be considered when gathering data, according to (Ishikawa, 1982): (1) will the data decide the facts, and (2) is the information obtained, evaluated, and compared in such a way that the truth emerges?

Data about grinding mill maintenance and failure systems were used. The data used in this study was on the mill circuits as established by the Mine. This information is gathered from secondary sources, specifically the Iduapriem Mine excel data capturing system, which keeps track of many data and variables. The data is based on a two-shift system every day, so each shift collects information as it happens before the conclusion of the change.

Maintenance data on the Mills was extracted from this system and recorded in Microsoft Excel for examination. The Data was obtained from 2019 to 2020, from January to December of the said years. The data is collated by the operation or production department; the data consist of any downtime related to the equipment under study; all the equipment is configured in series hence the name process plant. With such configuration, any equipment failure in the process chain result in the stoppage of the mainstream equipment where the equipment under study is situated.

### 3.3.3 Data Classification

There are two main types of downtimes found in the data set obtained from the Anglogold Ashanti Iduapriem mine, thus halting feeding to the Mill, impacting the output, and a failure resulting in the stoppage of the mainstream or the latter; however, weirdly occurred. Such an event is detrimental to the entire process organization since it will take multiple days to restore the plant into operation after such an event due to the siltation of the Tanks containing slurry material. Therefore, the mine classifies the data as the equipment under study is deemed unavailable whenever any other equipment fails and results in the stoppage of the leading equipment; this is because of the process flow effect. Furthermore, in the event of halting throughput due to maintenance-related downtime, the equipment again is deemed unavailable, affecting availability.

As a result, the first step in data categorization is to determine if the data point results from a failure of the major unit component, which is designated the mainstream in this study, or if it results from a downstream or upstream, or unit failure. This approach is essential to support future work where either equipment failure or halting of throughput is considered downtime. However, this work will consider both types of equipment down or halting throughput as a failure; this is justified under the plant configuration where the equipment is installed. Hence, a failure of one piece of equipment reflects in the mainstream's performance.

Therefore, the data obtained was classified as a failure or halting of feed (throughput); this was done manually per the downtime description in excel format. Downtimes from a planned stoppage were also classified as point 1 of the classification. Point 1 was taken out of the list as the scheduled maintenance period represents the MRP, Maintenance Required Period. After compiling the data set through the above means, a Pareto chart was developed to support Pareto analysis. This is to identify the frequent causes of failure and the top twenty failure that represents eighty percent of losses. In addition, the Pareto analysis considers the failure modes that resulted in the mainstream equipment not performing as intended. Table 3.1 below is extracted from the raw data obtained from the organization's processing department.

**Table 3.1 Number of Events Found in the Data**

| Year | Equipment | Number of Events |
|---|---|---|
| 2019 | SAG 1 | 188 |
| | SAG 2 | 367 |
| 2020 | SAG 1 | 273 |
| | SAG 2 | 336 |

Source: Authors' Construct (2021)

The data obtained consisted of Data elements such as the date of the event, the time of failure, the downtime as a result of the failure, the startup time, the unit responsible for the failure, the downtime description, and the downtime classification. The data element gives a clear indication of when the Mill went down and why. The section responsible for the data capturing operated on twelve-hour shift systems; hence, the data captured starts from the beginning of the shift and ends by the end of the change. The next shift takes over and continues till the end of the shift. The data made up of any downtime or any event resulting in loss of Key Performance Indicators (KPI) recorded both Maintenance-related downtimes and non-maintenance-related downtimes such as power interruption operational related such as unavailability of crushed and force majeure. As part of the data classification, all downtime resulting from non-maintenance was not considered in this work (see Table 3.2).

**Table 3.2 Failure Data Extracted from the Primary Source for Both Mills**

| SAG 1 2019 | | | SAG 2 2019 | | | SAG 1 2020 | | | SAG 2 2020 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Obs # | $X_i$ | $C_i$ | Obs # | $X_i$ | $C_i$ | Obs # | $X_i$ | $C_i$ | Obs # | $X_i$ | $C_i$ |
| 1.00 | 0.433 | 1.00 | 1.00 | 0.30 | 1.00 | 1.00 | 1.27 | 1.00 | 1.00 | 0.08 | 1.00 |
| 2.00 | 2.133 | 1.00 | 2.00 | 2.43 | 1.00 | 2.00 | 0.17 | 1.00 | 2.00 | 0.25 | 1.00 |
| 3.00 | 3.900 | 1.00 | 3.00 | 4.07 | 1.00 | 3.00 | 2.07 | 1.00 | 3.00 | 0.58 | 1.00 |
| - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - |
| 187.00 | 0.12 | 1.00 | 335.00 | 0.08 | 1.00 | 272.00 | 0.98 | 1.00 | 335.00 | 2.17 | 1.00 |
| 188.00 | 4.33 | 1.00 | 367.00 | 0.08 | 1.00 | 273.00 | 0.67 | 1.00 | 336.00 | 0.43 | 1.00 |

Source: Author’s Construct (2021)

The variable used in the data, Obs # represent Observation number, $X_i$ represent total hours, $C_i$ represent the number of count.

## 3.4 Model Specification

The equipment selected for the study from the above chart is as indicated in Figure 3.2 below. The Sag Mills are the primary grinding chambers for the crushed materials from the Crushing unit. The materials produced from the crushing unit are fed into the grinding Mills through a belt conveyor system. The Milled load is circulated through the cyclone units where underflow is returned to the secondary grinding Mills for regrinding for further material size reduction. The Milling plant is grouped into two circuits with installed equipment in series, though there are commonalities in the process. Maintenance of these circuits is independent of each other; however, the commonalities compel the stoppage of all mills during maintenance in such areas.

At the backdrop of the configuration, each Circuit is analyzed individually. SAG mills (semi-autogenous grinding mills) are tumbling mills with a shell diameter-to-length ratio of roughly two. SAG mills create both thrown and cascade ball-milling motions using shell linings designed to lift and fling alloy steel grinding balls up to 150 mm (6 in.) in diameter, thanks to their high aspect ratio. Crushing, attrition, and abrasion comminution techniques are used to reduce primary-crushed ores to ball-mill feed size. A feed chute transports ore with a top size of up to 200 mm (8 in.) and water to the feed end of a SAG mill; the ore is milled in the shell, and the milled product escapes through grates and pulp lifters at the discharge end (Royston, 2006).

Any failure related to the Primary Grinding Mills is included in each Mill's collected data collection. Owing to the configuration of the plant, the entire plant is categorized into three streams for this work, namely, Downstream, mainstream and upstream. Any failure from the down and upstream though affects the mainstream's operation. However, this work focuses on the mills and their accessories (see Figure 3.2).

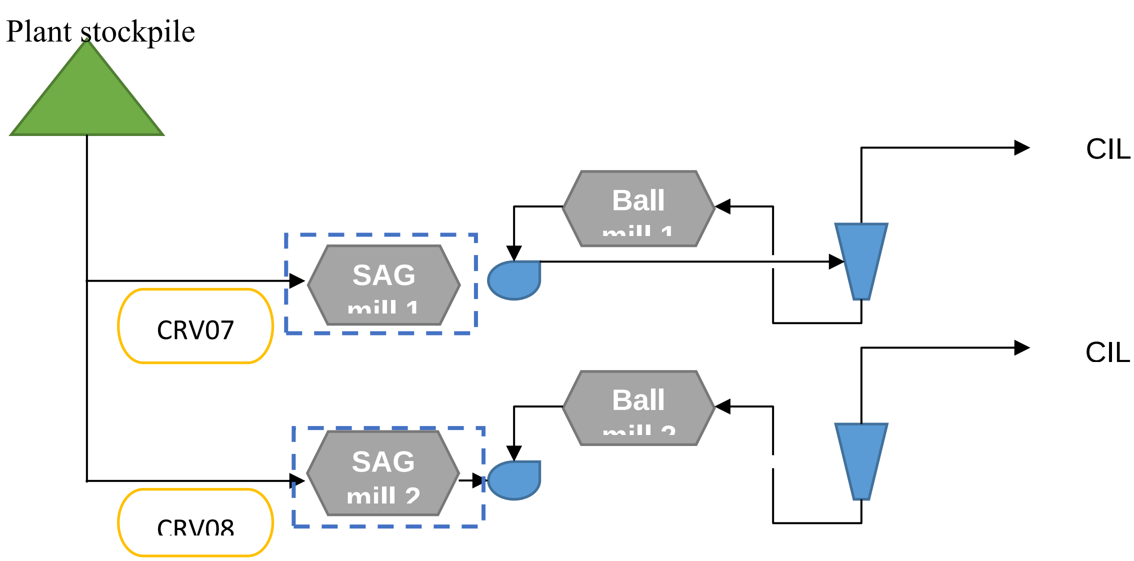


**Figure 3.2 Milling Plant Flow Chart**

Source: Authors' Construct

### 3.4.1 Pareto Analysis

Pareto Analysis is a commercial decision-making technique based on the 80/20 rule. It is a decision-making strategy in which a small set of input elements are statistically discretized as having the most effect on a desired or unwanted outcome (Will-Kenton, 2019). The 80/20 rule is another name for the Pareto Principle. The law of the crucial few and the concept of factor sparsity state that 80% of effects derive from 20% of causes or that 20% of your actions/activities will account for 80% of your results/outcomes (Margerita-Chang, 2020). It identifies the problem expanses or tasks that will have the biggest payoff. The tool has several benefits, including (a) Identifying and prioritizing problems and tasks, (b) Helping people to organize their workloads more effectively, (c) Improving productivity, and (d) Improving profitability.

The principal purpose of this distribution is to categorize maintenance interventions based on their frequency and then rank them based on their importance (Daphne-Mothes, 2018). The steps required to create a Pareto diagram are, (a) Develop interventions according to the nature of failure, (b) Sort those people into groups in increasing order, (c) Calculate the total number of interventions or the amount of time spent based on the type of diagram you want to examine (d) Calculate the percentages for each group: number of interventions/total time spent/total and (e) create a graph to get a Pareto curve.

### 3.4.2 Laplace Test

The centroid test, also known as the Laplace test, compares the midpoint of the observation period to the centroid of recorded arrival times. This metric approximates the standardized normal random variable. Because it is a tool for solving differential equations, the transform has many applications in science and engineering. For example, it rewrites linear differential equations as algebraic equations and multiplies convolutions. If the Laplace test $UL \geq 2$ shows strong evidence for reliability degradation, while if $UL \leq -2$, this indicates a reliability improvement.

### 3.4.3 Weibull Analysis

Because of its versatility, the Weibull distribution is recommended for dependability modeling (Vlok, 2011).

$$f(x)=γα((x−μ)α)γ−1exp(−((x−μ)α)γ)\ x≥μ;γ,α>0 \tag{3.1}$$

Where $γ$ is the shape parameter, also called the Weibull slope or the threshold parameter. $α$ is the scale parameter, also called the characteristic life parameter. Finally, $μ$ is the location parameter, the waiting time parameter or the shift parameter.

### 3.4.4 Mean Time Between Failure (MTBF)

Failure is at the heart of MTBF and dependability. Every product that has ever been created will ultimately fail, although hopefully not during its useful life. The chance of failure is determined using reliability and MTBF estimates. Many individuals will make assumptions based on a product's MTBF. If the MTBF is 100000 hours, for example, one may believe that they will not need to replace their product for a long time. That isn't the case at all. The client must take it a step further. Based on the MTBF, they should compute the reliability or the likelihood that it will survive as long as they intend to keep it in service. As stated in Table 3.2, it is the average time between system failures of the entire sample population and is given by:

$$MTBF = \frac{\sum X_i}{m} \tag{3.2}$$

where $X_i$ are the inter-arrival times of failures, and $m$ what is the total number of observed failures? The future or predicted MTBF can also be found, Vlok (2011) and is shown in Equation 3.3.

$$E\left(X_{r+1}\right)=\frac{\int_0^\infty xf\left(x\right)dt}{\int_0^\infty f\left(x\right)dx} \tag{3.3}$$

### 3.6.5 Maintenance Free Operating Period (MFOP)

Maintenance free operating period is a length of time during which a piece of equipment may carry out its given duties without requiring any maintenance. It's when no maintenance is necessary, urgent, or unexpected. Following each MFOP, there is a maintenance recovery period (MRP), during which the system is maintained to finish the following MFOP cycle. System maintenance, logistics, acquisitions, and sustainment processes might benefit from the MFOP idea (Thomas, 2013). The MFOP is shown in Equation (3.4) for both repairable and non-repairable systems.

$$MFOPS\left(t_{mf}\right)=\exp\left(\frac{t^\beta-\left(t+t_{mf}\right)^\beta}{\eta^\beta}\right) \tag{3.4}$$

where $\eta$ is the scale parameter, and $\beta$ is the shape parameter of the Weibull distribution equation 3.5.

$$MFOP=\eta\times\left[\ln\left(\frac{1}{MFOPS}\right)\right]^{\frac{1}{\beta}} \tag{3.5}$$

The notion of a maintenance-free operating time (MFOP) existed previously; it is essentially the same as a warranty period. Operators are considering this approach to extend the system's life, making it novel. It will be anticipated, in practice, to ensure that no unplanned maintenance operations are necessary throughout each set period of the process. Full part life tracking and a higher degree of component and module interchange will be essential to system safety and reliability engineering. The maintenance-free operating time (MFOP) is a period of operation during which an item may carry out all of its assigned duties with the bare minimum of maintenance without the operator being hampered due to system defects or constraints. In other words, an item will likely continue to operate for at least a period of thermo-mechanical fatigue (*tmf*) life units without the requirement for corrective maintenance owing to a component of the system failing in a system-wide critical failure. During the MFOP, the system can perform any planned minimum maintenance.

Furthermore, during an MFOP, the redundant components might fail without requiring any remedial action. The goal is to determine the likelihood of any unscheduled maintenance. Maintenance should be limited to a bare minimum throughout the MFOP. MFOP will compel the provider to analyze potential failure mechanisms, which will enhance the system's overall design, according to Hockley and Appleton (1997).

Giving a guaranteed maintenance-free operating time of a certain number of flying hours, miles, or days, on the other hand, leads to a decision on a reasonable likelihood of survival versus a higher cost (Crocker, 1997). The manufacturer will need to calculate the estimated cost of delivering the MFOP and, as a result, raise the price to avoid losing money while maintaining competitive pricing. A maintenance recovery phase frequently follows an MFOP (or cycles of MFOP) (MRP). This is the time frame in which the necessary planned maintenance is carried out. The data analysis strategy is summarized in Tables 3.3 and 3.4, respectively.

**Table 3.3 Reliability Measures**

| TYPES | SUMMARY | MEASUREMENT |
|---|---|---|
| Basic Reliability measures | Predict system able to operate without maintenance and logistic support. | • Reliability function<br>• Failure function |
| Mission reliability measures | Predict system ability to complete a mission. Considers only those failures causing mission failure | • Maintenance-free operating period (MFOP)<br>• Failure free operating period (FFOP)<br>• Mission reliability<br>• Hazard function |
| Operational reliability measures | Predict system performance operating in a planned environment | • Meantime between maintenance (MTBM)<br>• Meantime between overhaul (MTBO)<br>• Maintenance-free operating period. (MFOP)<br>• Meantime between critical failure<br>• Meantime between unscheduled removal. (MTBUR) |
| Contractual reliability | • Defines, measures, and evaluate manufacturers' program<br>• Considers design and manufacturing characteristics. | • Mean time between failure (MTBF)<br>• Meantime to failure. (MTTF) |

(Source: Kumar, 2012)

**Table 3.4 Definition of Variables and Measurements**

| Variable | Scale | Formulars | Source |
|---|---|---|---|
| MTBF | It is a basic measure of a system's reliability; the higher the MTBF, the higher the product's reliability. | $MTBF = \frac{Total\ running\ time}{No.\ of\ failures}$ | (Jonathan, 2020) |
| MFOP | It is an independent variable. It is an alternative performance measure to MTBF, or mean time between failures. | $MFOP = e\hat{}(-\lambda n)\ [1 + \lambda t + \frac{(nx)}{2!} + \cdots \frac{(\lambda t)x^2}{3!} + \frac{(\lambda t)x^{x-1}}{(n-1)})\ ]$ | (Amir, 2013) |

Source: Author's construct (2021)

## 3.7 Chapter Summary

A quantitative research technique was employed to reduce biases in analyzing the data acquired through secondary data to gather, analyse, interpret, and write a study found. The mining industry is increasingly becoming a high-cost venture with initial capital being extremely high; hence a piece of reliable equipment would be required to achieve higher utilization of the asset. The cost of equipment failure is categorized into two elements thus Cost of Production loss and Cost of maintenance.

To critically analyse Iduapriem Mine's physical asset management, the study adopted a two-year time series of secondary data relating to the most critical asset of the mine. In addition, failure data resulting from unplanned maintenance, such as corrective maintenance to breakdown maintenance data, is required; these failure data for the Mills were analysed. For this work, two types of events are needed for the main data set a) Event number one - Breakdown or unplanned maintenance and b) Event number two - Planned maintenance.

After identifying the Circuit or asset to be analysed, data collection from the exact unit, system, or Circuit begins. Microsoft Excel is mainly used to analyze the data set to edit and manage to suit the research work; this is not to edit to be biased but edit to be in line with the result; excel allows reducing the extensive data into a Pareto chart.

Data about grinding mill maintenance and failure systems were used. The data used in this study was on the mill circuits as established by the Mine. This information is gathered from secondary sources, specifically the Iduapriem Mine excel data capturing system, which keeps track of many data and variables. The data is based on a two-shift system every day, so each shift collects information as it happens before the conclusion of the change. The Data was obtained from 2019 to 2020, from January to December of the said years.

There are two main types of downtimes found in the data set obtained from the Anglogold Ashanti Iduapriem mine, thus halting feeding to the Mill, impacting the output, and a failure resulting in the stoppage of the mainstream or the latter; however, weirdly occurred. Therefore, the mine classifies the data as the equipment under study is deemed unavailable whenever any other equipment fails and results in the stoppage of the leading equipment; this is because of the process flow effect. Furthermore, in the event of halting throughput due to maintenance-related downtime, the equipment again is deemed unavailable, affecting availability. Methods used to analyse the data were Pareto, Laplace test, Weibull Analysis, Mean Time Between Failure, and Maintenance Free Operating Period.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.0 Introduction

This chapter presents the results and the discussion of the research work conducted to ascertain the objectives established as the purpose of this work. After completing the case study conducted at Angloglod Ashanti Iduapriem mine, the data anlysed establishes specific outcomes as results to be discussed. Data gathered on two identical circuits in operation were analysed over two years, from the beginning of 2019 to the end of 2020, the data trend were found to be similar in nature, therefore, 2019 and 2020 data were selected for the work, this is because most of the causes of the Mills downtimes in the previous data has been corrected, hence the need to use current data.

## 4.1 Results

### 4.1.1 Pareto graph Analysis

The data set was analyzed from January 1 to December 31, 2019, and from January 1 to December 31, 2020. After the calculation of the parameters, to present the predominant failures in the data set, categorization was done based on event number, actual time ($X_i$), event type ($C_i$), and global time ($T_i$).

Sag Mill 1 2019 Pareto analysis was performed supported with a graph to indicate the types of failures and the frequency of occurrence, the data sorted for Sag 1 in the year 2019 accounted for 118 events, and various failures were grouped into categories based on similitude, it was indicated clearly that Trunnion liner leakage, Feed end leakage through the cone, PLC failure and Gearbox oil flow/foundation bolts were the topmost downtimes as indicated in Figure 4.1.

The Sag 2 data for 2019 was sorted, and 367 events were found during the previously stated analysis period from the Pareto Chart. The Pareto chart for Sag 2 for 2019 is indicated in Figure 4.2. Cracked Trunnion journal was the highest and outlier, followed by Sag 2 Motor Bearing, mill discharge pump, and inching drive related failures were the top downtimes. The maintenance and failure data for Sag 1 during the year 2020 were sorted out of the original data; after sorting the data for the year 2020 for Sag 1, 273. The events discovered throughout the analysis period were imported into Microsoft Excel. The Pareto chart for Sag 1 for the year 2020 is indicated in Figure 4.3. The chart indicated that the predominant downtimes were high trunnion bearing temperature, Conveyor number 7 (CVR07) open joint, Tailings pump, and Feeder 3 jamming.

The maintenance and failure data for Sag 2 for 2020 was sorted out, and 336 events were discovered throughout the analysis period. Pareto analysis was performed with a graph to clearly show the types of failures and the frequency of occurrence; the Pareto chart for Sag 2 for the year 2020 is shown in Figure 4.4. According to the chart, the most common downtimes were caused by the Sag 2 trunnion Journal failures, Tailings Pump, Sag 2 Motor, GTSF Pump, and mill discharge pump.

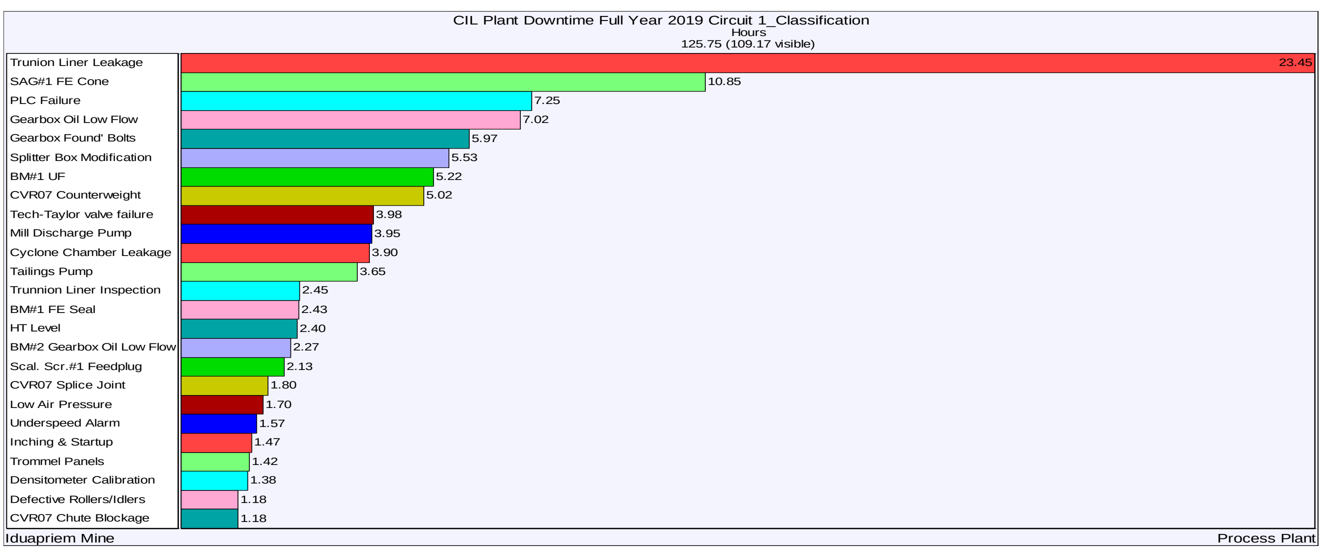


**Figure 4.1: Pareto Chart for Sag Mill 1, 2019**

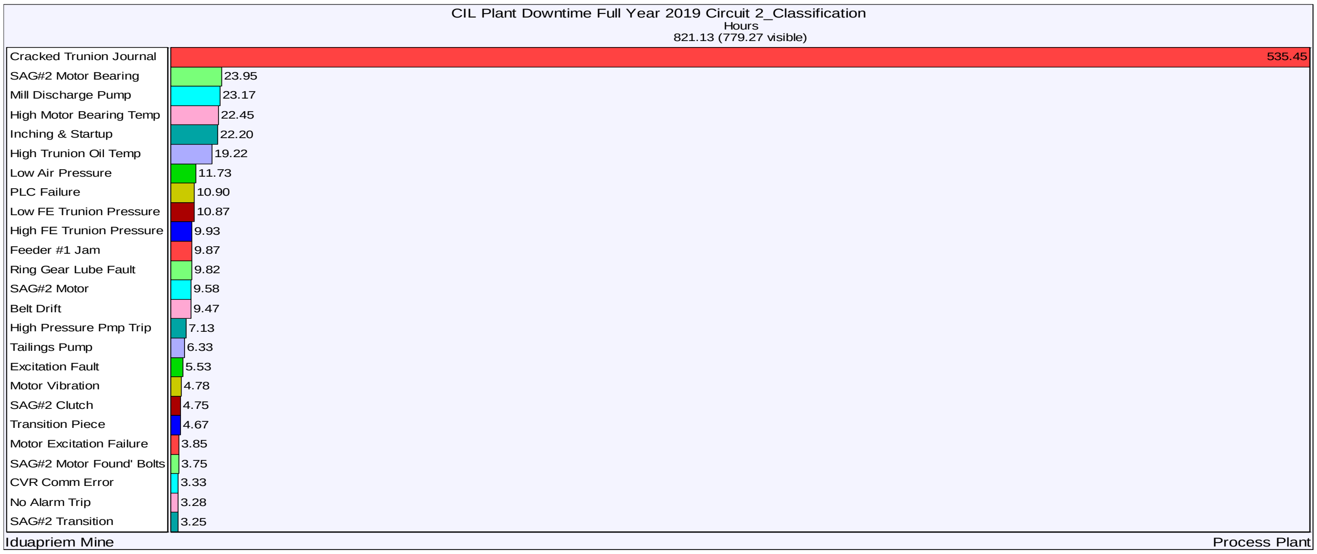


**Figure 4.2 Pareto Chart for Sag Mill 2, 2019**

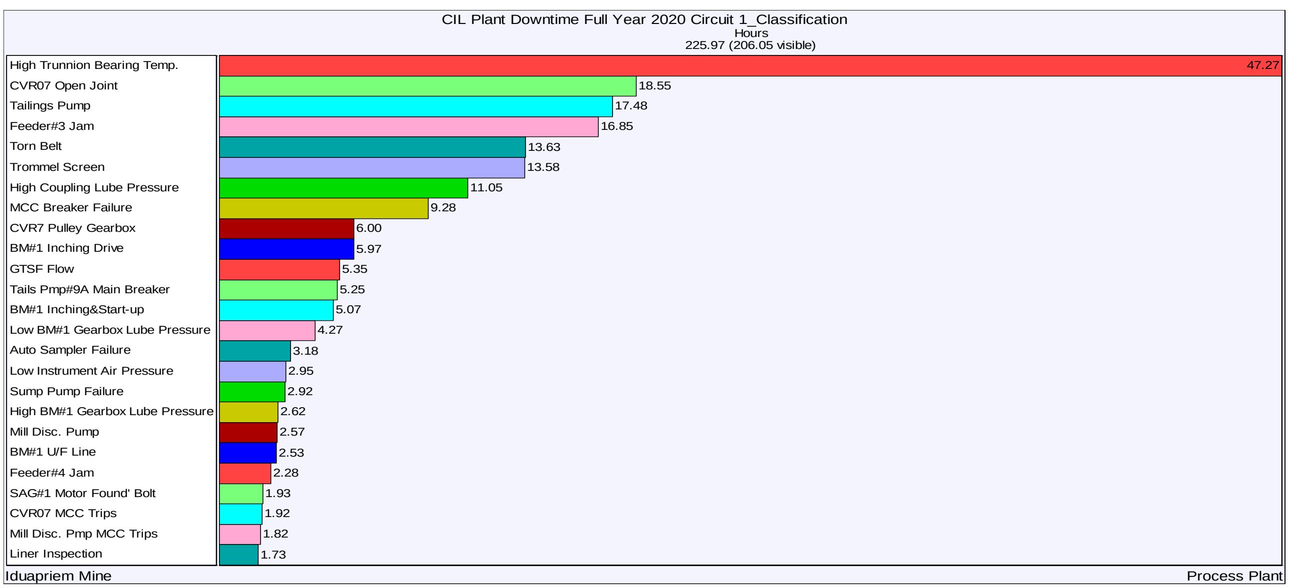


**Figure 4.3 Pareto Chart for Sag Mill 1, 2020**

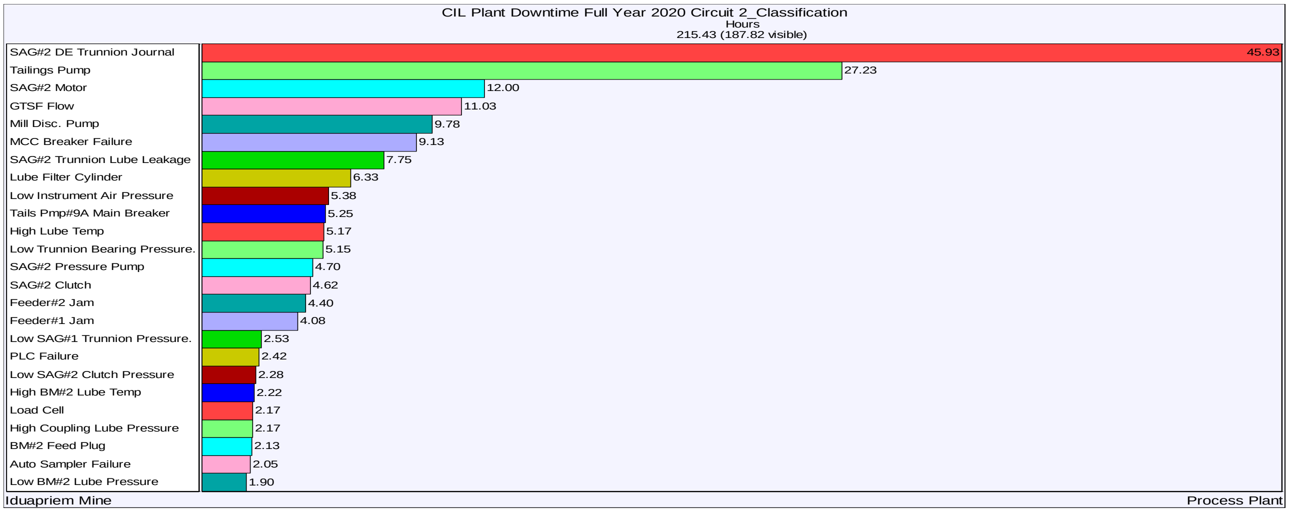


**Figure 4.4 Pareto Chart for Sag Mill 2, 2020**

The Laplace test was the first calculation performed on the data; from the data, the Laplace test results were all less than two; as indicated in Table 4.1, their figures indicate that the assets are in the reliability improvement zone. These results demonstrate the status of the asset as required by the objective set for this research work, hence satisfying the set objective.

**Table 4.1: Laplace Test for Sag Mill 1 and 2 for 2019 and 2020**

| # | Type | Year | Trend test | Result |
|---|---|---|---|---|
| 1 | | 2019 | | ULsag1 = -2.204 |
| 2 | Sag 1 | 2020 | Laplace test | ULsag1 = -8.63 |
| 3 | | 2019 | | ULsag2 = -11.65 |
| 4 | Sag 2 | 2020 | | ULsag1 = -2.31 |

Source: Author's Construct (2021)

To effectively analyse the data acquired, it was essential to determine the repairability of the Mills. This is after it has been determined through the Laplace concept that the Circuit's reliabilities are in the improvement zone; therefore, the characteristics of the reliability of the Circuits, which is made up of Mills, are confirmed Weibull analysis was adopted. The Weibull slope represented with the parameter $\beta$ is also equal to the probability density function shown in Figures 4.6 to 4.8. Therefore, the $\beta$ value, <1, as indicated in the figures, indicates that the studied asset is repairable. This was the same for Sag 1 for 2019 and 2020; Sag 2 was less than 1 for 2019 and 2020. The MTBF and MFOP figures calculated for the period under study are as indicated in Table 4.2.

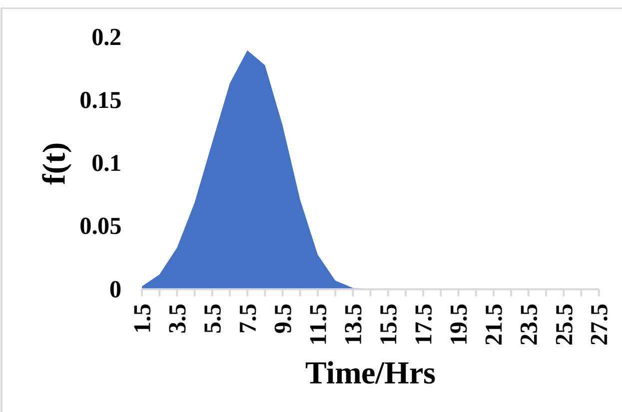


**Figure 4.5 Weibull Chart for Sag Mill 1, 2019**

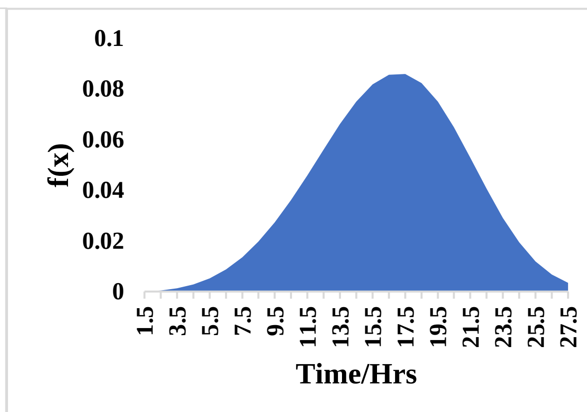


**Figure 4.6 Weibull Chart for Sag Mill 2, 2019**

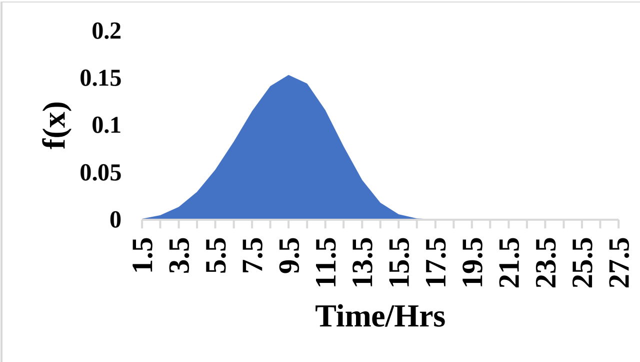


**Figure 4.7 Weibull Chart for Sag Mill 1, 2020**

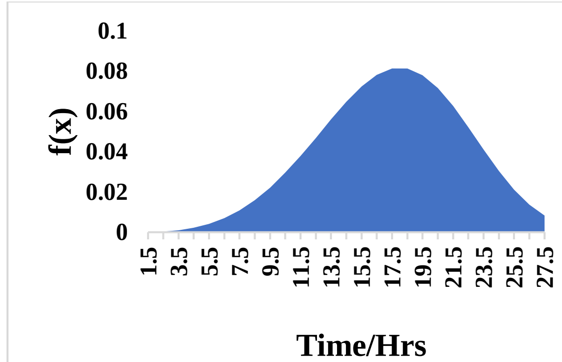


**Figure 4.8 Weibull chart for Sag Mill 2, 2020**

**Table 4.2 MTBF Vrs. MFOP**

| # | Equipment | Year | MTBF (hrs.) | | MFOP (hrs.) | |
|---|---|---|---|---|---|---|
| | | | Hrs | Weeks | Hrs | Weeks |
| 1 | Sag Mill 1 | 2019 | 51.7 | 0.3 | 755 | 4.5 |
| 2 | | 2020 | 33.7 | 0.2 | 36.6 | 0.2 |
| 3 | Sag Mill 2 | 2019 | 22.3 | 0.1 | 2378.3 | 14.2 |
| 4 | | 2020 | 27.5 | 0.2 | 1187.6 | 7.1 |

Source: Author’s Construt (2021)

## 4.2 Discussions

4.2.1 Comparative Analysis of MTBF and MFOP for the Mills

A comparative analysis can be conducted after calculating the two metrics (MTBF and MFOP) for the data set range. Firstly, MTBF. The final figures for the MTBF are recorded in Table 4.2 above, the duration calculated in hours and converted to weeks. The MFOP for both circuits is calculated in hours and converted to weeks for the period stated, and case studied. The well-utilized MTBF figures found for each Circuit as shown indicate that the duration before stoppage is minimal; as calculated, The MTBF for Sag Mill 1 was 51.7 hours or 0.3 weeks in the year 2019, this indicates that the Sag Mill 1 could operate without failure for 0.3 weeks, after which maintenance could be carried out. The type of maintenance, in this case, would be unplanned maintenance,  whiles Sag Mill 1 MFOP for the year 2019 was 4.5 weeks which was an indication that Sag Mill 1 could operate for 4.5 weeks before the plant would be stopped for maintenance to be carried out. Maintenance carried out under such conditions is preferred planned maintenance. The Sag Mill 1 parameters for 2020 were 0.2 weeks for MTBF and 0.2 Weeks for MFOP, indicating that Sag Mill 1 would be stopped every 0.2 weeks for unplanned and planned maintenance for MTBF and MFOP, respectively. Though the duration is the same, there is an added advantage for stopping on schedule instead of unplanned for MFOP and MTBF.

The Sag Mill 2 MTBF and MFOP figures calculated for 2019 resulted in 0.1 weeks and 14.2 weeks. This indicates that the Sag Mill 2 will have to be maintained as unplanned under the MTBF after every 0.1 weeks, whiles the plant would have to be planned and stopped after every 14.2 weeks under MFOP. In this period, it will be stopped instead of failed, as was the case in the MTBF.

The Sag Mill 2 MTBF and MFOP figures calculated for 2020 resulted in 0.2 weeks and 7.1 weeks. It indicates that Sag Mill 2 would be required for maintenance at 0.2 weeks as unplanned maintenance in the case of MTBF and 7.1 weeks for planned maintenance in the case of MFOP. Comparatively, the Mill wear parts will wear faster in the case of MTBF due to frequent stoppages and startups of the Mill. This increases the cost of maintenance and causes unrecoverable production loss, whiles in the case of the MFOP, the breakdown is disallowed. Therefore, all efforts are made to prevent unplanned stoppages. Hence, such losses are avoided. There is also the high power consumption due to the initial power requirement for starting up Mills from inertia, and high power would be required to move the Mill from the state of inertia. This, therefore, contribute to high operating cost.

Considering the impact of frequent stoppages such as (a) increase in wear rate, (b) higher power consumption, and (c) causes of fatigue in the circuits due to settlement of materials as a result of unplanned stoppage. Therefore, to efficiently and cost-effectively maintain Mills in the Gold production industry like Iduapriem Mine, The MFOP is preferred to the MTBF. Therefore, this comparison satisfies the second objective set for this research work.

Per the imperical review, this work confirms the result of the MFOP to be better than the MTFB for the management of Mills reliability, as clearly indicated by Shaalane (2012), the imperical results of the MFOP is better than the MTBF, also with the cost of maintenance increasing by time, maintenance managers are called upon to ensure cost effective maintenance in organisation such as Mining, unlike the past when maintenance was responsible for repairing broken goods.

According to Simoes at el,. (2011), maintenance has a broader viewpoint in todays open manufacturing firms, this requires maintenance managers to integrate and direct the maintenance efforts to meet organisational strategic goals efficiently and effectively (Maletic et al., 2014). These needs firm up the need use a proven method known as the MFOP to achieve such expectation as require managers.

MFOP as compared to MTFB on the Crushing equipment shows the inherent challenges with the MTBF, this can be said as the situation on the Mills, the outcome of this results clearly support the fact that MTFB has inherent drawbacks and must be replaced with MFOP in the management of Mills in the mining industry, the MFOP help to schedule and plan maintenance efficiciently and effectively, therefore required work execution outcomes are met due to efficient planning and scheduling which is aided by the use of MFOP

## 4.3 Industrial Evaluation and Validation of the Research

The data obtained from AngloGold Ashanti Iduapriem mine was successfully applied to the research work. An industry expert was approached to interrogate and review the practical value of the research work.

The validation was performed by a Plant Superintendent (Mechanical) in the AngloGold Ashanti Iduapriem Mine Milling plant. He indicated with a white paper confirming that he preferred the MFOP to the MTBF; according to him, "The existing maintenance metrics (MTBF) has not been able to help Iduapriem mine to holistically deal with its maintenance and breakdown challenges as can be seen from the Pareto chart.

The MFOP being practiced in the aviation industry is currently showing the way for any industry desirous of improving its maintenance practice, correctly anticipating and dealing with real and perceived challenges, and scaling up its profitability to embrace the MFOP metrics."

## 4.4 Chapter Summary

The data set was analysed from January 1 to December 31, 2019, and from January 1 to December 31, 2020. Sag Mill 1 2019 Pareto analysis was performed supported with a graph to indicate the types of failures and the frequency of occurrence, the data sorted for Sag 1 in the year 2019 accounted for 118 events, and various failures were grouped into categories based on similitude. The Sag 2 data for 2019 was sorted, and 367 events were found during the previously stated analysis period from the Pareto Chart. The maintenance and failure data for Sag 1 during the year 2020 were sorted out of the original data, and 273 events were discovered throughout the analysis period.The maintenance and failure data for Sag 2 for 2020 was sorted out, and 336 events were discovered throughout the analysis period.

The Laplace test is carried out, this test carried out to determine the reliability status of the Mills under study. The figures obtained ranges from -0.2ul to -11.6ul all indicating that position of the reliability of the Mills circuits. The figures confirmed that the Mills are in the reliability ascending zone. The repairability of the Mills was determine. This is after it has been determined through the Laplace concept that the Circuit's reliabilities are in the improvement zone; therefore, the characteristics of the reliability of the Circuits, which is made up of Mills, are confirmed. Weibull analysis was adopted. The Weibull slope represented with the parameter β is also equal to the probability density function.

Comparative analysis between Mean Time Between Failure and Maintenance Free Operating Period, this is to determine the best maintenance strategy to be adopted. The MTBF figures obtained were between 0.1 to 0.3 weeks. Whiles the Maintenance free operating periods data ranges from 0.2 to 7.1 weeks. This indicates the failure periods and when the plant will be required to be stopped for maintenance respectively, the Period for maintenance is known as maintenance required period (MRP). An industry expert was approached to interrogate and review the practical value of the research work.The validation was performed by a Plant Superintendent (Mechanical) in the AngloGold Ashanti Iduapriem Mine Milling plant. The superintendent recommends the implementation of the MFOP since the MTBF has not been able to reduce or minimise the failures in the operational process.

# CHAPTER 5

# CONCLUSION, FINDINGS, AND RECOMMENDATION

## 5.0 Introduction

The increasing cost of acquiring, installing, and operating assets such as Milling plants requires a reliable measure such as MFOP to reduce secondary costs and effects; this chapter provides a summary of the findings and provides a recommendation based on the outcome of the research work. A future research direction is also provided in this chapter.

## 5.1 Summary of Findings

As already explained about the deficiency of the MTBF, the analysis supports the fact that the largely used metric has limitations and does not give an accurate picture for detailed analysis of assets to improve reliability; with MTBF, failures are accepted and are allowed in the Mining industry such as AngloGold Ashanti Iduapriem, this assertion is supported by the allowable Mechanical and Electrical downtime budgeted for during operation, however, with MFOP, a detail, and more precise analysis is performed to determine the capability of an asset, as Laplace analysis earlier indicated the reliability improvement asset and reliability degradation asset. It resulted from the deficiency of the metric that resulted in its replacement in the aviation industry. Since the industry cannot allow for failures in the aircraft while in the air as Mills are allowed to fail in operation, there was the need to replace the metric with a safer and more reliable metric. Considering the figures obtained for the MTBF for both circuits under review, there was the temptation to relax as the management body of the organization; however, with the outcome of the MFOP, which is the acceptable metric in the aviation industry, the further direction is given by the metric to concentrate on the less reliable asset to improve its reliability.

Per the following objectives set,

i. To assess the Plant Reliability state of the Milling circuits of AngloGold Ashanti-Iduapriem Mine (AAIL)
ii. To conduct a comparative analysis between Meantime Between Failure (MTBF) with Maintenance Free Operating Period (MFOP).

The following were achieved.

- Reliability status of the assets: the Laplace test indicates that all the circuits are in the improvement zone; this indicates that the asset is being maintained and is under a continuous improvement path.

**Table 5.1 Comparative analysis of MFOP and MTBF**

| # | MFOP | MTBF |
|---|---|---|
| 1 | Assumes that success can be achieved and that failures can be predicted correctly. | Accepts that failure cannot be predicted or prevented with certainty. |
| 2 | Attempts to get rid of unplanned maintenance. | Accepts unexpected failure, allowing for unplanned maintenance. |
| 3 | Scheduled maintenance replaces costly unplanned maintenance. | Accepts failure as a valid reason for unplanned maintenance. |
| 4 | Allows for a more concentrated and tailored approach to maintenance and a greater understanding of the equipment by the operators. | By definition, MTBF is an average estimate that is not as targeted as MFOP. |
| 5 | Uses redundant and reconfigurable systems to its advantage. | All systems are treated the same. |

| | | |
|---|---|---|
| 6 | Maintenance downtime may be arranged around operational responsibilities thanks to MFOP. Given that the probability of failure time is acceptable. | The MTBF does not explicitly address this. |
| 7 | More correctly estimating which spares are needed can lower the logistic footprint. | Spare parts aren't always known or available. |

Source: Author's Construct (2021)

## 5.2 Recommendations

From the data, the recommended MFOP calculated were about four (04 weeks) for Mill Circuit 1 and ten (10) weeks for Mill Circuit 2. Thus, these are represented in the chart below; therefore, this frequency will eliminate the Mills' breakdown and failure. Hence reducing the cost related to breakdowns.

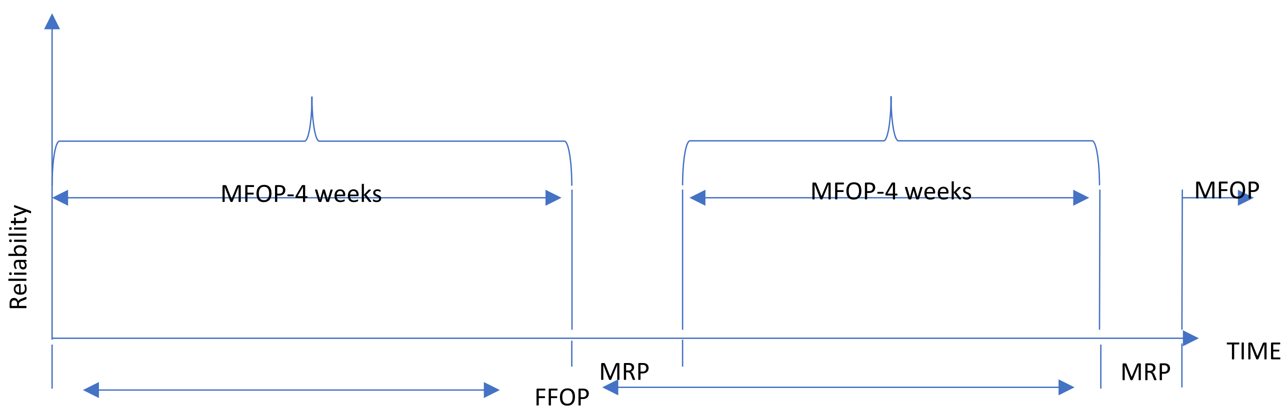


**Figure 5.1 Circuit 1 MFOP Representation**

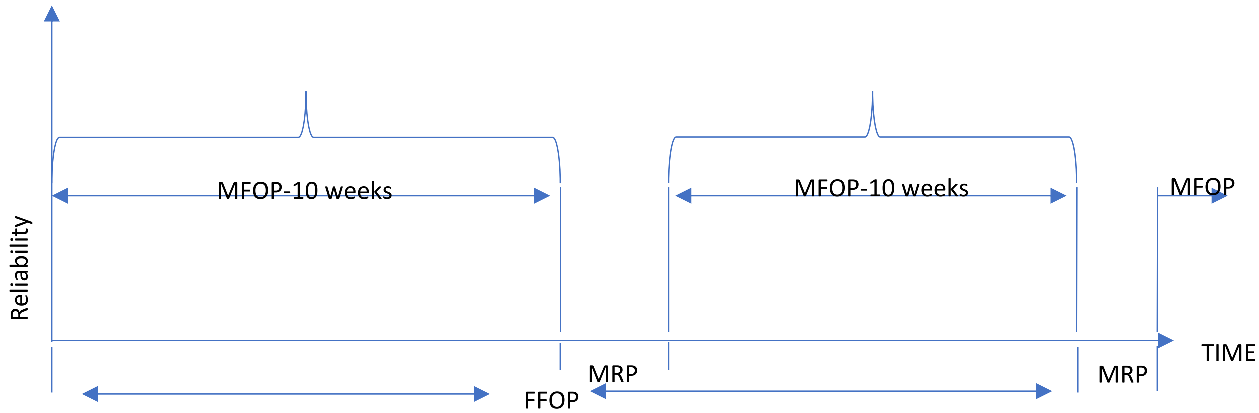


**Figure 5.2 Circuit 2 MFOP representation**

- It is therefore recommended that the MFOP be adopted with a shutdown (MRP) frequency of 4 weeks for circuit 1 as indicated in figure 5.1 above the period to operate the Circuit with minimal failures, after which MRP would be initiated to carry out maintenance to revive and restore the asset to reliable operation to continue another cycle of 4 weeks.

- Circuit 2 is recommended to operate under the metrics MFOP for a frequency of 10 weeks, after which a shutdown (MRP) would be required to revive and restore the asset to reliable operation to continue the cycle for another eleven (10) weeks

## 5.3 Implication

The outcome of implementation of this work transcend Anglogold Ashanti-Iduapriem Mine interest, the sustainability of the organisation depends partly on reliable plant operations, two significant implications are at stake,

Regulators;

The Mining Regulation of Mineral Commission of Ghana Subdivision 1.7 regulation 1701 refers to the "Returns for Statistacal Purposes", among the monthly returns are the Production Returns and Environmental incidents and accidents reports. As indicated in the MTBF, breakdowns are allowed whiles MFOP does not allow breakdowns. To achieve higher production target, it is required that plant works efficiently without breakdown and this is outcome of MFOP, to prevent potential breakdown that can result in environmental or incident such as oil spillage, MFOP is the best option among the two.

Mining Industry;

Efficient cost management is key to sustainability of Mining organization. According to Anderson, D., (2002). "Major impact on output of all machines/lines, contributing to long factory outages result in total production loss", and loss of production translate into less revenue. The organization incur cost anytime plant outage occurs due to the production lost time and cost of inventory usage. This impact on the attractiveness of the organization to share holders and efficient manpower as a result of competitiveness of the mining organizations in the country.

## 5.3 Future Research direction

The first challenge observed during the research work was the data obtained and the level of consistency of the data; some of the data were ambiguous and inaccurate until further investigation was conducted to confirm the clarity of the data; there is, therefore, the need to conduct a study in the field of data capturing to determine the best possible option and means to capture accurate data. Furthermore, just like a computer, the output will always be based on input. Hence, there is a higher chance of giving wrong work from the wrong data; future research may investigate to provide the best possible means to achieve accurate data.

The MFOP is confirmed through this research work that it can add significant value in the field of optimization of fixed asset maintenance such as Mills, and future research work may be required to develop the implementation strategy for the MFOP for a fixed asset such as Milling plants, thereby integrating the MFOP into the current maintenance management approach.

RCM (reliability-centered maintenance) is an industrial maintenance approach based on examining system functions, implications, and failure modes of process assemblies or components, which is still important in the aviation sector. Future studies may be necessary to evaluate the MFOP and RCM to determine which model is the best and how it can be integrated into the maintenance of fixed assets like mills.

## 5.4 Conclusison

Meeting the objectives of the research work, the recommendation, and the future research work direction provided, this research work is worth implementing in the maintenance of fixed assets such as Mills. The recommendation provided directly targets the challenges available in the Iduapriem Mine considered in the case study. The organization's management will benefit significantly by implementing the recommendation and, even more, by ensuring the implementation work is completed to secure the strategy into the maintenance program available.

# REFERENCES


Abd Rani, N.A., Baharum, M.R., Akbar, A.R.N. and Nawawi, A.H. (2015), "Perception of maintenance management strategy on healthcare facilities", *Procedia-Social and Behavioral Sciences*, No. 170, pp. 272-281.

Adolfsson, E. and Tuvstarr, D. (2011), "Efficiency in corrective maintenance: *A case study at SKF Gothenburg*, pp. 1-16.

Al Shaalane, A. (2012). Improving asset care plans in mining: Applying developments from aviation maintenance, *Doctoral dissertation, Stellenbosch: Stellenbosch University*, pp. 1-177.

Alvarez, D.L., Rosero, L.S., Rivera, S.R. and Romero, A.A. (2019), "A Framework For Asset Management in Electrical Systems*", IEEE Workshop on Power Electronics and Power Quality Applications,* No. 1, pp. 1-6.

Andrew K.S. and Jardine, A. K. S. (2019), Maintenance, Replacement and Reliability (Theory and Applications), Second Edition, CRC Press, 551 pp.

Aonn., (1985), "Maintenance Management and decision making" https://www.academia.edu/21593312/Maintenance_management_decision_making Accessed, Accessed: November 10, 2020.

Cholasuke, C., Bhardwa, R. and Antony, J. (2004), "The status of maintenance management in UK manufacturing organisations: results from a pilot survey", *Journal of Quality in Maintenance Engineering,* Vol. 10, No. 1, pp. 5-15

Coetzee, J.L. (1997), "Towards a general maintenance model", *Proceedings of IFRIM*, pp.1-9.

Coetzee, J.L., (1998), "A structured approach to Maintenance Auditing", *International Conference of Maintenance Societies, Adelaide, Australia*, pp. 1-8.

Flávio, J., Rocha, A., Mota, S. and Jorge, F. (2017), "Data processing approach and experimental results". *11th European Conference on Antennas and Propagation (EUCAP)*, pp. 2370-2374

Franco-Santos, M. and Bourne, M. (2005), "An examination of the literature relating to issues affecting how companies manage through measures", *Production Planning and Control,* Vol. 2, pp.114-124.

Garg, A. and Deshmukh, S.G. (2006), "Maintenance management: literature review and directions", *Journal of Quality in Maintenance Engineering,* Vol. 12, pp.205-238.

González-Marcos, A., Alba-Elías, F., Navaridas-Nalda, F. and Ordieres-Meré, J. (2016), "Student evaluation of a virtual experience for project management learning", *Computers and Education*, Vol. 102, pp.172-187.

Ishikawa, K., (1982), Guide to quality control, Second Edition, Asian Productivity Organization Tokyo, 566 pp.

Jantunen, E., Akcay, A., Campos, J., Holenderski, M.J., Kotkansalo, A., Salokangas, R. and Sharma, P. (2019), "Business drivers of a collaborative, proactive maintenance solution", *Cyber Physical System Based Proactive Collaborative Maintenance,* pp.7-35.

Kochhar, R. (1997), "Strategic assets, capital structure, and firm performance" *Journal of Financial and Strategic decisions*, Vol. 10, No 3, pp. 23-36.

Kosky, P., Balmer, R., Keat, W. and Wise, G. (2021), "Industrial Engineering", *Exploring Engineering,* pp. 1-14.

Kshirsagar, A.S., El-Gafy, M.A. and Abdelhamid, T.S. (2010), "Suitability of life cycle cost analysis as asset management tools for institutional buildings", *Journal of Facilities Management*, pp. 5-19.

Kumar, U.D. (1999), "New trends in aircraft reliability and maintenance measures", *Journal of Quality in Maintenance Engineering*, Vol. 5, No. 4, pp. 287-295.

Lee, H.L., Padmanabhan, V. and Whang, S. (1997), "The bullwhip effect in supply chains", *Sloan Management Review*, No. 38, pp. 93-102.

Long, J., Shenoi, R.A. and Jiang, W. (2009), "A reliability-centred maintenance strategy based on maintenance-free operating period philosophy and total lifetime operating cost analysis", *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, Vol. 223, No. 6, pp. 711-719.

Ma, Z. Z. L., and Sheng, W. (2014), "Analysis of the new asset management standard ISO 55000 and PAS", *China International Conference on Electricity Distribution (CICED),* No. 55 pp. 1668-1674.

Maletič, D., Maletič, M., Al-Najjar, B. and Gomišček, B. (2014), "The role of maintenance in improving company's competitiveness and profitability: a case study in a textile company", *Journal of Manufacturing Technology Management*, pp. 1-19.

Márquez, A.C. (2009), "The maintenance management framework: models and methods for complex systems maintenance", *Journal of Quality in Maintenance Engineering*, Vol. 15, No. 2, pp. 167-178

Modarres, M. (2006), "Risk analysis in engineering: techniques, tools, and trends", *CRC Press,* 367 pp.

Moon, S.M., Hong, D., Kim, S.W. and Park, S. (2012), "Building wall maintenance robot based on built-in guide rail", *International Conference on Industrial Technology*, pp. 498-503

Murray, M., Fletcher, K., Kennedy, J., Kohler, P., Chambers, J. and Ledwidge, T. (1996), "Capability assurance: a generic model of maintenance", *Proceedings of the 2nd International Conference of Maintenance Societies*, Melbourne, No. 72 pp. 1-5.

Murthy, D.P. and Blischke, W.R. (2005), "Warranty management and product manufacture", Springer Science and Business Media, 459 pp.

Myers, S.C. (1984), "Finance theory and financial strategy", *Interfaces*, Vol. 14, No. 1, pp. 126-137.

Ndur, S.A., Doe, J.M. and Asiam, E.K. (2015), "Natural cyanide attenuation in a tailings dam in South-Western Ghana", *Research Journal of Environmental and Earth Sciences*, Vol. 7, No. 2, pp. 24-28.

Nylander, R. (2015), "A model to cost-effectively improve the production flow by applying efficient maintenance: A case study, Degree Disertatiton, Linneaus University, pp. 1-49.

Ohring, M. (1995), Engineering materials science, Academic Press Inc. 161 pp.

Pareto, V., Marchionatti, R. and Mornati, F. (2007), *Considerations on the fundamental principles of pure political economy* , Routledge, 321 pp.

Parida, A. and Kumar, U. (2006), "Maintenance performance measurement (MPM). issues and challenges", *Journal of Quality in Maintenance Engineering*, Vol. 12, No. 3, pp. 239-251

Pencer, J., Krueger, S., Adams, C.P. and Katsaras, J. (2006), Method of separated form factors for polydisperse vesicles", *Journal of Applied Crystallography*, Vol. 3, pp. 293-303.

Petchrompo, S., and Parlikad, A.K., (2019). "A review of asset management literature on multi-asset systems", *Reliability Engineering and System Safety,* Vol. 181, pp. 181-201.

Simões, J.M., Gomes, C.F. and Yasin, M.M. (2011), "A literature review of maintenance performance measurement: A conceptual framework and directions for future research", *Journal of Quality in Maintenance Engineering*, Vol. 17, No. 2, pp. 116-137.

Singh, R.K., Garg, S.K. and Deshmukh, S.G. (2008), "Strategy development by SMEs for competitiveness: a review", *Benchmarking: An International Journal*, Vol. 15, No. 5, pp. 525-547.

Supriatna, A., Singgih, M.L., Widodo, E. and Kurniati, N. (2017), "Preventive maintenance considering OEE threshold for lease equipment", *In Proceedings of the Asia Pacific Industrial Engineering and Management Systems Conference,* pp. 13-18.

Swanson, L. (1997), "Computerized maintenance management systems: a study of system design and use", *Production and Inventory Management Journal*, Vol. 2, pp. 1-11.

Vlok, P.J. (2011). Introduction to practical statistical analysis of failure time data: Long term cost optimisation and residual life estimation. *Self-Published, Course Notes*, 67 pp.

Warren, (2020), "What is preventive maintenance? Types, benefit, cost and examples", *Team at Coast,* pp. 1-13

Williams, C. (2007), "Research methods", *Journal of Business and Economics Research,* No. 5, pp. 1-23.