An Integrated Framework for the Management of Strategic Physical Asset Repair/Replace Decisions

by

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March 2016

Declaration

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Abstract

An Integrated Framework for the Management of Strategic Physical Asset Repair/Replace Decisions

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December 15

The effective management of physical asset repair/replace decisions is essential to organizations that compete in physical asset intensive industries. Not only do these decisions require substantial capital investment, they also have a significant effect on an organization's profitability and financial performance. Physical asset repair/replace decisions fall within the domain of Physical Asset Management (PAM). PAM is a broad and complex field that comprises of multiple disciplines and principles for the effective management of physical assets, from concept to disposal. Managers of physical assets in physical asset intensive industries are regularly faced with the decision to either continue maintaining, or to replace a physical asset in operation. These decisions include, amongst many other factors, determining the optimal period when replacing a physical asset is more advantageous than maintaining it. Despite the importance and significant organizational impacts of this decision, judgement is often made in practice based on the intuition of the decision-maker and/or purely based on financial aspects. As PAM is a multi-disciplinary field, the management of physical asset repair/replace decisions should incorporate the impacts of multiple, financial and non-financial criteria.

This study therefore proposes a strategic, multiple criteria-based, decision-making framework for the management of physical asset repair/replace decisions. The framework is based on an extensive literature review that focusses on identifying the core concepts of PAM and strategic decision-making. Specific emphasis is placed on physical asset repair/replace decisions within the PAM domain as well as on the multi-criteria nature of these decisions.

The proposed framework therefore integrates principles from the fields of PAM, strategic decision-making and multi-criteria decision-making into a structured, stepwise decision-making methodology. The main objective of the proposed framework is to aid managers with the management of physical asset repair/replace decisions, by providing them with a practical, structured decision-making process. Moreover, the framework aims to provide a process that is easy to apply in practice in any physical asset intensive industry. A case study is conducted in the mining industry of Namibia to validate the framework and prove that all of the before mentioned objectives are met.

Uittreksel

'n Geintregreerde Raamwerk vir die Bestuur van Strategiese Fiesiese Bate Herstel/Vervang Besluite

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Die effektiewe bestuur van fiesiese bate herstel/vervang besluite is noodsaaklik vir organisasies wat in fiesiese bate intensiewe industrieë kompeteer. Hierdie tiepe besluite vereis nie net aansienlike kapitaal belegging nie, maar het ook 'n beduidende effek op die winsgewendheid en prestasie van die organisasie. Fiesiese bate herstel/vervang besluite val in die Fiesiese Bate Bestuur (FBB) domein. FBB is 'n wye en komplekse veld wat uit verskeie disiplienes en beginsels bestaan vir die effektiewe bestuur van fiese bates, van konsep tot die ontslae daarvan. Bestuurders van fiesiese bates in fiesiese bate intensiewe industrieë word gereeld gekonfronteer met die besluit om voort te gaan met die onderhoud van n spesifieke bate, of om dit geheel en al te vervang. Die voorgenoemde besluite behels, onder andere, faktore soos om die optimale punt van vervanging te bepaal waarna die onderhoud van die fiesiese bate minder voordeel het as om dit te vervang. Ten spyte van die belangrikheid en aansienlike impakte wat hierdie besluite op die organisasie het, word die besluit gereeld in praktyd op die intuïtief van die besluit-maker baseer en/of op suiwer finansieële aspekte. Sedert FBB 'n multi-disiplinêre veld is, moet die bestuur van fiesiese bate herstel/vervang besluite ook die impakte van verskeie, finansieële en nie-finansieële kriteria inkorporeer.

Daarom stel hierdie studie die ontwikkeling van 'n strategiese, multi-kriteria gebaseerde, besluitneemings raamwerk voor, spesifiek vir die bestuur van fiese bate herstel/vervang besluite. Die voorgenoemde raamwerk is gebaseer op 'n uitgebreide literatuuroorsig wat daarop fokus om die kern konsepte van FBB en

strategiese besluitneming te identifiseer. Spesifieke klêm word gelê op fiesiese bate herstel/vervang besluite in die FBB veld, asook op die multi-kriteria aard van hierdie besluite.

Die voorgestelde raamwerk integreer beginsels vanuit die FBB, strategiese besluitneming en multi-kriteria besluitneming velde om 'n gestruktureerde, stapsgewyse besluitnemings metodologie te skep. Die hoof objektief van die voorgestelde raamwerk is om bestuurders met die bestuur van fiesiese bate herstel/vervang besluite te help deur 'n praktiese, gestruktureerde proses aan te bied wat eenvoudig is om toe te pas in die prakteit van enige fiesiese bate intensiewe maatskappy. 'n Gevallestudie is uitgevoer in die mynbedryf van Namibië om die voorgestelde raamwerk te bekragtig en om te bewys dat al die bogenoemde objektiewe bereik is.

Acknowledgements

I would like to express my sincere gratitude to the following people and organizations:

- Prof. P.J. Vlok (study leader) for his support and guidance
- Jowandré, for his support, love and motivation
- My family, for their continued support and love
- Our Lord and Heavenly Father, for giving me the determination and strength to complete this thesis

The Author, December 2015

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Acronyms and Abbreviations

ACRG	Asset Care Research Group
AHP	Analytical Hierarchy Process
ANOPBT	Adjusted Net Operating Profit Before Tax
AUT	Additive utillity Theory
C	Cash and cash equivalents
CA	Current Assets
CAPM	Capital Asset Pricing Model
CBM	Condition-Based Monitoring
CBR	Case-Based Reasoning
CI	Consistency Index
CL	Current Liabilities
CM	Corrective Maintenance
CR	Consistency Ratio
DCF	Discounted Cash Flow
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
EAC	Equivalent Annual Cost
EBIT	Earnings Before Income and Taxes
EIA	Environmental Impact Assessment
ELECTRE	ELimination and Choice Translating REality
EMS	Environmental Management System
EVA	Economic Value Added
FEP	Fugitive Emissions Project
FFF	Five Forces Framework

FIT	Failure In Time
FMECA	Failure Mode and Effect Critical Analysis
FTA	Fault Tree Analysis
GHG	Green House Gasses
IAM	Institute for Asset Management
IBD	Interest Bearing Debt
IRR	Internal Rate of Return
ISO	International Organization for Standardization
KPI	Key Performance Indicators
MARR	Minimum Attractive Rate of Return
MAUT	Multi-Attribute Utility Theory
MCDT	Multiple Criteria Decision-making Technique
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MUT	Multiplicative Utility Theory
NOPAT	Net Operating Profit before Tax
NPV	Net Present Value
NWC	Net Working Capital
OEM	Original Equipment Manufacturer
PAM	Physical Asset Management
PAS	Publicly Available Specification
PDCA	Plan Do Check Act
PE	Price-Earnings Ratio
PM	Proactive Maintenance
PPE	Personal Protective Equipment
RBM	Risk-Based Maintenance
RCA	Root Cause Analysis
RCM	Reliability Centered Maintenance
RI	Random Matrix
ROA	Return On Assets

ROE	Return On Equity
ROIC	Return On Invested Capital
SAW	Simple Additive Weighting
SOP	Standard Operating Procedure
TBM	Time-Based Maintenance
TC	Technological Change
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
WACC	Weighted Average Cost of Capital
WSM	Weighted Sum Model

Nomenclature

Values

i^*	Internal rate of return	(%)
r_a	Expected return from asset	(%)
r_f	Risk free rate of return	(%)
r_m	Expected market return	(%)
E	Equity market value	USD/ZAR/N$
D	Organizational debt	USD/ZAR/N$
V	Sum of E and D	USD/ZAR/N$
CF	Cash Flow	USD/ZAR/N$

Constants

β	Risk Premium
R_e	Cost of capital
R_d	Cost of debt
λ_{max}	Maximum eigenvalue
μ_a	Degree
V(a), S	Score
X	Scaling constant
P	Problem descriptor

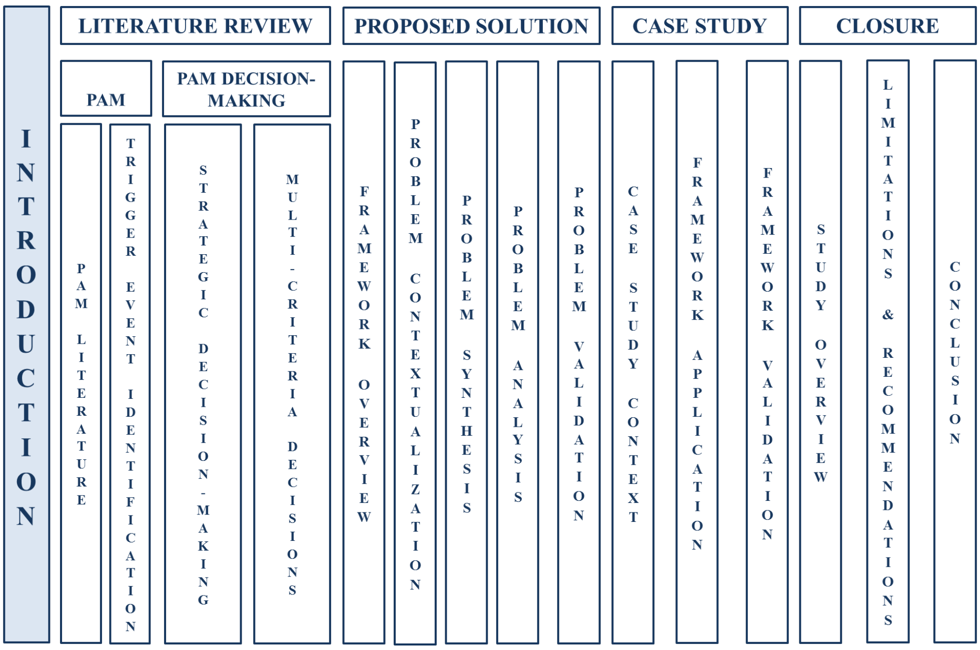
Variables

i, n, m, t, a, b, k, r	Any number from 0 to ∞
x_i, y_i	
x_n, z_n, p_n, s_n, c_n	
x_m, x_t, z_k, u_r	

Chapter 1

Introduction

This study proposes a strategic decision-making framework to aid management with physical asset repair or replace decisions in physical asset intensive industries. The aim of this chapter is to introduce the study by providing context to the research problem identified, as well as the research process with the relevant objectives and outcomes to be achieved. It includes a section detailing the background of the research problem and sections that detail the relevant fundamental topics, expected research objectives and outcomes. The chapter then concludes with the research design, the methodology that will be followed and the thesis outline. The figure below illustrates a high level overview of the document and acts as a roadmap to guide the reader through the course of the study.



1.1 Background

In large, physical asset intensive organizations the renewal and repair of physical assets form a significant part of the ongoing annual capital expenditure. All physical assets experience deterioration with age which consequently leads to devaluation. According to Cesca and Novaes (2012) the consequences of devaluation include a decline in the desired output as well as an increase in the associated operation and maintenance costs.

Nevertheless, with proper maintenance activities, an organization's physical assets can be in operation for much longer than its intended useful life. However, there comes a point when management has to weigh the costs and advantages of continuously maintaining and repairing an old physical asset against those associated with the possible replacement of the physical asset. In PAM these decisions are referred to as the physical asset repair/replace decisions.

This study is only concerned with the decisions regarding physical assets that are of significant investment. It is thus the responsibility of management to determine what signifies a significant investment. Therefore, depending on the size and structure of the organization, the value of these physical assets may differ. Consequently, **?** states that any physical asset replacement decision is regarded as an investment decision. Accordingly, these physical assets are also referred to as capital assets. Wallingford and Sticklen (1992) define a capital asset as an asset that 'has a useful life greater than a year and is expected to earn income sufficient to cover the operating expenses and amortized acquisitions cost associated with it'.

The main challenge of a physical asset repair/replace decision is determining the period in time when replacing the physical asset is more advantageous to the company, than repairing it. Optimal asset utilization and operational performance are critical to sustain a competitive advantage. Optimal asset utilization leads to increased production, reliability as well as improving the organization's return-on-capital, and consequently increasing shareholder value.

One challenge in the repair/replace decisions of physical assets is determining the exact time at which the possible replacement of a physical asset will be most advantageous. There are numerous studies regarding the determination of the ideal replacement age of physical assets, the most prominent being the economic life of the physical asset. Cesca and Novaes (2012) state that the economic life of a physical asset represents the optimal age at which the physical asset should be replaced. This topic is discussed in detail in Section 2.1.3.

As mentioned before, with proper maintenance physical assets can be in operation longer than its intended useful life. Therefore, the economic life mentioned above is merely an estimate of the optimal replacement age based on economic data, whereas the physical asset may be operational beyond the calculated economic life.

Consequently, the decision to continue repairing and maintaining a physical asset or to replace the physical asset is influenced by two contrasting cost objectives. On the one hand, the organization is required to invest a large sum of capital to replace the physical asset. On the other hand, the organization risks the failure of the physical asset which will lead to operational downtime and high repair costs. Therefore, the physical asset repair/replace decision revolves around the trade-off between cost and risk. According to Quertani *et al.* (2008) the advantages of replacing physical assets in timely manner include reduced operating and maintenance costs, reaching performance and production targets, compliance with regulatory requirements, maximization of the return on capital and increased shareholder wealth.

Frank *et al.* (2013) remarks that current repair/replace decision frameworks employed in organizations are based purely on economic criteria. However, there are quantitative factors that also influence and are influenced by the physical asset repair/replace decision such as competitive rivalry and corporate sustainability. Wallingford and Sticklen (1992) argue that when an organization is contemplating the possible acquisition of a capital asset, both the financial goals and non-financial issues, such as the qualitative factors mentioned before, associated with the decision and its environment must be considered. Subsequently, Frank *et al.* (2013) emphasize the need for a robust, multi-criteria framework that can be applied to physical asset repair/replace decisions.

According to Nooraie (2012) decisions that involve multiple criteria and capital investment are classified as strategic decisions. Thus the physical asset repair/replace decision is classified as a strategic decision.

From the aforementioned information, the physical asset repair/replace decision falls within the PAM domain, is classified as a strategic decision, involves multiple influencing criteria and finally, is triggered by some event that lead management to consider the possible replacement of the physical asset. The dominant research areas for this thesis can therefore be consolidated into four major fields of study contributing towards the issues related to the physical asset repair/replace decision: Physical Asset Management (PAM), replacement decision trigger event identification, strategic decision-making and multiple criteria decision-making.

The primary aim of PAM is the effective use of physical assets across their life cycles. Thus, PAM serves as the basis of this thesis since one of the major activities within the life cycle of a physical asset is the decision to either repair or replace a physical asset that is currently employed in operation. Another major part of PAM includes maintenance activities and tactics that are used in an organization and that has a significant effect on the repair/replace decision.

As mentioned before, the management of an organization must at some point consider the possible replacement of a physical asset that is in operation. The decision to replace a physical asset stems from some trigger event or events that lead management to consider the repair/replace decision. It is therefore necessary to identify these trigger events in order to anticipate the physical asset repair/replace decision.

The replacement of physical assets represent a significant capital investment and thus Elbanna (2006) states that any decision that requires the commitment of substantial funds is classified as a strategic decision. Strategic decisions are categorized as involving high levels of risk and uncertainty and are thus difficult to assess in terms of performance. Bierman Jr and Smidt (2012) argue that strategic decisions directly affect the basic course of the organization, consequently affecting the organization's expected profits and risks associated with these profits. All of the before mentioned characteristics of strategic decisions describe that of physical asset repair/replace decisions. It is therefore necessary to study strategic decisions in detail such that the different factors contributing to the eventual outcome can be determined and taken into account.

Finally, physical asset repair/replace decisions are of a multi-criteria nature. As mentioned before, current frameworks for these type of decisions are purely based on financial data. It is therefore necessary to determine which quantitative aspects influence and are influenced by the repair/replace decision and to then incorporate those aspects into the decision framework. Thus, multi-criteria decision-making methods have to be studied in order to determine the applicability of the various methods to the physical asset repair/replace decision.

In summary, physical asset repair/replace decisions form a significant part of a physical asset's life cycle and consequently of an organization's asset management strategy. The outcome of these decisions have a substantial effect on an organization's capital funds, shareholder wealth and competitive advantage and are thus classified as strategic decisions. Moreover, the multi-discipline nature of PAM as well as the incorporation of both qualitative and quantitative impacts on the outcome of the decision, signifies that physical asset repair/replace decisions are multi-criteria decisions. Combining the before mentioned information, the research domain of this thesis is presented in Figure 1.1. The next section addresses the problem statement as well as the research questions for this thesis.

1.2 Research Problem

According to BSi (2008) there are four major stages in the life cycle of a physical asset; the creation/acquisition stage, the utilization stage, continuous maintenance and finally, the renewal/disposal stage. The decision to either continue maintaining a physical asset or to replace the existing physical asset with a new one depends

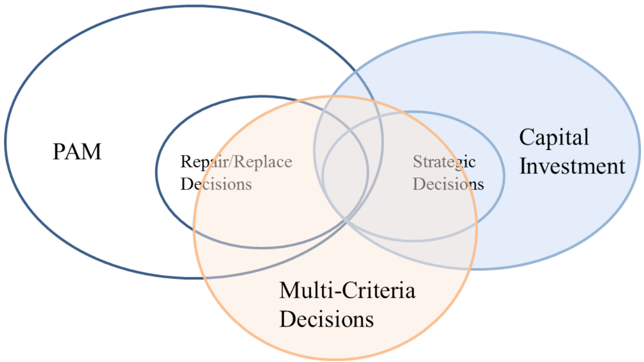


Figure 1.1: Research Domain

on the decisions made by asset manager of an organization. There are two main questions concerned with this decision: at what age should the physical asset be replaced and, if the physical asset reaches this age, is replacement the most advantageous decision at that time?

PAM aims to realize value from an organization's physical assets throughout its life cycle from acquisition to eventual disposal. Likewise, the aim of the physical asset repair/replace decision is to create value through the eventual outcome of the decision. Wendling (2011*a*) argues that most organizations base the estimation of the timing between the replacement of physical assets purely on financial and capital budgeting techniques. The most commonly used statistic is the economic life of a physical asset. Asselbergs (2013) state that at this age, the costs associated with a physical asset is at it minimum and therefore represents the best time to replace the physical asset.

Not only will the timely replacement of physical assets result in the creation of shareholder wealth, it will also lead to increased competitive advantage and optimum asset utilization and performance. Therefore, there is a need for a tool that can assist asset managers with the physical asset repair/replace decision.

There are numerous factors that can contribute to the consideration of the physical asset repair/replace decision within an organization. As mentioned before, if maintained properly, physical assets can be in operation for longer than their intended useful life. However, the ageing of a physical asset results in deterioration, loss of output and increased maintenance and operation costs. Apart from the financial aspects, there are other non-financial factors associated with an ageing physical asset that may also onset the consideration of the repair/replace decision.

Financial gain may be the main objective of profit seeking organizations, however within these industries there are other factors such as health and safety, associated risk, social and environmental sustainability, performance of the physical asset, as well as the availability of new technology that influence the decision to either maintain or replace a physical asset. Therefore, Wallingford and Sticklen (1992) suggest that when the physical asset replacement decision is considered, both the quantitative and qualitative aspects that form part of the decision must also be taken into account. Thus, there is a need for a multi-criteria decision-making framework that considers both the financial and non-financial factors associated with the repair/replace decision.

As mentioned before, the replacement of a physical asset is usually associated with the investment of a significant amount of capital. Furthermore, the physical asset replacement decision is described as being complex, unstructured and inherently risky, and is therefore described by Nooraie (2012) as a strategic decision. Therefore, there is a need for a multi-criteria decision-making framework that can assist asset managers with the strategic physical asset repair/replace decision.

In summary, asset managers require a tool that can assist them with the decision to either repair or replace a physical asset once the decision has been offset by either financial, non-financial or combination of factors. The framework should act as a guideline and should be practical, rather than complex and prescriptive. Furthermore, the framework should be flexible enough for application in all physical asset intensive industries. Finally, because of the multi-criteria nature of these decisions, the framework must accommodate both qualitative and quantitative data.

This study aims to address the above mentioned requirements with the development of a strategic, multi-criteria decision-making framework for the managers of physical assets in physical asset intensive industries. The framework should act as a guideline to assist the physical asset repair/replace decision-making process in asset management. It should provide asset managers with a structured, concrete approach to make informed physical asset repair/replace decisions and provide a holistic approach to the problem. The aforementioned research problems covered is therefore translated into the following null hypothesis which serves as the basis of this research study.

H_0

It is possible to improve the outcome of current physical asset repair/replace decisions by developing a multi-criteria decision-making framework to assist the management of physical assets in physical asset intensive industries.

This study aims to address the above mentioned requirements. The following section addresses the research objectives of the study.

1.3 Research Objectives

This section details the identification of the study specific research objectives. Based on the study background and research problem discussed in he previous two sections, the primary objective of this study is to:

Develop a strategic decision-making framework for the management of physical asset repair/replace decisions in physical asset intensive industries.

The above mentioned research objective aims to address the requirements and needs as set out in Section 1.2. It is therefore necessary to divide the above mentioned primary objective into manageable sub-objectives as follows:

1. Establish the fundamental concepts and principles within the relevant fields of study.
    a) Review the key concepts in PAM
    b) Identify the different stages within the physical asset life cycle
    c) Identify the physical asset repair/replace decision stage within the physical asset life cycle
    d) Review existing techniques used to determine the physical asset replacement
    e) Review the key concepts in strategic decision-making
    f) Establish the relationship between strategic decision-making and physical asset repair/replace decisions
    g) Highlight the multiple-attribute nature of repair/replace decisions
2. Master the physical asset repair/replace decision concept
    a) Review physical asset maintenance concepts
    b) Review physical asset replacement concepts
    c) Identify techniques used to forecast the replacement of physical assets
    d) Identify events that trigger the physical asset repair/replace decision
3. Master the field of strategic decision-making

a) Determine strategic decision-making characteristics
b) Identify the core concepts that form part of strategic decision-making characteristics

4. Develop a strategic decision-making framework for the management of physical asset repair/replace decisions

    a) Determine criteria for selecting a relevant decision-making method
    b) Determine relevant factors that will form part of the decision-making method
    c) Consolidate the factors and decision-making method into a structured, strategic decision-making framework

5. Validate the strategic decision-making framework

    a) Validate the framework in accordance with the relevant framework features
    b) Compare the outcome of the framework with that of actual industry results

The term framework is used extensively throughout the text in different contexts. According to the Oxford Dictionary, a framework is defined as "a basic structure underlying a system, context, or text.". The Business Dictionary defines a framework as a "broad overview, outline, or skeleton of interlinked items which supports a particular approach to a specific objective, and serves as a guide that can be modified as required by adding or deleting items.". Likewise, in this study the term framework refers to an outline of the physical asset repair/replace strategic decision-making process to assist the management of physical assets.

The framework developed in this study will therefore serve as a guide for the decision-making process by providing the decision-maker with the basic structure and as well as the main concepts that form part of the process and the effects thereof. Moreover, following the background and research problem statement, the proposed framework is intended to feature the following key characteristics:

1. Practical - Application of the framework in practice should be possible.

2. Flexible - Applications in various physical asset intensive industries of different types should be possible.

3. Holistic - The framework should serve as a holistic approach to the research problem, integrating multiple criteria to the eventual solution.

4. Structured - Structured, logical steps should guide the decision-maker through the decision-making process.

This study is aimed at achieving the before-mentioned objectives. The research process followed is guided by the various stated objectives. Furthermore, the framework is developed in accordance to the above-mentioned characteristics. The following section details the scope of the research study.

1.4 Scope

An important part of a research study is the definition of the scope and to establish the boundaries of the research prior to its execution. The research study scope determines the level of detail of the research and narrows the focus of the study on its intended purpose. This study has four main boundaries, all of which are related to the intended framework's field of application and function within that specific field:

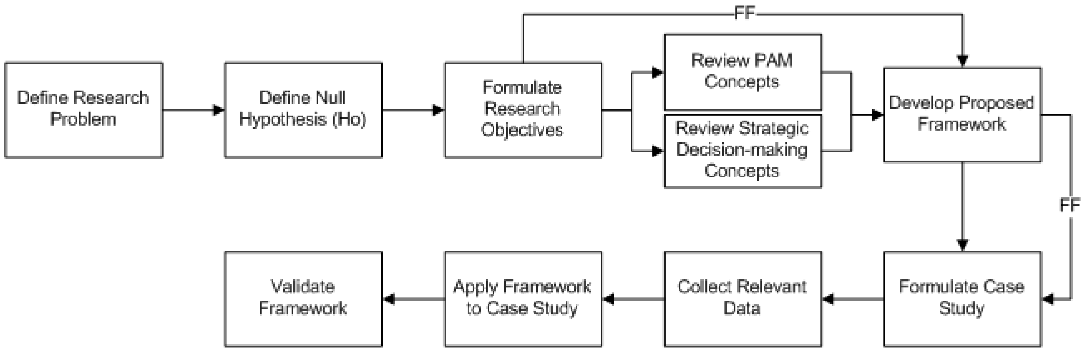
1. This study is concerned with the management of physical asset in physical asset intensive industries.
2. The physical assets that are considered in this study are those that are of a significant investment nature. Where the definition of a significant investment should be determined by the relevant organization implementing the framework.
3. This study and the intended framework is specifically focused on the physical asset repair/replace decision within the physical asset life cycle.
4. The proposed framework is intended to act as a decision-making guideline to guide the decision-making process. It is not intended to prescribe the decision-maker or provide specific solutions to the problem or decision encountered.

The above mentioned boundaries and constraints are incorporated throughout the execution of this study. The next section details the research design and research methodology.

1.5 Research Design and Methodology

According to Kothari (2004), the research methodology represents a systematic means of solving a research problem. Whereas research methods represent all of the techniques involved in conducting the actual research. It is however essential to define the research process before embarking on the intricate details of the before mentioned research methodology and involved research techniques. The research process includes the various actions and steps that will result in an effective research study. Figure 1.2 illustrates the research process followed in this research study.

Figure 1.2: Research Process Flow Diagram



The FF in Figure 1.2 is an abbreviation for a feed forward loop whereby the affected step is evaluated based on the criteria determined in the affecting step.

Furthermore, there are three main stages in this research study, firstly an extensive literature review to establish and identify the areas of interest within the relevant study fields. Thereafter a proposed framework is developed based on the information from the literature review, and finally, the framework is validated through the application of the framework to a real world case study.

The literature review follows a systematic, top-down approach. Therefore, the first section details the fundamentals of the PAM landscape, narrowing down to focus more specifically on the physical asset life cycle and physical asset repair/replace decisions. Thereafter, the possible trigger-events resulting in physical asset repair/replace decisions are discussed. The discussion then expands its focus to include fundamental concepts and characteristics of strategic decision-making and multiple criteria decision-making.

The proposed framework is then developed by the merger of the appropriate information from the above mentioned study fields into a single, structured framework. Finally, the proposed framework is validated through application to a case study in the Namibian mining industry.

The following section presents the outline of this research study, in each case a brief description of the chapter is provided.

1.6 Research Study Outline

As mentioned before in Section 1.5, this research study is conducted in a structured, logical manner that allows for easy flow and integration of key concepts. Each of the chapters in the study is therefore aimed at achieving certain research objectives. Therefore, refer to Table 1.1 for a summary of the structure of the study as well as the research objectives specific to the various chapters.

Table 1.1: Research Study Outline with Corresponding Objectives

Chapter	**Objectives**
Chapter 2: PAM	1a, 1b, 1c, 1d, 2a, 2b, 2c, 2d
Chapter 3: PAM Decision-Making	1e, 1f, 1g, 3a, 3b
Chapter 4: Proposed Solution	4a, 4b, 4c
Chapter 5: Case Study	5a, 5b

Chapter 1: Introduction
Chapter 1 is an introduction to the research study. It comprises of a background to the research study, followed by a description of the research problem and research objectives. Thereafter, the scope of the study is then detailed and finally, the research design and methodology are explained.

Chapter 2: PAM
Chapter 2 is the first of two chapters that form the literature analysis. The chapter places specific emphasis on the PAM domain and the discussion of the fundamental concepts. Special focus is placed on the physical asset life cycle and the physical asset repair/replace decision. Events that trigger the physical asset repair/replace decision within organizations are also discussed in this chapter.

Chapter 3: PAM Decision-Making
Chapter 3 is the second, and last chapter that forms part of the literature analysis. The chapter focusses on strategic decision-making, especially those that concern significant investments, and the characteristics that influence these decisions. Furthermore, the multiple criteria nature of physical asset repair/replace decisions are also discussed, followed by detailed explanations of various MCDM techniques that are applicable. The relationship between physical asset repair/replace decisions and strategic decisions is also emphasized in this chapter.

Chapter 4: Proposed Solution
Chapter 4 details the development of the proposed solution to the research problem. Throughout the chapter the various steps involved in the development of a strategic decision-making framework are discussed. In each section the relative inputs, objectives, outcomes and methods to be followed are addressed. The strategic decision-making framework is developed in such a manner as to comply with the research objectives of this study.

Chapter 5: Case Study
Chapter 5 entails the application of the framework developed in Chapter 4 to a case study in the mining industry of Namibia. The framework is applied to determine whether the physical asset repair or physical asset replace decision is the most advantageous option for the company under consideration, based on the data gathered. The case study is introduced by providing a brief overview, followed by a discussion of the preparation that needs to be done before the framework application. Thereafter, the framework is applied to the company data gathered and the relevant results are obtained and analyzed.

Chapter 6: Closure
Chapter 6 concludes the study by providing the closing remarks, limitations and recommendations for this research study. The limitations and recommendations are intended for possible improvement of this study, as well as for possible future research purposes.

1.7 Chapter Summary

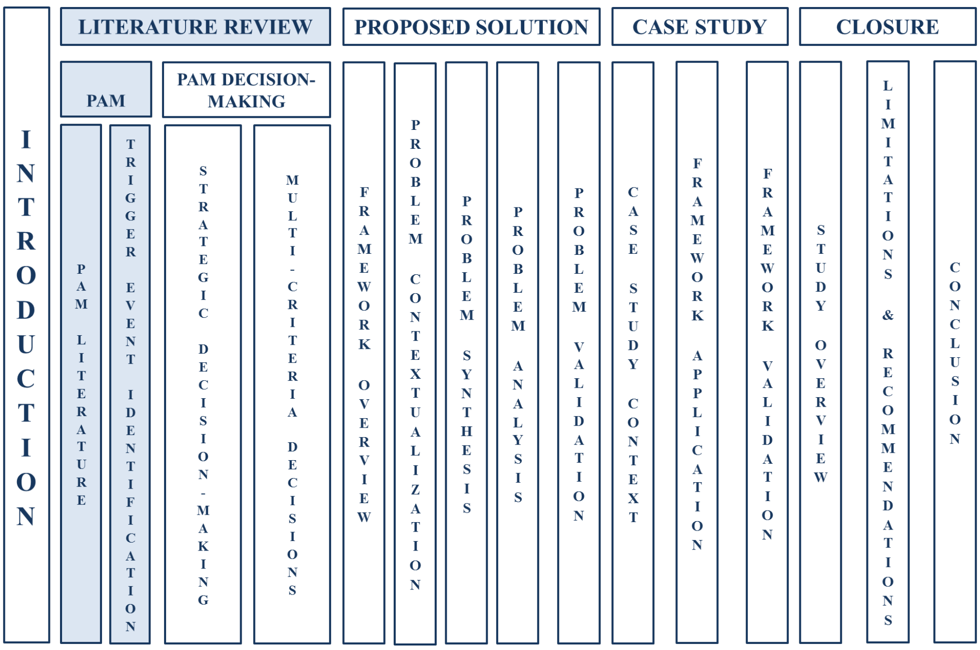
This chapter serves as an introduction to the research study. The first part of this chapter includes a background to the research study, followed by the definition of the research problem. Thereafter, the research objectives for this study is stated and discussed. Furthermore, the scope of the research study is defined in order to set the limits within which the study is to be performed. Thereafter, the research methodology and study outline is discussed. The main purpose of this study is to develop a decision-making framework to aid decision-makers and asset managers with the management of physical asset repair/replace decisions in physical asset intensive industries. Therefore, based on the previously mentioned information, this study is limited in its application based on the industries in which it can be applied.

The following chapter details the field of PAM and provides the fundamental concepts within the PAM landscape. Physical asset life cycle, physical asset repair/replace decisions and trigger-event identification are among the topics discussed in the following chapter.

Chapter 2

Physical Asset Management

This chapter aims to provide a detailed summary of Physical Asset Management (PAM) as a whole and thereby identify core concepts within this domain, specifically those concerning the replace/repair of an asset such as: life-cycle management, asset procurement, maintenance and asset financing. Thereafter, the identification of trigger events in the repair/replace process within PAM is studied in detail to single out the constraints involved in the prescribed decision-making process. This paves the way for the application of strategic decision making principles for repair/replace decision application.



2.1 Physical Asset Management

According to Hastings (2009) PAM has historically been ill defined and is commonly also referred to as 'asset management', however according to Woodhouse (1997) this term is used by a number of distinct professionals where the actual meaning of the term differs fundamentally in interpretation and usage. Woodhouse (2006) states that currently there are only three distinct areas of common use of the term. The first concerns the financial sector, where 'asset management' refers to the management of investment portfolio's or stocks in order to obtain the best combination of capital growth with the related interest rates. The second concerns those that practice maintenance of equipment and sell software. In this sector the term is aimed at attracting more attention to the credibility of maintenance activities as an important priority on the corporate agenda. Third and finally, the owners of infrastructure and plants, as well as their associated operators refer to 'asset management' as the best practice and sustainable use of the physical plant and its associated facilities.

The last description mentioned above refers to the basis of performance improvement opportunities that are available in all industrial sectors. In this regard, Woodhouse (1997) states that the term 'asset management' refers to the best combination of asset care and asset exploitation. Where asset care refers to all activities concerning maintenance, risk management and asset exploitation involved in the use of assets to achieve some performance objective or corporate goal. According to Amadi-Echendu *et al.* (2010*b*) this definition however encompasses a broad scope from the general management of the asset to the production and operational aspects that concern that specific asset. It is therefore necessary to define PAM in this study as the total management of physical assets, where the financial aspects regarding the economic value and management of the asset to the organization is considered of high importance.

The aim of this section is therefore to provide a comprehensive summary of all aspects of PAM. Where physical assets include all fixed or non-current assets such as plant, equipment, machinery, buildings and all other non-current assets that have significant value to the organization. Physical asset management is a systematic approach to the management of the above mentioned assets, from conception throughout their life cycle to eventually, disposal.

2.1.1 Physical Asset Management – Definition and Background

Nelson (2009) states that classic maintenance has historically been focused on maximizing the life and sustaining the condition of a physical asset. It is based on the strategy that by maintaining the condition of the individual units within a system, the delivery of the function of the entire system will then also be sustained.

However due to numerous limitations that accompany this focus, Amadi-Echendu *et al.* (2010*a*) argues that there has been a demand for an integrated, life-cycle based risk management system that encompasses a broader set of activities than just maintenance.

Woodhouse (2006) declares that the development of PAM started in the late 1980's in the oil and gas sector with the collapse of the oil prices, the Piper Alpha disaster and market globalization. Subsequently, the sector was forced fundamentally re-evaluate their business models at that time. During this time, the larger corporations discovered that even though they were enjoying strategic advantages and economies of scale above that of other, smaller organizations, they lacked integrated thinking. Thereby suffering from a lack of operational efficiency and flexibility. Thereafter, as discussed by Amadi-Echendu *et al.* (2010*a*), the organizations started to develop a more holistic, life-cycle focused approach to manage their infrastructure assets and thus the adoption and development of asset management began.

According to Hastings (2009) the function of asset management is to provide the organization with knowledge regarding the capacity of the asset in order to enable decision support activities within the organization. Amadi-Echendu *et al.* (2010*a*) states that until recently the asset management regime has focused primarily on two main areas. The first area focused on the information and communication technology that was needed to manage the different sources of data relating to the asset. The second area concentrated on the manner in which the asset management systems could be managed and integrated in order to make informed decisions regarding the assets.

It is however suggested that apart from the two before mentioned focus areas, more attention should be given to total asset management, thus, focusing on the overall dimensions of the management of the asset. McElroy (1999) defines asset management in the US Department of Transport as a 'systematic process of maintaining, operating and upgrading physical assets cost-effectively'. Also, Mitchell and Carlson (2001) characterize asset management as an integrated set of strategic and comprehensive processes aimed at attaining superior lifetime effectiveness, return and utilization rate from physical assets.

As mentioned above, there exists a need for an asset management system that would standardize industry demand. In 2004 the Institute of Asset Management (IAM) in collaboration with the British Standards Institution (BSi) published the Publicly Available Specification (PAS 55) as a response to industry demand for a standard for asset management. The aim of PAS 55 is to give guidelines and best practices on asset management and as IBM (2009) states, it is especially relevant in asset-intensive industries.

In January 2014 The International Organization for Standardization (ISO) published the first ever international standard for asset management, the ISO 5500X series. According to Van den Honert *et al.* (2013) the ISO 5500X series is based on the principles of PAS 55 and the core ideas of PAS 55 are also retained within this standard. Ma *et al.* (2014) state that where PAS 55 is overly concerned with physical assets, the ISO 5500X series focus more on the applicability of the standard to any type of assets within the organization. It is suggested throughout literature (Van den Honert *et al.*, 2013; Ma *et al.*, 2014; Woodhouse, 2014) that the ISO 5500X series of international standards will serve as a replacement for the PAS 55 standard as the organization will enjoy additional benefits as a result of improved asset management. However, as this section is merely to serve as a background and summary of PAM and since the ISO 5500X series is still relatively new and under development, PAS 55 will be used as the primary source.

PAS 55 represents the international consensus concerning the implementation of an integrated, multidisciplinary approach that will enable an organization to deliver its strategic goals and maximize value through the management of its assets throughout their whole life cycles. According to BSi (2008) PAM is defined as

> *systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan.*

It must however be noted that throughout the PAS 55 document the writers make use a number of different terms such as 'asset management', 'engineering asset management', 'physical asset optimization' and 'total asset management', all of these will be generalized in this thesis as PAM will henceforth be referred to as such.

As mentioned before, there are fundamental differences in the interpretation of asset management and therefore it is necessary to define the term 'asset', depending on the domain of use. According to Ouertani *et al.* (2008) an asset is defined as anything that holds significant economic value and that is owned by the organization, whereas BSi (2008) has a more focused definition and describes an asset as "...plant, machinery, property, buildings, vehicles and other items and related systems that have a distinct and quantifiable business function or service." It is however necessary to distinguish between the wide range of assets within an enterprise, therefore Koronios *et al.* (2007) classify assets as either being intangible or tangible. Intangible assets represent all those that are not of a physical nature such as knowledge, intellectual property, software and processes, whereas tangible assets are those that have a physical form such as fixed assets (buildings, infrastructure, machinery, etc.) as well as current assets (cash or inventories).

2.1.2 Public Available Specification 55 and Physical Asset Management

From the definition of an asset in the previous section it encompasses a broad range within the enterprise. The physical asset paradigm only represents one of the five broad categories of asset types that form part of the organizational strategic plan. It is however necessary to define the scope of PAS 55 relative to the broad range of organizational assets, therefore refer to Figure 2.1 for a depiction of the scope of PAS 55.

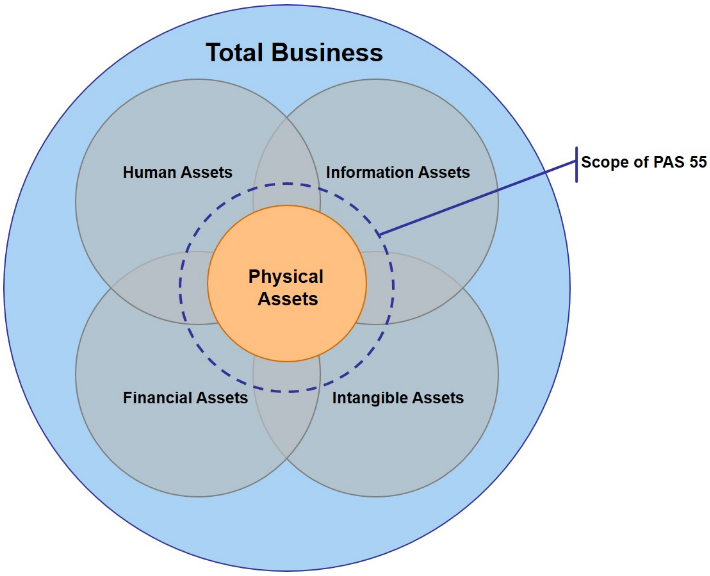


Figure 2.1: The scope of PAS 55, adapted from BSi (2008)

The following is a short description of each of the sections represented in Figure 2.1 above as they interact with the scope of PAS 55.

1. Total Business
   This section represents the overall vital context of the business, it includes the business objectives, regulations, policies, risk management and performance objectives.

2. Human Assets and PAS 55 interface
   Human factors are not explicitly discussed in the scope of PAS 55, however

they are critical to the overall success of the achievement of the asset management system. The interface between human assets and PAS 55 include motivation, knowledge, communication, experience, teamwork, leadership as well as roles and responsibilities.

3. Information Assets and PAS 55 interface
This section entails the data that is gathered with respect to the asset throughout its whole life. The interface between information assets and PAS 55 include data concerning the asset condition, activities, performance as well as opportunities and associated costs.

4. Intangible Assets and PAS 55 interface
Intangible assets represent all those assets that do not have a physical form. Therefore, the interface between intangible assets and PAS 55 include the organization's image, employee morale, social impact and the constraints that the organization faces in its ventures.

5. Financial Assets and PAS 55 interface
It has also been mentioned that the financial aspects regarding economic value of the assets play a significant role. Therefore, the interface between financial assets and PAS 55 include the asset life-cycle costs, value of the asset's performance, capital investment criteria and operating costs.

BSi (2008) declares that PAS 55 is specifically developed to cover the entire life cycle management of assets, in particular those assets that are central to an organization's purpose. Therefore, organizations that depend on the function and performance level of their physical assets for the delivery of products and/or services are dependent on the proper implementation of a core asset management system. Also, IBM (2009) states that the levels at which asset units can be identified and managed range from a singular, discrete asset to more complex functional systems, sites or networks, refer to Figure 2.2 for the hierarchical structure that represents the levels of assets and their management.

It is therefore necessary to properly define a physical asset management system as set out by PAS 55. Ouertani *et al.* (2008) defines PAM as "...the process of organizing, planning and controlling the acquisition, use, care, refurbishment, and/or disposal of physical assets to optimize their service delivery potential and to minimize the related risks and costs over their entire life through the use of intangible assets such as knowledge based decision-making applications and business processes." Stewart *et al.* (2003) state that not only does PAM allow for systematic planning, procurement, deployment, use, control and decompositions of physical assets, but it also allows for the integration of strategic-level management, system/network management and operations management into a single

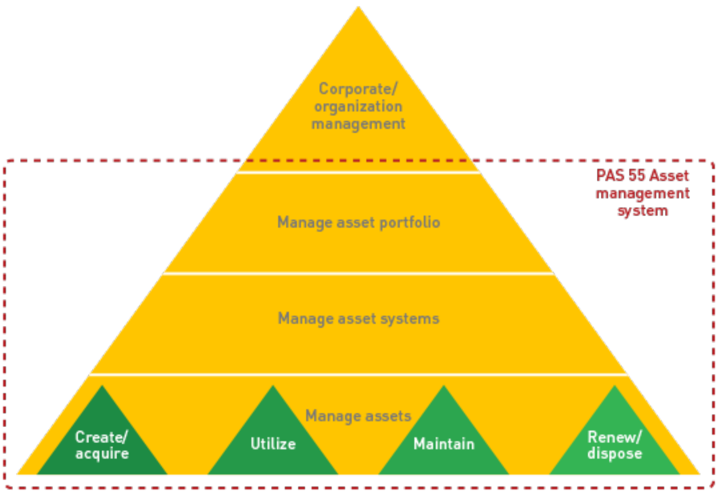


Figure 2.2: Hierarchical level of assets and their management, BSi (2008)

focus, thereby maximizing the value that the organization can get from asset performance.

From the above discussion of PAS 55 and PAM, there is a common thread that runs throughout the information. In numerous instances it has been stated that an asset has to be 'managed' throughout its entire life cycle. Also, from the information in Figure 2.2 the bottom-most tier encompasses the life cycle of an asset which falls well within the scope of PAS 55. For the purposes of this thesis it is necessary to discuss in detail the different stages that form part of the life cycle of a physical asset.

2.1.3 Asset Life cycle

As mentioned above, industries that are asset intensive rely on the performance of those assets to achieve business objectives. Melvin (2012) states that the optimal management of physical assets and their associated risks, performance and costs call for a logical, life-cycle orientated approach. The whole-life asset management of PAS 55 is based on the commonly used Plan-Do-Check-Act (PDCA) framework that allows for continuous improvement. BSi (2008) argues that by adopting a process-or-procedure-based approach as with the PDCA framework, the organization is able to align and integrate its PAM with other related management systems within the organization. Refer to Figure 2.3 for the layout of the PDCA framework.

The following is a short description of the respective components that form part of the PDCA framework as described by Benders (2011).

Figure 2.3: PDCA Framework, adapted from Deming (1986)

1. Plan
   During the planning stage, the PAM strategy, plans and performance objectives required to deliver satisfactory results that are aligned with the organization's PAM policy and also its overall strategic plan, are established.

2. Do
   This stage calls for the establishment of enablers (monitoring indicators) and other requirements, such as regulations, that are specific to the organizations. Also, the PAM plan is to be implemented during the execution of this stage.

3. Check
   During this stage the output results are monitored and measured against the strategy objectives, PAM policy as well as against the regulatory requirements that are specific to the organization. These results are then recorded and the reported.

4. Act
   In order to ensure that the asset management objectives are achieved and are continually improved upon, this stage calls for action to be taken if there are any irregularities regarding the reported results and the set out objectives. Therefore, this stage ensures the continuous improvement of the PAM performance and PAM system.

From the above discussion, the management of an asset throughout its life is process orientated. It is therefore necessary to define the life cycle of a physical asset as well as the different stages within its life cycle. BSi (2008) defines the life cycle of a physical asset as the "time interval that commences with the identification of the need for an asset and terminates with the decommissioning of the asset or any associated liabilities". For an illustration of the before mentioned life cycle of a physical asset, refer to the bottom-most tier in the hierarchical structure illustrated in Figure 2.2, also refer to Figure 2.4.

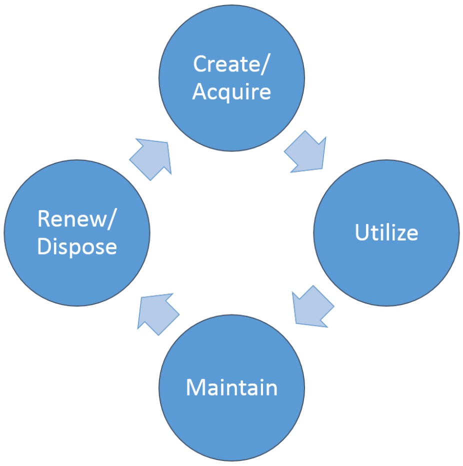


Figure 2.4: Life Cycle of a physical asset, adapted from BSi (2008)

The life-cycle process that is illustrated in Figure 2.4 is based on the 'cradle-to-grave' life of a typical physical asset and consists of four main stages. These four respective stages are described by Ouertani *et al.* (2008) as follows

1. Create/Acquire stage
   This stage includes all the activities that is involved in the financial and technical analysis and justification of the creation/acquisition of the asset.

2. Utilization stage
   The utilization stage deals with all the activities that are related to the installation, testing, as well as the commissioning of the newly acquired or repaired asset.

3. Maintain stage
   As the PDCA is a continuous improvement framework, this stage deals with effectively maintaining the asset for optimum availability, capability and longevity in order to achieve performance objectives.

4. Renew/Dispose stage
   The activities in this stage include those that are related to management of the assets that are already owned by the organization. Decommissioning of

assets calls for either disposal or renewal of the asset, also some of the assets may be re-used, re-manufactured or recycled.

From the life cycle illustrated in Figure 2.4 there exists some point when the organization has to decide whether to replace or carry on maintaining a physical asset. According to Cruzan (2009) this decision has historically been based on the experience and intuition of the people that work with similar physical assets. Winsor and Buncombe (2007) argue that the decision to repair or replace a physical asset should not only include the technical issues that are specific to that asset, but also the associated risks that can be quantified into financial and economic impacts. Cruzan (2009) also states that there are two main economic factors that determine whether a physical asset will be replaced or repaired. Firstly, if the cost of operating and maintaining the physical asset will exceed the cost of the actual replacement, the physical asset should be replaced. The second is based on past experience with similar physical assets, therefore if a similar asset has reached its end of life at approximately the same age as the one under consideration it should be replaced.

With regards to the first factor, Cesca and Novaes (2012) state that as physical assets age they are vulnerable to devaluation as a result of a decline in the output, increasing operation and maintenance expenses, etc. For instance, Wendling (2011*b*) declares that in the financial sector, accountants describe a physical asset as having a useful life. During this period the physical asset can always be repaired such that it returns to its useful state. Therefore, if a physical asset fails as a result of the failure of a discrete component, it is possible to repair, indefinitely, a physical asset that is composed of an aggregation of components. Consequently, any physical asset that consists of an aggregation of discrete components never has to reach the end of its useful life. Nevertheless, all companies replace physical assets, no matter the level of aggregated components. The difficulty lies in determining the point in the life of the physical asset when the replacement thereof results in the most benefit to the organization.

According to Asselbergs (2013) the economic life of a physical assets represents the optimum point to replace it. It is therefore necessary to define the concept of economic life. According to Cesca and Novaes (2012) economic life represents the length of the usefulness of the physical asset such that the annual sum of the maintenance and capital costs are at a minimum. Consequently, if the physical asset is kept beyond its economic life, the maintenance expenses will increase substantially, on the other hand, if the physical asset is replaced before its economic life it will not have been fully depreciated.

Numerous models have been developed in literature (Winsor and Buncombe, 2007; Jack and Van der Duyn Schouten, 2000; Love *et al.*, 2000; Iskandar *et al.*, 2005) that aim to determine optimal repair/replacement strategies, most of which are based on the economic life of a physical asset. The aim of this thesis is however not to determine this optimal point in an asset's life, but rather requires that this point already be identified by the organization. Emphasis is placed on the trigger events that identify this point in a physical asset's life, thereafter the proposed framework is applied in order to determine whether the replacement or the continuing repair of the physical asset is more advantageous to the organization. It is therefore necessary to discuss, in detail, physical asset maintenance and procurement within PAS 55 as these two stages in the life cycle of a physical asset form an integral part of the framework that is to be developed.

2.1.4 Physical Asset Maintenance/Repair

According to Muchiri *et al.* (2011) the current global economy and increasing demands from shareholders call for improved business performance. The performance of businesses that are dependent on physical asset performance rely on the reliability and productivity of those assets and production facilities for a competitive advantage. This demand for improved reliability and physical asset performance has highlighted the importance of maintenance as a vital component in sustaining quality performance and service delivery. The Maintenance Engineering Society of Australia (MESA) defines the function of maintenance as "the engineering decisions and associated actions necessary and sufficient for the optimization of specified capability." (Muchiri *et al.*, 2011). The capability of a physical asset is specified as the ability to perform a specific task within a predetermined range of performance levels.

Muchiri *et al.* (2011) argue that the deterioration of a physical asset starts the moment the asset is commissioned. Apart from standard wear and deterioration, operating the asset outside of its specified design limits or operational errors, failures may occur causing downtime, loss of quality, safety hazards, environmental pollution, etc.

Jardine and Tsang (2013) state that according to the classic view, the function of maintenance is to repair broken items. This narrow-minded approach is also known as reactive or Corrective Maintenance (CM). This approach limits the maintenance activities, such as repair and replacement, to reactive tasks that are triggered by failures. However, Pintelon and Parodi-Herz (2008) declare that a broader perspective of maintenance has emerged as a result of technological evolution in equipment and increasing competition in the business environment.

Therefore, an additional type of maintenance has emerged, namely precautionary or Proactive Maintenance (PM). The maintenance actions in PM can be predictive, preventative or proactive in nature. Each of the before mentioned actions have the primary goal of diminishing the probability of failure or to anticipate and avoid the failure of a physical asset and the consequences linked to such a failure.

Refer to Figure 2.5 for a depiction of the hierarchical structure of maintenance strategies. The following sections will provide clear and concise summaries of the PM strategies and philosophies that are commonly employed throughout industry today.

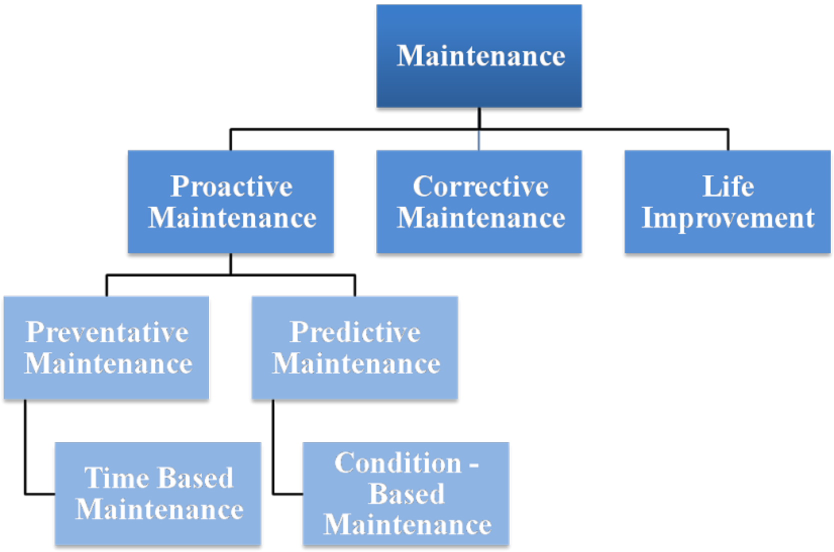


Figure 2.5: Maintenance Hierarchy, adapted from Barabady and Kumar (2005)

2.1.4.1 Time Based Maintenance

The most common and widely used PM strategy is Time Base Maintenance (TBM). Schneider *et al.* (2006) state that this strategy requires that inspections and maintenance tasks be carried out on a fixed-time basis as recommended by the Original Equipment Manufacturers (OEM). However, Labib (2004) argues that this PM strategy is not always the best strategy for minimizing operation costs and maximizing physical asset performance.

Firstly, the physical assets are operated in different environments and therefore requires different maintenance schedules. Secondly, as a result of the various different environments in which the physical assets operate, the OEM's often do not experience failures and have less knowledge of preventive tactics than those who operate and maintain the physical assets. Finally, OEM recommendations may not be optimal as they capitalize on maximizing spare part replacements through frequent PM's.

2.1.4.2 Condition Based Maintenance

As a result of the shortcomings of TBM, numerous organizations employ the Condition Based Maintenance (CBM) strategy. The motivation behind CBM is that 99% of equipment failures are preceded by tell-tale signs, indications and conditions and can therefore be anticipated if those signs are monitored.

Labib (2004) claims that CBM is one of the most popular and modern maintenance strategies discussed in literature. CBM is based on the information gathered from various physical asset condition monitoring activities. Information such as the temperature, vibrations, lubrication, contaminants and noise levels are recorded using various monitoring devices from which the age or operating condition of the physical asset can be determined. Maintenance activities and decisions are then based on the analysis of the recorded data.

Instead of performing maintenance activities on a fixed time basis, CBM activities are based on real-time assessment of physical asset condition and are performed just before failure. Thereby reducing unnecessary maintenance and its associated costs.

Schneider *et al.* (2006) state that the CBM process can be performed on a periodical basis or a continuous basis and can either be carried out 'on-line' or 'off-line'. 'On-line' monitoring is done when the physical asset is in a working state and 'off-line' monitoring is done when the physical asset is not running. The information gathered from CBM is then used for either diagnostic or prognostic decision-making.

Diagnostic decision-making involves the process of locating the source of a fault, whereas prognostic decision-making is the process of predicting or estimating when a possible failure may occur. One of the main drawbacks of CBM is that it is expensive and experienced personnel is needed to analyze and interpret the data.

2.1.4.3 Reliability Centered Maintenance

In a competitive environment however, the performance of the overall operating system relies on the effectiveness of the respective activities that form part of the system. An important principle to take into consideration in a competitive environment is the 80/20 principle: approximately 20% of the elements in the working environment represents 80% of the risk of a critical system failure (Kirby, 2012).

Organizations should determine which components are those with the highest potential risk of critical failure and prioritize monitoring, analyzing and maintenance activities of those components. Therefore, the concept of Reliability Centered Maintenance (RCM) is introduced. RCM is another PM strategy, however, instead focusing on the reliability of individual components in an operating system as with the before mentioned PM strategies, RCM aims to improve the performance of the system as a whole.

According to Rausand (1998) RCM is defined as "a systematic consideration of system functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective PM tasks." Therefore, the main focus of RCM is preserving the overall system function by prioritizing critical components that are essential for system reliability. RCM involves the development of a PM program, thus the potential consequences and associated risks and the likelihood of the occurrence of a physical asset failure must be determined such that the most critical ones can be identified.

Therefore, Moubray and Lanthier (1991) state that the first step in a RCM process is to determine the functions of each physical asset in the system under consideration. Thereafter, all functional failures need to be identified. These occur when a physical asset is unable to perform a function to the required standard. It is then necessary to identify all the possible events that may have caused the functional failure to occur, these are referred to as failure modes.

Once all the possible failure modes have been identified, the effects of each need to be determined. In other words, describing the effect that each of the respective failure modes will have on the system as a whole. These effects then need to be analysed to determine the consequences and to determine which failure modes will most strongly influence the system.

Throughout the RCM process a variety of input data is required such as physical asset design data, operational data from condition monitoring and reliability data. Reliability data is used to determine the criticality of the physical assets in the considered system as well as in the scheduling and prioritizing of maintenance tasks. Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR) and failure rate functions are the various reliability data inputs. According to Trinh and Ly (2013) MTBF is the predicted average/mean time between the inherent failures of a system during operation. The calculation of MTBF is based on historical failure data, ideally it is assumed that when the system fails, it is repaired immediately. Whereas MTTR represents the average/mean time to repair a failed component.

Finally, the failure rate function is essentially a probability density function that characterizes the relative frequency of the occurrence of a failure within an item population. The failure rate function is used to calculate the Failure In Time (FIT) which represents the number of failures that can be expected in one billion hours of operation.

Using this analysis it is then possible to determine the components that are most critical to the system as a whole and thus, as stated by Schneider *et al.* (2006), maintenance tasks can then be prioritized and scheduled accordingly.

2.1.4.4 Risk-Based Maintenance

The safety of a physical asset intensive industry is directly linked to the reliability of its operation, especially in industries that deal with hazardous substances and in severe operating conditions. In order to then increase safety as well as the efficiency of an operation, it is essential to minimize, or possibly eliminate, the occurrence of unscheduled system and component failures (breakdowns).

Khan and Haddara (2004) therefore introduced the concept of Risk-Based Maintenance (RBM). RBM is a maintenance strategy with the sole purpose of reducing the overall risk of operating facilities caused by unexpected failures. The risk based methodology consists of two main phases, namely the risk assessment phase and the risk-based maintenance planning phase.

Khan and Haddara (2003) state that the risk assessment phase consists of two distinct stages, risk-determination which consists of risk identification and estimation, and risk evaluation which consists of risk aversion and acceptance analysis. The risk estimation stage comprises four steps in total. Firstly, it is necessary to develop a failure scenario that describes the series of events that might have led to a possible system failure.

The failure scenario can consist of a single event or a combination of sequential events that might have led to the system failure. It is however important to keep in mind that a reasonable probability must exist that the described scenario can occur. Secondly, it is necessary to analyse the consequence if such a failure is to occur. The objective of this stage is to prioritize the physical assets and their respective components on the basis of their contribution to the system failure. Thereafter, a probabilistic failure analysis needs to be conducted using the Fault Tree Analysis (FTA).

FTA is a top-down, deductive technique used to determine the root cause of a system failure. The details of this technique are however outside of the scope of this thesis. By combining the FTA, failure data and reliability data, it is the possible to determine the frequency of occurrence of the failure. Finally, the outcomes of the probabilistic and consequence failure analysis are then combined to determine the risk that may result from the failure of the considered component.

The risk evaluation stage, as described by Khan and Haddara (2004), includes the identification of an acceptable risk criteria against which the estimated risk that was determined in the previous stage can be evaluated. After the risk assessment phase has been completed, the risk-based maintenance planning phase can commence. Systems that exceed the acceptable risk criterion are evaluated in detail in order to determine a better maintenance plan that will affect the probability of failure adversely. Lastly, the newly implemented maintenance plan is then re-evaluated to verify that its implementation results in an acceptable system risk level.

2.1.4.5 Total Productive Maintenance

The last PM strategy is discussed is Total Productive Maintenance (TPM). TPM is a holistic approach to maintenance that concentrates on productivity improvement, primarily by improving the availability and effectiveness of equipment.

According to McKone *et al.* (1999) TPM is defined as "the maximization of equipment effectiveness by establishing a comprehensive PM system covering the entire life of the equipment, spanning all equipment related fields and, with the participation of all employees from top management down to shop-floor workers, to promote PM through motivation management or voluntary small-group activities." Therefore, TPM emphasizes the human-machine relationship by creating a sense of ownership among the operators of the physical assets and strives for continuous improvement of product quality, equipment availability and operational efficiency.

There are a number of steps involved in the implementation of TPM in an organization. Chan *et al.* (2005) state that before implantation, top level management should establish a TPM office with the sole purpose of dealing and coordinating activities directly related to the implementation of TPM, such as education and training. Thereafter, the first step in the implementation of TPM in an organization is the development of a master training plan for each respective working level of employees and then to conduct and carry out TPM training throughout the organization.

The second step involves the establishment of the targets and basic policies that need to be achieved in order to successfully implement TPM as well as key points that are necessary in order to reach the objectives. These policies are usually those that strive for the three goals of TPM, zero breakdowns, zero defects and zero accidents. Once the policies have been established, the TPM office is tasked with the creation of the master plan for TPM development. The master plan details the principal TPM activities as well as the scheduled time for the completion of these activities. Completion of the master plan then calls for its implementation.

Implementing the TPM master plan is described by Katkamwar *et al.* (2013) as the eight pillars of TPM. Firstly, it is required to implement activities that are designed to improve the efficiency and availability of physical assets. This calls for the elimination of the 'six big losses' namely: breakdowns, set-ups and adjustments, small stops, reduced speed, start-up rejects and production rejects. Also, it calls for the adoption of the 5S methodology, whereby the workplace organization is governed by being sorted, systematic, sanitized, sustainable and standardized. Secondly, a maintenance system needs to be established that can be performed by the equipment operators themselves after receiving adequate training. In doing so the operators are included in the maintenance activities, thus creating a sense of ownership towards the equipment they operate.

Thirdly, a detailed and thorough procedure must be developed for continual small improvements (kaizen) that can reduce losses that effect worker efficiencies. These improvements can be carried out by any person in the organization, and is based on the idea that a large number of small improvements are more effective than a small number of large improvements. Thereafter, a PM system has to be established that will increase the efficiency, effectiveness and availability of the equipment. Also, quality maintenance forms an integral part of TPM as defect elimination is the basis for providing the highest possible quality and subsequently, customer satisfaction.

It is also necessary to continually train employees in order to create a multi-skilled workforce that can perform their tasks effectively and independently. Extra training should also be provided to the operators in order to increase their skill level and enable them to perform the maintenance tasks discussed earlier. TPM is not only applicable in the manufacturing facilities but must also be applied to the administrative facilities in an organization. Thereby improving the productivity and eliminating losses due to administrative inefficiencies. Finally, the last pillar of TPM is focused on safety, health and the environment. The main aim is creating a safe workplace and surrounding environment that cannot be damaged by any of the processes and procedures that are employed by the company.

From the hierarchical structure of maintenance strategies in Figure 2.5 there is an additional maintenance strategy apart from those that fall under CM and PM, namely design out maintenance. According to AMBoK (2014) design out maintenance is a tactic by which the causes of a failure are removed by making adjustments and modifications to the existing physical asset or to allow for other maintenance strategies to be more applicable in managing the cause of the failure.

Melvin (2012) argues that the central theme of PAS 55 is the understanding of the risk and criticality of physical assets. Therefore, determining the level of risk that is associated with a physical asset-related failure is extremely important. The failure of a critical physical asset can induce additional, substantial financial costs, safety hazards and environmental damage. It is therefore necessary to determine the priority of the maintenance of critical assets such that the risk associated is mitigated. Thus, Ventyx (2012) states that for PAS 55 to be successfully implemented in an organization, the maintenance strategy should be based on PM rather than CM such that critical physical asset maintenance activities can be prioritized according to the risk associated with their potential failure. Also, the financial implications of implementing PM over CM can be significant, Melvin (2012) names a few:

1. The cost of pro-actively maintaining a physical asset is often significantly lower than replacing a part after it has failed.

2. Unplanned failure of a physical asset may lead to prolonged downtime, thus losing more operational time and production than with a planned shut-down.

3. CM is more as expensive than PM, not only in monetary value, but also in production and operating time.

One of the main themes throughout this thesis is that the primary objective of any organization is to provide value to its shareholders. Therefore spending unnecessary money on maintenance activities will directly affect the financial performance of the organization and consequently the return on shareholder value. Eti *et al.* (2006) state that in industries that are physical asset intensive, maintenance costs can account for as much as 40% of the operational budget and therefore, improving the effectiveness of the maintenance function is a potential source of large financial savings. Therefore, apart from implementing the correct PM strategies that are suitable to the organization's needs, PAS 55 also ensures that the overall costs are minimized and the operational effectiveness is maximized. Thereby, as stated by BSi (2008), resulting in an optimized return on investment and increased return on shareholder value.

2.1.5 Physical Asset Replacement

The decisions regarding physical asset replacements that are dealt with in this thesis include only those that are of a significant investment nature i.e. capital assets. Nevertheless, Bierman Jr and Smidt (2012) state that an organization that is dependent on physical assets for producing goods and/or services is continually faced with the problem of determining whether the current physical asset resource commitments are worthwhile.

These decisions are comprised of the comparison of the present value of the physical assets to that of their potential future value benefits. As physical assets are utilized in everyday operation, over time they wear which in turn leads to increased operating and maintenance costs. Also, as technology advances, the current physical assets in use may become obsolete as more technologically advanced physical assets are introduced to the market.

Regardless of the function and application, the timely replacement of physical assets is necessary for effective and economically efficient operation of the organization. Dobbs (2004) states that the standard approach to the replacement decision of a physical asset is determining the trade off between the expected benefit and costs associated with extending the economic life of the existing plant and those associated with replacing the physical asset.

However, according to Hastings (2010) there are a number of additional factors that influence the decision regarding the replacement of a physical asset, in many cases more than one factor contributes to the eventual outcome of the decision. The following is a short summary of each of the factors that might contribute to a physical asset replacement decision.

1. Technical factors
   Technical factors comprise of aspects attributing specifically to the physical condition of the physical asset. These factors include the actual failure of the physical asset, as well as other factors such as reduced availability of logistical support (spares), reduced asset availability and reliability, and long term deterioration. Finally, if the risk of failure of the physical asset exceeds an acceptable level, the chance of replacement increases.

2. Commercial factors
   Commercial factors include those regarding the financial performance of the physical asset. Therefore, if the physical asset is declared operationally obsolete or if the operational capacity has to increase or decrease, the chances of replacement increases. Also, if the operating value associated with the current physical asset is lower than that of a possible replacement, the chances of replacement increases. Moreover, if the operating costs are high compared to that of the replacement, the chances of replacement increases.

3. Regulatory factors
   Replacement of a physical asset is inevitable if it poses health, safety or environmental threats. Also, in some cases government regulations favour the replacement of the physical asset. Likewise, if technical regulations change, for instance mandated increased fuel efficiency, the chances of replacement increases.

Refer to Figure 2.6 for a flow chart detailing the logic of physical asset replacement decisions in an organization focused on service provision and cost minimization.

The dominant decision box in Figure 2.6 summarizes the physical or operational reasons for the replacement of the physical asset. These include loss of performance, loss of reliability/availability, upgrade of the physical asset required, or safety, health or environmental risk capacity is exceeded.

Hartman (2001) defines the economic life of a physical asset as the age at which the replacement of the physical asset will result in the minimum operating, maintenance and salvage costs. From the graph in Figure 2.7 there exists two key conflicts in determining the economic life of a physical asset. Firstly, as the physical asset ages, the operation and maintenance costs increase. Secondly, declining

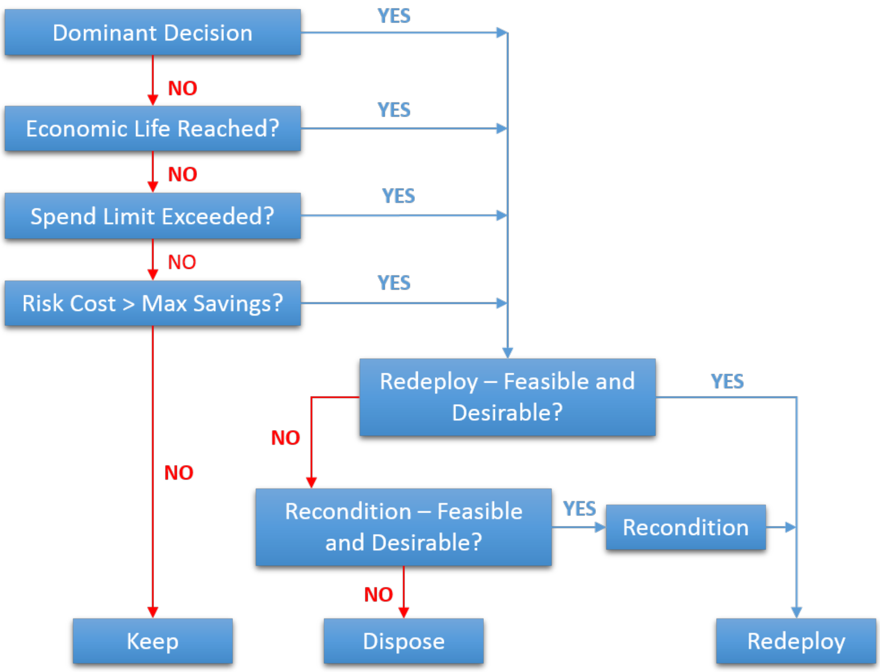


Figure 2.6: Replacement Analysis Flow Chart, adapted from Hastings (2010)

ownership costs associated with the ageing physical asset as the initial capital expenditure can be written off over a longer period of time.

The spend limit can be described as a set of rules that inhibits the organization to spend excessive amounts on the repair or refurbishment of an existing physical asset. This limit depends on the age, type and replacement costs associated with the physical asset. Finally, the risk cost is defined as the probability of an adverse event occurring multiplied by the associated cost if it does occur.

Apart from including the physical factors, financial aspects that are associated with the replacement of the physical asset also play a significant role in the eventual outcome of the decision. Unfortunately the value of a physical asset does not stay constant from acquisition to disposal as a result of depreciation, new technology, etc. Therefore, in addition to the framework illustrated in Figure 2.6, Bierman Jr and Smidt (2012) argues that a decision regarding the replacement of a physical asset should take into consideration the following factors:

1. Time value of money
2. Associated risk
3. Alternative options

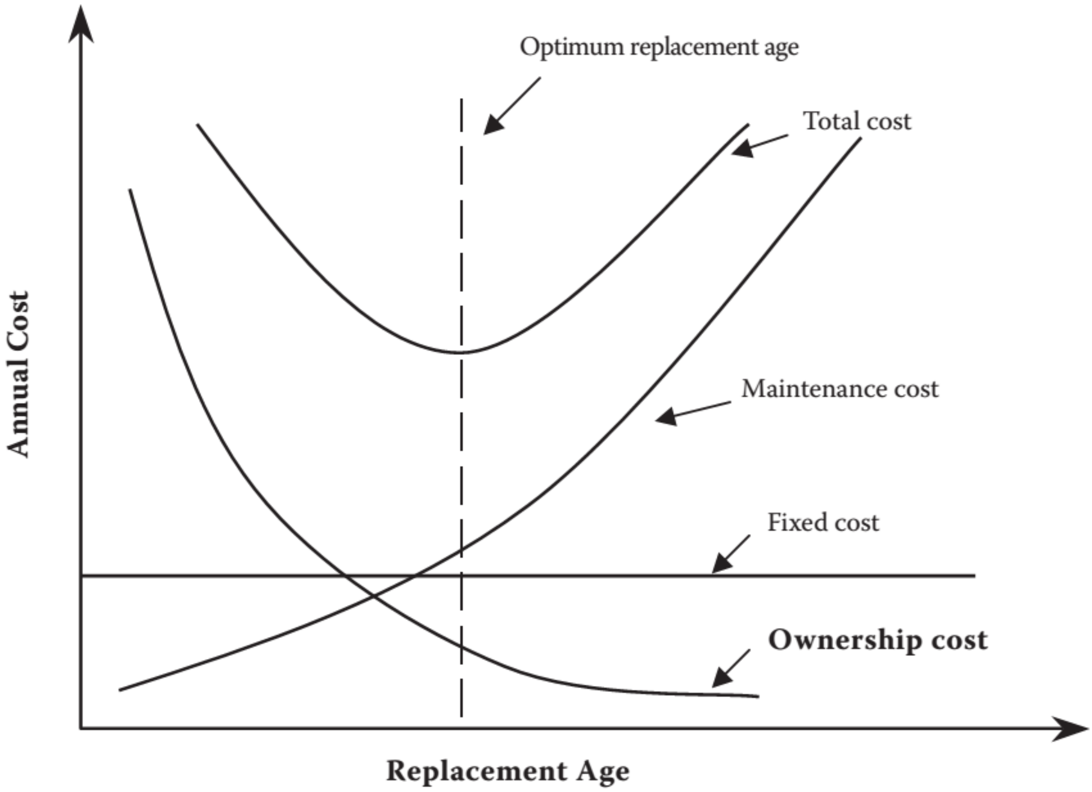


Figure 2.7: Economic Life of a Physical Asset, Campbell *et al.* (2011)

4. Future opportunities

The involvement of both time and risk in the decisions regarding the replacement of physical assets induce a lot of uncertainty in determining the level of return and the associated risk of a possible trade off.

Therefore, whatever the reason for the replacement decision, a supporting financial analysis accounts for the risk and time value of the physical asset is required. The following sections provide a concise summary of the different types of analysis.

2.1.5.1 Life Cycle Costing

According to Hastings (2010), it is important to recognize that the cost of acquiring a new physical asset will always be greater than the current year costs that are associated with keeping the old one. However, instead of comparing the current year costs to the acquisition costs, the annualized life cycle cost of the new physical asset needs to be determined. Liebert (2003) defines the annualized costs as the total life cycle cost of the physical asset divided by the number of years in the analysis period. According to the Commonwealth of Australia (2006) the analysis period is represented by the economic life of the physical asset. Also, it is assumed that the technique treats the equivalent life cycle cost as an annuity i.e. a continuing payment with a fixed total amount.

The total life cycle cost includes all costs of operating, maintaining, owning and disposing of the physical asset throughout its life cycle from acquisition to eventual disposal. Hastings (2010) therefore suggests that if the current year costs of an existing physical asset exceeds the annualized life cycle costs of a new one, the current physical asset should be replaced.

2.1.5.2 Time Value of Money

The time value of money is a factor that influences a wide range of business and investment decisions. Bierman Jr and Smidt (2012) state that the time value of money is one of the most developed and basic concepts of financial management. They argue that the present value of an amount of money is a function of the time of receipt. Therefore, the current value of an amount of money is more valuable than the promise or expectation of receiving the same amount at some future date. For this to be true, however, a positive interest rate is required at which the funds can be invested.

Determining the time of value of money includes the calculation of either the future value or present value of a potential investment. The present value is the calculation of the present equivalent of a future potential investment and the future value is the calculation of the future equivalent of a present investment. In capital budgeting decisions, however, Discounted Cash Flow (DCF) techniques are used to determine the present value equivalents of potential future investments. The present value of a physical asset represents the present value of the cash flows the asset is expected to generate throughout its life.

Howe and McCabe (1983) claim that once the present value of the physical asset has been determined, the organization can decide whether to invest in the physical asset by comparing the cost of purchasing the physical asset to the computed present value.

Alternatively, Dorfman (1981) argues that when the growth of the organization is the primary objective, a critical consideration in choosing whether to replace a physical asset is the extent to which they generate funds for possible reinvestment. Therefore, from this point of view, the decision of physical asset replacement should depend on the maximization of the Internal Rate of Return (IRR).

The IRR represents the expected return that can be earned on a possible investment. If the calculated IRR is more than the cost of capital as well as the internal organizational MARR, the physical asset should be replaced. Where the cost of capital represents the minimum desired rate of return that the company requires and the MARR the minimum attractive rate of return that the company will accept for possible investment of capital. This implies that the rate of return on the investment (replacement physical asset) is higher than the rate of return that could have been earned if the money was invested elsewhere with similar risk (Pratt, 2003).

2.1.5.3 Risk Based Physical Asset Replacement

As mentioned before, when making physical asset replacement decisions, it is important to consider all the costs associated with the life cycle of the physical asset, however Costa Lima and Fliho (2014) state that it is also important to consider the cost of money. As shareholders expect maximum return on their invested capital, the ratio of price/cost is an important factor in physical asset replacement decisions.

Ideally, increasing the price charged for the production of goods and/or services increases the returns generated however in competitive industries the solution is not that simple. It may be necessary to reduce the prices charged for these goods and/or services in order to compete with rivals; however this may increase the risk of failure or interruption of delivery of goods and/or services to customers. Therefore, organizations that rely on physical assets in a competitive industry need to develop a balance between cost and risk.

According to Johnson *et al.* (2011) the definition of risk varies depending on the types of consequences that are involved, e.g. financial, environmental, safety, reputation and network. In the asset management environment, risk is defined by the calculation of the MTBF, failure rates and the probability of failure, as discussed in Section 2.1.4. Information and data regarding the condition of a physical asset provides critical information required to make decisions in any stage of its life cycle.

Johnson *et al.* (2011) also state that most physical asset intensive industries have similar issues regarding the lack of failure data, limited available funds for investment and variability of physical asset types. Fortunately, there are two ways to consider risk. Firstly, each individual cause of risk can be determined using tools such as Failure Mode Effect and Critical Analysis (FMECA) which considers each physical asset individually, rather than as a population. Secondly, a more holistic approach can be used by which the general failure rate for all physical assets of the same type are considered, such as failure curves.

Regardless of how the risk is determined in an organization, they all follow more or less the same procedure. De Meel (2008) describes this process as an economic risk-based analysis. In this method it is firstly necessary to determine the condition and health of the physical asset from condition based information and expert opinions. These include statistically defined failure-probability curves that are derived from historical failure data. Also, the remaining life of the physical asset needs to be determined based on the condition data and information.

Depending on the organization, the health and condition data is then transformed into a risk value. There are numerous models in literature (Duarte *et al.*, 2010; Gjerde and Nordgard, 2009) that describe the calculation of these risk values, however the discussion of these models are outside of the scope of this thesis.

Once the risk values have been determined, Johnson *et al.* (2011) suggest the use of Multi Criteria Decision-making Techniques (MCDT) to determine whether the physical asset needs to be replaced. According to Xu and Yang (2001) MCDT refers to a decision-making process that occurs in the presence of multiple, usually conflicting, criteria. This technique is applicable to the economic risk-based analysis as the balance between associated risk and investment (cost) is a multiple criteria problem.

2.1.5.4 Physical Asset Replacement under Technological Change

As discussed throughout this section, the physical asset replacement problem considers the decision of whether an existing physical asset should optimally be replaced with an available new one. Mardin and Arai (2012) state that a new physical asset will not only perform better than the one currently in use, the initial operating and maintenance costs are lower and it has a lower deterioration rate as a result of Technological Change (TC).

Jaffe *et al.* (2003) define TC as the overall process innovation, invention and diffusion of technology. Thereby resulting in technological development, achievement and progress. Yatsenko and Hritonenko (2009) suggest that TC be divided into the following two distinct categories:

1. Continuous TC
   Continuous TC refers to continuous incremental improvements in existing physical assets. This form of TC is considered to occur at a constant rate in which the technological improvements are gradual and known.

2. Discontinuous TC
   Discontinuous TC refers to instantaneous changes in the technological parameters of the physical asset. This form of TC is best described as breakthroughs in existing technology and the arrival time may or may not be known with certainty.

Also, refer to Figure 2.8 for a graphical illustration of the difference between continuous and discontinuous TC.

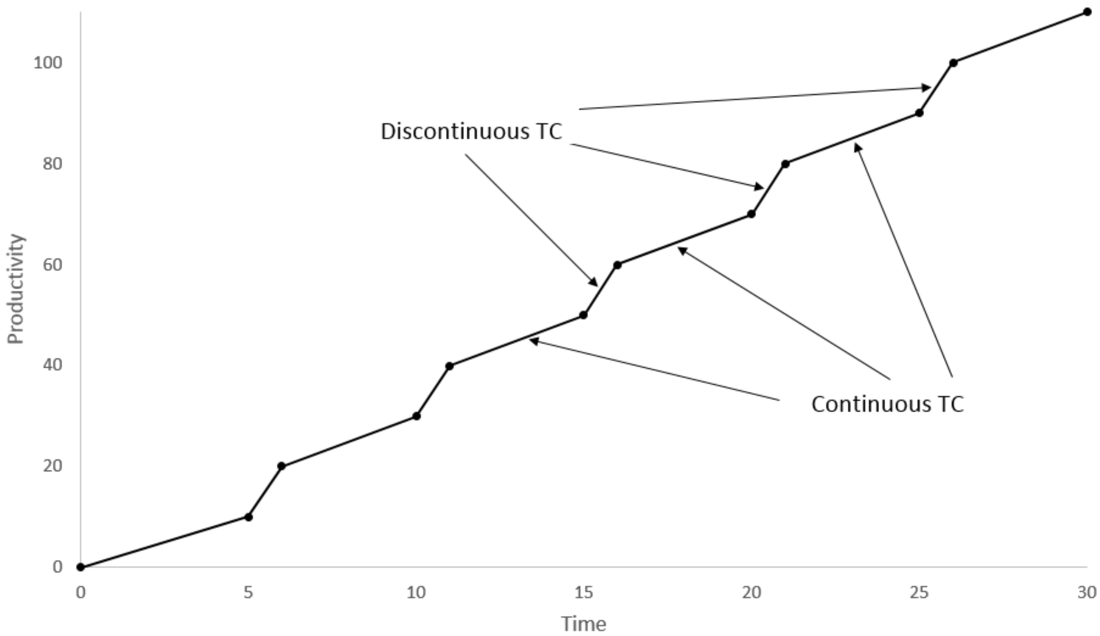


Figure 2.8: Continuous and Discontinuous Technological Change, adapted from Rogers and Hartman (2005)

Yatsenko and Hritonenko (2008*b*) state that TC is one of the key external factors that influence the replacement decisions of physical assets. TC is responsible for improving the efficiency and reducing the operating and maintenance costs of newer physical assets compared to that of existing ones.

Even though TC alone is not a valid enough reason for the replacement of a physical asset, both Yatsenko and Hritonenko (2008*a*) and Rogers and Hartman (2005) found that more intensive TC decreases the optimal service life of a physical asset. Therefore, higher levels of TC, discontinuous or continuous, affect the rational decision of replacing or upgrading physical assets.

The following section details the identification and discussion of the 'trigger-events' that lead to the consideration of the physical asset repair/replace decision.

2.2 Trigger Event Identification

According to Wendling (2011*a*) the repair of a physical asset cannot be postponed as the restoration of the physical asset's functionality is critical to reliability, production, safety, availability and loss of revenue. Whereas the replacement of a physical asset can be postponed, in support of continued repairs, even if doing so is not always economically efficient.

The replacement of a physical asset is not only a large expense, but it also has a significant effect on the operating costs. On the other hand, as discussed in Section 2.1.3, the repair costs associated with a specific physical asset increases as it ages and its condition deteriorates.

Therefore, at some point an organization's management must consider the decision to either repair or replace an existing physical asset. The purpose of this section is therefore to identify the 'trigger-events' that precede and steer management to consider the physical asset repair/replace decision.

2.2.1 Physical Asset Failure

The failure of a physical asset is probably the principal 'trigger-event' indicating that the asset should either be repaired or replaced. Even though most physical asset management practices attempt to prevent the failure of physical assets, such events may occur abruptly and without warning.

According to Tam and Gordon (2009) a physical asset failure event is caused by a chain of cause and effect relationships that can be induced by either of the following:

1. Deteriorated physical asset condition and an accompanying action that triggered the failure event.

2. Good physical asset condition and practices and an accompanying inappropriate action that triggered the failure event.

Both of the above mentioned failure events may have severe consequences such as financial losses, operational downtime, environmental damage, human injury and other undesired effects.

According to Smith (1993), the deterioration of a physical asset refers to fatigue, corrosion, degradation, abrasion and all other forms of 'wear and tear' that inhibits the physical asset to deliver to a desired performance level. There are numerous actions that might trigger the failure of a deteriorated physical asset, these actions are determined through a detailed Root Cause Analysis (RCA). Rooney and Heuvel (2004) define RCA as a process by which the causes of a failure is investigated and identified in order to prevent its recurrence.

In some cases, however, the physical asset is in a good condition but some inappropriate action triggers the asset to fail. Misumi *et al.* (2003) state that these inappropriate actions can also be referred to as human erroneous actions.

2.2.2 Age of the Physical Asset

As mentioned before in Section 2.1.3, the economic life of a physical asset represents the duration of its useful life during which the annual sum of its maintenance and capital costs are at a minimum. Therefore the economic life is calculated to determine the optimum point in a physical assets life cycle to replace it.

Moreover, as a physical asset nears its calculated economic life, management is forced to consider the decision of either replacing it or to continue with maintenance. The advantage of determining the economic life of a physical asset is that the purchase and transportation as well as other activities required for the replacement can be planned in advance. However, Li *et al.* (2006) argue that physical assets may reach their retirement age before or after the specified economic life.

The economic life of a physical asset as calculated by **?** and Ricke and Pfingsten (2002) is dependent on a number of financial factors and estimated parameters such as the operating costs, discount rates, inflation, depreciation, etc. Therefore, if proper maintenance is performed and if the operating conditions are more favourable than initially expected, the economic life might suggest an early retirement of the physical asset. Early retirement results in a waste of capital as an unnecessary investment is made for its replacement.

Therefore, replacing the physical asset once it reaches its economic life might not be the best decision for the organization.

2.2.3 Condition of the Physical Asset

As discussed in the previous section, a physical asset may become obsolete before or after its intended retirement age. The major contributor to the retirement of a physical asset is its condition, also referred to as its physical state. If a physical asset is in a physical or operational condition that falls below some minimum threshold, management is forced to consider the decision to either identify the maintenance activities that is needed to restore its required condition or to replace the physical asset.

It is therefore necessary to assess the condition of physical assets throughout their lifetime, as discussed in Section 2.1.4.2. The AAMCoG (2008) defines the condition assessment of a physical asset as "the technical assessment of the operational and physical conditions of an asset, using a systematic method designed to produce consistent, relevant and useful information".

Physical asset degradation, the criticality thereof as well as associated risks with continual operation and physical asset residual life, are all the intended outcomes of condition assessment. Therefore, the 'trigger-event' in this case is the worsening physical and/or operational condition of a physical asset.

2.2.4 Availability of Capital

According to Karabakal *et al.* (1994) some organizations may employ capital rationing whereby the capital that can be spent on the maintenance and replacement of physical assets is limited to a certain degree.

Therefore, once a physical asset nears its useful life and capital rationing is employed within the organization, asset managers need to consider the following; either continue maintaining the physical asset throughout the current financial period and risk failure with no funds for the replacement, or replace the physical asset early in the financial period and risk low funds for maintenance for the remainder of the financial period.

Another trigger event for the replacement of physical assets is the availability of capital at the end of the financial period as a result of the remaining budgetary funds. The availability of capital drives the decision for physical asset replacement and can lead to premature replacement of physical assets before reaching their useful life and consequently, resulting in an early retirement and waste of capital.

2.2.5 Maintenance Costs Exceeds Life Cycle Cost of Replacement

As mentioned before, ageing physical assets generally deteriorate, consequently resulting in rising operation and maintenance costs. Furthermore, Fan *et al.* (2013) state that the tendency of profit seeking organizations is to minimize fleet costs. Fleet costs are all costs involved throughout the life cycle of the organization's physical assets, which typically include acquisition costs, maintenance and operating costs, and the final salvage value of the physical asset.

All of the above mentioned costs are then taken into account and the Equivalent Annual Cost (EAC) of owning the physical asset throughout its life is calculated. This figure represents the annual cost the organization incurs for operating and owning that particular physical asset. This calculation is based on a predicted amount of service years, as well as discount rates and refurbishment costs.

A possible 'trigger-event' for the decision to replace a particular physical asset is when the EAC of operating and owning that asset is greater than the life cycle costs of a replacement asset. According to Gluch and Baumann (2004) the life cycle costs of a replacement physical asset include the initial investment costs and the estimated operating costs during its estimated lifetime. Ambrose *et al.* (2010) argue that an existing physical asset should be replaced if its associated EAC exceeds the cost of replacing it with a new one.

2.2.6 Physical Asset Performance

Muchiri and Pintelon (2008) state that the competitiveness of an organization is dependent on both the availability and productivity of its physical assets and production facilities. Therefore, in order to remain competitive within an industry, organizations must continually optimize and better their productivity. Moreover, this led to the development of different strategies within organizations to define and measure the performance of their physical assets.

Depending on the performance management system that is implemented within an organization, physical assets employed must satisfy a certain performance level to meet customer requirements and the organization's production objectives. These performance management systems and performance levels are determined by the management of the organization.

Therefore, if a physical asset's performance has been below the required level and continual corrective maintenance measures do not result in an improvement, it may 'trigger' the asset manager to consider its replacement. In this case the EAC might not be higher than the life cycle cost of replacing the physical asset, however the extra financial costs incurred may not compare to the loss of customers as a result of poor performance.

2.2.7 Additional Capability Required

As mentioned above, organizations strive to continually improve and optimize productivity to sustain a competitive advantage. Consequently, the production processes become more and more advanced and the need for additional physical asset capability arises. Moreover, the existing physical assets may no longer perform to the desired level as a result of this deficiency.

Lavelle *et al.* (2001) argue that a physical asset should be replaced if additional capability is required and the replacement physical asset can supply these capabilities while increasing the production rate, reducing operating costs and increasing production efficiency.

Therefore, the 'trigger-event' in this case would be that additional physical asset capability is required and changing or modifying the existing physical asset will not result in the desired performance. Also, the replacement decision will have to be considered if the replacement physical asset can not only provide the additional capabilities, but also production, efficiency and cost advantages above that of the existing physical asset.

2.2.8 Technology

As mentioned above, improving and optimizing production processes result in the requirement of additional capability, which in turn calls for improved technology. In some cases however, the existing physical assets may become technologically obsolete. According to Sandborn (2007) a physical asset becomes obsolete when it is no longer being manufactured, either because the demand has decreased or because the materials used in its manufacture is no longer available.

In cases where the physical asset has become technologically obsolete, replacement parts are difficult to find and expensive, and the skill required to maintain and repair the physical asset is hard to attain. This may 'trigger' the asset manager to consider the replacement of the physical asset.

Another technological 'trigger' is the associated advantages of increased production performance, reduced maintenance costs and lower deterioration rates that accompany the acquisition of a replacement physical asset. This is also discussed in Section 2.1.5.4.

2.2.9 Risk

As discussed in Section 2.1.5.3 there are different forms of risk e.g. financial, environmental, safety, reputation, security, network, etc. In physical asset intensive, profit seeking organizations, the risk associated with a particular physical asset is one of the main governing factors that determine its repair and/or replacement.

The first and foremost determinant of physical asset replacement is safety. If the physical asset presents an unacceptable health and safety risk to either the plant operators, the plant itself or the environment, it should be replaced.

Also, Javaherdashti *et al.* (2013) state that when the physical asset has reached a point where the probability of failure results in an unacceptable level of risk of any kind, being financial, environmental, security, etc. replacement of the physical asset should be considered.

The risk associated with a physical asset is obtained from the output of a risk assessment which is then used to develop appropriate actions and inspections to mitigate the risk. However, in some cases the risk has developed to such a level that replacement of the physical asset is the only means to mitigate the risk.

Therefore, the level of risk associated with a particular physical asset is a 'trigger' to the replacement decision.

2.3 Chapter Summary

In conclusion, Chapter 2 outlines the PAM landscape, particularly focusing on the physical asset life cycle and the physical asset repair/replace decision. It provides a general overview of the core concepts that form part of PAM and discusses the key components and methodologies within the PAM field.

Furthermore, the different stages within the physical asset life cycle are discussed, highlighting the stage within the life cycle concerning physical asset repair/replace decisions. Different physical asset maintenance strategies and philosophies are discussed as well as various scenarios that lead to the replacement of physical assets.

Finally, various 'trigger-events' that trigger the onset of the physical asset repair/replace decision within industry are discussed to provide some understanding of the origin of these decisions.

This chapter contributes towards achieving the first and second objectives of this research study. Accordingly, the following sub-objectives of each of the respective main objectives were achieved, refer to Section 1.3:

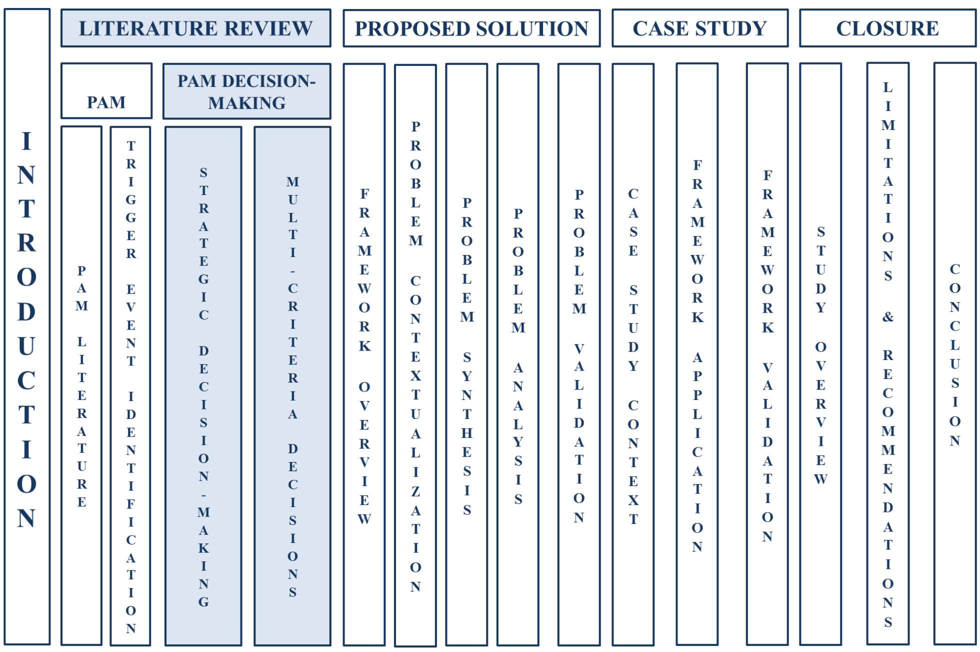
1. Establish the fundamental principles and concepts within the relevant fields of study.
   a) Review the concepts in PAM
   b) Identify the different stages within the physical asset life cycle
   c) Identify the physical asset repair/replace decision
   d) Review existing techniques used to determine the physical asset replacement
2. Master the physical asset repair/replace decision.
   a) Review physical asset maintenance concepts
   b) Review physical asset replacement concepts
   c) Identify events that trigger the physical asset repair/replace decision

This chapter is aimed at providing the reader with the basic understanding of PAM and the repair/replace decision within the life cycle of a physical asset. The following chapter, Chapter 3, explores the field of strategic decision-making and the characteristics thereof. It also aims to establish a correlation between strategic decisions and the physical asset repair/replace decision by comparing the characteristics and highlighting the multi-criteria nature of these decisions.

Chapter 3

Physical Asset Management Decision-Making

This chapter aims to provide a comprehensive summary of decision-making within PAM, particularly focusing on the repair/replace decisions of physical assets that are of a significant investment nature. The concept of strategic decision-making will be discussed in detail, highlighting the different core characteristics that influence strategic decision-making, as well as elaborating on the various aspects that form part of these characteristics. The before mentioned characteristics include; decision-specific characteristics, internal company characteristics, decision-making team's characteristics, and finally, external company characteristics.



This chapter also highlights the multiple attribute characteristics of physical asset repair/replace decisions. It briefly discusses the various multiple-criteria decision-making methods that are both applicable to the PAM domain and are currently used in industry.

3.1 Strategic Decision-Making

In recent years, the strategic decision-making process as well as the factors that influence this process have emerged as one of the most active areas of management research (Schwenk, 1995). According to Papadakis *et al.* (1998) strategic decisions, specifically those of an investment nature, have a significant impact on the long-term performance of the company and requires significant resource commitment. These decisions are described by Nooraie (2012) as being highly unstructured, long-term and complex, also they are inherently risky as they occur in a very uncertain environment. Likewise, Mauer and Ott (1995) state that physical asset repair/replace decisions involve high levels of uncertainty and investment. Therefore, based on the aforementioned characteristics exhibited by strategic decisions, and comparing them to that of physical asset repair/replace decisions discussed in the previous chapter, physical asset repair/replace decisions can be considered as strategic decisions.

However, in order to understand the concepts behind strategic decision-making, it is first necessary to define the strategy by which a company is governed.

According to Andrews (1997) a company's corporate strategy can be described as the series and patterns of different decisions that not only determines, but reveals the main objectives and/or goals that results in the specific policies and procedures that will result in the achievement of those objectives/goals. The corporate strategy also determines the range of business that the company is to undertake as it has a responsibility to its employees, shareholders and customers to make some economic and non-economic contribution. Gamble and Thompson Jr (2014) discovered that a company's corporate strategy is dependent on the approaches and competitive decisions that the management of the company makes that will attract and satisfy its customers, aid in performing its operations, lead to overall growth of the company itself and finally, help the company achieve its performance objectives and goals.

However, since this study is focused on physical assets, it is therefore necessary to rather focus on the physical asset management strategy rather than the corporate strategy. PAS 55-1 clause 4.3.1 defines the physical asset management strategy as a strategy that shall (BSi, 2008);

"...clearly state the approach and principal methods by which assets

> *and asset systems will be managed. This may include the criteria to be adopted for determining asset criticality and value, the life cycle and sustainability basis for asset management planning, the approach to asset risk and reliability management and the methods of optimization and decision-making."*

PAS 55 also states that the physical asset management strategy should be consistent with all other organizational strategies and policies, such as the corporate/business strategy. This section, however, will focus on the decision-making section of the physical asset management strategy.

As mentioned before, strategic decisions are highly unstructured and uncertain, this is primarily due to the complexity of strategic problems that arise within a company. As a result, strategic decision-making is therefore described as interdependent and incremental because the process is primarily guided by numerous contextual influences stemming from not only current circumstances, but also past and perspective future events (Nooraie, 2012).

Wernetfelt (1987) states that strategy is concerned with the future and therefore strategic management decisions are always made with uncertainty. Uncertainty can arise from any of the following four sources; demand, supply, competition and external factors. However when making strategic decisions there are a number of factors that influence the process by which those decisions are made. Nooraie (2012), Papadakis *et al.* (1998) and Elbanna (2006) suggest that the factors influencing the process and different stages of strategic decision-making can be divided into four main categories, namely:

1. Decision-specific characteristics
2. Internal company characteristics
3. Decision-making team's characteristics
4. External environmental characteristics

In the following sections each of the above mentioned factors are analyzed, as well as their effect of the strategic decision-making process.

3.1.1 Decision-Specific Characteristics

In previous studies such as those by Papadakis *et al.* (1998) and Elbanna (2006), it was found that very little research has been done and is available regarding the impact of decision-specific characteristics on the decision-making process. However, it has been suggested by Dean (1993) and Dutton (1993) that the same internal and external factors regarding the decision might be interpreted differently by managers in different companies and even within the same company.

Papadakis *et al.* (1998) argue that categorizing and labelling the decision early in the decision-making process has a substantial effect on the company's response to the decision. Those decisions that are labelled as being a crisis are treated very different than those that are labelled as being an opportunity.

Nooraie (2012) claims that there is some relationship between the familiarity and frequency of the decision and the process by which the decision is made. The magnitude of the impact of the decision is also said to have a significant effect on the decision-making process, where the magnitude of impact refers to the extent to which that specific decision impacts various sections of the company. Likewise, the riskiness and complexity of the decision also has a impact on the decision-making process. Schlit (1987) found that the higher the level of risk involved in the decision, the longer the duration of the decision-making process.

Even though a number of decision-specific characteristics have been mentioned, limited understanding of the impact of these characteristics on a company's decision-making process is available in literature.

3.1.2 Internal Company Characteristics

Internal company characteristics refer to factors such as the internal systems that are used in the company itself, the size of the company, the performance, and finally, the organizational structure and corporate control.

Firstly, Papadakis *et al.* (1998) state that the internal systems determine not only the flow of information throughout the hierarchical levels of the company, but also the level and nature of human interaction that takes place and influence the decision-making process. An example of an internal system within a company is the formal planning system that is employed by the company. However, Sinha (1990) argues that most of the strategic decisions take place outside of the structure of this formal planning system. Thus, the structure of the internal systems of the company cannot be directly related to having an effect on the decision-making process.

Secondly, according to Duhaime (1987) the size of the company also has an effect on the decision-making process. In this study it was found that there is a higher level of involvement in the decision-making process in smaller companies than that of larger companies. However, a study by Dean (1993) contradicts this and suggests that there is no relationship between the size of the company and the level of involvement in the decision-making process. Therefore, based on the aforementioned contradicting statements, a concrete correlation between company size and the level of involvement in the decision-making process cannot be made.

Thirdly, studies by Papadakis *et al.* (1998) and Dean (1996) found that there exists a positive relationship between a company's performance and the comprehensiveness and effectiveness of the decision-making process. According to Richard *et al.* (2009) and Venkatraman and Ramanujam (1986) the most basic indicator of business performance focuses on the outcome of its financial indicators. They are assumed to represent the accomplishment of the economic goals of the company and can be divided into three specific areas:

1. Financial performance
2. Market performance
3. Shareholder return

The main objective of all profit-seeking companies is to maximize shareholder wealth. Thomas and Evanson (1987) state that the profitability and efficiency of an operation is driven by financial performance. Therefore, in order to maximize shareholder wealth, the company should first and foremost make a profit. Thereafter, the long-term survival of the company depends on financial success, which in turn is dependent on constant growth and development of the company.

There are numerous methods by which the financial performance of a company can be evaluated, most commonly used are financial ratios that are calculated from a company's financial statements. Traditionally the indicators of financial performance are divided into four different categories as follows (Encyclopedia of Management, 2009):

1. Profitability ratios
   Profitability ratios simply indicate a company's ability to make a profit. There are a number of profitability ratios used to calculate the profitability of a specific company and to judge its performance by comparing it to other, similar companies. Some of these ratios include the net profit margin, the gross profit margin and the operating profit margin. All of these ratios are simply calculated by dividing the before mentioned profits by the revenue of the company. Other profitability ratios include the return on assets (ROA) that indicates how effectively a company is producing income from its employed assets and also the return on equity (ROE) that indicates the income that is generated from the invested shareholder capital.

2. Liquidity ratios
   The liquidity of a company is its ability to meet its short-term financial obligations. There are three main ratios used to determine the liquidity of a company. Firstly, the current ratio which indicates a company's ability

to pay its current liabilities from its current assets, where current assets are those assets that can be converted into cash in a short period of time (less than one year). Secondly, the acid test ratio or quick ratio which is a lot like the current ratio, however it omits inventory from its current assets. By omitting inventory from the current assets, this ratio only deals with the company's most liquid assets as inventory can take longer to convert into cash. Finally, the cash ratio which indicates the capability of a company to repay its short term debts by only taking into account the ratio of the company's cash and cash equivalents and its current liabilities.

3. Gearing ratios
   Gearing ratios are used to determine the financial leverage of a company, it measures the degree to which the company's activities are funded by the owner compared to that of the invested creditor's funds. The most common gearing ratios include the debt-to-equity ratio, which is a measure of the proportion of debt and equity that is used to finance the company's assets. Similar to the debt-to-equity ratio is the equity ratio that is a measure of the proportion of the company's assets that are financed by equity. There is also the debt ratio which is used as an indicator of the amount of leverage that a company is using by comparing its total assets to its total debt. Another important gearing ratio is the interest covering ratio that measures a company's ability to repay the interest owed on outstanding debts.

4. Investor ratios
   Investor ratios are used by potential investors to determine the attractiveness of an existing or potential investment. There are numerous investor ratios used in this evaluation, however they are dependent on the interests of the investor. Some of the more common investor ratios include the price-earnings (PE) ratio that indicates the current price of a company's shares compared to that the investor will pay per unit of earnings. Also, since the primary method of returning funds to the investors is by paying out dividends, the dividend yield and payout ratio of a company is a large determining factor of potential investment.

According to Chen (2002) the main downfall of financial ratio analysis is that literature regarding these analyses fail to concur on the importance of the different financial ratios that exist. Al-Tamimi and Lootah (2007) state that the use of financial ratios as the indicators of financial performance of a company is insufficient as there are no agreeable standards for the selection of the ratios to be used. Also, there are no suitable benchmarks established against which these ratios can be compared in order to determine the relative financial performance. Van Heerden

(2003) discusses the poor correlation between shareholder return and financial ratios that are purely based on profit. There is however a strong correlation between shareholder value and future cash flows and it is therefore suggested to rather use discounted cash flow based approaches such as the Net Present Value (NPV) or the Internal Rate of Return (IRR) and Economic Value Added (EVA) measures that have a closer correlation with shareholder value.

Furthermore, Lilian Chan (2004) and Eakins (2001) suggest that for decisions that are of a significant investment nature, capital budgeting techniques such as the NPV and IRR be used to determine the correlation between the potential investment and shareholder value. Capital budgeting refers to the process by which a company determines whether or not to undertake a potential investment.

The NPV is the most commonly used tool to determine the profitability of a potential investment. As reported by Luecke (2002), the difficulty in determining whether a potential investment is worthwhile is that the cash outflows and inflows occur at different times, therefore the value of those inflows and outflows cannot be compared directly. It is therefore necessary to translate both the cash outflows and inflows of a specific project to a common time period. The NPV is used to calculate the present values of the series of cash flows, where the present value is a measure of how much the money that is spent in the future is worth today. Thus, measuring the increase in the company's current worth by accepting the project that will stretch out into the future.

The IRR is another capital budgeting technique apart from the NPV. According to Eakins (2001) it is used to calculate the rate of return that the company will receive over the entire life of an investment made. The IRR incorporates the NPV by setting it equal to zero, thus instead of calculating the current worth of the investment that stretches into the future, the IRR calculates the discount rate that sets the present value of the cash outflows equal to the present value of the cash inflows. A simplified explanation of the IRR is that it can be thought of as representing the rate of growth that a particular project is expected to generate.

There are advantages and disadvantages concerning each of the above mentioned techniques. One advantage of the NPV as described by Eakins (2001) is that it properly accounts for the time changing value of money, however without an accurate discount rate it may pose some difficulty in the calculation of the present value. One distinct advantage of the IRR discussed by Luecke (2002) is that it is easy to interpret and analyze whereas the NPV method is very complex and requires multiple assumptions throughout the analysis and might prove difficult for someone without the financial background or theory to understand the concept.

The following section details the discussion of the IRR, with special focus on the information and calculations involved in determining the IRR of an organization.

3.1.2.1 Internal Rate of Return

According to Ricke and Pfingsten (2002) any physical asset replacement decision is an investment decision since the replacement of a physical asset involves the investment of a significant amount of capital. Repairing or replacing a physical asset can therefore be interpreted as two different projects that demands a significant amount of capital investment.

Magni (2010) states that the IRR is one of the best known and most commonly used indexing tools used in decision-making that involves either accepting or rejecting a possible investment project.

Accordingly numerous surveys, largely focused on large organizations, suggest that the primary method for the evaluation of different investment projects is the IRR. For example, in their survey of a 103 large organizations, Gitman and Forrester (1977) found that 53.6 % of the organizations used IRR as their primary method for evaluation. Also, a survey done by Scall *et al.* (1978) found that 86 % of organizations use IRR or Net Present Value (NPV) for the evaluation of investment projects.

As mentioned before, the IRR is used in capital budgeting as a rate of return to compare and measure the profit potential of an investment. In other words, the IRR is the discount rate at which the NPV of an investment becomes zero. The NPV in financial accounting is defined as the sum of the present values of the individual cash flows, both incoming and outgoing. The NPV is a standard method for using the time value of money to appraise long-term projects by measuring the excess or shortfall of cash flows, in present value terms, once all financing charges are met (Sporleder *et al.*, 2001).

In the case where the project or investment is unique, the IRR can be used to determine the return achieved by an investment and can also be used as a measure of the efficiency of the investment. Therefore Hartman and Schafrick (2010*b*) suggest that for decision-making purposes the IRR can be compared to the discounted rate for accepting or rejecting projects. Alternative projects or investments are evaluated upon the prognosis that a reasonable rate or return can be expected. It is therefore necessary to define the Minimum Attractive Rate of Return (MARR) as the minimum acceptable rate of return or benchmark rate of return. Thus, a project or investment is not economically viable if the IRR does not at least exceed the MARR. Refer to Figure 3.1.2.1 below for an illustration of the relationships between the different rate of return values. The rate of return on safe investments as illustrated below is based on the South African Treasury Bill return. Unlike rate of return calculations, the MARR is determined by financial managers and is used as a criterion against which alternative return on investments are measured to either accept or reject an investment decision (Schafrick, 2003). The following are the theoretical definitions and notations of the NPV and MARR.

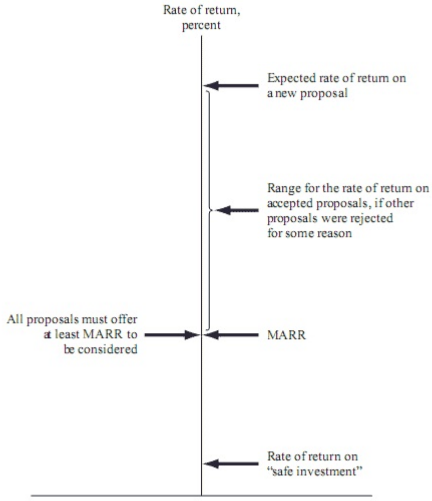


Figure 3.1: The size of MARR relative to other rates of return, (Engineering Economic Analysis, 2014)

A discrete cash flow stream is defined as x_0, x_1, ... , x_n, where n ranges from one to infinity. Using the cash flow stream definition above, Hartman and Schafrick (2010a) present the worth or value (NPV) of a particular project for an interest rate i as

$$\text{NPV}(i) = x_0 + \frac{x_1}{(1+i)^1} + \frac{x_2}{(1+i)^2} + ... + \frac{x_n}{(1+i)^n} \tag{3.1.1}$$

Also, the Net Future Value (NFV) of a project or investment at time n for an interest rate i is defined as

$$\text{NFV}(i) = x_0(1+i)^n + x_1(1+i)^{n-1} + x_2(1+i)^{n-2} + ... + x_n \tag{3.1.2}$$

According to Magni (2010) the IRR is expressed as i and is the rate that equates the present value, or equivalent future value, to zero.

$$0 = x_0 + \frac{x_1}{(1+i)^1} + \frac{x_2}{(1+i)^2} + ... + \frac{x_n}{(1+i)^n} \tag{3.1.3}$$

There are however various types of investments, according to Hartman and Schafrick (2010*a*) a conventional investment is defined as "*an investment that contains one or more negative cash outflows, followed by one or more positive cash inflows*". Whereas a non-conventional investment is defined as an investment that "*intersperses the positive and negative cash flows*", such as the investment of large amounts of capital into the periodic maintenance of physical assets.

Traditionally, a pure investment is one in which the organization invests money during every period of its life. The investment balance is either zero or negative and is calculated at the IRR, i^*, throughout the investment's life, n. A pure investment is one from which the organization is not allowed to borrow at any time during its life. Also, at the end of the investment's life, n, it is completely recovered, earning interest at i^* in the interim periods.

The investment balance for each period, t is defined as

$$\text{NFV}_t(i^*) = \sum_{m=0}^{t} x_m(1+i^*)^{t-m} \leq 0 \forall = (0, 1, ..., n-1) \tag{3.1.4}$$

At the end of the life, n, the investment balance is defined as

$$\text{NFV}(i^*) = \sum_{t=0}^{n} x_t(1+i^*)^{n-t} \equiv 0 \tag{3.1.5}$$

On the other hand, a pure loan always has a non-negative balance and the future value always equals zero at the IRR.

A mixed investment differs from the pure investment in the sense that the organization can invest money during some periods and owe the money during others.

From the above definitions, Hartman and Schafrick (2010*a*) argue that a conventional investment can consist of only pure investments, whereas a non-conventional investment can be either a mixed or a pure investment.

The slope of the NPV(i) according to its first derivative is expressed as

$$\frac{d\text{NPV}(i)}{di} = -\frac{x_1}{(1+i)^2} - \frac{2x_2}{(1+i)^3} - ... - \frac{nx_n}{(1+i)^{n+1}} \tag{3.1.6}$$

A pure investment is therefore defined, for all i in (-1, ∞), as

$$\frac{d\text{NPV}(i)}{di} < 0 \tag{3.1.7}$$

Assuming the i represents the cost of capital, the above definition is intuitive since the increase in the cost of capital will lead to a decrease in the value of the investment. Therefore, any increase in the interest rate i will lead to a decrease in the NPV of the investment.

A pure loan is therefore defined, for all i in (-1, ∞), as

$$\frac{d\text{NPV}(i)}{di} > 0 \tag{3.1.8}$$

As above, assuming the i represents the cost of capital, an increase in the i, where the cost of capital is fixed, makes a loan appear more attractive from the perspective of the entity providing the loan.

A mixed investment differs from the pure investment and loan as the first derivatives is both positive and negative over the interest rate interval (-1, ∞). A project is therefore considered to loan from the organization when the first derivative with respect to i is decreasing. Therefore, for a given interest rate i, the organization is loaning to a project if the following is true.

$$\frac{d\text{NPV}(i)}{di} = -\frac{x_1}{(1+i)^2} - \frac{2x_2}{(1+i)^3} - ... - \frac{nx_n}{(1+i)^{n+1}} < 0 \tag{3.1.9}$$

Also, an organization is considered to loan from an investment when the first derivative, with respect to i is increasing. Therefore, for a given interest rate i, the organization is loaning from an investment if the following is true.

$$\frac{d\text{NPV}(i)}{di} = -\frac{x_1}{(1+i)^2} - \frac{2x_2}{(1+i)^3} - ... - \frac{nx_n}{(1+i)^{n+1}} > 0 \tag{3.1.10}$$

From the above two equations, a maximum or minimum will occur for the NPV at $\bar{i}$. At this point, the project changes from either investing to borrowing, or from borrowing to investing. Therefore, from basic mathematics, the maximum or minimum point will occur when

$$\frac{d\text{NPV}(i)}{di} = -\frac{x_1}{(1+i)^2} - \frac{2x_2}{(1+i)^3} - ... - \frac{nx_n}{(1+i)^{n+1}} = 0 \tag{3.1.11}$$

From the above definitions and equations, it is evident that the slightest change in the interest rate influences the cash flows when computing the NPV. A sign change in the slope of the NPV function therefore signifies that the cash flow has changed to such an extent that the function has changed direction, consequently changing from a loaning to a borrowing function, or vice versa. Therefore, according to Hartman and Schafrick (2010a) at the values of i^* the project is neither borrowing, nor loaning.

The internal rate of return, or i^*, should therefore be calculated for both projects, replacing a physical asset and continuing the repair of a physical asset. The project with higher i^* should be favoured over the project with lower i^*.

As this study is specifically interested in the IRR associated with the repair/replace of physical assets, the cash flows associated with these physical assets need to be defined. Both the physical asset repair as well as the replace option cash flow consists of a number of cash inflows and cash outflows. The cash inflows associated with the physical asset repair/replace decision includes the annual income attributed the operation of the physical asset as well as the net proceeds upon selling the physical asset and possible tax benefits from its renewal or repair. Cash outflows include the initial investment in acquiring or repairing the physical asset, all expenses associated with the operation of the physical asset, adjustments, depreciation and finally, selling expenses such as a net loss or income tax charged on profit from selling the physical asset.

Therefore, as stated by Gitman and Zutter (2012) the major cash flow components for both the physical asset repair as well as the replace option are summarized as follows

1. Initial investment - the relevant cash outflows for a potential investment project at the time of inception.

2. Operating cash inflows - the relevant cash inflows, after tax, resulting from the implementation and operation of the physical asset.

3. Terminal cash flow - after-tax non-operating cash flows attributed to the liquidation of the project.

By determining the IRR for both the repair and the replace decision, the best option that is most advantageous to the organization can be determined. However the IRR should also be compared to the MARR, as mentioned earlier, before the final decision is made as some investments are expected to generate a higher return than others.

As suggested in Section 3.1.2, apart from the IRR there also exists a strong correlation between the EVA and shareholder value creation. Therefore, the next section entails the detailed discussion of the EVA and the calculations and steps involved in the determination of the EVA.

3.1.2.2 Economic Value Added

As mentioned before, the primary goal of a company is to maximize shareholder wealth by increasing the value of the company. According to Starovic *et al.* (2004) there are three factors that must be incorporated into the repair/replace decision of a physical asset in order to maximize shareholder value:

1. Cash over profit
   There is a better correlation between cash flows and shareholder value than with profits because future cash flows ultimately create economic value.

2. Returns must exceed cost of capital
   The returns of the company should not only be enough to cover the cost of debt, but it should be able to cover both the cost of debt and the cost of equity, also referred to as the cost of capital. The cost of debt represents the effective rate that the company owes due to all of its financing, these include current loans, bonds etc. Whereas the cost of equity represents the return that the company owes to its shareholders. It is therefore necessary that the returned profit of the company exceeds its cost of capital to avoid operating at a net loss.

3. Long and short-term value
   Potential investors are not only interested in the current profit levels of a company, they are also interested in the long-term value that the company offers. Thus, emphasizing the importance of exhibiting potential future value to possible investors.

In addition, Obermatt (2014) discusses a value driver tree developed by F. Donaldson Brown in 1914 that splits the value-based performance metrics into three respective sub-metrics to determine the source of the added value. These sources, or value drivers, include margins, leverage and capital efficiency, and also measures of growth. In short, the pillars of value creation consists of growth, returns and risk. Refer to Figure 3.2 below.

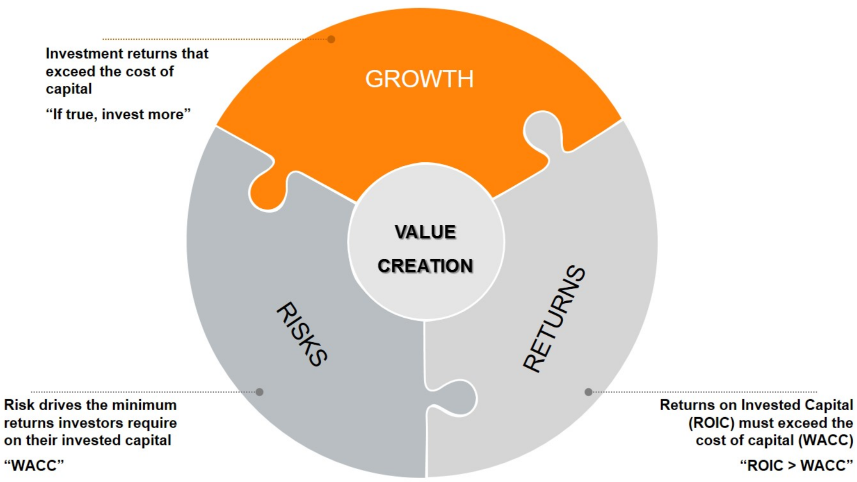


Figure 3.2: The Three Pillars of Value Creation

The value-based performance metrics, also known as Key Performance Indicators (KPIs) or financial ratios, all recognize that value creation only occurs when an organization's Return On Invested Capital (ROIC) exceeds the Weighted Average Cost of Capital (WACC). According to Damodaran (2007) the ROIC is an accounting measure that represents the efficiency by which a company's invested capital generates cash flow i.e. the return that the invested capital generates. Whereas Frank and Shen (2014) define the WACC as the average return that a company is obligated and is expected to pay its shareholders and creditors.

Obermatt (2014) also states that this value creation is one of the most important aspects to investors as it translates to increase the share price and enterprise value. The use of value-based performance metrics is essentially an attempt to manage operating performance from the capital markets perspective. Some of these metrics are based on discounted cash flows, others are based on investor expectations in the capital markets, but the most relevant and widely used metrics are those based on residual income, such as the EVA.

The EVA is a measure of performance that attempts to address all of the above mentioned factors. According to O'Hanlon (1998) the EVA is a single, value-based measure that can be used in valuing capital intensive projects, such as continuing the repair of a physical asset or replacing and the possible acquisition of a physical asset, ranking business strategies, setting management's performance targets and measuring overall company performance. It is also described by Bacidore *et al.* (1997) as the link between the company's market performance and its financial accounting data.

EVA requires that the cost of capital be assessed in the valuation as well as in measuring operating performance. It therefore reveals the incremental rate of return over an organization's cost of capital. In short, the EVA measures the value created from capital invested in an organization. Thus, EVA allows for the use of one metric for three related aspects of value-based performance management: performance assessment, incentive compensation and capital allocation. It is therefore necessary to describe, in detail the process by which the EVA is calculated as well as all of the other relevant factors and metrics that form part of the calculation. Van der Poll *et al.* (2011) suggest three distinct stages in the calculation of the EVA, firstly, calculating the profit, secondly, determination of the asset base of the company and finally, determining the WACC.

1. Calculation of the Profit
   The EVA is based on the Net Operating Profit after Taxes (NOPAT) and the Capital Change. Where NOPAT is dependent on the Adjusted Net Operating Profit before Taxes (ANOPBT) and the Taxation rate. ANOPBT is dependent on the Earnings Before Interest and Taxes (EBIT) and adjustments. Adjustments eliminates all non-operating and accounting-related positions in profits that dilutes the economic picture of performance, these

include goodwill and intangible assets, non-operating positions, volatile cost components and large investments.

According to Shil (2009) EVA is calculated as follows:

$$\text{EVA} = \text{NOPAT} - \text{Capital Change} \tag{3.1.12}$$

NOPAT is calculated as follows:

$$\text{NOPAT} = \text{ANOPBT} \times (1 - \text{Tax Rate}) \tag{3.1.13}$$

ANOPBT is calculated as follows:

$$\text{ANOPBT} = \text{EBIT} - \text{Adjustments} \tag{3.1.14}$$

2. Determining the capital base
   Capital Charge is dependent on the Average Invested Capital as well as the Cost of Capital. Where the Average Invested Capital is calculated from the beginning of the year using the value of the Fixed Assets as well as the Net Working Capital (NWC). NWC is calculated from the Current Assets (CA), Cash and cash equivalents (C), Current Liabilities (CL) and the current portion of Interest-Bearing Debt (IBD).

   Capital Charge is calculated as follows:

$$\text{Capital Charge} = \text{Average Invested Capital} \times \text{Cost of Capital} \tag{3.1.15}$$

   Average Invested Capital is calculated as follows:

$$\text{Average Invested Capital} = \text{Fixed Assets} + \text{NWC} \tag{3.1.16}$$

   NWC is calculated as follows:

$$\text{NWC} = \text{CA} - \text{C} - \text{CL} + \text{IBD} \tag{3.1.17}$$

   The capital charge is an absolute monetary value that is expected as a book return on the capital provided. It is calculated by multiplying the cost of capital with the invested capital. The invested capital is however calculated differently for financial and non-financial organizations. Organizations where financing is not part of business operations use ‘The Entity Method’ to calculate the capital charge. In this method the invested capital is the sum of debt and equity, with cash and cash equivalents subtracted. Whereas organizations where financing is part of the business operations use ‘The Equity Method’ to calculate the capital charge. In this method the invested capital is equal to the book equity.

3. Determining the WACC
Cost of capital can be calculated using two different methods, the entity method and the equity method. In the entity method, cost of capital is a weighted average of the cost of equity (WACC) and the cost of debt. In the equity method, the cost of capital is the expected return on all invested equity.

Cost of equity is typically derived from historic equity as it cannot be measured directly, whereas the cost of debt can be identified directly from existing debt obligations. The Capital Asset Pricing Model (CAPM) is one of the methods that can be used to calculate the cost of equity capital.

According to Perold (2004) CAPM is a model that describes the relationship between risk and expected return on a company's capital assets. The original model as described by Sharpe (1964) states that there are two inherent risks associated with an individual investment into a particular project, the first is systematic risk and the second, unsystematic risk. Systematic risk, also referred to as market risk is characteristic of the entire market such as interest rates, wars, recessions, etc. Whereas unsystematic risk is the risk associated with a specific industry or organization such as labor issues, environmental conditions, etc. The general idea behind CAPM is that investors need to be compensated for the risk they take on by making the investment. Sigman (2005) describes the CAPM formula as follows

$$r_a = r_f + \beta(r_m - r_f) \tag{3.1.18}$$

Where r_a is the expected return from the specific asset or investment, r_f is the risk-free rate of return, in other words the expected return from that asset or investment that is not correlated by the market, r_m is the expected return from the market and β is the risk premium or risk contribution. β can also be described as the sensitivity of the asset or investment's return to that of the market portfolio and is calculated by using regression and historical monthly returns data. The r_f is typically equal to the interest rate paid by government guaranteed debt securities. However, Alihodžić and Erić (2013) present a simpler method for the calculation of the WACC, refer to the equation below.

$$\text{WACC} = \frac{\text{E}}{\text{V}} \times R_e + \frac{\text{D}}{\text{V}} \times R_d(1 - \text{Tax Rate}) \tag{3.1.19}$$

Where E is the market value of the organization's equity, D is the debt of the organization and V is calculated as follows:

$$V = E + D \tag{3.1.20}$$

R_d represents the cost incurred by the organization for using debt capital or external equity, also referred to as the cost of debt. Whereas R_e represents the cost of equity and is described as the cost incurred by the organization for using internal equity. R_d is simply the interest rate that the organization pays to its lenders, however R_e is a more complicated metric and Alihodžić and Erić (2013) suggest that the CAPM described in Equation 3.1.18 above be used such that R_e in Equation 3.1.19 is equal to r_a.

Determining these in-depth financial metrics is however outside of the scope of this study. Thus the metrics, R_e and R_d, are obtained from consultation with the organizational financial manager, or some person and/or group of persons within the organization that is competent and is able to provide accurate information that reflects the actual performance.

From the above explanation, EVA is a metric that is directly linked to the creation of shareholder wealth. Unlike pure financial measures, the EVA recognizes an organization's cost of capital, thereby taking into consideration the riskiness of the organization's activities and operations.

Sullivan *et al.* (2002) adopt the EVA in physical asset replacement analysis, whereby the possible shareholder value is calculated for the replacement of a particular physical asset i.e. capital investment. By determining the EVA of the capital invested in the continued repair of a physical asset as well as the capital invested in the possible replacement of a physical asset, an organization can determine which option will yield a higher shareholder value.

The following section details the third characteristic of strategic decision-making namely, decision-making team's characteristics.

3.1.3 Decision-Making Team's Characteristics

This section emphasizes the role of the decision-makers on the decision-making process, where the term decision-maker refers to the top management of a company. The first factor that influences the strategic decision-making process is the risk propensity of the decision-makers. Wally (1994) states that a strong propensity and high tolerance for risk encourages the completion of the strategic decision-making process, however, Hitt (1991) found that the decision-maker's propensity did not have a significant effect on the objective criteria or the strategic decision. Another factor to consider is the education and experience of the individual decision makers. Nooraie (2012) suggests that the frequency, not type, of the decision maker's education has a positive effect on the innovation of the strategic decision-making process, whereas longer periods of management service has a negative effect. The decision-maker's cognitive diversity also affects the strategic decision-making process. Wally (1994) found that individual differences among members of the decision-making team has a positive relationship on the pace and creativity of the decision-making process.

In another study by Masomi and Ghayekhloo (2011) decision-makers are described as being rational and utility maximizing. In this study, the decision-making process is affected by two main cognitive factors attributed to the decision making team's characteristics, these include; heuristic factors and prospect theory factors. Heuristic factors refer the use of common practices or rules of thumb when making a decision in a risky and uncertain environment. Whereas prospect theory refers to a more descriptive framework that describes the way in which the individual makes a decision in a risky and uncertain environment. The findings of this study suggest that individual behavioural factors do have an effect on the decision-making process; however the impacts are of varying degrees depending on each individual studied. Moreover, the study also suggests that further research is required to further develop this topic.

Bashir *et al.* (2013) suggest both age and gender have a significant effect on the decision-making process and risk tolerance. Also, the individuals that form part of the decision-making team might not always exhibit rational thinking and are subject to emotional and cognitive errors when making a risky and uncertain decision. Furthermore, the study suggests that firm image or self-image is an important factor that affects the decision-making process. A person will make a decision that would ideally improve his/her own self-image and/or that of the company in which he/she is employed. The findings of the study also suggested that each of the above mentioned factors have an effect on the decision-making process, however concrete conclusions could not be made and thus suggests further research.

From the aforementioned information concrete findings and detailed analysis regarding the effect of the decision-making teams' effect on the decision-making process is not yet available in literature. Thus, the inclusion of the effect of decision-making teams' characteristics will not be included in this study.

The next section considers the fourth and final strategic decision-making characteristic namely, external company characteristics.

3.1.4 External Company Characteristics

Strategic decisions and strategic decision-making processes should adapt to potential opportunities, constraints, possible threats and all the other characteristics of the environment in which the company operates (Nooraie, 2012). Papadakis *et al.*

found that there are numerous environmental factors that have a significant impact of the strategic decision-making process, one of these factors is the dynamism of the environment which refers to the unpredictability and rate of change of the environment. Both Nooraie (2011) and Priem *et al.* (1995) found that rationality has a positive relationship with the outcome of the decision-making process, it is therefore suggested that a rational decision-making process be used. Another factor is the opportunities and/or threats present in the company's environment such as competition from similar companies in the same industry and even in other industries. Porter (1991) states that the competitive value the activities within a company can only be determined relative to some other rival company/companies that delivers a distinct set of products and/or services to some set of customers. Competition is also linked to another environmental factor, hostility. Nooraie (2012) describes environmental hostility as the situations in which the company is confronted with competition in terms of product/service price, distribution and production as well as unfavourable customer demand, regulatory restrictions and shortage of the supply of resources.

Moreover, social, environmental and economic sustainability also have a significant effect on the strategic decision as it forces the decision-maker to consider the long-term impacts of the outcome of the decision. It is thus necessary to explain, in detail, the effect of competition and sustainability on the decision-making process.

3.1.4.1 Competition

Porter (1991) introduced the Five Forces Framework (FFF) to identify an industry's weaknesses and strengths to develop and improve not only the industry structure, but more importantly the corporate strategy. Narayanan and Fahey (2005) and Grundy (2006) state that not only did this framework promote strategic management to become an important focus point in business management, but it is also one of the most common and widely applied analysis frameworks in today's strategic management. The FFF is based on the analysis of the level of rivalry within an industry as well as the development of the business strategy by assessing the opportunity, risk and profitability based on five key factors. These factors will be discussed in detail later.

According to Porter (2008) an organization's success is dependent on attaining a competitive position or series of competitive positions that lead to sustainable and superior financial performance to that of other organizations. Secondly, organizational success also depends on the alignment of the sets of internal goals and policies of the organization and that of the external opportunities and threats. Finally, an organization's strategy should be focused on the creation and exploitation of its distinctive competencies, in other words, the unique strengths that the organization possess above that of rival organizations.

Therefore, the FFF is a method of identifying the sources of value for an industry by evaluating not only the industry profit potential, but also the attractiveness of operating in that specific industry. It is therefore necessary to first identify the possible sources of value-added within an industry before the factors that determine the competitive success of an organization can be discussed.

According to Drake (2010) there are six main sources of value-added within an industry. Firstly, economies of scale is a cost advantage that is gained if a given increase in the production, marketing and/or distribution results in a less than proportional increase in the associated cost. Economies of scale are more common in large organizations with large scale operations and outputs, with cost per unit generally decreasing with an increase in the demand. Therefore, since the fixed costs associated with the production can be spread over a larger area, the costs generally decrease.

Secondly, economies of scope is a cost advantage that is gained from a decreasing average cost as a result of the organization increasing the number of different goods produced. Therefore, economies of scope are the efficiencies gained when an investment can support more than one activity.

Thirdly, organizations that are established within a given industry may experience cost benefits such as access to supplies of raw-material that are not available to those organizations that are new to the industry.

Another value-adding source is product differentiation. Organizations may invest in the development or incorporation of product attributes that is perceived as different and desirable to the target market. Thus, investing in the capacity to differentiate products through technological innovations, patents and reputation.

Also, established organizations in the industry may have access to existing, well developed distribution channels that provides a competitive advantage. Where Szopa and Pękała (2012) define a distribution channel as the path through which goods and/or services travel from the vendor to the customer or the path taken for the payment of those goods and/or services from the customer to the vendor.

As mentioned before, following the identification of the potential sources of value added within an industry, the competitive success of the organization can be analyzed.

Porter constructed a framework for the determinants of success in distinct businesses, refer to Figure 3.3.

The framework is built around five competitive forces that erode long-term industry average profitability, refer to Figure 3.4.

The framework as illustrated in Figure 3.4 can be applied at any level of industry, strategic group or even an individual organization. Ultimately, the function of the framework is to explain the sustainability of profits against direct and in-

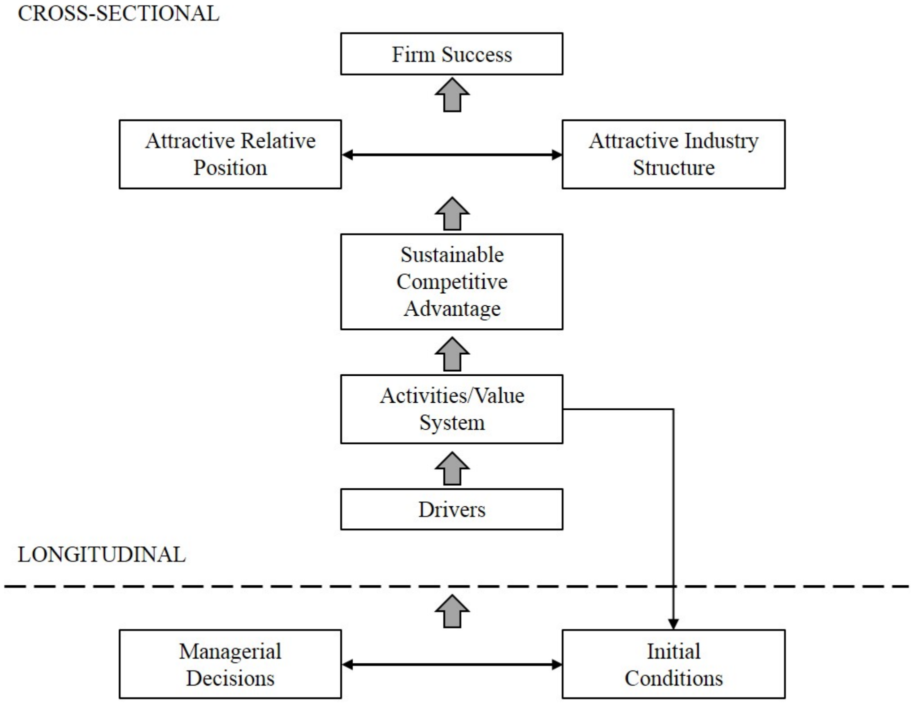


Figure 3.3: Determinants of Success in Distinct Businesses, (Porter, 1991).

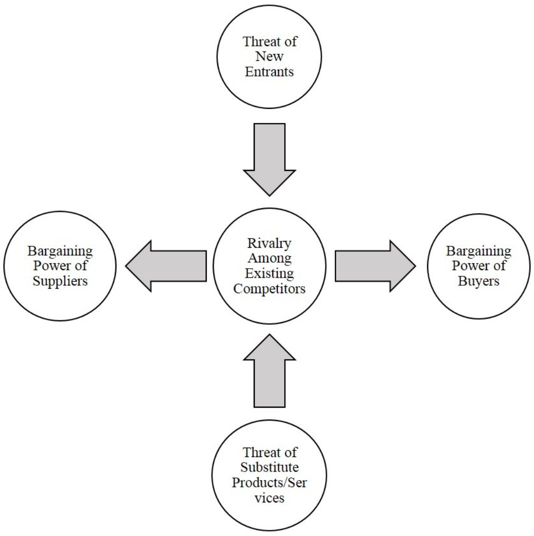


Figure 3.4: Five Forces: Summary of Key Drivers, (Porter, 1991).

direct competition, as well as against bargaining. The structure of an industry is partially exogenous and partially dependent on organizational actions. Therefore, according to Porter (1991) firm position and structure ultimately interrelate. Also, see link one in Figure 3.3.

Often managers define competition too narrowly as being dependent on only the direct competitors, however competition for profits stretches beyond established industry rivals to include the other four forces as depicted in Figure 3.4. These include customers, suppliers, potential entrants and substitute products. The extended rivalry resulting from the five forces mentioned before shapes the nature of the competitive interaction within an industry and also, defines the structure of the industry.

Therefore, Porter (2008) states that by understanding the competitive forces and their underlying causes uncovers the origins of an industry's actual profitability while at the same time supplying a framework to anticipate and possibly influence rivals. Thus, as this study is primarily focused on the physical asset repair/replace decision, it is crucial that decision-makers study the effect of both the physical asset repair and the replace option on the organization's profitability as well as on the industry rivals. Ideally the organization will choose the decision that results in added competitive advantage as well as increased profitability and financial performance. It is therefore necessary to evaluate and discuss each of the FFF components in detail and to identify the sources of each individual competitive force in the FFF.

1. Competitive rivalry within the industry
   Dälken (2014) claims that rivalry among existing competitors in the industry takes numerous familiar forms namely; price discounting, advertising campaigns, new product introductions and service improvements. High competitive rivalry within an industry limits an organization's profitability, also the degree to which the rivalry negatively influences the profit potential is dependent on firstly the intensity of the rivalry and secondly, the basis on which organizations within an industry compete.

   The level of competition between rival organizations within a specific industry is at its greatest if there are many rivals within the industry that are approximately equal in size. If an industry is saturated, the opportunities for new business or poaching business off of rivals is limited. Also, if the industry growth rate is low, the competition for market share among industry rivals is high.

   Furthermore, high exit barriers within the industry increases the level of competition since these exit barriers trap organizations in the market even though the organization might be earning low or negative returns. Exit barriers arise as a result of highly specialized assets or managements devotion to a certain business. Moreover, some organizations within an industry have goals that go beyond that of pure economic performance, for example some state owned organizations focus on prestige and employment as well as economic performance, where the latter is of less importance.

Porter (1991) states that the level of rivalry within an industry reflects not only the intensity of competition, but also identifies the basis of the competition. Since price competition among rivals is responsible for the direct transfer of the industry profits to its customers, rivalry that is purely price-based is especially destructive to an organization's profitability. As price reductions are easy for rivals to see and contest, numerous rounds of retaliation are likely to occur. As result of continuous price reductions among rivals, customers are trained to focus on the price of a product or service, rather than on product features and service.

According to Porter (2008) competition among rivals that revolve around something other than the price for example; support services, product features, brand image and delivery time are less likely to erode the profitability of an organization as it not only improves customer value, but it can also support higher prices. An industry where all or many organizations compete on the same product features and customer needs can result in a zero-sum game, where one organization's gain results directly in another's loss. This effect is more likely to occur if the competition is solely based on price, however if organizations take care to segment their markets correctly, it is unlikely to occur.

The competition among rivals can also be positive-sum, thereby increasing the average profitability of an industry. Unfortunately the opportunity for positive-sum competition is more likely to occur in industries that serve a diverse customer base. Also, if the rival companies within a specific industry aim to serve the needs of different customer segments, with a mix of different combinations of prices, services, products, brand identities or features, the positive-sum rivalry can result in not only increased profitability, but also possible expansion of the industry.

2. Threat of new entrants
   As discussed by Porter (2008), new industry entrants do not only introduce new capacity into the industry, they also seek to gain market share. This results in increased industry pressure on prices, costs and rate of the investments necessary to compete. Also, new entrants that are diversifying from other markets have the potential to use existing capabilities and cash flows to stir up competition. The threat of new entrants therefore negatively affects

the profitability of an industry. Therefore, established organizations in that specific industry must maintain low prices or increase investment to deter potential new entrants that pose a high threat.

Heger and Kraft (2008) declare that the degree of threat that a new entrant poses to the industry depends on the level of the entry barriers that are present and also on the level of resistance from established organizations within the industry. The benefits that incumbents have relative to new entrants are called entry barriers. In cases where the entry barriers are low and the retaliation from established organizations in the industry is minimal, the threat of entry is high. From the above discussion, the threat of entry is what decreases the profit potential and not whether entry into the industry actually occurs.

According to Blees *et al.* (2003) 36 of these barriers that hinder new organizations from entering a new industry have been identified. Even though each of these barriers pose their own threat to the new entrants, Porter (2008) suggests that they be grouped into seven major sources as a lot of these barriers are closely related.

Large organizations with large volume production capabilities and that operate on a large scale have the advantage of experiencing lowered unit prices as a result of supply-side economies of scale. As mentioned before, the fixed costs involved in the production activities of these companies can be spread over a broad unit base, resulting in lowered unit costs. As a result of the large scale operations and profits, these organizations also have the advantage of employing more efficient technologies and commanding better terms from suppliers. Therefore, as stated by Shepherd and Shepherd (2003) supply-side economies of scale deter new entrants as they are forced to enter the industry on a large scale to compete with these established organizations.

Werden (2001) discusses another important source of entry barrier, namely demand-side economies of scale or network effects where the consumer's willingness to pay for a product and/or service increases with the number of users of that product and/or service. Therefore, the more users using that specific product and/or service, the more valuable it becomes. This effect discourages new entrants into the industry by limiting value that the consumer's place on a new product and/or service. Also the price that the newcomer can demand for the product must be significantly lower while maintaining a high quality in order to build a large enough customer base to compete with incumbents.

It is a common phenomenon in industry that if customers switch from one supplier to another they will incur some cost. These costs arise from a number of different factors, including product specification altering for compatibility, process modification, transactional costs, introduction of new information systems and training of employees to use the new product. Lee *et al.* (2001) claim that the higher the cost of switching from one supplier to another, the higher the entry barrier the newcomer experiences.

As expressed by Porter (2008), obtaining sufficient capital to enter the industry as a newcomer is one of the most difficult entry barriers to overcome. This entry barrier is especially high if the capital investment required for unrecoverable expenses such as Research and Development (R&D) and upfront advertising or if the newcomer is to enter a capital intensive industry such as automotive, pharmaceuticals, oil refinery, etc. (Blees *et al.*, 2003). Therefore, the significant capital investment required to enter some industries deter new entrants and limit the pool of competitors.

In some industries the incumbency advantages are independent of size of the organization. Therefore, as discussed by Kaiser *et al.* (2011) regardless of the size, some incumbents may offer customers superior cost and quality advantages that are not available to potential competitors. These advantages can arise from sources such as established brand identity, access to superior raw materials, proprietary technology, most favorable geographic locations or experience that has allowed the organization to improve the efficiency of production.

According to Kaiser *et al.* (2011) and Porter (2008) another barrier that may hinder the entrance of newcomers into an industry is access to adequate distribution channels. Organizations that enter industries such as manufacturing and production need to secure distribution channels for the procurement of raw materials in order to produce their goods and/or services. However, wholesale and retail channels that are limited are more likely to be tied-up by incumbents, thus hindering newcomers from entering the industry. It is therefore necessary in some cases that newcomers bypass the established distribution channels and create their own as a result of the limited access.

Finally, Blees *et al.* (2003) state that restrictive governmental policies can either aid or hinder the entry of newcomers into an industry. These policies have the potential to either amplify or nullify the entry barriers, in some cases these policies limits or even completely blocks entry into certain industries as a result of restrictions and licensing requirements on foreign investments. Also, Porter (2008) suggests that expansive patenting rules that protects brand from being imitated and copied, as well as restrictions regarding the environment and safety regulations, raise the entry barriers for potential newcomers.

Apart from the seven sources as discussed above, the historical reaction of incumbents to newcomers will also determine whether or not a new organization will risk entering a specific industry.

3. Power of suppliers
De Swaan Arons and Waalewijn (1999) declare that powerful suppliers within an industry have the ability to capture more of the value for themselves by either charging higher prices, outsourcing costs to industry participants or by limiting quality on the products or services they provide. In manufacturing and producing industries large quantities of raw materials need to be supplied in the form of components, labour and other supplies. As a result, buyer-supplier relationships are established between the industry and the organizations that provide the necessary raw materials required for production. As mentioned above, if the suppliers to this industry is powerful and charge higher prices for the raw materials required, it results in a lower profitability for the industry.

A supplier group is therefore powerful if the industry in which it operates and competes is more concentrated than the industry it supplies goods and/or services to. Also, if the supplier group is not dependent on one industry in particular for its profits, but supplies to a number of different industries. In such situations, Kaiser *et al.* (2011) argue that it is not uncommon for the supplier to extract the minimum profits from each respective industry it supplies to.

Another factor that contributes to the power of supplier groups is high costs associated with switching from one supplier to another. Porter (2008) declares that this is the case with industries or organizations where highly specialized equipment and processes are essential for the production of their goods and/or services. This is also the case if the supplier group offers products that are differentiated and are usually protected by patenting. Furthermore, Cox (2001) states that powerful supplier groups are those that offer products and/or services that are unique and cannot be procured from any other supplier.

Finally, Porter (2008) claims that if the industry in which the buyer reside is more profitable, the supplier group can credibly threaten to forward integrate into that industry, thereby inducing suppliers to enter the market.

4. Power of buyers
Noll (2005) defines buyer power as the circumstance in which the demand side

of the industry is concentrated to such an extent that the buyers can exercise market power over the sellers to that specific industry. Therefore, under such market conditions powerful customers capture more value by forcing down prices below the normal retail prices offered by sellers, demanding more service or better quality. Generally strong buyer power relates to what an economist terms a monopsony - a market that consists of numerous suppliers but only a single buyer or oligopsy - a market with only a few buyers and numerous sellers. Buyers are therefore powerful if they have negotiating leverage relative to other organizations in the same industry.

Industries that have fixed costs on the products that they provide have a very high risk for large volume buyers, Porter (2008) suggests this introduces buyer power into the industry. Especially if those buyers purchase large volumes from a single vendor. Also, in industries that have high fixed costs, the pressure induced by the low marginal costs forces rival organizations to maintain capacity through constant discounting of their products and/or services.

Another factor that contributes to buyer power suggested by Kaiser *et al.* (2011) is standardized or undifferentiated products. If the seller produces products that are standard and undifferentiated, the buyer has the option to find an alternative company that will sell those products on more favourable terms. Likewise, if the quality of the buyer's products and/or services is mostly unaffected by the supplier industry's product, it is easier for buyers to switch from one supplier to another. Also, if the costs associated with switching from one supplier to another is minimal, buyer power is high as they can exert pressure on the supplier by threatening to switch to another.

Similarly, if the products procured from the supplier represent a significant part of the buyer's purchasing budget and cost structure, they are more likely to search for the cheapest option. This usually stems from procurement budget constraints, low profit margins or low cash flow.

Finally, Porter (2008) argues that if the buyer organization can credibly threaten to integrate backwards by either purchasing the supplier firm or a rival firm or by producing the procured product themselves, the buyer power is high.

5. Threat of substitutes
   Cheng (2013) defines a substitute product or service as one that performs a similar function to that of the original but in a different manner. A product's price elasticity is affected by substitute products, the more substitute products that become available, the more the demand becomes elastic since

there are more options to choose from. A high substitute threat negatively effects the industry profitability by placing a cap on retail prices. Organizations that fail to differentiate themselves from substitute organizations within an industry through either the superior performance of their products, marketing or some other property, will mostly likely suffer in terms of profit potential, and in some cases growth potential.

Kaiser *et al.* (2011) warn that the threat of substitution is high when a specific organization offers an appealing price to performance trade off compared to that of the product offered by the industry in which it competes. Also, if the costs associated with switching from the current product to the substitute product is minimal, the threat of substitution is high. These substitute products can exist in the same industry in which the current buyers compete or in other industries.

Porter (1991) argues that a successful organization is one that has an attractive relative position and consequently a competitive advantage above that of its industry rivals. As this study specifically deals with the physical asset repair/replace decision, it is essential that the decision maker evaluate the effect of the decision on all of the above mentioned competitive forces, thereby determining the effect on the organizational competitive advantage.

Ideally the decision to either repair an existing physical asset or to replace the physical asset with a newer version should result in the option that is more favourable to the organization. Thus, the decision that adds most to the organizational competitive advantage is the decision that is most favourable. By evaluating both the physical asset repair and the replace decision and the effect on the FFF, the decision-maker can determine which decision will result in added competitive advantage, which in turn results in sustainable and superior financial performance.

As mentioned earlier, another external company characteristic that influences the strategic decision-making process is sustainability. Therefore, the following section details sustainability and its importance in decision-making practices and frameworks. It also focus on social and environmental sustainability and the importance thereof in the physical asset repair/replace decision.

3.1.4.2 Sustainability

According to Gibson (2006) sustainability should be integrated in the framework and process for decision-making on factors that have lasting effects such as policies, plans and physical undertakings. Especially those that are of a significant investment nature. Incorporating sustainability as one of the factors that govern the decision-making process forces the decision-makers to consider the long-term effect of the decision on the company as well as on the industry in which the company operates. Research suggests that sustainability encourages good business practices, which in turn is sought out by potential investors, thereby encouraging potential investment into the company. Also, Goodland (2002) states that sustainability encourages innovation to develop new solutions to existing problems, which consequently leads to competitive advantage. Sustainability is a broad concept and can be divided into four main types:

1. Human sustainability
   Human sustainability refers to managing and sustaining human capital. Human capital is the private goods of individuals such as health, skills, education, leadership, knowledge and access to services.

2. Social sustainability
   Social sustainability refers to managing and sustaining social capital. Social capital represents the frameworks of investments and services that form the essential framework that enables a society to function effectively.

3. Economic sustainability
   Economic sustainability refers to managing and sustaining economic capital. Economic capital represents the capital that a financial institution deems appropriate to serve as a buffer to ensure that the company remains solvent. This buffer should be sufficient to support any possible risks that the company takes on.

4. Environmental sustainability
   Environmental sustainability refers to management and sustenance of environmental capital. Environmental capital represents all the natural resources of a country, both renewable and non-renewable. It can also be described as a state in which the demands that are placed on the environment can be satisfied without reducing the capacity of the environment to enable all people to live comfortably now, and in the future.

This section aims to provide a comprehensive summary of business or corporate sustainability. Business sustainability can be defined as "adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future" (ISSD, 1992).

According to Keeble *et al.* (2003), there is severe pressure on organizations to be transparent and accountable in their activities. Stakeholders are becoming increasingly interested in the information regarding the organizational activities, rather than purely focussing on the financial outcomes of their investments in the organization. Therefore, organizations have to maintain and develop their social, economic and environmental capital base.

In 1994, the phrase “triple bottom line”(TBL) was introduced by John Elkington, founder of a British company called Sustainability (The Economist, 2009). He argues that instead of solely focusing on the traditional measure of corporate profit, the organization should also incorporate a “people account” as well as a “planet account”, resulting in the development of the triple bottom line.

Singh *et al.* (2007) state that the TBL is based on the idea that an organization should not purely base its performance measurement in relation to the stakeholders that have a direct, transactional relationship with the organization, but should also include local communities and governments as stakeholders. Thus, emphasizing that the organization’s responsibilities are broader than purely the financial aspects of producing products and services.

The TBL consists of three bottom lines, profit, people and planet. The main aim is therefore to measure the financial, social and environmental performance of an organization over a predetermined period of time. Unfortunately it is extremely difficult to measure social and environmental factors in terms of monetary value or units, thus there exists no common unit of measurement for the three bottom lines.

According to Slaper and Hall (2011) there is also no universal standard for measuring the factors that comprise the TBL. Since different organizations have different priorities when it comes to environmental, social and economic sustainability, this allows the organization to adapt the general framework to its specific operations and needs.

As with PAS55 that describes a system for the optimized management of physical assets, standards exist that describe an optimized management system for the environmental and social aspects of an organization that contribute towards its sustainability performance.

In order to include sustainability as a determining factor into the decision-making process, it is necessary to discuss the concepts of environmental and social sustainability.

Environmental Sustainability

The ISO14001 International Standard was published in 1997 by the ISO as a standard for the implementation and adoption of Environmental Management Systems (EMS). Whitelaw (2004) defines EMS as “a set of management processes that requires firms to identify, measure and control their environmental impacts“. There are six steps that an organization must follow in order to comply with ISO14001, namely:

1. Develop an environmental policy.
2. Identify the organizational activities, services and products that come in contact and interact with the environment.
3. Identify and specify all regulatory and legislative requirements as set out by the organization itself as well as by the local government.
4. Identify the organization's environmental priorities and determine new objective targets for the reduction of overall environmental impacts.
5. If necessary, adjust and improve the organizational structure to comply and reach those objectives.
6. Check and improve the environmental management system.

This thesis will however not deal with the adoption and implementation of an EMS and requires the organization to have implemented such a system prior to the introduction of the proposed framework. It is however necessary to determine the environmental sustainability of the physical asset repair/replace decision. Therefore, a set of standardized units need to be developed with which the environmental sustainability of the physical asset repair decision and replace decision can be measured and compared.

The Department for Environment and Affiars (2006) therefore introduces the concept of using environmental KPIs as a tool for measuring environmental sustainability performance. Torres *et al.* (2012) define a KPI as a metric/unit used to measure and quantify the performance of the organization relative to reaching its objectives and targets.

According to Szekely and Knirsch (2005) there are four main criteria within the environmental dimension that can be classified as environmental sustainability KPIs, refer to the following:

1. Air resources: Analyze the contribution of the physical asset repair/replace decision to the regional air quality as well as the potential global effects such as global warming and stratospheric ozone depletion.
2. Water resources: Analyze the impact of the physical asset repair/replace decision on the quantity and quality of the available water i.e. water usage, pollution etc.
3. Land resources: Analyze the impact of the physical asset repair/replace decision on the biodiversity as well as the direct and indirect effect of the release of effluents and substances that cause soil pollution.

4. Mineral and energy resources: Analyze the contribution of the physical asset repair/replace decision to the depletion of non-renewable energy and mineral resources.

The KPIs of an organization are determined by incorporating the organizational policy, regulative and legislative requirements as well as the organizational targets and objectives. The establishment of environmental sustainability KPIs aid the organization in assessing its environmental sustainability performance, as well as to assess its progress towards the promotion of environmentally sustainable practices.

Therefore, determining the environmental sustainability performance of an organization is an objective evaluation of the above mentioned KPIs with regards to the physical asset repair/replace decision under consideration, and the impact it has on the environment.

Social Sustainability

The International Organization for Standardization (ISO) (2010) developed ISO26000 to serve as a guide for the integration of socially responsible behaviour into the operations of an organization. It also aids in identifying the underlying principles of social responsibility as well as the core subjects and issues related to social responsibility in practice.

According to Pojasek (2011) social responsibility should form an intrinsic part of the organizational strategy and should consequently be an integral part of decision-making and in implementing activities within the organization.

Labuschagne *et al.* (2005) state that social stakeholders exist within the organization as well as outside of the organization. Therefore, social sustainability can be divided into an internal and external focus.

Internal focused social sustainability is concerned with the health and well-being of the organization's employees, the equity and human rights aspects of obtaining employees, as well as disciplinary practices within the organization. Furthermore, development and training exercises that promote the employees are also included in this focus.

Externally focused social responsibility concerns the impacts of the organizational activities on all three levels of society; the national, regional and local community.

Assefa and Frostell (2007) argue that a socially sustainable system results in gender equality, promotion of employee and societal health and general well-being, fairness in the distribution of opportunity as well as promoting political participation and accountability.

However, social sustainability is not only a difficult concept to define and quantify, the indicators of social sustainability are frequently not based in theoretical research but rather in the practical understanding of organizational activities and impacts.

Therefore, Littig and Griessler (2005) suggest that the following set of three, broad indicators can be used to evaluate the social sustainability performance of an organization.

1. Satisfying of basic needs and improving the quality of life
   These indicators refer to income distribution, education and training, individual income, risk of poverty, unemployment, health, well-being and security.

2. Equal opportunities
   These indicators relate to the equal distribution of economic goods such as income and quality of life such as education, training and gender equity.

3. Social cohesion
   These indicators refer to factors concerning the involvement in society through integration into social networks as well as the participation in social activities.

On the other hand, Szekely and Knirsch (2005) state that even though there are numerous social sustainability frameworks in existence, the main factors that form part of all these frameworks are summarized as the following:

1. Internal Human Resources

   a. Employment stability: The impact of the physical asset repair/replace decision on the available job opportunities within the organization, as well as the fairness of compensation.

   b. Employment practices: To ensure that the operation of the physical asset to be repaired or replaced comply with the laws of the country, human rights declaration and fair employment standards and also ensure gender and racial equality.

   c. Health and safety: Assess the impact of the operation of either the current physical asset or the physical asset to be procured on the health and safety of employees working on or near the physical asset. Also, to analyze the measures taken to prevent the risk of health and safety and the occurrence of a health and/or safety incident.

2. External population

a. Human capital: Assess the impact of the physical asset repair/replace decision on the employees' ability to work and generate an income. Also, assess the impact on the employees' health and safety, physiological well-being, education, training and skill levels.

b. Productive capital: Assess the effect that the physical asset repair/replace decision place on infrastructure availability for the employee to maintain production.

c. Community capital: Assess the effect of the physical asset repair/replace decision on sensory stimuli, for example aesthetics, noise, odour level, cultural properties, security, impact on poverty and economic welfare.

According to Szekely and Knirsch (2005) the establishment of sustainability indicators and metrics aid an organization in measuring the social sustainability performance, as well as to assess the organization's progress in promoting socially sustainable practices.

Thus, determining the social sustainability is an objective evaluation of the above mentioned factors in context of the physical asset repair/replace decision and the impacts it has on society.

Economic Sustainability

According to Doane and MacGillivray (2011) there are two approaches to economic sustainability; an internal focus and an external focus. The internal focus is concerned with the financial and economic performance of the organization, whereas the external focus is concerned with the organization's influence on the wider economy as well as on social and environmental impacts.

Labuschagne *et al.* (2005) argue that since the internal focus directly relates to the profitability of the organization, and since the proposed framework is focused on assessing the economic sustainability of an organization, external economic contributions, as mentioned above, are allocated to social sustainability.

Furthermore, the financial and economic performance of the organization is discussed in detail in Section 3.1.2 as the calculation of the IRR and the EVA, respectively.

As mentioned before, PAM is a multi-disciplinary field and thus the decision to either repair or replace a physical asset is not only classified as strategic, but also as consisting of multiple influencing criteria. Therefore, the following section details the concept of MCDM techniques.

3.2 Multiple Criteria Decision Making

In Section 2.1.5.3 it was suggested that MCDM should be used to determine whether a physical asset needs to be repaired/replaced. Also, from the information discussed in the previous sections, it is evident that there exist multiple criteria that should be taken into account when making this decision.

In addition, PAS 55-1 clause 4.3.1 emphasizes the need for developed and clearly defined techniques and frameworks for physical asset replacement decisions. These techniques and frameworks should however have clearly defined boundaries and thorough descriptions to enable consistency throughout the decision -making process.

Furthermore, PAS 55-2 clause 0.4 re-emphasizes the importance of decision making in PAM by stressing the importance of adequate information for good decision making ((BSI), 2008).

> *"In particular, it is important to understand the relationship between asset management activities and their actual potential effect upon short-term and long-term costs, risks, performance and asset life cycles. Only then can informed decisions be made about the optimal mix of life cycle activities."*

Moreover, apart from adequate information regarding the physical asset life cycle and condition, PAS 55-2 clause 4.3.3.2 stresses the importance of adopting methods that incorporate this information for good decision making ((BSI), 2008).

> *"Organizations should adopt robust and auditable methods for optimization, appropriate to the criticality and complexity of the decisions being made, and ensure consistent assumptions about the significance of contributing factors."*

Therefore, emphasizing the importance of the establishment of techniques and frameworks for decisions regarding, in this case, the replacement of physical assets.

According to Mateo (2012) every decision is made within some decision environment. This environment is defined as the collection of alternatives, information, preferences and values available at the instance when the decision is to be made. Montibeller and Franco (2010) state that the standard way of analyzing decisions under uncertainty is by representing the various options and uncertainties in a decision tree. The best option is then selected as the one with the highest expected value.

However, the difficulty in decision making is the multiplicity of the criteria that have to be considered before the decision can be made. Complex problems that feature high levels of uncertainty, conflicting objectives, various forms of information and data and multi perspectives and interests can unfortunately not be solved by a simple decision tree as described above. Therefore, MCDM was introduced as a tool to address complex decisions involving multiple, conflicting criteria or objectives.

Belton and Stewart (2002) define MCDM as, "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". Therefore, addressing the adoption of methods that address the criticality and complexity of physical asset repair/replace decisions, as well as taking into account the different factors affecting this decision, as described by PAS 55.

According to Xu and Yang (2001) MCDM problems share the following common features, even though they might be different in context.

1. Multiple criteria that often form a hierarchy
   Most problems, in this case the physical asset repair/replace decision, can be evaluated on the basis of attributes/criteria. When making this decision, there are several factors/criteria that might influence the eventual outcome, thus it necessary to determine the combination that will result in the best outcome.

2. Conflict among criteria
   As mentioned above, there are numerous factors/criteria to take into account when making the physical asset repair/replace decision. These factors are in most cases conflicting and it is therefore necessary to determine the trade off that will result in the best outcome.

3. Hybrid nature
   The criteria that are considered in the decision may not have the same units of measurement or may even be non-quantitative. Also, the criteria that are considered may be of an deterministic and probabilistic nature.

4. Uncertainty
   High levels of uncertainty are involved in the physical asset repair/replace decision. In some cases the decisions are subjective, there might also be a lack of sufficient information that also causes uncertainty.

5. Large scale
   The criteria that are considered may consist of numerous attributes/criteria that are evaluated on different levels of hierarchy.

6. Inconclusive outcomes
   Due to the high levels of uncertainty and the subjective nature of some of the

judgments, the outcomes of MCDM problems/decisions may in many cases be inconclusive and have many suitable solutions.

Ideally, the solution to a MCDM would be to maximize the profit and minimize all the costs involved.

Even though there are numerous MCDM techniques in literature, not all are applicable to the physical asset replacement decision. It is therefore necessary to analyse different MCDM techniques in literature in order to determine their applicability to the physical asset repair/replace decision by evaluating their respective advantages and disadvantages.

Velasquez and Hester (2013) identify a number of common MCDM methods by conducting a comprehensive review of available literature. In this review, twelve common methods were identified as well as their applicability to real world problems and respective advantages and disadvantages. The following sections will provide concise summaries of some of the MCDM methods that are applicable to the physical asset replacement decision.

3.2.1 Multi-Attribute Utility Theory (MAUT)

Løken (2007) describes MAUT as "a more rigorous methodology for how to incorporate risk preferences and uncertainty into multi criteria decision support methods". MAUT is therefore a utility based theory that can aid in the selection of the best course of action by assigning a utility value to all consequences of the decision and then determining the best action by calculating the best utility.

Franceschini *et al.* (2006) state that the fundamental goal of MAUT is to substitute the input information with an arbitrary value referred to as utility, such that quantitative and qualitative information can be compared. Usually the utility values range from zero to one, where zero represents the worst case and one the best case. Thereafter, the outcome of MAUT is simply the maximization of the combined utility value.

There are two types of MAUT in literature: additive and multiplicative utility theory.

3.2.1.1 Additive Utility Theory (AUT)

AUT or Weighted Sum Model (WSM) is described by Løken (2007) as one of the most commonly used approaches in literature and is described by the following function:

$$V(a) = \sum_{i=1}^{n} x_i y_i(a) \tag{3.2.1}$$

$$\sum_{i=1}^{n} x_i = 1.0 \tag{3.2.2}$$

Where x_i represents the relative weight factor for the ith attribute/criterion and $y_i(a)$ represents the utility outcome of a for the ith attribute/criterion. Also $V(a)$ is described as a partial value function that represents the performance of alternative a on the ith attribute/criterion. Thus $V(a)$ represents the scaled total score of alternative a. Once the total score of all the alternatives have been calculated, MAUT states that the alternative with the highest score is preferred.

3.2.1.2 Multiplicative Utility Theory (MUT)

MUT is similar to AUT, however, instead of addition in the model there is multiplication and is described by the following equation:

$$V(a) = \frac{\prod_{i=1}^{n}[Xx_i y(a) + 1] - 1}{X} \tag{3.2.3}$$

$$\sum_{i=1}^{n} x_i \neq 1.0 \tag{3.2.4}$$

Where x_i is the relative weight factor of the ith attribute/criterion and $y(a)$ is the utility outcome of a for the ith attribute/criterion. X is the scaling constant found iteratively using the following formula:

$$1 + X = \prod_{i=1}^{n}(1 + Xx_i) \tag{3.2.5}$$

To ensure that all attributes are independent, $-1 < K$ must be satisfied, implying utility independence.

According to Velasquez and Hester (2013) the major advantage of MAUT is that it takes uncertainty into account by incorporating the utility factor. However a disadvantage of this method is that for a high level of accuracy, it is extremely data intensive. Nevertheless, this method has been applied in economic, financial, water management, agricultural and energy management decisions as a result of its ability to account for uncertainty.

3.2.2 Analytic Hierarchy Process (AHP)

Saaty (2000) defines AHP as "...a framework of logic and problem-solving that spans the spectrum from instant awareness to fully integrated consciousness by organizing perceptions, feelings, judgements and memories into a hierarchy of forces that influence decision results". Triantaphyllou and Mann (1995) describe AHP as a process that uses a multi-level hierarchical structure of the objectives, criteria/attributes and alternatives of the decision under consideration. Thereby the decision can more easily be comprehended and subjectively evaluated. These subjective evaluations are then transformed into numerical values such that each of the criteria/attributes can be ranked on a numerical scale.

According to Bhushan and Rai (2004) there are six steps involved in the AHP, each of these are discussed briefly.

1. Step 1
   The decision under consideration is decomposed into a hierarchy of criteria/attributes, sub-criteria/attributes, goals and alternatives. It is important that every element is connected to another, if not directly, at least in an indirect manner. Figure 3.5 illustrates a generic hierarchical structure.

2. Step 2
   Subjective data is then collected from decision-makers or experts regarding the hierarchical structure through pairwise comparisons of the elements in a row compared to that of the elements in the row immediately above it.

3. Step 3
   The data collected in Step 2 is then organized into a square matrix. The matrix is constructed as follows:

   i) Diagonal entries are all equal to one.

   ii) Criteria/attributes in the ith row are superior to those in the jth column, if and only if the value of element (i, j) is larger than one; otherwise the element in the jth column is superior to that of the element in the ith row.

   iii) The i, j element in the matrix is the reciprocal of the j, i element.

4. Step 4
   Principal eigenvectors and the corresponding normalized column vectors are then calculated. These eigenvectors describe the relative importance of the criteria/attributes being compared. The normalized column vectors are referred to as the weights with respect to the criteria/attributes and ratings with respect to the alternatives.

5. Step 5
   It is then necessary to calculate the consistency of the order-n matrix by

calculating the Consistency Index (CI), where

$$\mathrm{CI} = (\lambda_{max} - n)/(n - 1) \tag{3.2.6}$$

Where λ_{max} is the maximum eigenvalue of the decision matrix. The CI is then compared to that of a Random Matrix (RI) such that the Consistency Ratio (CR) = CI/RI is less than 0.1.

6. Step 6
   The weights of the sub-criteria/attributes are then multiplied by the ratings of each alternative to obtain the local ratings. Thereafter, the local ratings are multiplied by the weights of each of the criteria/attributes and aggregated in order to obtain the global ratings.

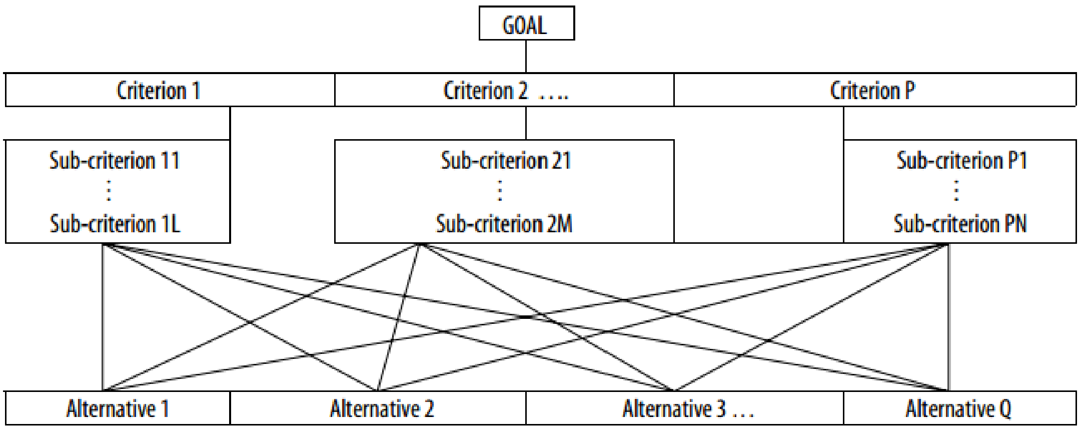


Figure 3.5: Generic hierarchical structure, Bhushan and Rai (2004)

According to Velasquez and Hester (2013) the major advantage of AHP is its ease of use whereby decision-makers and experts can easily compare relative weights of alternatives. Another advantage is its scalability, therefore it can easily adjust to accommodate the size of the decision making problem. Also, it is not as data intensive as MAUT.

However, the judgments made by experts and decision-makers may be subject to inconsistencies as the criteria are not raked in isolation, but rather relative to one another. One of the major disadvantages of AHP is its susceptibility to rank reversal caused by the addition or deletion of an alternative. Nevertheless, AHP has been applied in resource management, performance-type problems, public policy, planning and corporate policy and strategy.

3.2.3 Fuzzy Theory

Fuzzy set theory is described by Zimmermann (2010) as a framework that naturally deals with decision problems in which the source of imprecision is the absence of a defined set of criteria/attributes. Therefore, Balmat *et al.* (2011) state that fuzzy set theory provides a technique of solving decision problems that deal with imprecise and uncertain data. Furthermore, fuzzy set theory takes into account the possibility of insufficient information and the evolution of the available knowledge.

Moreover, Zimmermann (2010) argues that fuzzy set theory provides a rigid mathematical framework in which obscure conceptual phenomena can be accurately and rigorously studied. According to Ponce-Cruz and Ramírez-Figueroa (2010) the mathematical foundations of fuzzy set theory rest in classical set theory.

According to El-Wahed (2008) a fuzzy multi-criteria model can be expressed as follows:

$$Min_s Z \cong [z_1(x), z_2(x), ..., z_k(x)]^T \tag{3.2.7}$$

Where

$$S = \{x \in X | Ax \leq b, x \in R^n, x \geq 0\} \tag{3.2.8}$$

There are different approaches to solving the above equation, all of which depend on transforming the above equation from a fuzzy model to a crisp model by determining the appropriate membership function. Therefore, let X denote a reference universal set. Then a fuzzy subset A of X is defined by the following membership function:

$$\mu_A : X \rightarrow [0, 1] \tag{3.2.9}$$

The above membership function assigns each element $x \in X$ a real number in the specified [0,1] interval. Also, $\mu_A(x)$ represents the degree to which x belongs to A. From which a fuzzy set can be expressed as:

$$F = \sum_{i=1}^{n} \mu_A(x_i)/x_i \tag{3.2.10}$$

As mentioned before, the advantage of using fuzzy set theory is that it allows for the input of imprecise data. Velasquez and Hester (2013) also state that fuzzy set theory allows for a complex problem to be encompassed by only a few rules. However, apart from the advantages of fuzzy set theory, it is often a difficult method to develop and may require numerous simulations before it can be applied to a real world problem.

Nevertheless, because fuzzy set theory makes provision for insufficient information it has been applied and used in areas such as engineering, medical, environmental, management and economics.

3.2.4 Case-Based Reasoning (CBR)

Xu (1994) describes CBR as a process by which past experiences and cases can be retrieved from memory and adapted to guide the solving of a current, similar problem using an analogical reasoning process. Therefore, Xu (1994) states that "CBR systems base their intelligence and inference on known cases rather than on rules.“

According to Kolodner (1992) there are two types of CBR: problem solving CBR and interpretive CBR. Problem solving CBR is focused on the construction of solutions that are suitable to the new problem by modifying the solutions to a previous, similar problem. Whereas with interpretive CBR new problems are evaluated and justified on the basis of similarities or differences with that of previous solutions.

Aamodt and Plaza (1994) introduce the classic CBR model that can be described by the following four processes.

1. Retrieve
   During this process a similar case/problem is selected from a database of historical cases/problems that have been encountered and solved.

2. Reuse
   The reuse process entails the adaptation of the solutions to the cases/problems that have been identified in the previous stage to that of the current case/problem.

3. Revise
   The adapted solution that was developed in the reuse phase is then verified in the real world in order to possibly correct or improve it in the revise phase.

4. Retain
   Finally, during this stage the feedback from the revise phase is then used to update the current knowledge, particularly the database of historical cases.

Bergmann *et al.* (2009) state that similarity is an important concept in CBR as historical cases are selected based on their similarity to current cases.

Similarity is generality formalized as the following function.

$$sim : P \times P \rightarrow [0, 1] \tag{3.2.11}$$

In the above equation two problem descriptors from P are compared and produces an assessment of the similarity as a real value in the range $[0, 1]$ such that a high value represents a high similarity.

Also, for a problem p a particular case $c_1 = (p_1, s_1)$ is preferred over a case $c_2 = (p_2, s_2)$ if the $sim(p, p_1) > sim(p, p_2)$. This is true since the retrieval process in the CBR cycle lists c_1 before c_2.

Furthermore, the preference order as induced by the similarity function should be in line with the utility of the solution's applicability to the problem p during the reuse process in the CBR cycle. Therefore, case c_1 should be chosen over case c_2 if the utility of s_1 for solving problem p is higher than that of s_2.

Thereafter, the revise process is executed in which a correctness rating provides feedback to the applicability of the solution to this particular case. Finally, during the retain process the revised case is then added to the existing database for future problem solving.

According to Velasquez and Hester (2013) the major advantage of CBR is that it can improve over time, especially as more cases are added to the existing database. Also, as the solutions to problems are retrieved from an existing database, little effort is required in the acquisition of additional data.

A major disadvantage of CBR however is its sensitivity to inconsistency in the available data. Also, as mentioned before, an existing database of solutions to different problems is required and thus it is only applicable to industries where a substantial number of previous cases already exist.

Nevertheless, CBR is used in the comparison of engineering designs, medicine and insurance.

3.2.5 Data Envelopment Analysis (DEA)

According to Ray (2004), DEA can be described as a data-orientated, non-parametric procedure by which the efficiency of a Decision-Making Unit (DMU) can be measured. Thanassoulis *et al.* (2012) state that the non-parametric procedure mentioned before is based on a linear programming method that defines the DMU as the ratio of the sum of its weighted output levels to that of its weighted input levels.

The efficiency of a DMU is described by Cooper *et al.* (2011) as the evaluation of its ability to convert a system input to a system output. In organizational terms, efficiency can be defined as "the demand that the desired goals are achieved with the minimum use of the available resources.", (Martić *et al.*, 2009). In this case, the DEA will be used to measure the relative efficiencies of different alternatives to a multiple criteria decision and thereby determine the best suited to the problem.

It is therefore necessary to introduce the Charnes-Cooper-Rhodes (CCR) model that describes the "ratio-form" of DEA. The model is constructed as follows.

Assume there are n number of DMU's to be evaluated and that each DMU consumes changing amounts of m inputs to produce s amounts of different outputs.

More specifically, DMU_j consumes x_{ij} of input i that results in an amount y_{rj} of output r. Therefore, for a selected entity k

$$Max\ \ h_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \tag{3.2.12}$$

Such that $0 \leq h_k \leq 1$, subjected to the following constraints

$$\frac{\sum_{r=1}^{s} u_r y_i}{\sum_{i=1}^{m} v_i x_j} \leq 1 \quad \text{for } j = 1, 2, ..., n \tag{3.2.13}$$

$$u_r \geq \varepsilon \quad r = 1, 2, ..., s \tag{3.2.14}$$

$$v_i \geq \varepsilon \quad i = 1, 2, ..., i \tag{3.2.15}$$

Where
v_i is the relative weight of input i.
m is the number of inputs.
u_r is the relative weight of output r.
s is the number of outputs.
h_k is the relative efficiency of DMU_K.
n is the total number of entities.
ε is a non-Archimedean element smaller than any positive real number.

Therefore, the most efficient alternative will have a $h_k = 1$ while all the other alternatives will have a $h_k < 1$.

Velasquez and Hester (2013) state that a major advantage of DEA is its ability to accommodate and handle multiple inputs and outputs. Also, adopting the CCR model, efficiency can be quantified and analyzed, this may also uncover relationships that were previously hidden by other MCDM.

It must however be noted that the major disadvantage of DEA is its sensitivity to the input and output data. By using DEA it is assumed that all input and output data are exactly known, which in reality is not always the case.

Nevertheless, DEA has been and is still being used in areas such as economics, utilities, safety, medical, business problems and retail.

Other MCDM methods such as goal programming, Simple Additive Weighting (SAW), ELimination and Choice Translating REality (ELECTRE) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are also being used in industry, however they are not common, well researched and applicable to the physical asset repair/replace decision as MAUT, AHP, ANP, Fuzzy set theory, CBR and DEA. Therefore, the MCDM method to be used for this particular thesis is to be chosen from the five MCDM methods that were discussed in this section.

3.3 Chapter Summary

In conclusion, Chapter 3 outlines the strategic decision-making landscape. Attributes specific t strategic decisions are discussed and compared to that of physical asset repair/replace decisions. Thereafter, based on the comparison, physical asset repair/replace decisions are classified as strategic decisions.

Furthermore, the factors that influence the strategic decision-making process are discussed and divided into the following four main categories: decision-specific characteristics, internal company characteristics, decision-making team characteristics and external company characteristics.

Within the internal company characteristics category the shortcomings of purely financial ratios are highlighted and the application of capital budgeting techniques as well as value based performance metrics are discussed. Moreover, the IRR and EVA is discussed in detail to replace financial ratios as an indicator of internal company performance.

The external company characteristic category includes a detailed discussion of the factors that influence the environment in which the organization operates. Emphasis is placed on the effect of competition as well as social and environmental sustainability on the decision-making process.

Finally, the multi-criteria nature of physical asset repair/replace decisions are discussed. Five different multi-criteria decision-making techniques that are applicable to the physical asset repair/replace decision are considered. Each of these methods are explained in detail, as well as their particular application in industry.

This chapter therefore contributes to achieving the first and third objectives. Consequently, the following sub-objectives within the relevant main objectives were achieved, refer to Section 1.3:

1. Establish the fundamental concepts and principles within the relevant fields of study.

    a) Review the key concepts in strategic decision-making

b) Establish a relationship between strategic decision-making and physical asset repair/replace decisions

c) Highlight the multi-attribute nature of physical asset repair/replace decisions

2. Master the field of strategic decision-making.

   a) Determine strategic decision-making characteristics

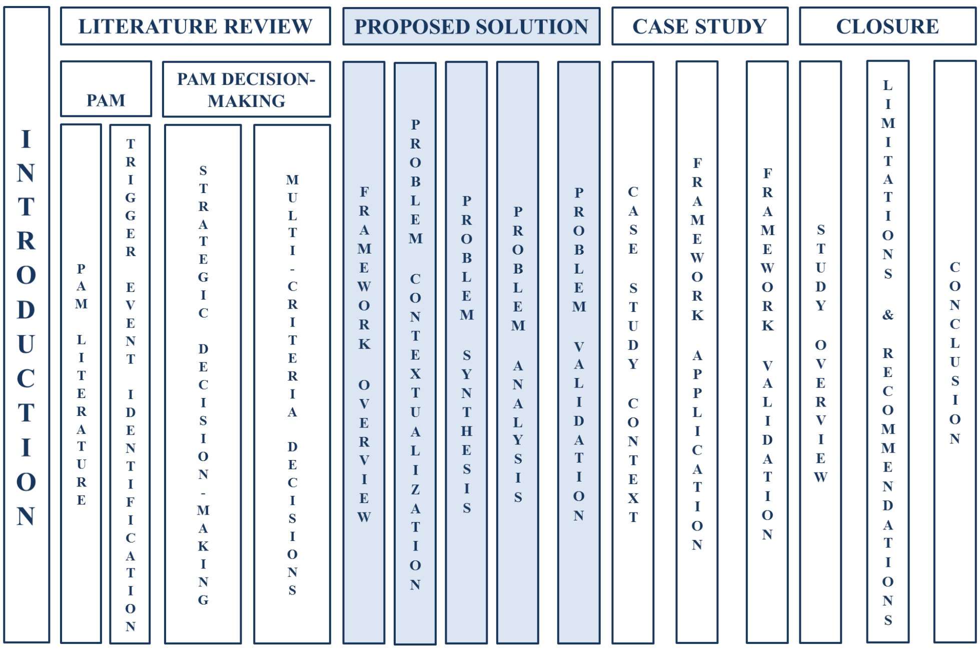
   b) Identify the core concepts that form part of the strategic decision-making characteristics

The following chapter, Chapter 4, uses the literature discussed in Chapters 2 and 3 as a foundation to propose a solution to the problem statement and to develop a framework that can be implemented to achieve said solution.

Chapter 4

Proposed Solution

The literature analysis for this study consists of Chapter 2, exploring the PAM landscape and physical asset life cycle, and Chapter 3, discussing the strategic decision-making landscape and the multi-criteria nature of physical asset repair/replace decisions. This chapter employs the literature discussed in the previous two chapters as a foundation to propose a strategic decision-making framework for the physical asset repair/replace decision in physical asset intensive industries. Firstly, a general overview of the development of the framework is provided, thereafter, the respective components that form part of the framework are discussed in detail with accompanying examples.



4.1 Framework Overview

It is clear from the literature review that the physical asset repair/replace decisions considered in this study not only involve significant investment of capital, but also high levels of risk and uncertainty. Asset managers within organizations face multiple decisions regarding the physical asset life cycle throughout their daily operation. These decisions may have a large impact on the organization as a whole and are often based on the past experience and intuition of the decision-maker. In many organizations the physical asset repair/replace decision is based on an estimated economic life, a purely financial metric. Whereas other factors such as the value addition of the physical asset, effect on and from competitive rivals, as well as the environmental and social sustainability of the physical asset are completely neglected. Thus, asset managers are in need of a structured guideline that can aid them in this decision-making process.

The main objective of this study is to develop a strategic decision-making framework to aid decision-makers with the physical asset repair/replace decision. It is intended to assist asset managers to decide if the replacement or the continued repair of a physical asset is the best option for the organization, at that particular time.

The thorough and broad literature base developed in Chapters 2 and 3 serves as the basis for this framework. Section 2.1.3, in particular, elaborates on the various methods currently used in physical asset repair/replace decision-making. The economic life of a physical asset is the best known and widely used metric to determine the age at which a physical asset should be replaced, such that the operation and maintenance costs are at a minimum. Past experience with similar physical assets as well as the decision-maker's intuition are the other factors that determine the physical asset repair/replace decision. Also, Section 2.2 summarizes the various 'trigger events' that may precede the physical asset repair/replace decision. All of the 'trigger events' discussed in Section 2.2, apart from physical asset failure, provide a good starting point for the development of the framework.

This section is intended to provide the reader with a detailed overview of the development of the framework. The research objectives stated in Section 1.3 are repeated below, followed by a detailed discussion of the framework development, as well as the framework properties.

4.1.1 Research Objectives Repeated

The research objectives specific to this study are introduced in Section 1.3. This chapter, however, is particularly concerned with the fourth research objective:

Develop a strategic decision-making framework for the management of physical asset repair/replace decisions

a) Determine criteria for selecting a relevant decision-making method

b) Determine relevant factors that will form part of the decision-making method

c) Consolidate the factors and decision-making method into a structured, strategic decision-making framework

By incorporating the information obtained from the thorough literature review, the following section details the development of the framework.

4.1.2 Framework Development

The proposed solution to the research problem is a strategic decision-making framework for the management of physical asset repair/replace decisions. Literature from PAM, strategic decision-making as well as multiple criteria decision-making influence the development of the framework through an iterative process. This study is specifically focused on physical asset repair/replace decisions because of the potential effect that these decisions may have on the organization as a whole. Not only do these decisions affect the operations within an organization that are attributed to the physical asset under consideration, but also the overall organizational performance and profitability.

Table 4.1 illustrates the steps involved in the overall development of the proposed strategic decision-making framework. From Table 4.1 there are six steps involved in the overall development of the framework, each grouped under its own work cluster, namely; Problem Research, Problem Conceptualization, Problem Contextualization, Problem Synthesis, Problem Analysis and Framework Validation. As stated in Table 4.1, the Problem Research and Problem Conceptualization steps are covered in Chapters 2 and 3. Thus, the user of the framework starts the framework development process from the Problem Contextualization step onwards. Refer to Figure 4.1 for a detailed process flow diagram of the framework development from the Problem Contextualization step to the eventual Framework Validation step.

The objective of the development of the strategic physical asset repair/replace decision-making framework is to provide a structured decision-making process as well as enable a holistic solution to the decision.

The Problem Contextualization step is one of the most important steps in the development of the framework as it involves the identification of the MCDM process to be followed, as well as the main criteria that are included in the decision-making process. As illustrated in Figure 4.1, each of the six MCDM techniques

Figure 4.1: Strategic physical asset repair/replace decision-making framework development process

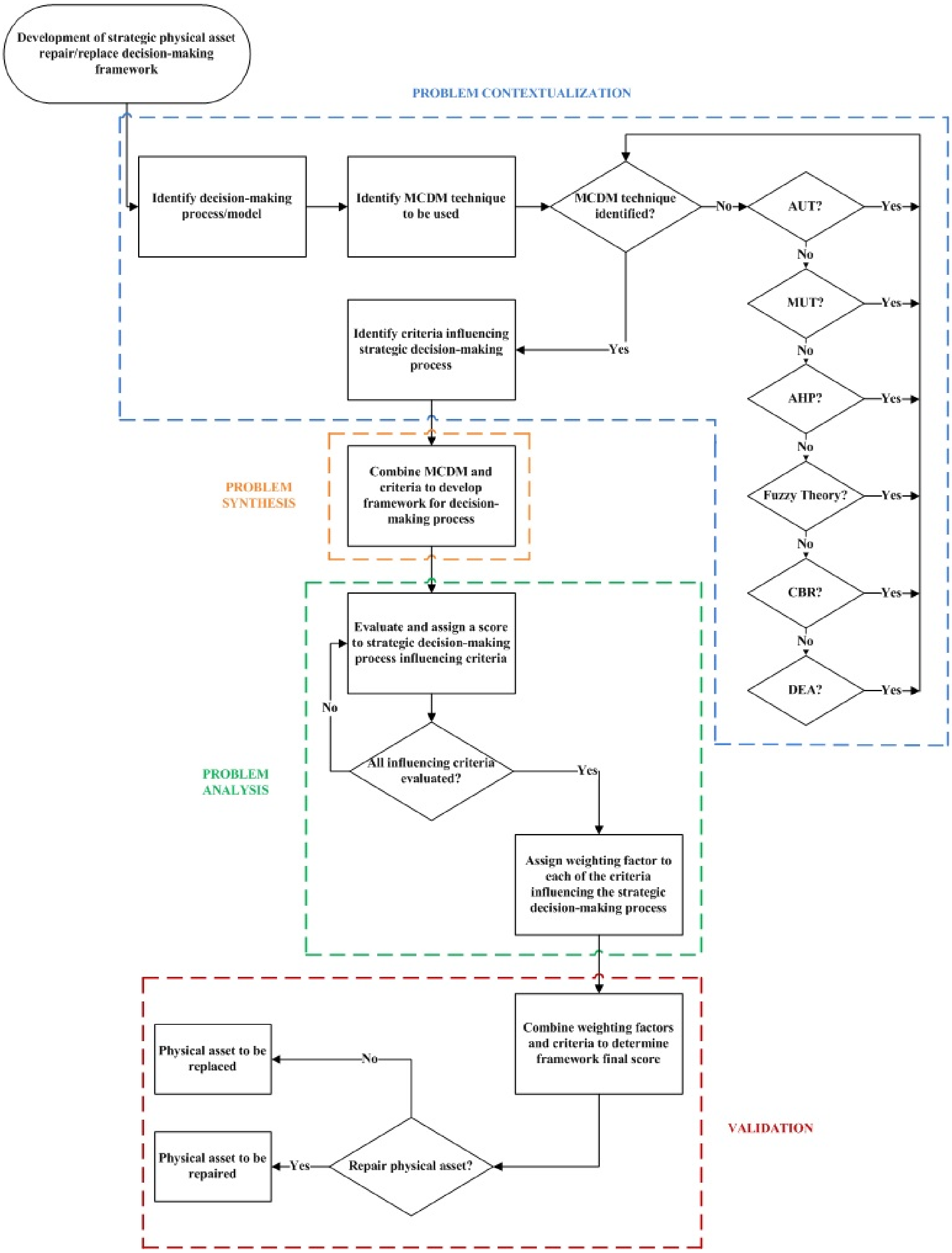


Table 4.1: Development of proposed strategic physical asset repair/replace decision-making framework

Step	Work Cluster	Description	Reference
1	Problem Research	Examine the literature in the relevant fields of study	Chapters 2 and 3
2	Problem Conceptualization	Determine the main focus areas within the relevant fields of study	Chapters 2 and 3
3	Problem Contextualization	Identify the strategic physical asset repair/replace decision-making governing process/model	Section 4.2
4	Problem Synthesis	Develop the strategic physical asset repair/replace decision-making framework	Section 4.3
5	Problem Analysis	Assess criteria influencing the strategic physical asset repair/replace decision-making process	Section 4.4
6	Framework Validation	Evaluate strategic physical asset repair/replace decision-making framework	Chapter 5

discussed in Section 3.2 are evaluated for possible application to the strategic physical asset repair/replace decision. Thereafter, the various criteria that influence the strategic physical asset repair/replace decision are identified from the information discussed in Section 3.1.

A distinctive feature of the Problem Contextualization step is the integration between PAM and strategic decision-making. Physical asset repair/replace decisions form part of a stage within the life cycle of a physical asset, which in turn falls within the PAM domain, refer to Section 2.1. Whereas the criteria that influence the physical asset repair/replace decision are determined from the strategic decision-making characteristics discussed in Section 3.1. These characteristics are those that are specific to decisions of significant capital investment.

Following the Problem Contextualization step is the Problem Synthesis step, refer to Figure 4.1. The main objective of this step is to combine and further integrate the identified MCDM technique in the Problem Contextualization step with the relevant influencing criteria in order to develop a framework for the strategic physical asset repair/replace decision-making process.

In the Problem Analysis step, each of the identified, relevant criteria are evaluated and assigned a score corresponding to the performance of that particular criterion. Thereafter, as illustrated in Figure 4.1 each of the criteria are assigned a weighting factor according to the importance/relevance to the particular physical asset repair/replace decision under consideration. This allows for some flexibility as these factors will have different weights within different organizations as well as with different decisions within a specific organization.

The steps in Figure 4.1 follow a logical sequence and are intended to guide the user through the strategic physical asset repair/replace decision-making framework development process. Furthermore, the methodology is intended for the evaluation of the repair/replace decision of a single physical asset of significant investment. Where a physical asset can consist of multiple constituent parts, or it may refer to some constituent part of a piece of equipment that is also of a significant investment nature.

Each of the steps illustrated in Figure 4.1 is discussed in detail in the following sections. The discussion follows the same sequence as that of the proposed framework in Figure 4.1. In each of the steps the inputs, outputs, considerations, assumptions and objectives are discussed, also, a relevant example is included to provide the user with a clear understanding.

The identification of the relevant MCDM technique and the evaluation of the criteria that influence the strategic physical asset repair/replace decision is discussed first in Section 4.2. Thereafter, the identified MCDM technique as well as the decision-making process and relevant criteria is integrated to form the strategic decision-making framework in Section 4.3. The identified criteria are then assessed and their weighting factors determined in Section 4.4. Finally, the validation of the strategic decision-making framework is discussed in detail in Section 4.5.

4.1.3 Proposed Framework Features

From Section 1.3 the following features are those required by the proposed framework:

- Practical: Application of the framework in practice should be possible.
- Flexible: Applications in various physical asset intensive industries of different types should be possible.
- Holistic: The framework should serve as a holistic approach to the research problem, integrating multiple criteria to the eventual solution.
- Structured: Structured, logical steps should guide the decision-maker through the decision-making process.

The physical asset repair/replace decision is a common phenomenon within physical asset intensive industries, therefore the proposed framework should provide asset managers with a structured and holistic approach to the decision. The framework should also be practical and flexible enough that it can be applied to, and implement in, different physical assets and different industries, respectively.

These features will increase the probability of the implementation of the framework in practice.

Furthermore, other features that are unique to the proposed framework include the consideration of multiple criteria, other than financial factors, in the physical asset repair/replace decision. It accommodates the physical asset repair/replace decision in organizations where financial performance may not be the main objective, such as governmental organizations.

Moreover, the step-wise, structured framework allows for the consideration and comparison of multiple possible physical asset replacement options. Apart from steering the decision-maker in the direction of the most advantageous decision, the evaluation of the criteria within the framework can also be used as a target against which the performance of the current physical asset or possible replacements can be measured.

Lastly, the proposed framework is flexible in the manner that the importance of the various criteria that form part of the framework are determined by the decision-maker, and will therefore be specific to the organization as well as the particular physical asset in consideration.

The following sections will discuss the remaining steps involved in the development of the proposed framework. It must be noted that because of the importance of the following sections regarding the discussion of the development of the strategic physical asset repair/replace decision-making framework, these sections will be elevated in the Table of Contents. This is not to confuse the user, but to rather highlight the importance of the execution of these steps.

4.2 Problem Contextualization

Both the Problem Research and Problem Conceptualization steps illustrated in Table 4.1 have been covered in detail in Chapter 2 and 3. Thus, the detailed discussion of the proposed framework commences with the Problem contextualization step, refer to Figure 4.1. In this step, the decision-making process and model is identified through the evaluation of the MCDM technique that is most applicable to the problem, as well as the identification of the relevant criteria that forms part of the framework.

4.2.1 Identification of MCDM Technique

The first step in the contextualization of the problem is the identification of the MCDM technique that would be most suitable to the physical asset repair/replace decision.

Objective: Determine MCDM technique most suitable to research problem.

Output: MCDM technique that serves as basis of framework development.

It is therefore necessary to restate and summarize the characteristics and factors that influence the strategic physical asset repair/replace decision, refer to Section 3.1 and Section 2.1.5.

1. High levels of uncertainty
   The physical asset repair/replace decision is essentially based on the prediction of the future behaviour of the currently employed physical asset as well as the potential behaviour of a new physical asset to be acquired. These predictions are then compared and the best option is chosen. Thus, the decision involves a significant amount of uncertainty.

2. Significant capital investment
   As mentioned before, this study is only concerned with physical asset repair/replace decisions that involves significant capital investment.

3. Complex
   Current decision-making techniques applied to the physical asset repair/replace decision are mostly designed to focus on one primary objective, and neglect other factors that may have a effect on the decision. Physical asset repair/replace decisions are not one dimensional and are composed of multiple attributes that influence the outcome of the decision.

4. High level of risk
   The significant capital investment nature of the physical asset repair/replace decisions dealt with in this study can have a significant effect on the long term performance of the organization. Consequently, these decisions are classified as being inherently risky.

5. Quantitative data
   Continuously repairing or replacing a physical asset has significant financial and operational implications on the organization, the decision therefore involves a large amount of quantitative data that can be obtained from financial statements and records.

6. Qualitative data
   Apart from the financial implications of the physical asset repair/replace decision, there are qualitative factors that effect the outcome of the decision. Examples of these factors are sustainability and the effect of the decision on competition.

It is necessary to evaluate the various MCDM techniques discussed in Section 3.2 to identify the MCDM technique that is most suitable to the strategic physical asset repair/replace decision and that incorporates most of the above mentioned characteristics and factors.

In order to incorporate the above mentioned characteristics and factors, it is suggested that the MCDM techniques discussed in Section 3.2 be evaluated against the above mentioned characteristics. In this manner the characteristics of the various MCDM techniques can be compared to that of the strategic physical asset repair/replace decision and the most favourable technique can be identified for application in the proposed framework.

To better explain the evaluation suggested above, refer to the following example. Suppose Company X is considering the repair/replace decision of one of their physical assets that is of a significant investment nature. This decision is triggered by the reduced capacity of the physical asset as a result of deterioration and age. Company X requires a specific production schedule that is based on the yearly budget for the production of its products. However, due to the reduced capacity of the physical asset under consideration, Company X is falling behind on its production. Thus, from Section 2.2 the events that triggered the onset of the physical asset repair/replace decision is the reduced capacity as well as deterioration and age.

In order to apply the framework suggested in the study and according to the process illustrated in Figure 4.1, the asset manager is to identify a MCDM technique that is most applicable to the decision under consideration. The physical asset repair/replace decision that the asset manager is considering exhibits all of the characteristics discussed above. Thus, for the asset manager to identify the most suitable MCDM technique he/she must analyze each of the MCDM techniques discussed in Section 3.2 and determine which technique can incorporate the most of these characteristics.

For instance, the AUT, MUT and Fuzzy Theory techniques are able to incorporate data that exhibit high levels of uncertainty. AUT, MUT, CBR and DEA techniques are able to incorporate data that have high levels of risk, whereas Fuzzy Theory and AHP are unable to incorporate risk. Also, AUT, MUT, AHP, Fuzzy Theory and CBR are able to incorporate qualitative data, but DEA can not. In this manner the decision-maker must evaluate the applicability of each of the MCDM techniques to the characteristics of the strategic physical asset repair/replace decision and determine the technique that is most applicable.

In Table 4.2 below the various MCDM techniques discussed in Section 3.2 are analyzed against the characteristics of the strategic physical asset repair/replace decision.

From the data in Table 4.2, both the AUT and the MUT techniques incorporate

Table 4.2: MCDM Technique Analysis

	REPAIR/REPLACE DECISION CHARACTERISTICS					
MCDM TECHNIQUE	UNCERTAINTY	COMPLEXITY	RISK	QUALITATIVE DATA	QUANTITATIVE DATA	EASE OF APPLICATION
AUT	X	X	X	X	X	X
MUT	X	X	X	X	X	X
AHP		X		X	X	X
Fuzzy theory	X	X		X	X	
CBR		X	X	X	X	
DEA		X	X		X	

the various characteristics of the strategic physical asset repair/replace decision. The AHP technique contains most of the before mentioned characteristics, however from Section 3.2.2 its dependability on the judgement of the decision-maker as well as its inability to include uncertainty makes it unfit for this particular application. Fuzzy theory also includes most of the characteristics, however, as stated in Section 3.2.3, its inability to include risk and the data intensive nature of the technique inhibits its use for the application of this framework. The DEA technique is unable to include qualitative data as well as uncertainty in its application. Also, from Section 3.2.4 and 3.2.5, CBR is highly specific to a particular scenario and DEA is extremely data intensive and sensitive to the quality of the input data. Therefore, both the CBR and DEA techniques are not applicable to this particular framework.

As mentioned before, both the AUT and the MUT technique include all of the evaluated characteristics of the strategic physical asset repair/replace decision. From Section 3.2.1 both of these methods are described as a Multi-Attribute Utility Theory (MAUT). These methods are specifically developed to include qualitative and quantitative data, as well as risk and uncertainty. In these techniques the consequences of the decision under consideration are assigned a utility value and the best coarse if action is determined by calculating the best overall utility value. These properties make these techniques ideal for this particular application. The application of AUT and MUT are similar, however, in the case of AUT the model is based on a simple addition equation, whereas the MUT model is based on a multiplication equation and the determination of a scaling constant.

One of the objectives of this framework, as discussed in Section 1.3, is that it should be practical and application in industry should be possible. Thus, the inclusion of a MCDM technique based on some complicated mathematical calculation is out of the question. Therefore, the AUT technique is the most suitable MCDM technique for the strategic physical asset repair/replace decision and will thus be used in the proposed framework.

The following section entails the discussion and identification of the main criteria that influence the strategic physical asset repair/replace decision within physical asset intensive industries.

4.2.2 Identification of Influencing Criteria

There are numerous criteria that influence the strategic physical asset repair/replace decision. However, as mentioned before, in most industries the outcome of the physical asset repair/replace decision is based on a single influencing criterion namely, financial performance. There are however numerous other criteria that influence these decisions that are not purely based on financial gain. It is therefore necessary to identify the main criteria that influence these decisions such that these criteria can be incorporated into the eventual outcome of the strategic physical asset repair/replace decision.

Objective: Identify the main criteria influencing strategic physical asset repair/replace decision.

Output: Multiple criteria that influence the strategic physical asset repair/replace decision for integration in the proposed framework.

As mentioned in the text above, this section details the identification of the main criteria that influence both a strategic decision as well as the physical asset repair/replace decision, hence referred to as a strategic physical asset repair/replace decision. The identification of these main criteria will enable the integration thereof into the proposed framework.

From Section 3.1 strategic decisions have four distinct characteristics, namely:

1. Decision-specific characteristics
2. Internal company characteristics
3. Decision-making team's characteristics
4. External environment characteristics

From the discussion in Section 3.1.1, limited understanding and literature is available on this topic and thus these characteristics are not included in this study. Also, the decision-making team's characteristics discussed in Section 3.1.3 are difficult to represent as it consists of the individual's experience, risk propensity and cognitive diversity. Each of the before mentioned factors can change with every decision and it is therefore suggested that these characteristics also be disregarded in this study.

The internal company characteristics represent those factors that determine the organization's performance. It is also stated in Section 3.1.2 that there exists a positive relationship between an organization's performance and the comprehensiveness and effectiveness of decision-making. As stated in Section 1.1, the performance of an organization is not purely based on financial performance, but also on the creation of shareholder wealth. A number of common financial ratios used throughout industry are discussed in Section 3.1.2, however literature regarding these ratios fail to concur on the importance as well as benchmarks of these financial ratios. It is therefore suggested to rather use discounted cash flow techniques that have a close correlation to the creation of shareholder value and hence, the organization's performance.

As mentioned throughout this study, the physical asset repair/replace decision is one of significant investment of an organization's capital. In other words, the potential investment of a large amount of capital to either repair or replace a physical asset can be represented as two potential projects demanding significant investment. It is therefore necessary to determine which of the two projects would be most advantageous to the organization, both financially as well as for possible future growth. Two different capital budgeting techniques are discussed in Section 3.1.2, namely the NPV and the IRR. The NPV is used to determine the current monetary value of a potential project that stretches out into the future, whereas the IRR is used to calculate the rate of growth that a possible project is expected to generate.

From Section 3.1.2.1 and 3.1.2.2, one major difference between the NPV and the IRR is that the NPV is represented by a monetary value and the IRR by a percentage value. Also, the calculation of the NPV is complex and involves multiple assumptions to accurately predict the time changing value of money, whereas the IRR is easier to calculate and analyze. One of the objectives of the proposed framework, as mentioned in Section 4.2.1, is that the framework should be able to be adopted in practice. Therefore, the representation of the current monetary value of a potential project might not add as much value as a percentage value representing the potential growth that a project is expected to create. Such a value is easy to interpret and analyze, as well as compare against that of other potential projects.

Thus, the first criteria that will form part of the proposed framework is the rate of return of the potential investment. The evaluation of this criteria includes the calculation of the IRR of the decision under consideration. For a detailed discussion as well as a worked example of the IRR calculation, refer to Section 4.4.1.

Criteria 1: Physical asset repair/replace decision rate of return

The main objective of any organization is to first and foremost make a profit, however for continual profit creation the organization needs to create shareholder wealth. Shareholders are the 'owners' of the organization and therefore require sufficient return on their investment into the organization. In order to maximize the organization's shareholder wealth, the value of the organization has to increase. It is therefore necessary to incorporate value-based performance metrics into the physical asset repair/replace decision to determine the organization's operating performance from a capital markets perspective.

Section 3.1.2.2 describes in detail the pillars of value creation, as well as the importance of value creation within an organization. As discussed in Section 3.1.2.2, the EVA is a value-based performance measure used in the valuation of capital intensive projects by measuring the value created from capital invested into a potential project. As mentioned before, the physical asset repair/replace decision can be interpreted as two different capital intensive projects. By determining the value created by each of the two projects, the project that is most advantageous, and that will create the most shareholder value can be identified.

Thus, the second criteria that forms part of the proposed framework is the value created by the potential investment, and includes the calculation of the EVA of the decision under consideration. For a detailed discussion as well as a worked example of the EVA calculation, refer to Section 4.4.2.

Criteria 2: Value created by physical asset repair/replace decision

From Section 3.1.4, external company characteristics include potential opportunities, constraints, possible threats and all other characteristics of the environment in which the organization operates. These factors have a significant effect on the outcome of the physical asset repair/replace decision.

One of these factors discussed in Section 3.1.4 is the opportunities and threats present in the environment that the organization operates in. Especially the competition that the organization experiences from other similar organizations in the same industry. As mentioned in Section 3.1.4.1, competitive advantage leads to sustainable and superior financial performance and organizational success. Therefore, the outcome of the physical asset repair/replace decision should be of such a nature that it improves the organization's competitive advantage above that of rival organizations within the industry in which the organization operates.

It is thus necessary to analyze the effect of the physical asset repair/replace decision on the organization's rival companies and to then include this in the proposed framework. Section 3.1.4.1 details the analysis of competition through the use of the FFF and the respective key drivers. In order to analyze the effect of the physical asset repair/replace decision on rival organizations, it is necessary to analyze the effect on the following 5 competitive forces.

1. Competitive rivalry within the industry
2. Threat of new entrants

3. Power of suppliers
4. Power of buyers
5. Threat of substitutes

In Section 3.1.4.1 it is also stated that by identifying the effect of the physical asset repair/replace decision on the above mentioned competitive forces, the industry profit potential as well as the attractiveness of operating in that specific industry is also identified. Thereby the organization can evaluate the decision not only in terms of the effect on the industry rivals, but also on possible future opportunities in that specific industry.

Thus, the third criteria that forms part of the framework is the analysis of the effect of the physical asset repair/replace decision on the five competitive forces suggested by Porter. A detailed discussion as well as a worked example can be found in Section 4.4.3.

Criteria 3: Effect of physical asset repair/replace decision on five competitive forces

In Section 3.1.4.2 it is strongly suggested that sustainability be included in any decision-making framework, especially those that concern a decision of significant investment. Literature suggests that the incorporation of sustainability in such frameworks, as well as overall business practices, encourage good business practices which in turn encourages potential investment. It is also suggested in Section 3.1.4.2 that the incorporation of sustainability induces innovative solutions to decisions which then directly results in added competitive advantage.

As a result of the increased pressure on organizations to be transparent and accountable in their business activities, shareholders are shifting their focus from a purely financial point of view and are becoming increasingly more interested in the organizational activities. Section 3.1.4.2 introduces the concept of the TBL whereby organizations are advised to not only focus on the financial implications of the physical asset repair/replace decision, but to also incorporate the effect that the decision might have on the social and environmental aspects. Thus implying that the organization's responsibilities are broader than only the economic aspects of producing goods and services.

It is therefore suggested that both the effect of the physical asset repair/replace decision on social and environmental sustainability be incorporated into the proposed framework. Thus, the fourth and fifth criteria incorporated into the proposed framework is the effect of the physical asset repair/replace decision on social sustainability and environmental sustainability, respectively. For a detailed discussion, as well as a worked example of this, refer to Sections 4.4.4 and 4.4.5.

Criteria 4: Effect of physical asset repair/replace decision on social sustainability.

Criteria 5: Effect of physical asset repair/replace decision on environmental sustainability.

Each of the above mentioned criteria is determined from the characteristics of strategic physical asset repair/replace decisions in Section 3.1. In many instances throughout this study it is suggested that the physical asset repair/replace decision should not be purely based on the financial implications thereof, but should also include other, non-financial factors that are also influenced by this decision. The above determined criteria therefore includes the potential growth of the investment decision, the potential value that the investment decision can add to the organization, the effect of the investment decision on the organizational rivals and competitive advantage, as well as the impact of the investment decision on the social and environmental sustainability.

The following section details the process by which the MCDM technique as well as the relevant influencing criteria determined in this section are combined and integrated into a single strategic decision-making framework for the physical asset repair/replace decision.

4.3 Problem Synthesis

Following the Problem Contextualization step discussed in the previous section is the Problem Synthesis step. In this step the MCDM technique determined in Section 4.2.1 and the relevant influencing criteria determined in Section 4.2.2 are combined and integrated to develop the proposed strategic physical asset repair/replace decision-making framework as well as the decision-making process to be followed.

Objective: Develop a decision-making process that can be incorporated into the physical asset repair/replace decision framework.

Outcome: A structured decision-making process that can be followed during the implementation of the physical asset repair/replace decision framework.

From Section 4.1.3 the proposed framework should be structured and include logical steps that guide the decision-maker through the decision-making process.

It should also be holistic, integrating the various influencing criteria into one, practical framework that is flexible enough to be applied in any physical asset intensive industry. It is therefore necessary to develop a structured process with logical steps that guides the decision-maker in the application of the proposed strategic physical asset repair/replace decision-making framework.

The initial step in the development of the proposed framework is the evaluation of the relevant MCDM techniques, as discussed in Section 4.2.1. In this study, the AUT technique is chosen as the most applicable MCDM technique to the strategic physical asset repair/replace decision. Thus, the decision-making process followed by the decision-maker in this study is based on the AUT technique.

In Section 4.2.2 criteria are identified that influence the strategic physical asset repair/replace decision. From Figure 4.1, following the identification of the relevant MCDM technique, each of these criteria are evaluated and assigned a score corresponding to their performance. Thereafter, each criterion is assigned a weighting factor corresponding to their relative importance to the decision under consideration. Finally, the criteria and their relevant scores and weighting factors are combined and added together to calculate a final score for the decision under consideration. This process is followed for both the physical asset repair option as well as for the physical asset replace option. The final score for the repair and the replace options are then compared to determine the most advantageous decision for the organization based on the data collected.

The process described above is illustrated in more detail in Figure 4.2. The rectangular blocks in the process diagram represent actions to be taken and the diamond shaped blocks represent decisions that have to be made within the process.

As mentioned before, the initial step involves the evaluation of the relevant MCDM techniques from which a single, applicable technique is chosen. From the process diagram in Figure 4.2, this action step is followed by a decision block whereby the user is required to take one of two possible paths.

The first path includes determining the relevant influencing criteria that forms part of the framework, these are discussed and identified in Section 4.2.2. Thereafter, these criteria are evaluated individually, refer to Section 4.4 for a detailed discussion. Each of these criteria are then assigned a score that corresponds to their performance in that particular criterion. Thereafter, each criterion is assigned a weighting factor corresponding to their importance to the decision under consideration, also see Section 4.4.6. Once each of the criteria have been evaluated and their respective scores and weighting factors have been determined, the user is then again posed with a decision block. This decision block is merely a check to determine if all the influencing criteria, relevant scores and weighting factors have been determined before the final framework score can be calculated.

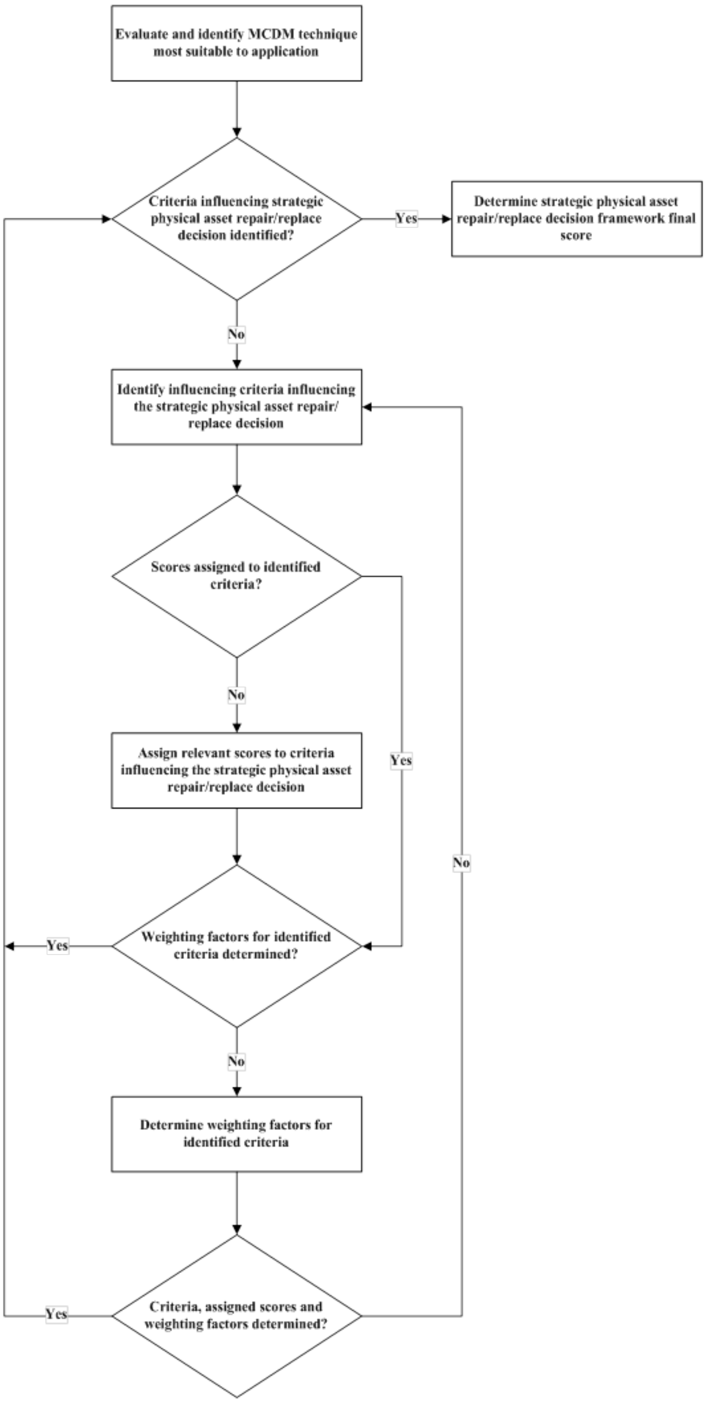


Figure 4.2: Strategic physical asset repair/replace decision-making process adopted in the proposed framework

The second path involves the calculation of the strategic physical asset repair/replace decision-making framework final score. This path can only be taken if the influencing criteria, relevant scores and respective weighting factors have been determined for all the criteria. Thus, the second path will follow the completion of the first path discussed above. The calculation of the strategic physical asset repair/replace decision-making framework final score involves the integration of the influencing criteria with the relevant scores and respective weighting factors into the chosen MCDM technique. This score is calculated for both the physical asset repair decision, as well as for the replace decision.

The strategic decision-making process described above does not go beyond the calculation of the decision-making framework final score. If the decision-maker is to follow the process illustrated in Figure 4.2 for both the physical asset repair decision, as well as for the physical asset replace decision, a set of two scores is available for comparison. As mentioned before, this framework is merely to serve as a guide for the strategic physical asset repair/replace decision and thus, the outcome of the decision framework final score is merely an indication of the performance of either the repair or replace option in the respective criteria that are included in the proposed framework. Thus, the eventual outcome of the physical asset repair/replace decision is still dependent on the decision-maker. The two scores determined can therefore be compared and the most advantageous option identified, however the decision-maker is still to use his/her discretion to make the final decision.

A decision-making framework is a structure that serves as a guide to aid the decision-maker in selecting the best outcome to the decision under consideration. Thus, the decision-making process discussed above forms an integral part of the proposed framework for the strategic physical asset repair/replace decision. It is therefore necessary to evaluate the various influencing criteria identified in Section 4.2.2 as well as their relative importance to the strategic physical asset repair/replace decision.

The following section details the evaluation of the influencing criteria and their respective weighting factors to be included in the proposed strategic physical asset repair/replace decision-making framework. For each criterion, the objective and outcome of the evaluation is stated, also a relevant worked example is included.

4.4 Problem Analysis

Following the Problem Synthesis step discussed above, is the Problem Analysis step, refer to Figure 4.1. The Problem Analysis step entails the analysis and evaluation of the influencing criteria identified in Section 4.2.2 as well as determining the weighting factors corresponding to each of these identified criteria. This evaluation of the relevant influencing criteria as well as the identification of their weighting factors is illustrated in Figure 4.1 and discussed in Section 4.3.

Objective: Evaluate and analyze each of the identified criteria that influence the physical asset repair/replace decision and assign a weighting factor to each.

Outcome: Structured methods by which the influencing criteria can be evaluated and analyzed, as well as proposed methods for assigning weighting factors to each of these factors.

It is therefore necessary to restate the criteria that were identified as a result of their influence on the strategic physical asset repair/replace decision, refer to Section 4.2.2.

Criteria 1: Physical asset repair/replace decision rate of return
Criteria 2: Value created by physical asset repair/replace decision
Criteria 3: Effect of physical asset repair/replace decision on five competitive forces
Criteria 4: Effect of physical asset repair/replace decision on social sustainability
Criteria 5: Effect of physical asset repair/replace decision on environmental sustainability

The above mentioned criteria are evaluated in detail in the following sections. In each section the objective and outcome is stated, followed by a detailed discussion of the relevant criteria and the calculations involved in the evaluation. Furthermore, as stated in Section 4.3 and illustrated in Figure 4.2, each evaluated criterion is assigned a score that represents the performance of either the repair or the replace decision in that respective criterion. It is thus suggested that the decision-maker make use of a five-point scoring system where, depending on the performance of either the repair or the replace option, the evaluated criteria is assigned a score between 0 and 5, refer to Table 4.3. Ideally the outcome of the criterion evaluation is compared to some baseline value in order to determine the performance and to assign a score of between 0 and 5.

The scoring of the criterion performance relies on the discretion of the decision-maker or the user of the proposed framework. Thus, the method of determining the criterion scores in the following worked examples merely serve as an example. It should thus be noted that the performance score rating system can be adjusted by the decision-maker to best suit his/her application of the proposed framework. This again induces some flexibility into the application of the proposed framework, as the scoring system can be adjusted to suit a particular situation or decision.

Also, for the same decision various baseline values can be used to measure the performance of a particular criterion in different aspects. For a more practical explanation, refer to the following criteria worked examples.

Table 4.3: Criteria performance score rating

Score	0-1	2-3	3-4	4-5
Description	Poor Performance	Intermediate Performance	Satisfactory Performance	Superior Performance

Each of the above mentioned criteria is evaluated and analyzed in detail in the following sections with an accompanying worked example to aid the decision-maker with the evaluation techniques used.

4.4.1 Physical Asset Repair/Replace Decision Rate of Return

As discussed in Section 4.2.2, the IRR is used to calculate the rate of return generated by the potential investment to either repair or replace the physical asset. It is therefore necessary to discuss, in detail, the calculations as well as the information required to determine the IRR.

Objective: Detail the calculations and information necessary to determine the physical asset repair/replace decision IRR.

Outcome: Structured and practical method for physical asset repair/replace decision IRR calculation.

From Section 3.1.2.1, the first step in the calculation of the IRR is to establish the financial information necessary for the calculations involved, therefore, refer to Equation 4.4.1 below for the NPV equation.

$$\text{NPV}(i) = x_0 + \frac{x_1}{(1+i)} + \frac{x_2}{(1+i)^2} + ... + \frac{x_n}{(1+i)^n} \tag{4.4.1}$$

Where x_0 to x_n represent the cash flows generated by the investment from its acquisition to period n, and i is the interest rate earned throughout these cash flow periods.

As stated in Section 3.1.2.1 the IRR is the interest rate at which the NPV is equal to zero, therefore Equation 4.4.1 above is modified to form Equation 4.4.2 below

$$0 = x_0 + \frac{x_1}{(1+i)} + \frac{x_2}{(1+i)^2} + ... + \frac{x_n}{(1+i)^n} \tag{4.4.2}$$

Therefore, when NPV = 0, i in Equation 4.4.2 above represents the IRR of the investment over n cash flow periods.

Thus, from Section 3.1.2.1 the financial information necessary for the calculation of the physical asset repair/replace decision is as follows:

1. Initial investment amount
2. Cash flow period to be analyzed $(0 - n)$
3. Operating cash inflows
4. Terminal cash flows
5. Organizational specific MARR

Gitman and Zutter (2012) state that the initial investment consists of both the installation cost of the new asset as well as the cost of acquisition. The initial investment for the physical asset repair decision can be obtained from the organization's Balance Sheet, whereas the initial investment for the physical asset replace decision represents the not only the cost of the new physical asset, but also all modification and alteration costs associated with its acquisition and installation. This value has to be estimated as the IRR is calculated before the physical asset is acquired and the costs are incurred.

The cash flow period analyzed is determined by the decision-maker. It can consist of different periods for the repair decision and the replace decision; they need not be of the same length.

Furthermore, the operating cash inflow generated by the repair decision must be specific to the physical asset under consideration. It may therefore be necessary to set up a Cash Flow Statement for the physical asset under consideration, indicating all cash inflows and outflows attributed to that specific physical asset over the cash flow period, these cash inflows and outflows are discussed in Section 3.1.2.1. The before mentioned cash flow values are found in the Balance Sheet as well as the Income Statement and Cash Flow Statements of the organization. However for the replace decision the cash flows attributed to the physical asset to be acquired must be estimated over the desired cash flow period.

These cash inflows and outflows include the sales attributed to the physical asset under consideration, operating expenses and other expenses attributed specifically to the physical asset, depreciation as well as tax allowances and losses resulting from the repair or replacement of the physical asset. Gitman and Zutter (2012) state that physical asset intensive company are permitted, for tax purposes, to charge a percentage of the cost of physical assets against the yearly sales. The before mentioned cost is referred to as depreciation. The operating cash flow is therefore described as the cash flow that the company generates from its normal operating activities.

The terminal cash flow is the cash flow generated through liquidation of the physical asset. Therefore it consists of the salvage value of the physical asset, costs involved in removing the physical asset as well as the effect of tax on the disposal/sale of the physical asset.

It is also necessary to determine the organizational specific MARR. The MARR is defined in Section 3.1.2.1 as the minimum rate of return that is acceptable on a potential investment. Once the IRR of the repair and replace decisions are calculated, the respective IRRs are compared to the MARR to determine if either of the IRRs are acceptable, only then can the best option be determined. If the calculated IRRs are less than the MARR is does not necessarily mean that the decision should immediately be discarded. It merely indicates that the rate of return generated from the investment of capital into the decision is less than the minimum rate of return that the company would accept for a purely financial investment.

Once all of the above mentioned information is obtained, can the IRR for the physical asset repair decision as well as for the replace decision be determined using Equation 4.4.2 above. Thereafter the respective IRRs are compared to the organizational specific MARR to determine if either of the two calculated IRRs exceed the MARR. If both exceed the MARR, the option with the highest IRR value is chosen. However, if both are less than the MARR, neither the repair or the replace option is suggested. Moreover, if either the repair or the replace option IRR exceed the MARR and the other does not, the one above that of the MARR is chosen.

Therefore, the method of calculating the IRR for the physical asset repair/replace decision is summarized as follows:

1. Determine existing physical asset considered for replacement initial investment

2. Determine new asset to be acquired initial investment

3. Determine cash flow generated by existing physical asset for n periods, where n can be decided by the decision maker

4. Estimate the cash flow that will be generated by the new physical asset to be acquired for t periods, where t can be equal to n, or any other period decided by the decision maker

5. Determine the organizational specific MARR

6. Calculate the IRR for both the repair (existing physical asset) and the replace (new physical asset to be acquired) decision

7. Compare both IRRs to the MARR. If both IRRs are more than MARR refer to number eight below. However, if one or both of the IRRs are less than MARR, the return generated from these investments are less than the rate that the company deems attractive. This does not mean that the decision-maker should discard these options, if the IRR calculated is more than the cost of capital, which represents that absolute minimum rate of return required by the company, continue to number 8 below

8. Compare the two IRRs to one another, the IRR that is the highest represents the highest rate of return and is therefore suggested as the best option, with regards to the IRR

Refer to the following section for a worked example of the calculation of the physical asset repair as well as the physical asset replace IRR.

4.4.1.1 IRR Worked Example

As mentioned before, the analysis and evaluation of each of the criteria identified in Section 4.2.2 is accompanied with a worked example. In this manner the decision-maker implementing the strategic decision-making framework has a clear understanding of the calculations and information involved. This section specifically deals with the calculation of the IRR for both the physical asset repair decision, as well as for the physical asset replace decision. As stated in the previous section the initial investment, cash flow periods as well as the operating and terminal cash flows that took place in that period are required for the calculation of the IRR. Also, the company specific MARR is required for comparison.

As mentioned before, Company X represents a physical asset intensive organization that is considering the replacement of one of their physical assets. Company X requires a return of at least 10% for an investment to be considered viable. The current physical asset that is employed within the operations of Company X requires an initial investment of ZAR 600,000 to be completely refurbished and the new physical asset that Company X is considering requires an initial investment of ZAR 1,200,000. Refer to Table 4.4 below for the cash flow generated by the existing physical asset over a period of six years, as well as the estimated cash flows to be generated by the physical asset to be acquired.

The existing physical asset is depreciated on the straight line method whereby a fixed 10% of its initial value of ZAR 1,000,000 is deducted every year it is in operation, irrespective of the investment to refurbish the physical asset. In year 0, as indicated in Table 4.4 the existing physical asset has already been in operation for five years. Thus, in year five the existing physical asset is completely depreciated. Moreover, according to SARS (2014/2015) a special tax allowance of 20% of the improvement costs over a five year period is allowed to be deducted. Company X does not sell the existing physical asset in year five, but rather uses its parts as spares on site therefore instead of creating an additional cash outflow for the purchase of spare parts, Company X uses the stripped parts and saves this cash outflow. However, as the value of these parts cannot be accurately measured and the before mentioned is not an actual cash flow, just a possible cash saving, the terminal value of the existing physical asset is assumed to be zero.

The replacement physical asset is also depreciated at 10% of its initial value on the straight line method. Thus the accumulated depreciation attributed to the replacement physical asset increases with ZAR 120,000 every year. Moreover, from SARS (2014/2015) the company is given a special tax allowance of 40% of the physical asset's initial value in the first year the physical asset is acquired and 20% in the three succeeding years following acquisition. Note that the replacement physical asset will not be liquidated in year five and thus there is no terminal cost included in the cash flow statement.

Table 4.4: Cash Flow Example

Cashflow Period (years)	Net Cash Flow Existing Physical Asset (x_n)	Net Cash Flow of Physical Asset to be Acquired (x_n)
0	ZAR (600,000)	ZAR (1,200,000)
1	180,000	240,000
2	200,000	290,000
3	260,000	340,000
4	210,000	310,000
5	0	350,000

From the information in the text above, the organizational specific MARR is 10%. It is therefore necessary to calculate the IRR for both the existing physical asset, as well as for the potential physical asset to be acquired.

Using the cash flows illustrated in Table 4.4 above, the IRR calculation for the existing physical asset is as follows,

$$0 = x_0 + \frac{x_1}{(1+i)} + \frac{x_2}{(1+i)^2} + ... + \frac{x_n}{(1+i)^n} \tag{4.4.2}$$

Where $x_0 = \text{ZAR}(800,000)$, $x_1 = \text{ZAR}180,000$, $x_2 = \text{ZAR}200,000$, $x_3 = \text{ZAR}260,000$, $x_4 = \text{ZAR}210,000$, $x_5 = \text{ZAR}0$ and $i =$IRR, therefore

$$0 = (-800,000) + \frac{180,000}{(1+i)} + \frac{200,000}{(1+i)^2} + \frac{260,000}{(1+i)^3} + \frac{210,000}{(1+i)^4} + \frac{0}{(1+i)^5} \quad (4.4.3)$$

Thus, the cash flow generated for the existing physical asset in Table 4.4, i is equal to 14.9%. Refer to Appendix A.1, Figure A.1 and Table A.1 for the Excel sheet formulae and calculated answers, respectively.

Using the cash flows illustrated in Table 4.4 above, the IRR calculation for the physical asset to be acquired is as follows,

$$0 = (-1,200,000) + \frac{240,000}{(1+i)} + \frac{290,000}{(1+i)^2} + \frac{340,000}{(1+i)^3} + \frac{310,000}{(1+i)^4} + \frac{350,000}{(1+i)^5} \quad (4.4.4)$$

Thus, the cash flow generated for the physical asset to be acquired as illustrated in Table 4.4 above, i is equal to 8.20%. Refer to Appendix A.1, Figure A.1 and Table A.1 for the Excel sheet formulae and calculated answer, respectively.

The information determined in this example can therefore be summarized as follows:

MARR = 10%
IRR(existing physical asset) = 14.9%
IRR(physical asset to be acquired) = 8.2%

From the information above, the IRR calculated for the physical asset to be acquired is less than the MARR as well as the IRR calculated for the existing physical asset. Thus, according to the IRRs calculated for this specific example, replacing the physical asset is not suggested. Furthermore, since the IRR calculated for the existing physical asset is more than the MARR and the IRR calculated for the acquisition of a new asset, it is suggested that the existing physical asset stay in operation. Therefore, for this example, the physical asset repair decision outweighs the physical asset replace decision.

Furthermore, as stated in Section 4.4 the repair and the replace option evaluated IRRs are to be assigned a score between 0 and 5. Thus, as the repair option IRR exceeds the organizational MARR with 4.9%, it indicates superior performance and is assigned a score of 4, refer to Table 4.3. However, as the replace option IRR is 1.80% less than the MARR it indicates relatively poor performance and is assigned a score of 1.

Repair Option Score = 4
Replace Option Score = 1

The following section details the evaluation of the value created by the physical asset repair/replace decision.

4.4.2 Value Created by Physical Asset Repair/Replace Decision

As discussed in Section 4.2.2 the EVA is used to calculate the economic value added to the organization by the potential investment to either repair or replace the physical asset. It is therefore necessary to discuss, in detail, the calculations and information required to determine the EVA of the respective decision.

Objective: Detail calculations and information needed to determine the EVA generated by the physical asset repair/replace decision.

Outcome: Structured and practical method for the calculation of the EVA for the physical asset repair/replace decision.

As with the calculation of the IRR, the first and most important step in calculating the EVA is to establish what information is needed for the calculations involved. EVA is discussed in detail in Section 3.1.2.2, refer to Equation 4.4.5 below.

$$\text{EVA} = \text{NOPAT} - \text{Capital Charge} \tag{4.4.5}$$

Where NOPAT is the Net Operating Profit After Tax and Capital Charge is the return that is expected on the organization's capital. Refer tp Equations 4.4.6, 4.4.7 and 4.4.8 for the calculation of the NOPAT and the Capital Charge.

$$\text{NOPAT} = \text{ANOPBT} \times (1 - \text{Tax Rate}) \tag{4.4.6}$$

$$\text{ANOPBT} = \text{EBIT} - \text{Adjustments} \tag{4.4.7}$$

$$\text{Capital Charge} = \text{Average Invested Capital} \times \text{Cost of Capital} \tag{4.4.8}$$

ANOPBT is the Adjusted Net Operating Profit before Taxes, and EBIT is the Earnings before Interest and Taxes. The adjustments in Equation 4.4.7 refers to the depreciation as well as the Selling, General and Administrative (SG&A) expenses, and all other operating expenses. The Average Invested Capital in Equation 4.4.8 above is calculated as follows

$$\text{Average Invested Capital} = \text{Fixed Assets} + \text{NWC} \tag{4.4.9}$$

Where NWC refers to the Net Working Capital and is calculated as follows

$$\text{NWC} = \text{CA} - \text{C} - \text{CL} + \text{IBD} \tag{4.4.10}$$

Where CA represents the organization's Current Assets, C the Cash and cash equivalents and CL the Current Liabilities. IBD in Equation 4.4.10 above represents the Interest Bearing Debt of the organization, this includes all debts and loans that charge an interest percentage to hold such as ban loans and corporate bonds.

Finally, from Section 3.1.2.2 the Cost of Capital in Equation 3.1.15 is equal to the WACC and is calculated using the following equation.

$$\text{WACC} = \frac{\text{E}}{\text{V}} \times R_e + \frac{\text{D}}{\text{V}} \times R_d(1 - \text{Tax Rate}) \tag{4.4.11}$$

Where E is the market value of the organization's equity, D is the debt of the organization, R_e is the cost of capital, R_d is the cost of debt and V is calculated as in Equation 3.1.20.

Thus, the financial information needed for the calculation of the organization EVA is the NOPAT, CA, CL, C, IBD, NWC, total assets, debt and total liabilities, all of which can be obtained from the organization's Income Statement and Balance Sheet. The R_e and R_d however cannot be obtained from either of the before mentioned financial statements. From Section 3.1.2.2 R_d simply represents the interest that the organization pays its lenders and R_e is calculated using the CAPM as follows

$$r_a = r_f + \beta(r_m - r_f) \tag{4.4.12}$$

Where r_a is equal to R_e, r_f is the risk-free rate of return, r_m is the expected rate of return from the market and β is the risk premium. However, determining these in-depth financial metrics are beyond the scope of this study, thus the values for R_e and R_d is ideally obtained from the organizational financial manager.

Thus, the financial information necessary for the calculation of the EVA for the physical asset repair/replace decision is as follows:

1. Organization Income Statement to calculate EBIT, ANOPBT and NOPAT
2. Organization Balance Sheet to calculate NWC, Average Invested Capital, V, E, D and WACC
3. Consultation with organization financial manager to determine R_e and R_d

Once all of the above mentioned information has been determined, only then can the EVA be calculated. As mentioned before, the EVA represents the value that is created by an investment in excess of the required return of the organization's investors. A positive EVA represents value created by the investment and the opposite for a negative calculated EVA. The EVA for the physical asset repair decision can therefore be calculated from the current Income Statement and Balance Sheet of Company X. Whereas, the replace decision is more complicated as the user will have to adjust the Income Statement and Balance Sheet of the organization according to the estimated increase in revenues, fixed assets, expenses etc.

The EVA is calculated for both the repair and the replace decision, thereby comparing the two calculated values. If the calculated EVA value for the replace decision is higher than that of the repair decision, the organization will benefit by replacing the physical asset. However, if the EVA for the replace decision is equal to, or lower than the repair decision, replacing the physical asset will not result in any additional value added to the organization. Therefore, the method for calculating the EVA for the physical asset repair/replace decision is summarized as follows:

1. Acquire organization Income Statement and Balance Sheet before acquisition of physical asset considered for replacement.

2. Adjust Income Statement and Balance Sheet for the acquisition of the new physical asset.

3. Calculate the EVA for both the repair (existing physical asset) and the replace (new physical asset to be acquired) decision.

4. Analyze the respective calculated EVA's for organization value addition, a positive EVA represents value added.

5. Compare the repair decision EVA and the replace decision EVA, increasing EVA from the repair to the replace decision indicates value added to the organization if the physical asset is replaced. However, a decreasing EVA suggests that replacing the physical asset will not add any value to the organization and that the existing physical asset should stay in operation.

Refer to the following section for a worked example of the calculation of the physical asset repair/replace decision EVA.

4.4.2.1 EVA Worked Example

This section deals with the calculation of the EVA for the physical asset repair decision, as well as for the physical asset replace decision. As stated in the previous section, the Income Statement and Balance Sheet is required for the calculation of the EVA.

For the purposes of continuity, as with the calculation of the IRR, let Company X represent a physical asset intensive organization that is considering the replacement of one of their physical assets. Thus, from the previous section, the first step is the calculation of the NOPAT, EBIT and ANOPBT. Refer to Appendix A.2 and Table A.2 for the Income Statement of Company X before the acquisition of the new physical asset, i.e. the repair decision.

Table 4.5 is a summary of the EBIT, ANOPBT and NOPAT calculated in the Income Statement in Table A.2.

Table 4.5: EVA Example: EBIT, ANOPBT and NOPAT for the repair decision

Metric	Value (ZAR)
EBIT	516,000
ANOPBT	216,000
NOPAT	129,600

It is therefore necessary to estimate the effect of the acquisition of the new physical asset on the Income Statement and to make the necessary adjustments. In this example it is assumed that the acquisition of the new physical asset will increase Company X's revenues with 25%, the purchases, opening and closing stock with 20% and the depreciation with ZAR 20,000. The SG&A expenses increase with 10% and the interest expenses are assumed to remain the same. Thus, refer to Appendix A.2, Table A.3 for the adjusted Income Statement of Company X after the acquisition of the new physical asset, i.e. the replace decision.

Table 4.6 is a summary of the EBIT, ANOPBT and NOPAT calculated in the Income Statement in Table A.3.

Following the calculation of the NOPAT for both the repair and the replace decision is the calculation of the NWC, Average Invested Capital, V, E, D and WACC. Thus, refer to Appendix A.2 and Table A.4 for the Balance Sheet of Company X before the acquisition of the physical asset, i.e. the repair decision.

The following is a summary of CA, C, CL and IBD from Table A.4.

From the information in Table 4.7 and Equation 3.1.17 the NWC is calculated as follows:

Table 4.6: EBIT, ANOPBT, NOPAT for the replace decision

Metric	Value (ZAR)
EBIT	163,000
ANOPBT	(517,000)
NOPAT	(517,000)

Table 4.7: CA, C, CL, IBD for repair decision

Metric	Value (ZAR)
CA	1,145,800
C	328,000
CL	21,300
IBD	3,060,000

$$\text{NWC} = \text{ZAR}1,145,800 - \text{ZAR}328,000 - \text{ZAR}21,300 + \text{ZAR}3,060,000 = \text{ZAR}3,856,500$$

From the information in Table A.4 the value of Company X's fixed assets equal ZAR 3,256,500. Thus, using the value of the fixed assets, the NWC and Equation 3.1.16, the Average Invested Capital is calculated as follows:

$$\text{Average Invested Capital} = \text{ZAR}3,256,500 + \text{ZAR}3,856,500 = \text{ZAR}7,113,000$$

The next step is the calculation of the Cost of Capital or the WACC. As mentioned in the previous section, the CAPM is used to calculate the WACC, it is therefore necessary to determine E, D, V, R_e and R_d, refer to Equation 3.1.19.

Table 4.8 is a summary of E, D as well as the value of Company X's total assets and total liabilities from which V is calculated, refer to Table A.4.

As mentioned in the previous section, the in depth details involved in determining R_e and R_d are outside of the scope of this study. Therefore, assume Company X is informed by its banker that the lending rate for the long-term loan is 12%, so R_d is equal to 12%. Also, assuming Company X issued its common stock at ZAR 100 per share with an issuing cost of ZAR 15 per share, resulting in proceeds of ZAR 85 per share. Moreover, assume that ZAR 12 per share is used for future earnings, determined by the company analyst. Thus, R_e is calculated as follows:

Table 4.8: E, D and V, Total Assets and Total Liabilities for the repair decision

Metric	Value (ZAR)
E	1,329,600
D	3,060,000
Total Assets	4,411,300
Total Liabilities	3,081,700
V	7,493,000

$$R_e = \frac{\text{ZAR}12}{\text{ZAR}85} = 14.1\%$$

Therefore, with a 40% tax rate and using Equation 3.1.19, the WACC is calculated as follows:

$$\text{WACC} = \frac{\text{ZAR } 1{,}329{,}600}{\text{ZAR } 7{,}493{,}000} \times 14.1\% + \frac{\text{ZAR } 3{,}060{,}000}{\text{ZAR } 7{,}493{,}000} \times 12\%(1 - 40\%)$$

$$\text{WACC} = 5.44\%$$

Finally, using the NOPAT, WACC and the Average Invested Capital, the EVA of the repair decision for Company X is calculated as follows:

$$\text{EVA} = \text{ZAR}129,600 - 5.44\% \times \text{ZAR}7,113,000 \tag{4.4.13}$$

$$\text{EVA} = \text{ZAR}(257,347)$$

For the physical asset repair decision, the EVA is negative, this implies that the continued repair of the physical asset is not adding any value to the organization. It is therefore necessary to calculate the EVA for the physical asset replace decision. As stated in Section 4.4.1.1 Company X is considering the acquisition of a new physical asset with an initial investment value of ZAR 1,200,000. The before mentioned initial investment is financed through an additional long-term loan.

From the information in Table A.5 the equipment under fixed assets increased with the ZAR 1,200,000 initial investment and the accumulated depreciation increased with the additional ZAR 20,000 estimated in Table A.3. The long-term loan also increased with an amount of ZAR 2,020,000. As with the repair decision, following the calculation of the NOPAT, Table 4.6, is the calculation of the NWC,

Table 4.9: CA, C, CL, IBD for replace decision

Metric	Value (ZAR)
CA	1,308,800
C	328,000
CL	21,300
IBD	5,080,000

thus refer to Table for a summary of the CA, C, CL and IBD obtained from Table A.5.

Thus, using the information in Table 4.9 and Equation 3.1.17, the NWC is calculated as follows:

$$NWC = ZAR1,308,000 - ZAR328,000 - ZAR21,300 + ZAR5,080,000 = ZAR6,038,700$$

Following the calculation of the NWC is the calculation of the Average Invested Capital, thus using the NWC obtained, as well as the value of the fixed assets from Table A.5 and Equation 3.1.16, the Average Invested Capital is calculated as follows:

$$ZAR4,485,500 + ZAR6,038,700 = ZAR10,524,200$$

Thereafter, the WACC is determined by using the values for E, D, V, in Table 4.10 as well as the calculated values for R_e and R_d.

Table 4.10: E, D, V, Total Assets and Total Liabilities for the replacement decision

Metric	Value (ZAR)
E	683,000
D	5,080,000
Total Assets	5,791,300
Total Liabilities	5,108,300
V	5,763,000

The value for R_d and R_e are the same as that of the repair decision since the lending rate, as well as the cost per share, issuing cost and proceeds are assumed to stay the same. Thus, $R_e = 14.1$ % and $R_d = 12$ %. Also, the tax rate is assumed the same as for the repair decision at 40 %, thus WACC for the replace decision is calculated as follows:

$$\text{WACC} = \frac{\text{ZAR}683,000}{\text{ZAR}5,763,000} \times 14.1\% + \frac{\text{ZAR}5,080,000}{\text{ZAR}5,763,000} \times 12\%(1 - 40\%)$$

$$\text{WACC} = 8\%$$

Finally, using the NOPAT, WACC and the Average Invested Capital, the EVA for the replace decision of Company X is calculated as follows:

$$\text{EVA} = \text{ZAR}(517000) - 8\% \times \text{ZAR}10,524,200$$

$$\text{EVA} = \text{ZAR}(1,358,936)$$

The EVA for the replace decision is also negative, implying that replacing the physical asset will not add any value to Company X. In this particular case, both the repair and the replace decision calculated EVA's are negative, thus neither of the options would add value to the organization. The decision-makers should therefore consider other options, for instance acquiring a cheaper replacement physical asset or decreasing their long-term debt, both of which will have a significant impact on the EVA calculation. Moreover, the calculated EVA for the repair decision is less negative than that of the replace decision, thus, even though neither of the two options add value to the organization, the repair decision is the better option.

Furthermore, as stated in Section 4.4 the repair and the replace option evaluated EVAs are to be assigned a score between 0 and 5. Thus, as both the repair option as well as the replace option EVAs are negative, both indicate extremely poor performance and are assigned scores of 0, refer to Table 4.3.

Repair Option Score = 0
Replace Option Score = 0

The following section deals with the effect that the physical asset repair and replace decision has on the organization's competitors and its competitive advantage.

4.4.3 Effect of Physical Asset Repair/Replace Decision on The Five Competitive Forces

As mentioned before, the environment in which an organization operates, especially the rival companies within the same industry as well as within other industries, have a significant impact on the outcome of the physical asset repair/replace decision. Ideally the outcome of this decision results in increased or sustained competitive advantage above that of rival organizations. Competitive advantage, as stated previously, contributes greatly to an organization's financial performance and overall success. Thus, as discussed in Section 4.2.2 the effect of the decision on the organization's competitors is analyzed.

The effect of the physical asset repair/replace decision on rival companies is determined by analyzing the effect of the decision on the five forces suggested in Section 4.4.3. It is therefore necessary to discuss, in detail, the analysis of the five competitive forces.

Objective: Detailed discussion of the analysis of the five competitive forces that are influenced by the physical asset repair/replace decision.

Outcome: Structured and practical method for the analysis of the effect of the physical asset repair/replace decision on the five competitive forces.

The five competitive forces, as discussed in detail in Section 4.4.3, are as follows:

1. Competitive rivalry within the industry
2. Threat of new entrants
3. Power of suppliers
4. Power of buyers
5. Threat of substitutes

Competitive rivalry among competing companies within an industry refers to the struggle for market share within that specific industry. The level of competitive rivalry within an industry is mainly determined by the number of rivals in that industry that are approximately equal in size, and basis on which they compete. Saturated industries pose limited opportunities for new business or poaching business and thus provoke competition for market share. It is thus necessary to determine the level of competitive rivalry within the industry in which the organization competes, and the effect of the physical asset repair/replace decision on the competitive rivalry. In this manner the best option is determined that results in the possible acquisition of a higher level of market share.

New entrants that enter into an industry introduce new capacity as well as added competition for market share. Also, as some of these new entrants may have diversified from other industries they induce additional capabilities and cash flows into the industry. From Section 4.4.3 the main determinant of the degree of the threat of entry is the level of the entry barriers that exist. Some of these entry barriers include resistance from established organizations in the industry, low unit pricing, large production volumes, economies of scale and switching costs. The threat of new entry therefore negatively effects the profitability of the industry. Thus, it is necessary to determine the effect of the physical asset repair/replace decision on the threat of new entry, as this threat should ideally be as low as possible.

From Section 4.4.3, a powerful supplier group exists if the industry in which it competes and operates is more concentrated than the industry it supplies goods and/or services to. Also, a supplier group is powerful if it is not dependent on one industry in particular, but supplies to a number of industries. These powerful supplier groups have the power to increase the cost of the materials required by the organizations in the buyer industry, thus lowering the profitability of the buyer groups. Thus, if the organization under consideration relies heavily on the selling of goods and/or services to buyer groups, high selling power is ideal. However, if the organization is in the buyer group and depends on acquiring its goods and/or services from selling groups, low selling power is ideal. Thus, the effect of the physical asset repair/replace decision on the power of the suppliers is determined, selecting the option that hinders supplier power most.

On the other hand, a powerful buyer group exists if the market in which the organization competes consists of numerous seller groups but only a single, or minimum amount of buyer groups. Thus, the buyer organizations have the power to reduce the cost of the goods and/or services acquired from the buyer groups as well as the quality of the goods and/or services provided. The higher the buyer power, the lower the profitability of the seller group. Thus, if the organization under consideration relies heavily on the acquisition of goods and/or services from sellers, high buyer power is ideal. However, if the organization is in the seller group and depends on selling its goods and/or services to buyer groups, low buyer power is ideal. Thus, the effect of the physical asset repair/replace decision on the power of the buyers is determined, selecting the option that is most advantageous to the organization.

Lastly, the introduction of substitute products and/or services increase price elasticity. More elastic demand negatively effects the profitability of the industry. Substitute products and/or services perform a similar function as the original, but in a different manner. Thus, organizations within an industry that fail to differentiate themselves from substitute organizations through either superior performance or some other property, suffer in terms of profit potential. It is therefore necessary to determine the effect of the physical asset repair/replace decision on the threat of substitutes. Thereby identifying the option that results in the most differentiation from its rivals.

None of the above mentioned forces can be analyzed from financial statements like the IRR and EVA, or any other quantitative data obtainable within the organization. The five competitive forces is analyzed by someone who has intricate knowledge of the industry and the competitive environment in which the organization operates. Thus, the user of the proposed framework is expected to either possess this knowledge him or herself, or consult a particular person or group of people in the organization that have this knowledge.

As the five competitive forces are of a qualitative nature it is necessary to convert the effect of the physical asset repair/replace decision on each of the respective forces into quantitative measures for comparison. It is therefore suggested that the user of the framework make use of a point rating system. Whereby the relative effect of the physical asset repair or replace option on each of the respective forces is rated with a value between zero and five. Such that zero represents no effect at all and five represents a significant effect on the respective competitive force, refer to Table 4.3.

The aim of rating the effect of the physical asset repair/replace decision on the FFF is to analyze the changes in the market in which the organization competes, as well as to analyze the future attractiveness of the current market. Thus, this analysis will steer the organization in the direction of the option that is most profitable in future.

The following detailed worked example will serve as further explanation of the suggested method for rating the effect of the physical asset repair/replace decision on the five competitive forces.

4.4.3.1 Competitive Forces Worked Example

This section deals with the analysis and rating of the effect of the physical asset repair decision as well as the replace decision on the FFF. As stated in the previous section, the information used for this section cannot be obtained from financial statements and originates from expert opinion.

Thus, this worked example will again consider the case of Company X that is considering the acquisition of a new physical asset of a significant investment nature. As discussed in the previous section, each of the five competitive forces are analyzed and the effect of the repair and the replace decision on these forces are determined. Each of the forces is then assigned a score of between 0 and 5 depending on the performance of the repair or replace option in that particular instance, refer to Table 4.3 for the performance rating system utilized.

1. Competitive rivalry within the industry
   The first competitive force as stated in Section 4.4.3 is the competitive rivalry within the industry. Thus, presume that the physical asset Company X is

considering for replacement produces a certain product Y. By analyzing the industry in which Company X competes, it is found that out of the nine rival companies, two produce a product that is similar to product Y. It is also found that of the remaining seven rival companies, one has the option to produce a product similar to product Y if it chooses to diversify.

Furthermore, even though product Y is similar to that of the rival companies, it has a number of features that differentiates it from those products. Also, Company X has the advantage of supplying superior product support services and delivery time. At present Company X controls 60% of the market for the production of product Y, despite the two rival companies. Thus, by thoroughly examining the industry in which Company X competes, as well as the possible rivals in the industry, it can be concluded that the competitive rivalry within the industry is relatively low.

The acquisition of the new physical asset will allow Company X to further differentiate product Y by allowing faster production and higher quality. The new physical asset also has the added feature of producing other products following a slight, low cost modification, whereas the current physical asset can only produce one product of a single type. Thus, considering all of the before mentioned information and consulting the Financial Manager of Company X, the effect of the physical asset repair option on the competitive rivalry within the industry was given a rating of two and the replace option was assigned a rating of four, refer to Table 4.3.

Repair Option Rating: 2
Replace Option Rating: 4

Not replacing the physical asset will hinder the differentiation of product Y as well as hinder the company from possibly expanding their product base in the future. Thereby increasing the chances of other rival companies acquiring more market share, consequently resulting in the low rating. Acquisition of the new physical asset will increase production speed and quality, provide the added advantage of possibly expanding the product base and allow for further differentiation of the company from its rivals. Thereby decreasing the chances of rival companies acquiring more market share, consequently resulting in the high rating.

2. Threat of new entrants
   As discussed in Section 4.4.3 the threat of new entry is the threat of new rival companies entering the market in which Company X competes. As mentioned above, even though the current physical asset allows for high

volume production, it only allows for the production of one type of product. Also, as the physical asset has been in operation for a number of years its production rate is at maximum level with no option of any further increase. Furthermore, the unit pricing of product Y cannot be lowered any further without negatively affecting the profitability. Thus, considering the before mentioned information as well as consultation with the Financial Manager, the repair option is given a rating of two according to the performance rating in Table 4.3.

The new physical asset allows for faster production of products that are of a higher quality. It also allows for possible future expansion and differentiation of products. Initially the physical asset will have a high investment of capital, however the cost of producing product Y is lower than that of the current physical asset, thus if necessary the unit prices can be lowered without negatively affecting the profitability. Thus, the replace option is given a rating of four according to the performance rating suggested in Table 4.3.

Repair Option Rating: 2
Replace Option Rating: 4

The ability to produce high volume products at a faster rate and with higher quality will increase the entry barriers into the market, thus lowering the threat of new entrants. However, the production of product Y with no option to further lower the unit price if necessary, as well as no future expansion lowers the entry barriers, allowing for new rivals to enter the market in which Company X competes.

3. Power of suppliers
As mentioned before, powerful suppliers exist if the organization is not dependent on one industry, but supplies goods to various industries and companies. Fortunately Company X supplies product Y to six different companies, five of which depend on Company X as their sole supplier of a product of type Y. As mentioned before, there are two rival companies that produce a product that is similar to product Y. Thus, the possibility of the buyers switching from Company X to another company if the unit price of product Y were to increase, is relatively high. Also, since the current physical asset does not allow for any further modification of product Y, Company X does not have the option of differentiating its product further from that of the other companies. Thus, the repair option is assigned a rating of two from the performance rating in Table 4.3.

The new physical asset, however, allows for faster and higher quality production of product Y. It also allows for the modification of product Y to enhance features, as well as the possible production of other products. Thus differentiating product Y from that of rival products and allowing for added capacity and the possibility of supplying new products to current buyers and sourcing new buyers. Differentiating product Y to one that meet the requirements of buyers and is exclusive to Company X, ensure loyal customers that will have difficulty switching to other suppliers. Also, providing the option to produce additional, specialized products Company X can source more buyers, thereby increasing the supplier power of Company X. Thus, the replace option is given a rating of four according to the performance ratings in Table 4.3.

Repair Option Rating: 2
Replace Option Rating: 4

The additional options that come with replacing the physical asset allows Company X to broaden its customer base, as well as the option to further distinguish product Y from that of rivals. Consequently increasing the supplier power, which in turn positively affects the profitability of Company X. If the physical asset is not replaced, the possibility exists that current buyers will switch to other suppliers as they produce products similar to product Y. Also, the current physical asset does not allow for future expansion.

4. Power of buyers
   Powerful buyer groups exist if there are numerous seller groups but only a single or minimal amount of buyer groups. Company X sources its raw material for the production of product Y from two respective companies, Company A and Company B. Company A sells its raw materials to eight other companies, other than Company X and Company B sells its raw material to four other companies. Company X has the smallest demand of the eight companies that buy from Company A, and the second largest demand of the companies that buy from Company B.

   If Company X were to continue with the operation of the current physical asset, the demand will stay the same. Thus, the threat of leaving Company A will be minimal as there are eight other companies that they supply their raw material to. Also, the threat of leaving Company B will be moderate since they will lose a relatively large buyer, but still have four other companies that they supply to. Thus, the repair option is given a rating of three from the performance ratings in Table 4.3.

If, however, Company X acquires the new physical asset, the production volume of product Y will increase. Also, adding additional features to product Y or producing other types of products require additional raw materials to be sourced. The raw material required for the additional production volume can be obtained from both Company A and Company B. Thus, increasing the demand of Company X such that it has the third largest demand from Company A and the largest demand from Company B. In the event that Company X start producing additional products to that of product Y, the demand will increase such that it has the second largest demand from Company A and the largest from Company B. Also, Company X will have to source some of its raw material from other companies, as neither Company A nor B are able to satisfy the demand. Thus, the replace option is given a rating of four according to the performance ratings in Table 4.3.

Repair Option Rating: 3
Replace Option Rating: 4

The buyer power of Company X is determined by the effect on the selling company if Company X were to switch to another company and the selling company were to loose Company X as a customer. If there are numerous companies that source from the same buyer as Company X and that have a larger demand than Company X, the effect will be relatively low. If however Company X is responsible for a large sum of the selling company's produce, then the effect will increase. Buyer power has a direct effect on a company's profitability, since the buying company has the ability to influence the cost price of the raw materials it buys from the selling company. Thus, a higher buyer power is always preferable and thus the replace option resulted in a higher rating than the repair option.

5. Threat of substitutes
A substitute product is one that performs the same function as that of product Y, but in a different manner. The more substitutes on the market, the more choices the buyers have and the easier it is for them to switch from one supplier to another. High substitute threat negatively effects the profitability of a company by placing a limit on the retail prices.

If Company X were to repair the current physical asset and continue producing product Y as is, the chance of substitution by the two companies that produce a similar product to that of product Y increases. As the current physical asset does not allow for any further differentiation or higher volume production, Company X cannot compete with similar products in terms of product features or lowered prices. It also increases the chance of any of the other seven rival companies to start producing a product similar to product Y if they deem such an operation profitable. Thus, the repair option is given a rating of two from the performance rating in Table 4.3.

On the other hand, the new physical asset allows for further differentiation of product Y by adding additional features that will separate product Y from that of the rival companies. It also allows for the production of additional products such that Company X does not primarily rely on the production of product Y for the generation of revenues. Producing new and improved products of a higher quality will distinguish Company X from its rivals and decrease the threat of possible product substitution. Thus, the replace option is given a rating of five according to the performance ratings in Table 4.3.

Repair Option Rating: 2
Replace Option Rating: 5

As mentioned before, the threat of substitute products increase if there are other products in the same market that are similar to that of product Y. Buyers then have the option to switch from one supplier to another for lower prices, faster service, better quality etc. Thus, adding additional features to product Y decreases the chance of substitution as the product is unique to Company X.

For each of the above discussed competitive forces the option to repair the physical asset, as well as the option to replace the physical asset is considered. It is also evident that for the analysis of the five competitive forces, the company requires some market research regarding rival companies, as well as supplying and buying companies. Thus, as mentioned before, the analysis requires the expertise of a person within the company that posses this knowledge for the analysis to reflect the actual market situation.

The analysis of the five competitive forces for Company X, regarding product Y, revealed that in each case, the physical asset replace decision is preferred. It is however necessary to calculate the average scores for the effect of the five competitive forces for both the repair option as well as for the replace option. Thus, refer to the following average calculations.

$$\text{Repair Option} = \frac{2+2+2+3+2}{5} = 2.2 \tag{4.4.14}$$

$$\text{Replace Option} = \frac{4+4+4+4+5}{5} = 4.2 \tag{4.4.15}$$

Thus, in terms of additional competitive advantage and future performance enhancement, it is suggested that the physical asset be replaced. Furthermore, the above calculated average scores represent the average performance ratings for the repair and the replace options according to the performance rating system in Table 4.3.

The following section will detail the effect of the physical asset repair/replace decision on the organization's social sustainability.

4.4.4 Effect of Physical Asset Repair/Replace Decision on Social Sustainability

As mentioned before in Section 3.1.4.2, sustainability forms an integral part of the decision-making process, especially those that concern decisions that are of a significant investment nature. Incorporating sustainability into the decision-making process ensures that the decision-maker consider the long-term effect of the decision on the organization, as well as on the environment in which the organization competes.

Social sustainability represents social capital, which in turn represent the investments and services that enable a society to function properly. In Section 3.1.4.2 it is suggested that the social sustainability performance of a physical asset repair/replace decision be divided into the following fields:

1. Internal Human Resources

    a. Employment stability: The impact of the physical asset repair/replace decision on the available job opportunities within the organization, as well as the fairness of compensation.

    b. Employment practices: To ensure that the operation of the physical asset to be repaired or replaced comply with the laws of the country, human rights declaration and fair employment standards and to also ensure gender and racial equality.

    c. Health and safety: Assess the impact of the operation of either the current physical asset or the physical asset to be procured on the health and safety of employees working on or near the physical asset. Also, to analyze the measures taken to prevent the risk of health and safety and the occurrence of a health and/or safety incident.

2. External population

    a. Human capital: Assess the impact of the physical asset repair/replace decision on the employees' ability to work and generate an income. Also, assess the impact on the employees' health and safety, physiological well-being, education, training and skill levels.

b. Productive capital: Assess the effect that the physical asset repair/replace decision place on infrastructure availability for the employee to maintain production.

c. Community capital: Assess the effect of the physical asset repair/replace decision on sensory stimuli, for example aesthetics, noise, odour level, cultural properties, security, impact on poverty and economic welfare.

Thus, from Section 3.1.4.2, in order to analyze the effect of either the physical asset repair decision or the physical asset replace decision on the social sustainability of the organization, each of the above mentioned fields need to be considered where applicable. It is also stated in Section 3.1.4.2 that the establishment of social sustainability indicators aid in the analysis of the organization's social sustainability performance.

Thus, it is suggested that the above mentioned fields within social sustainability serve as the basis for the establishment of social sustainability indicators. As with the analysis of the five competitive forces in Section 3.1.4.1, the effect of the physical asset repair/replace decision can only be analyzed by someone with an objective knowledge of the organization's activities, and the effect thereof on the social sustainability performance of the organization under consideration. Thus, the user of the framework is expected to either posses this knowledge him/herself, or consult a particular person or group of people within the organization that have this knowledge.

As the analysis of the social sustainability indicators is also of a qualitative nature, it is necessary to convert the analysis of the effect of the physical asset repair/replace decision on social sustainability into quantitative metrics. Therefore, as suggested in Section 3.1.4.1, the user of the framework is to make use of a point rating system as illustrated in Table 4.3.

The aim of analyzing the effect of the physical asset repair/replace decision on social sustainability is to determine the impact and effects that these decisions have on the social systems in which the organization operates. Thus, incorporating the impacts on social sustainability into the strategic physical asset repair/replace system serves as an indicator to the organization's social sustainability performance for the decision under consideration.

The following detailed worked example will serve as further explanation of the suggested method of determining the effect of the physical asset repair/replace decision on the organization's social sustainability.

4.4.4.1 Social Sustainability Performance Worked Example

In accordance with the information supplied in Section 4.2.2 each of the identified criteria is accompanied by a worked example. This section specifically deals with the analysis of the physical asset repair/replace decision on the organizational social sustainability performance. In each case, the effect of the physical asset repair decision and the effect of the physical asset replace decision is considered separately. As mentioned in Section 4.4.4, the information used for the evaluation of the effect of the physical asset repair/replace decision on the organizational social sustainability performance cannot be obtained from financial statements and is obtained from expert opinion.

This worked example will again consider the case of Company X contemplating replacing one of their existing physical assets with a newer version. As mentioned in Section 4.4.4, the effect of the physical asset repair/replace decision on the organizational sustainability performance is measured by means of social sustainability indicators, specifically those that concern the organization's internal human resources as well as the external population. Therefore, the effect of the physical asset repair decision, as well as the effect of the replace decision for Company X is determined by analyzing the effects of the respective decision on the before mentioned social sustainability indicators.

Firstly, the indicators that form part of the internal human resources of Company X are considered for both the physical asset repair decision, as well as for the physical asset replace decision. Thus, from Section 3.1.4.2 the first indicator of social sustainability within internal human resources is employment stability. The current physical asset in operation requires a total of three employees to operate and to produce product Y. Each of these employees receives the same compensation, regardless of their gender, race and/or age as they all received similar training. Company X has a total work force of 20 members thus, the operation of the physical asset is directly responsible for 15% of the employees of Company X. It must also be noted that apart from the direct employees that is needed for the operation of the physical asset, indirect employment is also needed for the administration and human resources linked to the operation of the physical asset. From the cash flow statement in Table A.1 in Appendix A and the Balance Sheet in Table A.4, the initial value of the physical asset under consideration accounts for 53.3% of Company X's equipment, refer to the following calculation.

$$\frac{\text{Value of physical asset}}{\text{Value of total equipment}} \times 100\% = \frac{\text{ZAR}1,000,000}{\text{ZAR}1,875,000} \times 100\% = 53.3\% \quad (4.4.16)$$

The operation of the current physical asset is also responsible for the generation of most of the revenues through the production and sales of product Y. Therefore, apart from directly employing the operators that run the physical asset, other administrative and sales positions are also dependent on the operation of the physical asset.

The replacement physical asset considered by Company X operates in much the same manner as the current physical asset and also requires a total of three employees for operation. Each of these employees will have to receive some additional training as the new physical asset provides some additional features and operating modes, as discussed in the previous sections. As with the current physical asset, providing that all three employees receive the same training, all three employees will receive the same compensation, regardless of gender, race and/or age. Also, from the cash flow statement in Table A.1 and the Balance Sheet in Table A.5 in Appendix A, the value of the replacement physical asset accounts for 39% of the total value of Company X's equipment, refer the following calculation.

$$\frac{\text{Value of physical asset}}{\text{Value of total equipment}} \times 100\% = \frac{\text{ZAR}1,200,000}{\text{ZAR}3,075,000} \times 100\% = 39\% \qquad (4.4.17)$$

As with the repair option, there is direct and indirect labour that depends on the operation of the physical asset, both from the technical side as well as from the sales and administrative side.

The second indicator of social sustainability within internal human resources is employment practices. Both the current physical asset in operation, as well as the one considered for replacement comply with the laws of the country as well as with the human right declaration. As mentioned before, the compensation of all employees operating the current physical asset and those that will operate the replacement physical asset is equal and not based on gender, race and/or age. Also, the employment of the operators of the physical asset, both the current one in operation and the one considered for replacement, is not based on either the person's gender, race or age, but rather on fitness for the position and the relevant experience.

The third and final indicator of social sustainability within internal human resources is health and safety. The current physical asset in operation and the physical asset considered for replacement produce high levels of noise and have various moving parts that can pose a safety risk to its operators. However, all operators are provided with the relevant Personal Protective Equipment (PPE) to ensure that all noise levels are below that required by law. Also, all moving parts are covered with guards and covers to prevent direct contact with the employees. Relevant safety Standard Operating Procedures (SOP) are available in the case of maintenance and operation to prevent operators and other employees from injury and causing harm to themselves or others.

Secondly, the effect of both the physical asset repair decision as well as the replace decision on social sustainability indicators that fall within external population is considered. The first indicator within external population is human capital. As mentioned in Section 3.1.4.2, the effect of the decision on human capital deals with the effect on the individual's ability to work and generate an income, as well as the impact on his/her health and safety, well-being, education, training and skill levels. The physical asset that is currently in operation requires the operators to have operational specific training. As mentioned before, three operators are needed for the current physical asset. All three operators are given the same training such that if one of the operators is ill or classified as unfit for work, one of the other two operators can take over his/her responsibilities until he/she returns or is replaced. There are numerous other physical assets that operate in much the same manner as the current physical asset in operation, thus even if the operator decides to work for another company and he/she has undergone the relevant training, he/she will be able to generate an income, if that company employs such a physical asset.

As stated before, the new physical asset that is considered for replacement operates in the same manner as the current one in operation and also requires three operators. The Original Equipment Manufacturer (OEM) of the new physical asset provides the operators with the necessary additional training that is required to operate the extra features provided by the new physical asset. All three operators are given the same training so that, as mentioned before, if one operator is ill or unfit for work, one of the other two operators will be able to take over his/her responsibilities. The additional training sets these operators apart from those that received the general training for these types of physical assets, consequently increasing their training and skill levels and the value of the operators to Company X.

The second indicator that falls within the external population is productive capital. According to Section 3.1.4.2, the effect of a decision on productive capital is the effect that the decision has on the infrastructure availability for the employee to maintain production. For both the repair decision, as well as for the replace decision, the infrastructure required by the physical assets are the same, thus the employees will be able to maintain production with the current infrastructure as is.

The third and final indicator that falls within the external population is community capital. As mentioned before, the current physical asset as well as the physical asset considered for replacement produce high levels of noise, however all operators are issued with the relevant PPE to ensure that the noise level is below that required by law. Also, Company X's production facility is situated in an industrial area with no residential areas in the near area. As stated before, the operation of the physical asset is responsible for the direct employment of three operators and indirectly responsible for numerous administration jobs as well. Thus, Company X contributes towards job creation and supports the economic welfare of its employees.

Considering all of the above mentioned information regarding the social sustainability indicators, and the effect of the physical asset repair as well as the replace decision on the social sustainability of Company X, the following scores have been assigned according to Table 4.3.

Repair Option: 4
Replace Option: 4

Higher assigned scores indicate that the respective decision promotes the development of social sustainability within the company and the opposite is true for lower assigned scores.

The following section deals with the effect of the physical asset repair/replace decision on the environmental sustainability of an organization.

4.4.5 Effect of Physical Asset Repair/Replace Decision on Environmental Sustainability

As stated in Section 4.4.4.1, sustainability is an important factor that must be incorporated into the physical asset repair/replace decision-making process. Also, as mentioned in Section 3.1.4.2, an organization that complies with the ISO14001 standard is required to implement an EMS whereby the organization is required to identify, measure and control its environmental impacts. This thesis however does not consider the development and implementation of an EMS, but requires the organization to already have an EMS in place before the application of the proposed framework.

It was thus suggested that the environmental sustainability performance of an organization be measured by means of environmental sustainability KPIs, refer to the following repetition of the four main criteria.

1. Air resources: Analyze the contribution of the physical asset repair/replace decision to the regional air quality as well as the potential global effects such as global warming and stratospheric ozone depletion.

2. Water resources: Analyze the impact of the physical asset repair/replace decision on the quantity and quality of the available water i.e. water usage, pollution etc.

3. Land resources: Analyze the impact of the physical asset repair/replace decision on the biodiversity as well as the direct and indirect effect release of effluents and substances that cause soil pollution.

4. Mineral and energy resources: Analyze the contribution of the physical asset repair/replace decision to the depletion of non-renewable energy and mineral resources.

The purpose of analyzing the effect of the physical asset repair and replace decision on the environmental sustainability of the organization, is to determine the impact that the physical asset has on the environment it operates in. Also, as stated in Section 3.1.4.2 the analysis of environmental sustainability KPIs not only aid the organization with assessing its environmental sustainability performance, but also serves as a method to assess the progress of the organization towards the promotion of environmental sustainable practices.

Therefore, in order to fully incorporate the effect the physical asset repair/replace decision has on the environmental sustainability of the organization, each of the above mentioned criteria have to be considered. Furthermore, as stated in Section 3.1.4.2, determining the impact of the physical asset repair and replace decision on the environmental sustainability of the organization involves an objective evaluation of effect of the respective decision on the above mentioned factors. Thus, as with the evaluation of the impacts on the organizational social sustainability, the evaluation of the impacts of the physical asset repair and replace decision on the organizational environmental sustainability is based on expert opinion.

The following worked example will provide more clarity regarding the suggested method for the evaluation of the effect of the physical asset repair/replace decision on the organization environmental sustainability.

4.4.5.1 Environmental Sustainability Performance Worked Example

This section deals with the analysis of the impact of the physical asset repair/replace decision on the organizational environmental sustainability. The effect of the physical asset repair decision, as well as the physical asset replace decision on each of the four main criteria as stated in Section 4.4.4.1 is analyzed, from which an overall score is determined for the environmental sustainable performance of the respective decision. As mentioned in the previous section, the information used in this analysis is determined from an objective evaluation of the respective decision on the environmental sustainability criteria, as well as expert opinion.

As with the other worked examples in this chapter, as well as for the sake of continuity, this worked example also considers the case of Company X contemplating replacing one of their physical assets. As stated in Section 4.4.4.1, the effect of the physical asset repair/replace decision on the organizational environmental sustainability is determined using environmental KPIs, divided into four main criteria. These criteria include; air resources, water resources, land resources, and mineral and energy resources. For each of the before mentioned criteria, the impact of the physical asset repair decision, as well as the physical asset replace decision is determined, respectively.

Firstly, the effects of the physical asset repair/replace decision on the air resources are analyzed. The current physical asset in operation, as well as the one considered for replacement, have no discharge or exhaust gasses that cause a direct form of air pollution. However, both are electrically powered and have a power rating of 500kW. Thus, indirectly the power consumption from the national grid contributes to air pollution and ozone depletion caused by the power generation industry.

Secondly, the impacts of the physical asset repair/replace decision on the water resources are analyzed. Although the parts used to make product Y are manufactured using water, the operation of the current physical asset as well as that of the one considered for replacement does not directly require any water. Moreover, as mentioned before, both the physical assets are electrically powered and thus contribute to the use of water resources by power generation companies. Also, both physical assets do not produce any waste substances that, with improper disposal, can mix with water resources and cause possible contamination. If however the lubrication oil and grease used on various gears, bearings and other moving parts are not applied carefully and the excess cleaned properly, contamination of disposal water can occur.

Thirdly, it is necessary to analyze the effects of the physical asset repair/replace decision on the land resources. During the construction phase of Company X's factory premises a large piece of land was prepared for the various buildings that form part of the factory. During this process many trees, bushes and other unwanted shrubs were removed, the land was levelled and various ditches were dug in order to lay electrical cables and water lines. The building housing the current physical asset is therefore responsible for some degradation of the area's biodiversity, however it must be noted that the land was already part of an industrial area that has been in use for a number of years. Also, the physical asset that is considered for replacement will be situated in the same building as the current one in operation, and will thus not require the construction of any additional space. As mentioned above, both physical assets do not produce any effluents that can cause soil pollution, however if the lubrication oil and grease is not disposed of correctly, it may result in water and soil pollution.

Lastly, the impacts of the physical asset repair/replace decision on the mineral and energy resources are considered. As stated above, the current physical asset in operation, as well as the one considered for replacement, are both electrically powered. Thus, since most of the electricity in South Africa is generated from coal power stations, both physical assets indirectly contribute to depletion of coal, a non-renewable resource.

Therefore, considering all of the above mentioned information and taking into account the combined effect of the operation of physical asset repair/replace decision on the environmental KPIs, the following scores have been assigned to the respective decisions.

Repair Option: 4
Replace Option: 4

Even though the operation of the physical asset indirectly contributes towards the depletion of coal and air pollution, options are not yet available in the country to generate electricity more environmentally friendly with the high voltages and currents needed for the operation of the physical assets. Moreover, the physical asset itself does not directly contribute towards air pollution and the depletion of coal. Furthermore, the negligible effect the operation of the physical assets have on the water and soil resources in combination with no direct impacts on air and non-renewable resources, result in an overall high score with regards to environmental sustainability.

As with the analysis of the physical asset repair/replace decision on social sustainability, higher scores indicate that the respective decision does not contribute considerably to the deterioration of environment.

The following section entails the evaluation of the respective weighting factors that are assigned to the five criteria analyzed in this section. This also forms part of the Problem Analysis stage, refer to Figure 4.1 in Section 4.1.2.

4.4.6 Determining Framework Criteria Weighting Factors

From Section 3.2.1.1, each of the evaluated criteria that form part of the strategic physical asset repair/replace decision-making framework have to be assigned a relevant weighting factor. This weighting factor represents the importance of that specific criterion to the framework as a whole. Also, as mentioned in Section 4.1.3, an important feature of the framework is flexibility. Thus, depending on the decision under consideration, as well as the industry or organization of application, the weighting factors are not fixed and can be adjusted to best suit the particular situation. From Figure 4.1 the identification of these weighting factors also form part of the Problem Analysis stage of the strategic physical asset repair/replace decision-making framework.

Furthermore, from Section 4.2.1 the AUT technique is identified as the MCDM technique that is most suitable to the physical asset repair/replace decision. It is thus necessary to restate the basic computations involved in the calculation of the AUT, refer to Section 3.2.1.

$$V(a) = \sum_{i=1}^{n} x_i y_i(a) \tag{4.4.18}$$

$$\sum_{i=1}^{n} x_i = 1.0 \tag{4.4.19}$$

Where x_i represents the relative weight factor for the ith criterion and $y_i(a)$ represents the score assigned to the ith criterion.

For this study, i is equal to five, corresponding to the five criteria identified in Section 4.2.2, namely

Criteria 1: Physical asset repair/replace decision rate of return
Criteria 2: Value created by physical asset repair/replace decision
Criteria 3: Effect of physical asset repair/replace decision on five competitive forces
Criteria 4: Effect of physical asset repair/replace decision on social sustainability
Criteria 5: Effect of physical asset repair/replace decision on environmental sustainability

Each of the above mentioned criteria are evaluated, in detail in Sections 4.4.1 to 4.4.5. In each case the impacts of the physical asset repair decision, as well as the replace decision are evaluated and assigned a relevant score. This section however entails the identification of the weighting factors of each of the above mentioned criteria. As mentioned before, the identification of the weighting factors is dependent on the organization in which the strategic physical asset repair/replace decision-making framework is applied, as well as on the discretion of the decision-maker or decision-making team.

As stated in Equation 4.4.19, the sum of the weighting factors must be equal to one. Thus, each of the above mentioned influencing criteria are assigned a fractional value according their importance, which when added together, are equal to one. Therefore, for continuity as well as to better illustrate the process of identifying the weighting factors, Company X is again considered.

As with any other profit seeking company, the main aim of Company X is to provide a return to its investors by means of making a profit. However, as stated in Section 2.1.5 there are numerous other factors that also influence the decision to either repair or replace a physical asset. The factors considered in this study are those represented by the identified influencing criteria stated before. It is thus necessary to determine the relative importance of each of the influencing criteria with respect to the interests of Company X in the production of product Y.

First and foremost, the financial impacts of the physical asset repair/replace decision is considered. As mentioned before, Company X is a profit seeking company, consequently making a profit is an important organizational objective. As discussed in Section 3.1.2.1, the costs of either repairing or replacing the physical asset under consideration is interpreted as two different projects or potential investments. Therefore, if Company X were to invest capital into either of the two before mentioned projects, the project with the higher rate of return would be most advantageous. The same is true for investing capital into the project that would yield the highest future economic value. It was thus decided by the decision-making team of Company X that the impact of the rate of return and the value created by the physical asset repair/replace decision are equal and accounts for 50% of the total weight of the five influencing criteria.

From Section 3.1.4.1 the performance of Company X relative to that of its competitors have a significant effect on the company's profitability and competitive advantage. Also, from Section 4.4.3 a company's competitive advantage above that of rival companies have a substantial impact on financial performance. Consequently, Company X's decision-making team decided that the impact of the physical asset repair/replace decision on the FFF represents 20% of the total weight of the five influencing criteria.

Finally, as stated in Section 4.4.4, incorporating social and environmental sustainability into the strategic physical asset repair/replace decision-making framework, forces the decision-maker or decision-making team to consider the long-term effects of the decision on the company as well as on the industry in which the company operates. Also, from Section 3.1.4.2 incorporating social and environmental sustainability into the decision-making framework promotes good business practices, which in turn attracts new potential investors. It was thus decided by the decision-making team of Company X that the impact of the physical asset repair/replace decision on the social and environmental sustainability are equal and accounts for the remaining 30% of the total weight of the influencing criteria. Therefore, refer to Table 4.11 for a summary of the weighting factors of the identified influencing criteria.

From the weighting factors illustrated in Table 4.11, it is evident that the financial impacts of the physical asset repair/replace decision have the greatest effect on the outcome of the decision. However, as mentioned before, even though the financial factors play a significant role in the outcome of the decision, other factors like the impact of the decision on the competition as well as sustainability also contribute, to some extent, to the outcome of the decision. Therefore, what

Table 4.11: Influencing criteria and corresponding weighting factors

Criteria	Weight	Weighting Factor
Physical asset repair/replace decision rate of return	25%	0.25
Value created by physical asset repair/replace decision	25%	0.25
Effect of physical asset repair/replace decision on FFF	20%	0.2
Effect of physical asset repair/replace decision on social sustainability	15%	0.15
Effect of physical asset repair/replace decision on environmental sustainability	15%	0.15

sets this framework apart from others is that the eventual result of the physical asset repair/replace decision is not solely dependent on financial factors, albeit the high contribution of financial factors to the result of the decision.

Following the identification of the relevant weighting factors in the Problem Analysis stage of the strategic physical asset repair/replace decision-making framework, is the Problem Validation stage, refer to Figure 4.1. Thus, the following section details the combination of the identified influencing factors with their relevant weighting factors, and the integration of the respective criteria to calculate a single score for both the physical asset repair decision, as well as for the physical asset replace decision.

4.5 Problem Validation

From the strategic physical asset repair/replace decision-making framework development process illustrated in Figure 4.1 as well as from the process flow diagram illustrated in Figure 4.2, this section details the combination of the relevant weighting factors with the respective identified influencing criteria. Furthermore, this section also includes the final integration of the combined influencing criteria and weighting factors into the calculation that determines the final framework score for the physical asset repair decision, as well as for the physical asset replace decision.

Therefore, it is thus necessary to restate the various influencing criteria with their calculated scores from Section 4.4 as well as the identified weighting factors from Section 4.4.6, refer to Table 4.12.

Table 4.12: Influencing criteria, corresponding assigned scores and weighting factors

Criteria	Repair Decision Score	Replace Decision Score	Weighting Factor
Physical asset repair/replace decision rate of return	4	1	0.25
Value created by physical asset repair/replace decision	0	0	0.25
Effect of physical asset repair/replace decision on FFF	2.2	4.2	0.2
Effect of physical asset repair/replace decision on social sustainability	4	4	0.15
Effect of physical asset repair/replace decision on environmental sustainability	4	4	0.15

From the information illustrated in Table 4.12, it is evident that both the qualitative and quantitative criteria that were identified in Section 4.2.2 have all been converted to a single scoring system using Table 4.3. Thus enabling the integration of both the qualitative and quantitative influencing criteria into the strategic physical asset repair/replace decision-making framework.

Therefore, the final score for both the repair decision as well as the replace decision is calculated using the AUT technique with the relevant criteria scores and weighting factors. Refer to the following equations and computations for the calculation of the strategic physical asset repair/replace decision-making framework final scores.

Firstly, the final framework score for the repair decision is calculated as follows

$$V(a) = \sum_{i=1}^{n} x_i y_i(a)$$

Where $y_i(1) = 4$, $y_i(2) = 0$, $y_i(3) = 2.2$, $y_i(4) = 4$ and $y_i(5) = 4$. Also,

$$\sum_{i=1}^{n} x_i = 1.0$$

Where $x_i(1) = 0.25$, $x_i(2) = 0.25$, $x_i(3) = 0.2$, $x_i(4) = 0.15$ and $x_i(5) = 0.15$. Such that

$$V(a)_{repair} = (4 \times 0.25) + (0 \times 0.25) + (2.2 \times 0.2) + (4 \times 0.15) + (4 \times 0.15)$$

$$V(a)_{repair} = 2.64$$

Secondly, the final framework score for the replace decision is calculated using $y_i(1) = 1$, $y_i(2) = 0$, $y_i(3) = 4.2$, $y_i(4) = 4$ and $y_i(5) = 4$, such that

$$V(a)_{replace} = (1 \times 0.25) + (0 \times 0.25) + (4.2 \times 0.2) + (4 \times 0.15) + (4 \times 0.15)$$

$$V(a)_{replace} = 2.29$$

Therefore, from the strategic physical asset repair/replace decision-making framework final scores calculated for both the physical asset repair and the replace decision, it is suggested that the current physical asset that is in operation be kept in operation. This suggestion stems from the result that the physical asset repair score was slightly higher than that of the physical asset replace score. It is however evident that the two calculated scores are very close, therefore even though it is not the most advantageous decision to replace the physical asset at this current point in time, it might be a better decision in a few months, depending on the maintenance costs attributed to the current physical asset in operation.

As mentioned before, the application of this framework is merely to serve as an indication of the most advantageous decision based on the identified influencing criteria. The outcome of the physical asset repair/replace decision is still mostly dependent on the discretion of the decision-maker, or decision-making team. Therefore, given the small difference between the physical asset repair score and the physical asset replace score, the decision-maker or decision-making team might decide to rather replace the physical asset, instead of taking the recommended repair route.

4.6 Chapter Summary

This chapter details the development of a strategic physical asset repair/replace decision-making framework for the management of physical asset repair/replace decisions of significant investment. The development of the framework is supported throughout the chapter by a comprehensive literature study in Chapter 2 and 3. This chapter provides the reader with a thorough overview of the framework, the purpose as well as application. In each section the various steps involved in the development of the framework is discussed in detail, considering the objectives, inputs, involved processes, and outputs.

The proposed framework aims to provide decision-makers with a practical, structured and flexible process to serve as a guide in making physical asset repair/replace decisions, regardless of the industry in which the decision arises. The framework developed in this chapter is unique as it integrates the impacts of the physical asset repair/replace decision on multiple criteria to determine the eventual outcome of the decision, rather than focusing on a single financial aspect.

Therefore, based on the research objectives stated in Section 1.3, this chapter focused on the fourth research objective, achieving the following objectives and sub-objectives:

Develop a strategic decision-making framework for the management of physical asset repair/replace decisions

a) Determine criteria for selecting a relevant decision-making method

b) Determine relevant factors that will form part of the decision-making method

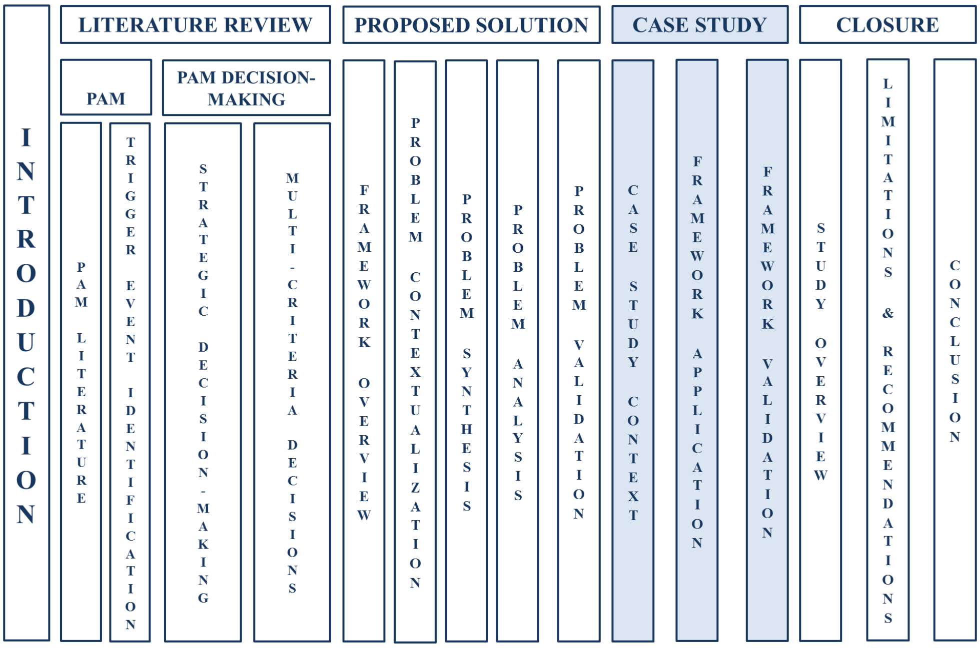
c) Consolidate the factors and decision-making method into a structured, strategic decision-making framework

The following chapter, Chapter 5, applies the strategic physical asset repair/replace decision-making framework developed in this chapter to a case study of a physical asset repair/replace decision in a physical asset intensive company. The aim of Chapter 5 is to assess the validity of the developed framework if applied in practice.

Chapter 5

Case Study

This chapter consists of a case study conducted in cooperation with a physical asset intensive company in the mining industry of Namibia. The aim of this chapter is to assess the validity of the strategic physical asset repair/replace decision-making framework developed in Chapter 4, by applying the framework to a real world physical asset repair/replace decision.



This chapter entails, firstly, an overview and background of the company under consideration in preparation of the case study. Thereafter, the application of the proposed framework is discussed in a similar format to that of Chapter 4, whereby each criterion is discussed and evaluated individually. Finally, the chapter concludes with a summary of the results obtained, as well as the suggested decision outcome that would be most advantageous to the company under consideration.

This chapter consists of five main sections namely; case study overview, case study preparation, current company practices, framework application and framework validation.

5.1 Case Study Overview

As mentioned before, the strategic physical asset repair/replace decision-making framework is validated by considering a case study in the Namibian mining industry. The management of physical asset repair/replace decisions is a common and significant issue in the mining industry, especially those that concern decisions regarding significant investments of capital. Also, the mining industry, in particular a copper smelter, is heavily dependent on the operation of physical assets for the production of a particular product. Therefore, the copper smelter is a good representative for physical asset intensive industries as a whole, and thus suitable as a case study for the validation of the proposed framework.

According to Balbach (1999) the aim of a case study can be described as a method '*to study intensely one set of something as a distinct whole*'. Also, Rowley (2002) states that a case study is a data-based investigation that inquires about a current-day situation or phenomena within the context of its real life. Thus, rather than attempting to replicate a particular phenomenon or situation, a case study aims to better understand the particular phenomenon or situation.

The remainder of this section details the case study overview by focusing on the context of the case study as well as the identified business problem.

5.1.1 Case Study Contextualization

This research study was conducted in collaboration with the Asset Care Research Group (ACRG) at Stellenbosch University. The ACRG acts as an intermediary to facilitate interactions regarding PAM related topics between research and industry. The copper smelting company under consideration is a subsidiary of large international organization engaged in the exploration, acquisition, mining and processing of precious metals.

Extensive research and consultations with both academic and practising professionals, identified the management of physical asset repair/replace decisions as an area worth investigating, in order to revise the current decision-making methods in practice. For confidentiality purposes, the copper smelter under consideration is referred to as Company Cu for the remainder of this study.

A site visit to Company Cu was conducted in August 2015 to evaluate and investigate the physical asset repair/replace decisions they deal with, as well as the management thereof. The operations and processes at Company Cu are physical asset intensive, however the equipment and machinery in use are outdated and worn from years of operation. Initially the site investigation was focused on individual physical assets that require large capital investment. However the investigation also revealed that because Company Cu is an extremely large company that is physical asset intensive, considering the repair/replace decision of a single physical asset would not reflect in the yearly financial statements.

It was thus decided to focus on the physical asset repair/replace decision of an entire processing plant, as this was a decision that Company Cu was considering at the time. Therefore, the site investigation was narrowed to focus specifically on the physical asset repair/replace decision of the Slag Mill. The equipment and machinery used in the Slag Mill are old, and after evaluation, the throughput tonnage and availability of the Slag Mill is lower than that needed for optimal production. Company Cu was thus considering to either refurbish the old equipment and machinery in the Slag Mill plant or to replace major components in the Slag Mill plant with newer and more modern versions. The next section provides an introduction to the process and equipment involved in Slag Mills.

5.1.2 Introduction to Slag Mills

As mentioned before, Company Cu's main activity is the smelting of copper ore. In the smelting process, the ore is exposed to extremely high temperatures, thus melting the ore. During this process, the metal in the ore separates from the impurities, also referred to as slag. Slag is thus a combination of compounds that are removed from the copper ore, however not all of the copper is removed from the slag during the smelting process. Thus, the Slag Mill is responsible for the recovery of the copper that is still present in the slag and that would otherwise be lost. It is thus necessary to comprehend the processes involved in the Slag Mill to better understand the plant and to complete the case study.

The Slag Mill plant that is under consideration consists of small processing circuit that includes grinding, thickening, flotation and filtration, also refer to the process flow diagram in Figure 5.2:

The grinding circuit in the Slag Mill consists of two ball mills and a rod mill that is responsible for grinding the granulated slag from the smelting process. Thereafter the ground material is transported with water to the thickeners where a special combination of chemicals is added to the material. Following this, the material is transported to the flotation banks. The flotation banks consist of agitators that excites the material, inducing turbulence. During agitation, compressed air is also introduced into the circuit to further excite the material. The chemicals that

Figure 5.1: Slag Mill Plant at Company Cu

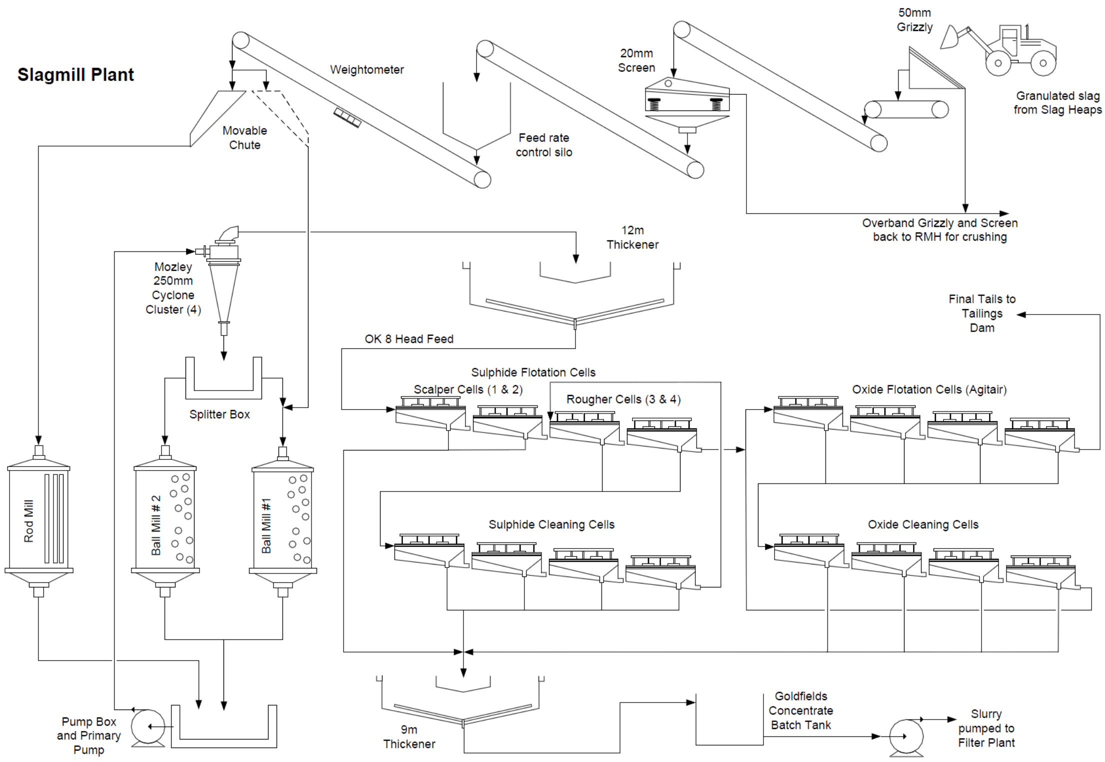
were added in the thickeners then react with the ground slag such that the copper particles in the slag become hydrophobic. Bubbles form in the flotation banks from the excitation and start overflowing from the flotation banks into launders. During the agitation process, the hydrophobic copper particles stick to the bubbles thereby exiting the flotation banks with the overflow. The slurry collected in the launders is then pumped to the filter plant for the remaining processes involved in the recovery process.

The contextual background provided in the above detailed description and related figures is a sufficient background to the study. The following section details the business problem involved in the study.

5.1.3 Case Study Business Problem

In the mining industry, the decision to either repair or replace a physical asset is a common occurrence, also the outcome of the decision is mostly based on pure financial factors. However as discussed before in Section 4.2.2, there are numerous other factors, other than financial performance, that should have an impact on the physical asset repair/replace decision.

Figure 5.2: Slag Mill Process Flow Diagram



On the other hand, repairing or replacing a physical asset requires a significant investment of capital, and thus the financial impacts do have a large impact on the outcome of the decision. Nevertheless, even though the financial impacts are significant, other factors such as the effect of the decision on the company's competition and sustainability must also be included in determining the outcome of the decision.

The objective is therefore to determine whether repairing or replacing the physical asset under consideration is the most advantageous decision, based on the impacts of more than one governing factor. From investigation, the decision to either repair or replace the Slag Mill at Company Cu is, like most other profit seeking companies, based purely on the financial aspects thereof. The following questions summarize Company Cu's main concerns:

1. What will the refurbishment of the current equipment and machinery in the Slag Mill cost?

2. What will replacing the major equipment and machinery in the Slag Mill cost?

3. Will either of the two options have an effect on the availability and throughput tonnage?

In the case of Company Cu, the existence of the Slag Mill in the production process plays and important role in recovering copper that would otherwise go to waste. Even though the Slag Mill plant is small compared to that of the smelting plant, the equipment and machinery that needs to be refurbished or replaced is very expensive. Therefore, there is a need to find a balance between risk and cost in context of the major components of the Slag Mill. Optimal operation of the Slag Mill has a significant effect of the financial aspects of Company Cu as it accounts for significant copper savings which in turn leads to increased revenue.

The strategic physical asset repair/replace decision-making framework proposed in Chapter 4 acts as a guideline for managers of the physical asset repair/replace decisions in physical asset intensive companies. Application of the proposed framework to Company Cu therefore aims to address the decision to either refurbish or replace major components in the Slag Mill. The following section details the preparation involved for the case study to be considered.

5.2 Case Study Preparation

As mentioned before, the strategic physical asset repair/replace decision-making framework is validated by means of a representative case study. Therefore, the validation of the proposed framework involves the application of the framework proposed in Chapter 4 to a problem in real world practice.

According to Ghauri (2004) the application of a case study requires an adequate amount of preparation. Also, according to Welman *et al.* (2005) there are three major aspects of case study research namely; triangulation, clearly defined boundaries of the case, and the search for recurring evidence. Triangulation is described as the collection of data from different sources and through different methods.

This section details, firstly, the framework validation methodology followed in this study. Thereafter, the scope of the case study is discussed, elaborating on the boundaries of the case study. Finally, the data requirements are discussed detailing the data preparation and triangulation.

5.2.1 Framework Validation Methodology

As stated in Section 5.1, the case study is performed at Company Cu, a copper smelting company. The case study is performed by applying the strategic physical asset repair/replace decision-making framework to the management of the physical asset repair/replace decision of the Slag Mill major equipment and machinery. Refer to Section 4.1.2, Figure 4.1 for an illustration of the proposed strategic physical asset repair/replace decision-making framework.

In order to validate the proposed framework, a validation process needs to be followed. The main steps involved on the framework validation process is listed below.

1. Case study scope definition
2. Case study data requirements
3. Company current practices
4. Proposed framework application
5. Framework validation

The first step in the framework validation process is the definition of the scope of the case study. Thereafter, the data required for the case study is discussed, followed by a description of the current company practices that involve the management of physical asset repair/replace decisions. Furthermore, the application of the proposed framework to the case study is discussed, and lastly, the validation of the proposed framework.

As the decision to either refurbish or replace the major equipment and machinery in the Slag Mill was initiated in 2014, the application of the strategic physical asset repair/replace decision-making framework follows the scheme of a retrospective case study. The outcome of the case study is a recommendation regarding the decision that is most advantageous to Company Cu based on the application of the framework proposed in Chapter 4.

5.2.2 Case Study Scope Definition

According to Turbit (2005) defining the scope of a study is essential. In broad, defining the scope of a study is the process of developing a mutual understanding of what is to be included, or excluded from a study. In other words, the definition of the scope of the case study is the establishment of its boundaries. Ideally the boundaries of a case study should be large enough for it to be representative, but small enough so that the amount of information is manageable.

This study therefore focusses specifically on the physical asset repair/replace of the major equipment and machinery in the Slag Mill of Company Cu. The machinery and equipment mentioned before include: mills, transformers, voltage converters, various electrical motors, various pumps, gearboxes and accompanying bases, pinion and girth gears for the mills, trunnions, and all the labour, transport and instrumentation costs that are involved. Currently the availability of the Slag Mill is between 80% and 85%, however ideally the availability should be 95% for optimal production. Thus the repair/replace decision is based on increasing the plant availability, and it is therefore necessary to determine which option would be the most advantageous for Company Cu.

As mentioned before, as a result of the large asset base of Company Cu, considering the repair/replace decision of a single physical asset would be meaningless as it would not show in the company's financial statements. Therefore this study considers the repair/replace decision of multiple physical assets in the Slag Mill plant, for the purposes of increasing the plant availability and throughput tonnage. Thus, for the remainder of this study, the repair/replace decision of the major equipment and machinery in the Slag Mill is referred to as the repair/replace decision of the Slag Mill.

During application of the proposed framework, the combined effect of the refurbishment or replacement of the above mentioned equipment and machinery will be considered. Therefore, the effect of an individual pump or electrical motor will not be considered, rather the combined effect of all the pumps, electrical motors, mills and all other equipment and machinery that are planned to either be refurbished or replaced are considered. Thus, the consideration of the refurbishment and replacement decisions are therefore based on all the activities included in increasing the availability of the Slag Mill.

Therefore, the scope of the physical asset repair/replace decision for this study includes the costs of all the activities included in either refurbishing the Slag Mill or replacing the Slag Mill in order to increase the availability and throughput. Table 5.1 illustrates the costs that are included and excluded in the Slag Mill refurbishment decision, as well as for the Slag Mill replacement decision.

From the information in Table 5.1 all of the costs associated with the Slag Mill refurbishment and replacement are those that are directly related to activities involved to either refurbish or replace the Slag Mill. The costs that are excluded in both cases include the those associated with production, such as adjusting the recovery process as well as the costs associated with the possibility of a change in the production labour.

The following section details the data requirements for this case study as well as the methods by which the data are collected from the various sources.

5.2.3 Case Study Data Requirements

Successful application of the proposed framework is dependent on the quality of the quantitative and qualitative data obtained from Company Cu. As mentioned in Section 4.2.1, both qualitative and quantitative data is required for the framework

Table 5.1: Case Study Scope Definition

SCOPE		
DECISION	**INCLUDED**	**EXCLUDED**
Slag Mill Refurbishment	All repair costs	Process adjustment costs
	All costs of buying spare parts	Production labour adjustment costs
	All servicing costs	
	All involved labour costs	
	All involved transport costs	
	All costs of consumable materials used	
Slag Mill Replacement	Costs of all new equipment	Process adjustment costs
	Costs of all new machinery	Production labour adjustment costs
	Costs of all installations	
	All commissioning costs	
	All involved labour costs	
	All involved transport costs	
	All costs of consumable materials used	
	All costs of infrastructure adjustments	

application. The quantitative and qualitative data is retrieved from Company Cu's financial statements, as well as relevant feasibility studies and management reports. Also, additional data required is obtained from various discussions and consultations with relevant area managers and experts.

During the data gathering process it was discovered that there exists a relatively large gap between the data that is ideal for the application of the proposed framework, and that available in practice. The following are some of the issues that were experienced during the data gathering process.

1. Poor use of cost codes - As with many large organizations, Company Cu makes use of a cost code system for the documentation of various costs according to their departments. However, for each department Company Cu has at least twenty different cost codes, thus allowing all individuals having access to a purchase request book to book costs against a different cost code for the same department.

2. General financial statements - Company Cu has an extremely large asset base, all belonging to more than five different plants. Instead of grouping the expenses, income, value of assets etc. according to the various plants, the financial statements are generalized for the whole of Company Cu. Thereby complicating the isolation of the Slag Mill from all the other plants.

3. Lack of single source data - The data regarding the costs associated with a specific plant are documented with various different departments. Thus,

complicating the data gathering process.

4. Poor data availability - Some of the data are not documented and are communicated by word of mouth. Also, because a lot of the equipment and machinery are from the 1960's, information regarding spares and associated costs are extremely difficult to obtain.

The factors mentioned above are not specific to Company Cu, and are issues that occur at most companies in the mining industry. Therefore, it is important that the proposed framework make provision for such issues, especially in situations when data availability is limited.

The following section details the current practices at Company Cu, specifically focussing on the relevant processes involved in the management of physical asset repair/replace decisions.

5.2.4 Company Current Practices

This section details the current practices that are in place at Company Cu. Firstly, the general physical asset repair/replace processes and procedures are discussed, detailing the various stages involved. Thereafter the practices specific to the assessment of the Slag Mill repair/replace decision are discussed.

5.2.4.1 Company Cu Project Execution Practices

As mentioned before in Section 3.1, decisions that require a significant investment of capital, such as the physical asset/repair decision, can be seen as potential projects. A standard procedure is in place at Company Cu for the management of projects that require significant research, planning and capital investment. The procedures involved are detailed in two documents titled 'Project Functional Procedures' and 'Engineering Projects Procedure'. The before mentioned documents detail the various stages, sub-stages and involved tasks in the management of these projects. Management of these projects fall under the Engineering Projects department of Company Cu, however the instigation of such capital intensive projects originate from upper management.

The various stages that fall within the pre-described procedure are illustrated in Figure 5.3. From the information in the Project Delivery Model, there are four stages in the management of capital intensive projects. As mentioned before, these projects originate at the company executive level. The first stage of the procedure entails the initiation of a capital intensive project from the executive level by determining if such a project is in line with the company strategy. Thereafter, once the project has been initiated, a cost centre is developed for the acquisitions and expenditures that are involved in the planning and execution of the project.

Figure 5.3: Project Delivery Model of Company Cu

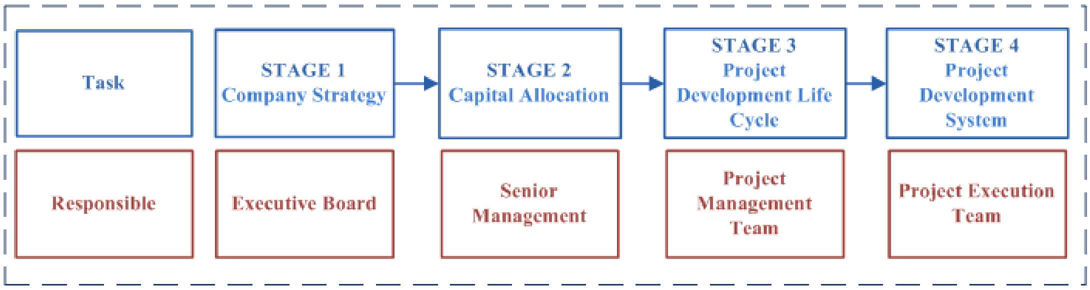
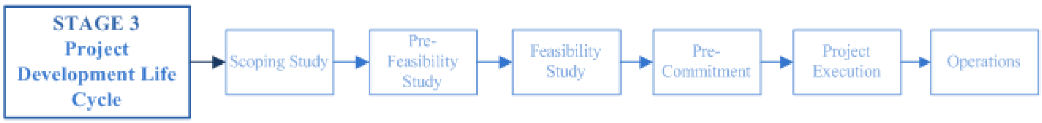


Figure 5.4: Project Life Cycle Development of Company Cu



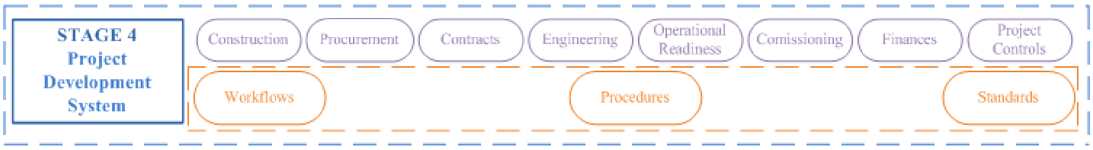
This stage of the procedure falls within the responsibility of the company's senior management. The third stage involves the development of the project life cycle, refer to Figure 5.4 for a more detailed illustration of the steps involved in this stage.

From the different steps illustrated in Figure 5.4, the scoping study involves a high level research study of the intended project regarding the project work, limits and responsibilities of the various role players. The pre-feasibility study includes the identification of the project design criteria, assessment of possible alternatives, engineering involved for the project and the identified alternatives, infrastructure needs, construction workforce, and finally, procurement management and logistics. For each of the before mentioned factors, a cost as well as a time needs to be estimated.

Following the pre-feasibility study is the feasibility study. During this step the project and engineering design criteria are evaluated as well as the engineering involved in the execution of the project. This includes the location selection, process flow, equipment design, infrastructure, electrical requirements, as well as the hydrology and water management. Other important aspects include the assessment of water treatment, construction needs and workforce, procurement management and logistics. As with the pre-feasibility study, the document must be accompanied with an estimated cost and execution time, however the estimation of these values need to be accurate and will serve as the cost and time budget.

Furthermore, once the feasibility study is complete and has been approved, the

Figure 5.5: Project Development System of Company Cu



pre-commitment follows. In this step, all of the feasibility deliverables have been determined, the project scope and designs have been finalized and the project is ready for execution, pending the issuing of the required permits. Once all the required permits and approvals have been received, the project execution step materializes. During this step all of the planned work from the feasibility study is completed, ideally within the planned time frame and budget. Finally, once all the planned work is complete and the quality is satisfactory, the project is handed over to operations.

The last stage in the Project Delivery Model in Figure 5.3 is referred to as the project development system, refer to Figure 5.5.

This stage is a summary of the factors involved in the successful execution of a project. From the information in Figure 5.5 the construction, procurement, contracts, engineering, operational readiness, commissioning, finances and project controls involved in the project must be executed with the proper procedures and standards, detailing the appropriate work flows involved in each case.

The following Section details the steps involved in the assessment of the Slag Mill repair/replace decision.

5.2.4.2 Slag Mill Repair/Replace Decision Practices

The decision to consider either the refurbishment or replacing the major components in the Slag Mill originated from the executive level, as a result of another ongoing project that requires the Slag Mill to be operational and running at higher throughput tonnage.

Currently, the availability of the Slag Mill is between 80% and 85% with an average daily throughput of about 500 tons. The required availability is determined to be 95% and the daily throughput 700 tons. From the aforementioned information, the events that triggered the consideration of the Slag Mill repair/replace decision is the physical asset performance, the age of the physical asset as well as the need for additional capabilities. All of the before mentioned trigger events are discussed in Sections 2.2.6, 2.2.2 and 2.2.7, respectively.

Therefore, the rationale behind the Slag Mill repair/replace decision is to increase the current plant availability as well as the throughput tonnage.

As mentioned before, the Slag Mill is responsible for the recovery of copper from the slag that is a by-product of the smelting process. It is also stated that the copper recovered by the Slag Mill would otherwise be wasted if not for the recovery process. It must also be noted that apart from the copper present in the slag, there are also other precious metals, in small concentrations, that are recovered through this process.

If the Slag Mill were to run at 25 tons per hour, with a availability of 83% it would result in a total throughput of 504 tons of slag per day. Also, the current recovery rate for copper is 80% and for the other precious metals, 90%. Unfortunately, for the purposes of confidentiality, the specific concentrations of copper and the other precious metals cannot be disclosed. Nevertheless, Company Cu is paid a fixed price per metric ton of copper smelted. Therefore, the total amount of savings that the Slag Mill accounts for equals USD 6,360 or N$ 85,860 per day, refer to Exchange-Rates.org (2015) for the current exchange rate between USD and N$. This amount consists of the copper recovered from the Slag Mill multiplied by the price charged per ton of copper smelted. Therefore, the yearly savings equals N$ 31,338,900 with an average availability of 83%.

If the daily throughput tonnage were to increase to 700 ton per day with a availability of 95% as required, the hourly throughput tonnage would increase to 30.7 ton per hour. Thus, the savings would increase to USD 9,461 or N$ 127,717. Therefore, the yearly savings would amount to N$ 46,616,613 with an average availability of 95%. Furthermore, the increased throughput tonnage as well as plant availability would thus result in a 48.7% increase in the yearly savings, refer to Equations 5.2.1 and 5.2.2.

$$\%\text{Savings} = \frac{\text{Savings at 700 tph and 95\%} - \text{Savings at 500 tph and 83\%}}{\text{Savings at 500 tph and 83\%}} \times 100 \qquad (5.2.1)$$

$$\%\text{Savings} = \frac{\text{N\$}46,616,613 - \text{N\$}31,338,900}{\text{N\$}31,338,900} \times 100 = 48.7\% \qquad (5.2.2)$$

From the calculations of the possible yearly savings by increasing the throughput tonnage as well as the availability, it is obvious why Company Cu is considering the Slag Mill repair/replace decision.

The following section details the application of the strategic physical asset repair/replace decision-making framework proposed in Chapter 4 to the case study. Concluding the following section is the validation of the of the proposed framework and a discussion of the framework findings compared to that of the current practices at Company Cu.

5.3 Strategic Physical Asset Repair/Replace Decision-Making Framework Application

This section deals with the application of the strategic physical asset repair/replace decision-making framework to the case study. As mentioned in Section 4.1.3, one of the features of the framework is that is should be applicable in real world practice. Thus, the results obtained from the application of the framework is in agreement with the data collected for the case study.

From Section 4.2.2 the influencing five criteria are as follows:

1. Physical asset repair/replace decision rate of return
2. Value created by physical asset repair/replace decision
3. Effect of physical asset repair/replace decision on five competitive forces
4. Effect of physical asset repair/replace decision on social sustainability
5. Effect of physical asset repair/replace decision on environmental sustainability

Also, from the flow diagrams in Figure 4.1 and Figure 4.2, each of the above mentioned framework influencing criteria are evaluated and assigned a score between zero and five, based on the score rating system illustrated in Table 4.3. For the purposes of application in this chapter, the above mentioned table is restated below as Table 5.2.

Table 5.2: Criteria performance score rating

Score	0-1	2-3	3-4	4-5
Description	Poor Performance	Intermediate Performance	Satisfactory Performance	Superior Performance

The first step in the application of the proposed framework, is therefore to gather the data necessary for the case study. The following section details the data gathering process as well as the data collected for the case study.

5.3.1 Data Gathering

In Section 4.4 the data required for each of the above mentioned influencing criteria is discussed. Therefore, this section details the data gathering process at Company Cu In each case the data obtained from Company Cu is discussed as well as the shortcomings experienced. The analysis of each of the influencing criteria is discussed in detail with the relevant calculations involved. Thereafter, each of the evaluated criteria are assigned a relevant score from which the framework final score is then calculated and the results discussed.

5.3.1.1 Slag Mill Repair/Replace Decision and IRR

The first influencing criterion from Section 5.3 is the physical asset repair/replace decision rate of return. From the detailed discussion in Section 4.4.1 the following information is necessary for the calculation of the physical asset repair/replace decision IRR.

1. Initial investment amount
2. Cash flow period to be analyzed $(0 - n)$
3. Operating cash inflows
4. Terminal cash flows
5. Organizational specific MARR

Unfortunately, as mentioned in Section 5.2.3, Company Cu does not keep separate cash flow statements for the various production plants, instead all of the information is grouped together in a single statement. Also, as the Slag Mill has been in operation since the 1960's, the financial statements regarding the initial investment for the Slag Mill is not available any more. Moreover, an estimate of the current value of the Slag Mill is not accurate since a lot has been changed and replaced in 40 years, and information regarding the equipment still in use is difficult to come by. It must however be noted that Company Cu is in the process of electronic cataloguing of all information and data that is available for the current equipment and machinery in use.

Even though the above mentioned issues hindered the gathering of the data necessary for the calculation of the repair/replace decision IRR, it was however possible to obtain estimates regarding the refurbishment costs, as well as the costs of replacing major equipment and machinery in the Slag Mill. Furthermore, the estimated monthly production costs as well as maintenance costs could also be obtained from budget statements and cost estimates.

Therefore, with regards to the repair decision, the estimated total investment to refurbish the Slag Mill serves as the initial investment, similarly, the estimated total cost to replace the major equipment and machinery serves as the initial investment amount for the replace decision. Also, as calculated above, the savings that the Slag Mill accounts for with respect to the repair/replace decision is assumed to be an income in the calculation of the IRR. Furthermore, the company specific MARR was obtained through consultation with Company Cu's Financial Manager. Therefore, from the information needed to calculate the Slag Mill repair/replace decision IRR listed above, only information regarding the cash flow period is outstanding.

As most of the before mentioned information is based on estimates by industry professionals, the calculation of the IRR would be more accurate over a shorter period with less unknowns. Thus, it was decided that n would equal five, where one period is equal a year of operation. Therefore, year 0 represents the year in which either refurbishment or the replacement of the Slag Mill took place. Thereafter, years one, two, three and five contain 365 days and year four 366 days.

All of the work involved in the refurbishment or replacement of the Slag Mill will be completed within year zero, as a result the entire initial investment amount is allocated in year zero. Refer to Section 5.3.2.1 for the calculation of the Slag Mill repair/replace decision IRR.

5.3.1.2 Slag Mill Repair/Replace Decision and EVA

The second influencing criterion from Section 5.3 is the value created by the physical asset repair/replace decision. Refer to Equations 4.4.5 to 4.4.12 for the various calculations involved in determining the physical asset repair/replace decision EVA. The following is a summarized list of the information required for the calculation of the EVA.

1. Net Operating Profit After Tax (NOPAT)
2. Current Assets (CA)
3. Current Liabilities (CL)
4. Interest Bearing Debt (IBD)
5. Net Working Capital (NWC)
6. Total assets, total debt and total liabilities

All of the above mentioned information is obtained from Company Cu's Balance Sheet and Income Statement. The financial statements for 2015 were not yet completed for consideration in this study, however, the Slag Mill repair/replace decision was introduced at the end of 2014, beginning of 2015. Thus, the year-end financial statements for 2014 is used for the calculation of the Slag Mill repair/replace decision EVA, refer to Appendix B.1 and B.2 for Company Cu's Income Statement and Balance Sheet for the year ended 2014. It must however be noted that since neither the refurbishment nor the replacement costs are accounted for in the financial statements of 2014, it is necessary to adjust the statements somewhat to include these costs in order to calculate the respective EVA's. Refer to Section 5.3.2.2 for the calculation of the Slag Mill repair/replace decision EVA, as well as the explanations of the financial statement adjustments for the respective decisions.

5.3.1.3 Slag Mill Repair/Replace Decision and Five Competitive Forces

The third influencing criterion listed in Section 5.3 is the effect of the physical asset repair/replace decision on the five competitive forces. As stated in Section 4.4.3 the analysis of the effect of the physical asset repair/replace decision of the five competitive forces, is essentially an analysis of the effect of the decision on the company's competitive rivals. The five competitive forces are listed below as:

1. Competitive rivalry within the industry
2. Threat of new entrants
3. Power of suppliers
4. Power of buyers
5. Threat of substitutes

As stated in Section 4.4.3, none of the above mentioned forces can be measured from financial statements or any other quantitative data source. The effect of the Slag Mill repair/replace decision on each of the before mentioned forces can only be analyzed by an individual, or group of individuals, within the company that posses an intricate knowledge of the competitive environment in which Company Cu competes. Thus, the qualitative data required to analyze the effect of the Slag Mill repair/replace decision on the five competitive forces was obtained through consultations with numerous individuals that have knowledge of the environment in which Company Cu competes.

It must be noted that the Slag Mill repair/replace decision does not involve the introduction of any new functions within the copper recovery process, rather the aim is to improve the current recovery process to increase the availability and throughput tonnage of the plant. Furthermore, the Slag Mill is responsible for supplying a recovery service to the copper smelting process, rather than producing a product. Thus, the analysis of the Slag Mill repair/replace decision on the five competitive forces is based on the service it provides, unlike the fictional company considered in Section 4.4.3.1. Refer to Section 5.3.2.3 for the analysis of the effect of the Slag Mill repair/replace decision on the five competitive forces.

5.3.1.4 Slag Mill Repair/Replace Decision and Social Sustainability

As stated in Section 3.1.4.2, the integration of sustainability into a decision-making process has a significant effect on the decision-making process. Therefore, the fourth criterion that forms part of the strategic physical asset repair/replace decision-making framework is social sustainability. From Section 4.4.4, social sustainability represent the investments and services that enable a society to function properly. It is also suggested that the effect of the Slag Mill repair/replace decision on social sustainability be measured by means of the following indicators:

1. Internal Human Resources
   i. Employment stability
   ii. Employment practices
   iii. Health and safety
2. External Population
   i. Human capital
   ii. Productive capital
   iii. Community capital

As with the analysis of the effect of the Slag Mill repair/replace decision on the five competitive forces, the data required for this analysis is also of a qualitative nature, and cannot be obtained from financial statements or some other quantitative data source. The effect of the Slag Mill repair/replace decision on social sustainability can only be analyzed by an individual, or group of individuals, that can objectively examine Company Cu's practices and the effect thereof on the social systems in which it operates.

In 2011, a site wide Environmental Impact Assessment (EIA) was undertaken by an outside company to determine the impacts of the operations of Company Cu on the environment, as well as the social environment in which the company operates. The majority of the data required to analyze the effect of the Slag Mill repair/replace decision on social sustainability was thus obtained from the before mentioned EIA as well as Company Cu's sustainability report for 2014. Additional information was obtained from numerous consultations with personnel and employees working in the Slag Mill as well as from personal observation. Refer to Section 5.3.2.4 for the analysis of the impacts of the Slag Mill repair/replace decision on the social sustainability.

5.3.1.5 Slag Mill Repair/Replace Decision and Environmental Sustainability

The fifth and final criterion in the strategic physical asset repair/replace decision-making framework is environmental sustainability. As mentioned in Section 4.4.5 any company that complies with the ISO14001 standard is required to identify, measure and control the impacts of its operations on the environment. It is thus necessary to determine the effect of the Slag Mill repair/replace decision on the environmental sustainability of Company Cu. Furthermore, the effect of the Slag Mill repair/replace decision is analyzed by means of the following environmental sustainability indicators:

1. Air resources
2. Water resources
3. Land resources
4. Mineral and energy resources

Similar to the analysis of the effect of the Slag Mill repair/replace decision on the five competitive forces and social sustainability, the data needed for the analysis of the effect on the environmental sustainability is also of a qualitative nature. As mentioned in Section 5.3.1.4, an EIA regarding the social and environmental impacts of Company Cu was undertaken in 2011. In this document each of the above mentioned environmental sustainability indicators are discussed for the entire site of Company Cu. Fortunately, it is possible to highlight the effects attributed specifically to the operations of the Slag Mill and the impacts thereof. Also, apart from the information in the EIA, additional information was obtained from personal observation and information from Company Cu's environmental department. Refer to Section 5.3.2.5 for the analysis of the effect of the Slag Mill repair/replace decision on the environmental sustainability.

The following section details the analysis of each of the influencing criteria identified in the proposed framework, according to that data collected for the Slag Mill repair/replace decision at Company Cu.

5.3.2 Strategic Physical Asset Repair/Replace Decision-making Framework Influencing Criteria Analysis

This section details the evaluation of each of the influencing criteria identified in Section 4.2.2 according to the data obtained from Company Cu. Each section includes a detailed analysis of the relevant criterion under consideration as well as the calculations needed to evaluate the performance of the criterion. Furthermore, following the analysis each of the criteria are also assigned a relevant score according to that illustrated in Table 5.2. Thus, this section will follow the same sequence and methods as the worked examples discussed in Section 4.4.

5.3.2.1 Slag Mill Repair/Replace Decision IRR Evaluation

As mentioned in Section 5.3.1.1 Company Cu does not keep separate cash flow statements for the various plants on site. Also, technically the Slag Mill does not directly make any revenue, rather it recovers copper from the slag that is again transferred back into the smelting process, which in turn generates revenue. Also, as stated in Section 5.2.4.2 the Slag Mill repair/replace decision is aimed at increasing the average daily throughput to 700 tons with an average availability of 95%.

Moreover, as stated in Section 5.3.1.1, information regarding the monthly production and maintenance costs could be obtained from the budget statements for the year. Thus, the theoretical copper and other precious metals recovered from a throughput tonnage of 700 tons and availability of 95% can be calculated, as well as the theoretical cost saving attributed to the recovery process in the Slag Mill. It must however be noted that by replacing the major equipment and machinery in the Slag Mill increases the recovery of Copper to above 85%, whereas the repairing these components only result in an average cooper recovery of 80%.

From Section 5.3.1.1 the initial investments for both the Slag Mill repair and replace decision refers to the total capital investment estimated from the costs summarized in Table 5.1. The total initial investment for the Slag Mill refurbishment is estimated to equal N$ 77,900,000, this amount includes the estimated costs of the repair of major equipment as well as the associated labour costs. Furthermore, the total initial investment for the Slag Mill replacement is estimated to equal N$ 100,500,000, where this amount includes the costs of the replacement of the major equipment in the Slag Mill, as well as the associated labour costs. The before mentioned major equipment refers to those components that would, if repaired or replaced, result in an increased throughput tonnage as well as higher plant availability.

According to the budget statements for Company Cu, the estimated monthly maintenance cost equals N$300,000 and the estimated production costs for a throughput of 700 tons at 95% availability equals N$ 1,600,000. It is thus necessary to calculate the theoretical savings attributed to the copper recovery process in the Slag Mill for both the repair and the replace decision. From the information in Section 5.2.4.2 Company Cu is paid a fixed amount per metric ton of copper smelted. It was also stated that the five cash flow periods considered in the calculation of the Slag Mill repair/replace decision IRR is equivalent to five operational years. Thus, with an availability of 95%, recovering an average of 18 tons of copper a day, the copper savings attributed to a year of operation is equal to USD 3,453,083 or N$ 46,616,613.

Furthermore, the Slag Mill equipment is depreciated on the straight line basis with 10% of the original value each year. As the original value of the Slag Mill is unknown, the depreciation for the repair decision is based on the initial investment required to refurbish the entire plant. Since depreciation does not involve actual cash flow, it is not included in the cash flow of both the repair and the replace option.

Moreover, as stated in Section 4.4.1.1, SARS (2014/2015) allows a company in the mining industry a special tax allowance of 20% of the value of the improvement for five consecutive years and a 40% special tax allowance in the first year for the acquisition of new equipment followed by 20% for the following three years. This also does not involve actual cash flow and is thus not included in the cash flow of both the repair and replace option. However, the before mentioned tax allowance does have an effect on the corporate income tax that Company Cu is obligated to pay every financial year. By deducting the aforementioned tax allowances, assuming that Company Cu makes a profit, decreases the corporate tax the company has to pay at the end of the financial year. Thus, this results in a cash inflow from corporate tax that the company should have paid, but because of the special tax deduction, does not have to. Moreover, from PWC (2014) the corporate tax rate in Namibia is equal to 33%.

Thus, the cash inflow for the special tax deduction for the repair decision, as well as for the first three years following the replacement of the Slag Mill option, is calculated as follows

$$\text{Cash Inflow from Tax} = \text{Value of Refurbishment} \times 20\% \times 33\% \tag{5.3.1}$$

And the cash inflow for the special tax deduction for the first year for the Slag Mill replacement option is calculated as follows

$$\text{Cash Inflow from Tax} = \text{Value of Replacement} \times 40\% \times 33\% \tag{5.3.2}$$

Therefore, considering all of the before mentioned information, the cash flow for the five year period is calculated as follows

$$\begin{aligned}\text{CF}_n = {} & \text{Recovery Savings} - 12 \times (\text{Maintenance Costs} + \text{Operational Costs}) \\ & + \text{Cash Inflow from Tax}\end{aligned} \tag{5.3.3}$$

Note that the Recovery Savings are calculated for 365 days in year one, two, three and five, and for 366 days in year four. In order to calculate the Recovery Savings the copper recovery rate for the replacement decision is taken as 85% and 80% for the repair decision. Therefore, the cash flows for periods one to five of the Slag Mill replace decision are calculated as follows

$$\text{CF}_1 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}13,266,000 \quad (5.3.4)$$

$$\text{CF}_2 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}6,633,000 \quad (5.3.5)$$

$$\text{CF}_3 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}6,633,000 \quad (5.3.6)$$

$$\text{CF}_4 = \text{N\$}44,407,114 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}6,633,000 \quad (5.3.7)$$

$$\text{CF}_5 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) \quad (5.3.8)$$

Also, the cash flows for periods one to five of the Slag Mill repair decision is calculated as follows

$$\text{CF}_1 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}5,141,400 \quad (5.3.9)$$

$$\text{CF}_2 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}5,141,400 \quad (5.3.10)$$

$$\text{CF}_3 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}5,141,400 \quad (5.3.11)$$

$$\text{CF}_4 = \text{N\$}44,407,114 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}5,141,400 \quad (5.3.12)$$

$$\text{CF}_5 = \text{N\$}44,285,783 - 12 \times (\text{N\$}300,000 + \text{N\$}1,600,000) + \text{N\$}5,141,400 \quad (5.3.13)$$

Table 5.3: Slag Mill Repair/Replace Decision Cash Flows

Cash Flow Period, n	Replace Decision	Repair Decision
0	N$ (100,500,000)	N$ (77,900,000)
1	N$ 34,751,783	N$ 24,022,137
2	N$ 28,118,783	N$ 24,022,137
3	N$ 28,118,783	N$ 24,022,137
4	N$ 28,240,114	N$ 24,136,331
5	N$ 21,485,783	N$ 24,022,137

The cash flows for the Slag Mill repair/replace decision is summarized in Table 5.3.

According to the Financial Manager of Company Cu, the company specific MARR for this particular decision regarding the Slag Mill repair/replace decision equals 15%. Therefore, a potential investment of capital into either repairing or replacing the Slag Mill is only acceptable if the calculated IRR exceeds the MARR. Considering all of the before mentioned information, it is possible to calculate the IRR for the Slag Mill replace and repair decision, refer to Equations 5.3.14 and 5.3.15.

$$\begin{aligned} 0 = (-\text{N\$}100,500,000) + \frac{\text{N\$}34,751,783}{1+i} + \frac{\text{N\$ 28,118,783}}{1+i^2} \\ + \frac{\text{N\$ 28,118,783}}{1+i^3} + \frac{\text{N\$ 28,240,114}}{1+i^4} + \frac{\text{N\$ 21,485,783}}{1+i^5} \end{aligned} \tag{5.3.14}$$

$$\begin{aligned} 0 = (-\text{N\$}77,900,000) + \frac{\text{N\$}24,022,137}{1+i} + \frac{\text{N\$ 24,022,137}}{1+i^2} \\ + \frac{\text{N\$ 24,022,137}}{1+i^3} + \frac{\text{N\$ 24,136,331}}{1+i^4} + \frac{\text{N\$ 24,022,137}}{1+i^5} \end{aligned} \tag{5.3.15}$$

From the calculations in Equations 5.3.14 and 5.3.15, the calculated IRR for the Slag Mill replace decision is equal to 13% and the IRR for the repair decision is calculated as 16%. The information regarding the calculation of the Slag Mill repair/replace decision can therefore be summarized as follows

$\mathbf{MARR} = 15\%$
$\mathbf{IRR_{replace}} = 13\%$
$\mathbf{IRR_{repair}} = 16\%$

From the information above, the calculated IRR for the Slag Mill repair decision is higher than that of the replace decision. Also, when compared to Company Cu's MARR, the Slag Mill repair decision IRR exceeds the MARR by 1%, whereas the Slag Mill replace decision is 2% below the minimum attractive rate of return for investments. Therefore, based on the above calculated IRR's for the Slag Mill repair and replace decisions, the most beneficial decision, in terms of financial rate of return, is the Slag Mill repair decision. As mentioned in Section 5.3, is therefore necessary to assign both the Slag Mill repair as well as the replace decision with a relevant score, according to Table 5.2. Thus, since the Slag Mill repair decision is 1% above that of the MARR, it is assigned a score of 4 due to its superior performance. On the other hand, the Slag Mill replace decision is 2% below the MARR and is accordingly assigned a score of 1 corresponding to its poor performance. The assigned scores for the Slag Mill repair/replace decision can therefore be summarized as follows

$\mathbf{IRR_{replace}} = 1$
$\mathbf{IRR_{repair}} = 4$

The following section details the calculation of the Slag Mill repair/replace decision EVA as well as th determination of the relevant assigned scores.

5.3.2.2 Slag Mill Repair/Replace Decision EVA Evaluation

From the information in Section 5.3.1.2, the financial statements for 2015 are not yet available and thus the financial statements for the year ended 2014 are used to calculate the Slag Mill repair/replace EVA, refer to Appendix B for the Balance Sheet and Income Statement of Company Cu. It is also stated in Section 5.3.1.2 that neither the refurbishment nor replacement costs have been accounted for in the 2014 financial statements, thus the statements should be adjusted accordingly. Furthermore, as stated before, the aim of the Slag Mill repair/replace decision is to increase the plant throughput tonnage and availability to 700 tons a day and 95%, respectively. Moreover, similar to Section 5.3.2.1, the cost savings attributed to the copper recovery process is assumed to generate a revenue and thereby contributes towards the income generated for the financial year.

From Section 5.2.4.2, with an average availability of 83% and average throughput tonnage of approximately 504 tons per day at a rate of 80% copper recovery, the Slag Mill accounts for N$85,860 savings per day. The savings for a 365-day totals N$31,338,900. Also, as stated in Section 5.3.2.1 the estimated monthly maintenance and production costs equal N$300,000 and N$1,600,000, respectively. Furthermore, the initial investment for the Slag Mill repair decision is estimated as N$77,900,000 and the replace decision as N$100,500,000. Finally, the savings for a 365-day year with an average availability of 95% and daily throughput tonnage of 700 tons is theoretically calculated to equal N$43,874,460 and N$46,616,613 for the Slag Mill repair and replace decision, respectively.

Using the before mentioned information, the Income Statement of Company Cu is adjusted as follows for the Slag Mill repair decision, also for the adjusted Income Statement refer to Appendix B.3.

1. Revenue increases with (N$43,874,460-N$35,478,000)/12
2. Slag Mill production costs increase with N$1,600,000
3. Maintenance costs increase with N$77,900,000/12
4. Depreciation increases with (N$77,900,000*0.1)/12
5. Special Tax Allowance equals (N$77,900,000*0.2)/12
6. Financing Costs increase with 2.4%

Note that the values for the recovery savings i.e. additional revenues stated before are based on a whole year of operation, thus in order to adjust the Income Statement, the additional revenue generated is divided by 12. Moreover, the refurbishment cost, special tax allowance as well as the depreciation costs are also spread over a whole year, therefore these costs are also divided by a factor of 12. In order to finance the refurbishment of the Slag Mill an additional long-term loan is acquired, therefore the financing costs increase with a percentage relative to the costs of the existing long-term loans.

Accordingly the Balance Sheet of Company Cu is adjusted with following, also refer to Appendix B.4 for the adjusted Balance Sheet.

1. Machinery and Equipment decreases with the monthly depreciation of (N$77,900,000*0.1)/12
2. Cash and cash equivalents decrease with the first of twelve instalments equal to N$77,900,000/12
3. Asset retirement decreases with N$77,900,000
4. Long-term debt increases with N$80,140,272
5. Accumulated Profit/(Loss) decreases with N$9,411,103

Furthermore, the Income Statement of Company Cu is adjusted with the following for the Slag Mill replace decision, also refer to Appendix B.5 for the updated Income Statement.

1. Revenue increases with (N$46,616,613-N$35,478,000)/12
2. Slag Mill production costs increase with N$1,600,000
3. Maintenance costs increase with N$300,000
4. Depreciation increases with (N$100,500,000*0.1)/12
5. Special Tax Allowance equals (N$100,500,000*0.4)/12
6. Financing Costs increase with 3.1%

Similarly to the repair decision, the additional revenue generated is divided by a factor of twelve. The depreciation cost as well as the special tax allowance is also divided by 12 to compensate for a whole year of operation. Moreover, the acquisition of replacement equipment and machinery requires Company Cu to take out an additional long-term loan, thus the financing costs increase with a percentage relative to the existing long-term loans.

Accordingly, the Balance Sheet of Company Cu is adjusted as follows for the Slag Mill replace decision, refer to Appendix B.6 for the adjusted Balance Sheet.

1. Machinery and Equipment increases with N$100,500,000 while at the same time decreasing with the depreciation of (N$100,500,000*0.1)/12
2. Long-term debt increases with N$24,095,138
3. Accumulated Profit/(Loss) decreases with N$5,252,075

From the detailed discussion of the EVA in Section 4.4.2 as well as from the worked example in Section 4.4.2.1, once the relevant Balance Sheets and Income Statements have been obtained, the EVA can be calculated. Moreover, from Section 4.4.2, the first step in determining the Slag Mill repair/replace decision EVA is the calculation of the NOPAT, EBIT and ANOPBT. Refer to Table 5.4 for a summary of the aforementioned values from the Income Statements in Appendix B.3 and B.5.

From the information in Table 5.4, all of the values are negative, thereby indicating that Company Cu made a loss in 2014. It must also be noted that since Company Cu made a loss, no tax was deducted from the ANOPBT and thus the NOPAT is equal to the ANOPBT in both the Slag Mill repair and replace decision calculations.

The next step in determining the EVA is the calculation of the NWC, Average Invested Capital, V, E, D and WACC. Therefore, refer to Table 5.5 for a summary of the CA, C, CL and IBD obtained from the Balance Sheets in Appendix B.4 and B.6 for the Slag Mill repair and replace decisions.

Table 5.4: Summary of Slag Mill Repair/Replace Decision EBIT, ANOPBT and NOPAT

Metric	Repair Decision Value (N$)	Replace Decision Value (N$)
EBIT	(194,534,223)	(190,374,997)
ANOPBT	(206,317,468)	(217,491,795)
NOPAT	(206,317,468)	(217,491,795)

Table 5.5: Summary of Slag Mill Repair/Replace Decision CA, C, CL and IBD

Metric	Repair Decision Value (N$)	Replace Decision Value (N$)
CA	114,824,777	121,316,444
C	9,426,121	15,917,788
CL	186,543,027	186,543,027
IBD	3,450,714,679	3,474,809,817

Using the information in Table 5.5 and Equation 4.4.10, the NWC for the Slag Mill repair and replace decision is calculated as follows:

$$\text{NWC}_{\text{repair}} = \text{N\$}114,824,777 - \text{N\$}9,426,121 - \text{N\$}186,573,027 + \text{N\$}3,450,714,679 \quad (5.3.16)$$

$$\text{NWC}_{\text{repair}} = \text{N\$}3,369,540,308$$

$$\text{NWC}_{\text{replace}} = \text{N\$}121,316,444 - \text{N\$}15,917,788 - \text{N\$}186,543,027 + \text{N\$}3,474,809,817 \quad (5.3.17)$$

$$\text{NWC}_{\text{replace}} = \text{N\$}3,393,665,446$$

Using the above calculated values for the Slag Mill repair and replace decision NWC's, the Average Invested Capital is calculated using Equation 4.4.9.

$$\text{Average Invested Capital}_{\text{repair}} = \text{N\$}3,645,962,357 + \text{N\$}3,369,540,308 \quad (5.3.18)$$

$$\text{Average Invested Capital}_{\text{repair}} = \text{N\$}7,015,502,665$$

$$\text{Average Invested Capital}_{\text{replace}} = \text{N\$}3,745,624,857 + \text{N\$}3,393,665,446 \quad (5.3.19)$$

$$\text{Average Invested Capital}_{\text{replace}} = \text{N\$}7,139,290,303$$

Following the determination of the Slag Mill repair/replace decision NWC's is the calculation of the WACC, refer to Equation 4.4.11. It is thus necessary to determine the values of E, D, V, R_e and R_d. Table 5.6 is a summary of E, D and V obtained from the relevant Balance Sheets in Appendix B.4 and B.6. Note that E represents the market value of equity, thus it cannot be less than zero and is obtained from the financial statements of the group as a whole. Unfortunately, because of confidentiality reasons, these statements cannot be illustrated in this study.

Table 5.6: Summary of E, D and V for Slag Mill Repair/Replace Decision

Metric	Repair Decision Value (N$)	Replace Decision Value (N$)
E	3,327,035,993	3,327,035,993
D	3,450,714,679	3,474,809,817
V	6,777,750,672	6,801,845,810

In order to calculate the WACC for both the Slag Mill repair and replace decisions, the values for R_e and R_d also need to be determined. After consultation with the Financial Manager of Company Cu, the lending rate of all long-term liabilities equal 4.5% since Company Cu borrows funds from the parent company and not from the bank. Also, the share capital of 1,300 illustrated in all of the Balance Sheets in Appendix B represents 1,300 shares that cost N$1 each. The issuing costs amount to 12 cent per share, thus the proceeds from a single share amounts to 88 cents. Furthermore, 8 cents per issued share is used for the purposes of future earnings. Therefore, the values for R_e and R_d are calculated similar to that in Section 4.4.2.1 as the following

$$R_e = \text{Lending Rate} = 4.5\%$$

$$R_d = \frac{\text{N\$}0.08}{\text{N\$}0.88} = 9.1\%$$

Therefore, with a corporate tax rate of 33%, as stated in Section 5.3.2.1 the WACC is calculated using Equation 4.4.11 as follows

$$\text{WACC}_{\text{repair}} = \frac{\text{N\$3,327,035,993}}{\text{N\$6,777,750,672}} \times 4.5\% + \frac{\text{N\$3,450,714,679}}{\text{N\$6,777,750,672}} \times 9.1\%(1 - 33\%) \tag{5.3.20}$$

$$\text{WACC}_{\text{repair}} = 7.6\%$$

$$\text{WACC}_{\text{replace}} = \frac{\text{N\$3,327,035,993}}{\text{N\$6,801,845,810}} \times 4.5\% + \frac{\text{N\$3,474,809,817}}{\text{N\$6,801,845,810}} \times 9.1\%(1 - 33\%) \tag{5.3.21}$$

$$\text{WACC}_{\text{replace}} = 7.6\%$$

Using the calculated WACC's for the Slag Mill repair and replace decisions, as well as the calculated Average Invested Capital, it is possible to calculate the Capital Charge for the repair and the replace decision. Therefore, the respective Capital Charge values are calculated using Equation 3.1.15.

$$\text{Capital Charge}_{\text{repair}} = \text{N\$7,015,502,665} \times 7.6\% = \text{N\$533,178,203} \tag{5.3.22}$$

$$\text{Capital Charge}_{\text{replace}} = \text{N\$7,139,290,303} \times 7.6\% = \text{N\$542,586,063} \tag{5.3.23}$$

Finally, using Equation 4.4.5 the EVA for the Slag Mill repair and replace decision is calculated as follows:

$$\text{EVA}_{\text{repair}} = \text{N\$(206,317,468)} - \text{N\$533,178,203} = \text{N\$(739,495,671)} \tag{5.3.24}$$

$$\text{EVA}_{\text{repair}} = \text{N\$(217,491,795)} - \text{N\$542,586,063} = \text{N\$(760,077,858)} \tag{5.3.25}$$

The calculated EVA for the Slag Mill repair decision, as well as for the Slag Mill replace decision is negative, thereby suggesting that neither of the decisions will add any value to Company Cu. From the information illustrated in the Income Statements in Appendix B, Company Cu makes a net loss for 2014, this is one of the main reasons for the negative EVA's. Also, Company Cu is heavily dependent on long-term liabilities as a method of financing the smelting operations, which also contributes greatly to the negative EVA's. Furthermore, as a result of the negative EVA's for both the Slag Mill repair, as well as the Slag Mill replace decision, both are assigned a score of zero. The scores for the Slag Mill repair/replace decision evaluation can therefore be summarized as follows

$\mathbf{EVA}_{\text{repair}} = 0$
$\mathbf{EVA}_{\text{replace}} = 0$

The following section details the evaluation of the impact of the Slag Mill repair/replace decision on the five competitive forces, thereby determining the impact on Company Cu's industry rivals.

5.3.2.3 Slag Mill Repair/Replace Decision FFF Evaluation

The third influencing criterion identified in Section 4.2.2 is the effect that the Slag Mill repair/replace decision has on the five competitive forces. According to Company Cu's "Code of Business Ethics", fair competition amongst industry rivals is fundamental to the development of the company as a whole. As stated before, Company Cu provides a smelting service and does not produce a particular product, thus this evaluation is based on the service delivery of the Slag Mill to Company Cu, compared to that of other, similar companies.

The ore smelted at Company Cu is of a particular chemical composition, as a result there are only a few companies world-wide that can provide the same service. Copper ore is imported and transported to Company Cu via road or rail, thereafter the ore is smelted and transported to treatment facilities to further purify the copper. Therefore, Company Cu is merely responsible for the smelting service, however during the smelting process by-products are produced. Slag is one of the main by-products of the smelting process. As discussed in Section 5.1.2, the slag produced at Company Cu comprises of waste materials and copper. The purpose of the Slag Mill is therefore to recover the copper still present in the slag. Thus, the impact of the Slag Mill repair/replace decision on the FFF is evaluated based on not only the service that the Slag Mill provides to Company Cu, but also on the service that Company Cu provides its customers.

From Section 5.3.1.3 the first competitive force to be analyzed, is the effect of the Slag Mill repair/replace decision on competitive rivalry within the industry. According Company Cu's "Code of Business Ethics", it emphasizes principles of fair trade throughout all of the company's operations and supports fair competition. Also, as mentioned before, Company Cu is one of very few companies in the world that can accommodate this special type of copper ore, moreover it is the only company in the whole of Africa. Based on the aforementioned information, the competitive rivalry within the industry in which Company Cu operates is relatively low, irrespective of the Slag Mill repair or replace decision. Therefore, as a result of the low competitive rivalry, the impacts of the Slag Mill repair and replace decision are both assigned a score of five.

Competitive Rivalry$_{\text{repair}} = 5$
Competitive Rivalry$_{\text{replace}} = 5$

The second competitive force is the impact of the Slag Mill repair/replace decision on the threat of new entrants. From the financial statements in Appendix B, the capital required to operate in the same league as Company Cu is extremely high. Also, Company Cu has been in existence for many years and has established itself in the copper smelting business. Moreover, the physical assets and infrastructure required to smelt copper at a higher capacity and lower price than Company Cu requires substantial investment. Thus, the entry barriers set by Company Cu for possible entry into the industry are almost impossible to breach. Furthermore, there are other methods of smelting copper ore that would not result is such high concentrations of copper present in the slag, thus eliminating the need for the existence of the Slag Mill. However, the chances of Company Cu ever employing these methods are slim as it would result in the production of a harmful chemical above the levels allowed by law. Therefore, effect of the Slag Mill repair and replace decisions on the threat of new industry entrants are also both assigned a score of five.

Threat of New Entrants$_{\text{repair}} = 5$
Threat of New Entrants$_{\text{replace}} = 5$

Thirdly, the impact of the Slag Mill repair/replace decision on the power of suppliers is analyzed. As mentioned before, Company Cu is responsible for the smelting of a particular type of copper ore, as a result its facilities are designed around this material. Also, the copper smelted by Company Cu is limited in availability and can only be obtained in certain areas around the world. Therefore, as Company Cu provides a smelting service, the price of this service can be negotiated by the suppliers. Fortunately, Company Cu is also able to smelt the copper ore mined locally, however these mining companies have resorted to leaching activities to remove the copper from the copper ore. Furthermore, since the operation of the Slag Mill is dependent on the smelting of ore and the production of slag, the effect that the before mentioned price negotiations have on the smelting process, directly affects the Slag Mill, regardless of the repair or replace decision. Therefore, as a result of the influence of the suppliers on the operation of the Slag Mill, both the repair and replace decisions are assigned a score of three.

$\textbf{Power of Suppliers}_{\text{repair}} = 3$
$\textbf{Power of Suppliers}_{\text{replace}} = 3$

The fourth competitive force is the effect of the Slag Mill repair/replace decision on the power of buyers. Copper is a commodity and is therefore highly effected by the world market. As a result of the current economic dip, the copper price has dropped to record lows, consequently the operations of Company Cu has suffered greatly. From the before mentioned information, it is evident that the power of buyers is significant, irrespective of the Slag Mill repair or replace decision. Consequently, both the Slag Mill repair as well as the replace decisions are assigned a score of two.

$\textbf{Power of Buyers}_{\text{repair}} = 2$
$\textbf{Power of Buyers}_{\text{replace}} = 2$

The fifth and final competitive force is the impact of the Slag Mill repair/replace decision on the threat of substitutes. As mentioned before, Company Cu has considered using a different method of smelting copper that would rend the Slag Mill useless due to the low copper concentrations in the slag. However, this method would result in the production of a harmful chemical with concentrations above that allowed by legislation. Thus, the chances of the implementation of this smelting method is negligible. Moreover, copper is a commodity and one of the most useful metals on earth. According to Boric (2006), because of its desirable properties, copper is used in almost every major industry in the world, therefore the chances of it being replaced by a product that exhibits similar properties is highly unlikely. Thus, accordingly the Slag Mill repair and replace decision are each assigned a score of five.

$\textbf{Threat of Substitutes}_{\text{repair}} = 5$
$\textbf{Threat of Substitutes}_{\text{replace}} = 5$

Finally, similar to Section 4.4.3.1 the average score for the effect of the Slag Mill repair and replace decision is calculated. Therefore, refer to Equation 5.3.26 and 5.3.27 for the calculation of the average score of the Slag Mill repair decision and the Slag Mill replace decision, respectively.

$$\textbf{FFF}_{\text{repair}} = \frac{5+5+3+2+5}{5} = 4 \tag{5.3.26}$$

$$\mathbf{FFF}_{\text{replace}} = \frac{5+5+3+2+5}{5} = 4 \tag{5.3.27}$$

Thus, from the information in Equations 5.3.26 and 5.3.27, both the Slag Mill repair and replace decision have an average score of four. Therefore, from the analysis of the impact of the Slag Mill repair/replace decision on the FFF, both the repair and the replace decisions have relatively high scores, thereby implying that both options will result in future performance enhancement and additional competitive advantage. Moreover, according to the aforementioned analysis and in terms of the effect on competitive rivalry, both the Slag Mill repair and replace decisions are beneficial for Company Cu.

The following section details the analysis of the effect of the Slag Mill repair/replace decision on Company Cu's social sustainability.

5.3.2.4 Slag Mill Repair/Replace Decision Social Sustainability Evaluation

As mentioned in Section 4.4.4 the inclusion of social sustainability into a strategic decision-making framework forms an integral part of the decision-making framework. Moreover, as stated in Section 5 this case study is conducted at a copper smelting company in Namibia, a country with a total population of approximately two million people. According to Konrad Adenauer Stiftung, (KAS) (2015) the total unemployment rate in Namibia for 2015 is equal to 29.6% and 41.7% for individuals between the ages of 15 and 34. Furthermore, the Namibian economy is heavily dependent on mining and the export of raw materials for further processing.

The population of the district in which Company Cu is located is estimated to be around 23,000 of which approximately 18,000 live in the town in which Company Cu is located. Moreover, Company Cu is responsible for the employment of approximately 1,200 people either directly, or through contractor companies. The presence of Company Cu and other heavy industrial companies in the district has resulted in the availability of a large, skilled and diverse workforce. Using the before mentioned information and that obtained from the EIA and Company Cu's 2014 sustainability report, the impact of the Slag Mill repair/replace decision on the social sustainability can be determined. According to the discussion in Section 5.3.1.4, analyzing the effect of the Slag Mill repair/replace decision on social sustainability is done using the following performance indicators.

1. Internal Human Resources

    i. Employment stability

   ii. Employment practices
   iii. Health and safety

2. External Population
   i. Human capital
   ii. Productive capital
   iii. Community capital

In terms of the internal human resources, the first factor to consider is the effect of the Slag Mill repair/replace decision on employment stability. As mentioned before, Company Cu employs approximately 1,200 people of which 22 are permanently employed at the Slag Mill. Therefore, approximately 1.8% of Company Cu's employees are employed in the Slag Mill. These employees are responsible for the production as well as all the maintenance activities. Each of the before mentioned employees are compensated according to their level of skill as well as according to the number of normal and overtime hours worked. Comparing the initial investment of the Slag Mill repair decision and replace decision to the total value of Company Cu's fixed assets in the Balance Sheets found in Appendix B.4 and B.6, equal 2.1% and 2.7%, respectively. Thus, 1.8% of the employees are responsible for 2.1% and 2.7% of Company Cu's physical assets, implying that the Slag Mill is slightly understaffed. The Slag Mill repair decision is purely dependent on the current employees for the relevant maintenance, improvement and installation activities involved. Whereas contractor companies are responsible for most of the replacement of the major equipment and machinery that form part of the Slag Mill replace decision. The contracting of outside companies for the Slag Mill replacement decision has no effect on the job security of the people currently employed at the Slag Mill, they are merely responsible for installation and commissioning where after the permanent employees will continue with the maintenance and upkeep activities. Also, the new equipment and machinery does not require any additional labour and thus, the current employee base remains the same.

The second factor within internal human resources is the effect of the Slag Mill repair/replace decision on employment practices. According to the sustainability report, Company Cu regards its employees as its most valuable stakeholders. Moreover, Company Cu supports equality in the work place as well as fair compensation, regardless of the persons race, gender or age. Moreover, Company Cu complies with the Affirmative Action Act of 1998 that legislates that all Namibian based companies are to provide equal opportunities, (Government Gazette of the Republic of Namibia, 1998). The operation of the physical assets in the Slag Mill that are considered either for repair or replacement all comply with Company Cu's safety regulations, with the relevant safety guards and precautions in place. Furthermore, even though the employees at the Slag Mill are predominantly males, the employment of females with the same skill sets and experience are not discarded, it is more a result of an overall low percentage of females in the mining industry in Namibia. The before mentioned remains the same regardless of the Slag Mill repair or replace decision.

The last factor within internal human resources is the effect of the Slag Mill repair/replace decision on health and safety. In any physical asset intensive industry there are inherent safety risks to employees, especially operations that involve moving, rotating and electrical machines and equipment. As mentioned before, the necessary safety precautions have been put in place to mitigate any safety risk to employees. Also, all employees are issued with Personal Protective Equipment (PPE) that include the following; hard hat, acid-and-fire resistant overalls, safety boots, ear plugs, safety glasses, gloves and respirators. Each plant is allocated a safety representative trained in basic first aid in case of emergency. There is also a clinic situated on site in case of minor injuries or tests. Regular air quality tests are conducted to ensure that the health of employees are not affected by below standard air quality. In terms of the equipment considered for repair or replacement, neither pose a health or safety risk if the proper procedures and followed and the necessary precautions are taken to ensure safe operation.

Regarding the external population, the first factor to consider is the effect of the Slag Mill repair/replace decision on human capital. According to Company Cu's sustainability report, the company assigns a substantial proportion of its financial resources to training employees. This includes mainly training focused on safety and the development of employee skills, approximately 2922 hours of training was provided in 2014. Training employees not only increases their skill levels, but also increases their attractiveness for employment in other, similar industries. Thus, the provided training not only benefits the employee and their contribution to Company Cu, but also the employees potential future, should he/she decide to leave Company Cu. The installation of new equipment and machinery in the Slag Mill requires the production and maintenance employees to receive specific training in order to operate and maintain these items after commissioning, whereas the current employees are already familiar with the current machines and equipment. Furthermore, the Slag Mill repair and replace decision both result in increased copper recovery, thereby increasing Company Cu's cost saving and can thus result in a higher production bonus at the end of the year.

The second factor within external population is the impact of the Slag Mill repair/replace decision on productive capital. No additional infrastructure is required for either the Slag Mill repair decision or the Slag Mill replace decision, the current infrastructure is sufficient in both cases. Thus, the employee is not only able to maintain, but to increase the production and recovery rate with no additional costs spent on additional infrastructure.

The third and final factor within external human capital is the effect of the Slag Mill repair/replace decision on community capital. According to Company Cu's sustainability report for 2014, a total of USD700,000 has been invested into education, infrastructure and a community fund for the town since 2010, this equates to approximately N$9,450,000. Also, Company Cu has issued 21 bursaries since 2009 and has invested USD278,000 or N$3,753,000 into the community trust fund in 2014. All of the before mentioned activities aims at increasing the standard of living of the local community, decreasing poverty and unemployment, improving economic welfare and increasing the level of education. The Slag Mill is responsible for relatively high noise levels, however the plant is situated far away from the office blocks and employees working in the Slag Mill are issued ear plugs to protect their hearing. Moreover, the chemicals used in the recovery process are not harmful, however it gives off a potent smell, because of this and for potential dust inhalation, employees are issued respirators. The repair or replace of the major equipment in the Slag Mill will however not result in reduced noise and odours, however increased recoveries and cost savings may result in more investment into the local community.

From the analysis of the various factors that influence the social sustainability performance of the Slag Mill repair/replace decision, a relevant score for the repair as well as the replace decision is assigned. In most of the above analysis, the Slag Mill repair and replace decision performed equally, however there are some minor differences. The introduction of new equipment and machinery requires additional training of both the production and maintenance personnel, also increased copper recoveries through an improved process may result in additional funds invested in the local community, as a consequence of increased cost savings. Therefore, the effect of the Slag Mill repair decision on social sustainability is assigned a score of 3.5 and the replace decision is assigned a score of 4.

$\textbf{Social Sustainability}_{\text{repair}} = 3.5$
$\textbf{Social Sustainability}_{\text{replace}} = 4$

The following section discusses the effect of the Slag Mill repair/replace decision on the environmental sustainability of Company Cu.

5.3.2.5 Slag Mill Repair/Replace Decision Environmental Sustainability Evaluation

From Section 4.4.5 the inclusion of environmental sustainability into the strategic decision-making framework induces the consideration of the long-term effects of the outcome of the decision. According to Company Cu's sustainability report for 2014, the company prides itself in promoting sustainable growth and environmental responsibility in all of its business operations. Similar to the analysis of the effect of the Slag Mill repair/replace decision on the social sustainability of Company Cu, this analysis is also based on the analysis of the respective decisions on environmental sustainability performance indicators, refer to the following.

1. Air resources
2. Water resources
3. Land resources
4. Mineral and energy resources

The first environmental sustainability indicator to be analyzed is the effect of the Slag Mill repair/replace decision on air resources. In 2012 Company cu launched a Fugitive Emissions Project (FEP) whereby the emission controls were upgraded to decrease the effect of the smelting operations on the environment. The Slag Mill is not responsible for the emission of any Green House Gasses (GHG's) into the atmosphere, however as mentioned before the chemicals used in the recovery process do emit a strong odour. Furthermore, the slag processed in the Slag Mill has to go through a crushing process before it is fed to the Slag Mill, this process results in the creation of a lot of dust. Contained in this dust are harmful substances that can effect the health of employees as well as the fauna and flora in the surrounding areas. Therefore, the Slag Mill operation is indirectly responsible for dust creation, however Company Cu is currently in the process of installing dust suppression systems to drastically reduce the creation of dust during the crushing of slag.

Secondly, the impact of the Slag Mill repair replace decision on water resources is analyzed. During the flotation and recovery process in the Slag Mill, tailings are produced. Tailings is essentially a slurry consisting of fine waste particles from the slag and water. The tailings produced in the Slag Mill is pumped to a tailings dam where the particles are allowed to settle. From the tailings dam, the water is pump to two unlined dams from which it is then pumped back to the Slag Mill to re-use as process water. The fine particles in the tailings contain contaminants such as heavy metals, according to the EIA after an extended period of time these contaminants may leach into ground water supplies. Currently no traces of heavy metals have been found, however high levels of sulphate leaching is evident in the ground water surrounding Company Cu. The Slag Mill is heavily dependent on water for its milling and flotation process, and even though the process water is re-used, high volumes of ground water and municipal water is also required. According to Company Cu's sustainability report, Company Cu used 1,161,000 cubic meters of ground water, 203,000 cubic meters of municipal water, 1,364,000 cubic meters from other sources and 384,000 cubic meters of recycled process water. Thus, only 12.3% of the water used is recycled process water. In 2014 however Company Cu launched a surface water management project whereby all water within the premises is collected, retained and re-used throughout all processes requiring water. Unfortunately, the Slag Mill repair/replace decision will not increase or decrease the water current usage.

The third environmental sustainability indicator is the effect of the Slag Mill repair/replace decision on land resources. Company Cu's premises is located about 5km outside of town, with a hill creating a barrier between the town and Company Cu's premises. Company Cu occupies approximately 1450 hectares of land on which all of its operations are situated. As mentioned before, the particles that settle out of the tailings water produced by the Slag Mill contain contaminants and heavy metals. These contaminants enter the soil and can possibly leach into the ground water. Also, the dust particles that settle from the crushing process also contain these contaminants and are dispersed throughout the company premises via wind. Both of the before mentioned activities result in soil pollution, however as mentioned before, Company Cu is actively busy implementing measures to counter these effects. Once again the Slag Mill repair or replace decision is not a determining factor in either increasing or reducing the soil pollution that is currently taking place.

Finally, the last environmental sustainability indicator involves the analysis of the effect of the Slag Mill repair/replace decision on mineral and energy resources. None of the machinery and/or equipment considered for repair or replacement use fossil fuels as a driving mechanism. However all of them use electricity, according to Company Cu's sustainability report for 2014 Company Cu used 447,000 gigajoules of electricity in 2014. This energy is directly sourced from the national grid, which in turn uses coal and diesel to generate power. Thus, indirectly the operation of the Slag Mill is responsible for the depletion of non-renewable resources. Moreover, the lubrication used in all of the machinery and equipment is made from non-renewable resources. The replacement of the major equipment and machinery in the Slag Mill with newer and more efficient versions will however result in lower electricity usage, whereas the repair of the current machinery and equipment will result in the same or even higher electricity usage.

From the information discussed above it is evident that the operations of Company Cu have a significant impact on the environment in which it operates. However in most cases the Company is actively in the process of improving and possibly eradicating the negative impacts of its operations on the environment. Nevertheless, in terms of environmental sustainability performance, both the Slag Mill repair and replace decision is low in all of the before mentioned aspects. In terms of the effect on the mineral and energy resources, the Slag Mill replace decision performs slightly better than the Slag Mill repair decision. Therefore, the impact of the Slag Mill repair decision is assigned a score of 1.5 and the Slag Mill replace decision is assigned a score of .

$\textbf{Environmental Sustainability}_{\text{repair}} = 1.5$
$\textbf{Environmental Sustainability}_{\text{replace}} = 2$

From the strategic physical asset repair/replace decision-making process illustrated in Figure 4.2, following the analysis of each of the framework influencing criteria and assigning each with a relevant score is the determination of the weighting factors corresponding to the importance of the relevant criteria. Thus, the following section details the evaluation of the respective weighting factors assigned to the five influencing criteria analyzed in this section.

5.3.3 Criteria Weighting Factor Evaluation

In the previous sections the influencing criteria that form part of the strategic physical asset repair/replace decision-making framework are evaluated, each is assigned a relevant score corresponding to the performance of the Slag Mill repair/replace decision in that specific criterion. As stated in Section 4.4.6, each of the before mentioned criteria are to be assigned a weighting factor that represents the importance of that specific criterion to the framework as a whole. The evaluation of these weighting factors are completely reliant on the discretion of the decision-maker or decision-making team. It also depends in the specific decision under consideration, the industry of application and state of the company at the time of the framework application.

From the discussion in Section 4.4.6 the weighting factors should satisfy the following statement:

$$\sum_{i=1}^{n} x_i = 1 \tag{5.3.28}$$

Where x_i represents the relative weight factor for the ith criterion. For this study i equals five, corresponding to the five criteria evaluated in Sections 5.3.2.1 to 5.3.2.5, these criteria are restated below:

1. Slag Mill repair/replace decision IRR evaluation
2. Slag Mill repair/replace decision EVA evaluation

3. Slag Mill repair/replace decision FFF evaluation
4. Slag Mill repair/replace decision social sustainability evaluation
5. Slag Mill repair/replace decision environmental sustainability evaluation

It is thus necessary to determine the importance of the above mentioned criteria to Company Cu and to accordingly assign each criterion with a relevant weighting factor. From the financial statements in Appendix B, Company Cu is a profit seeking company, irrespective of the net loss it made in 2014. As with any other profit seeking company, any potential investment requires a guarantee that the investment will result in some financial return, or future advantage. Thus, the first and most important objective of a potential investment is to generate additional shareholder value. Therefore, the decision that results in the highest evaluated IRR and EVA is given preference and is most advantageous to Company Cu with regards to increasing shareholder value. Consultation with the relevant financial management staff suggested that these two criteria should account for at least 50% of the total weight of the five criteria. According to Company Cu's 2014 Annual Report, the estimated economic life of Company Cu is to end in 2023. Therefore, a total of eight years of economically viable operation is still available. Thus, the return on a potential investment would in this case be of higher importance than the future economic value it would create for the company. Consequently, the Slag Mill repair/replace decision IRR is assigned a weight factor of 0.35 and the Slag Mill repair/replace decision EVA, 0.15.

As discussed in Section 5.3.2.3, Company Cu provides a service for smelting copper, a commodity. Also, Company Cu is one of very few companies in the world that is able to smelt the special type of copper ore transported to Company Cu. Therefore, Company Cu's competitive rivalry and the possibility of industry rivals is relatively low, thus the Slag Mill repair/replace decision FFF is assigned a weight factor of 0.1.

From the information in Section 5.3.2.4, Company Cu contributes significantly to the social sustainability of the town in which it operates. It promotes education and skills development by providing funding and training to locals and employees. Also, according to Company Cu's 2014 sustainability report, the company remains strongly focused on improving the social structure through community development. Thus, the Slag Mill repair/replace decision social sustainability is assigned a weight factor of 0.2.

With reference to the information discussed in Section 5.3.2.5, the operations of Company Cu have a significant impact on its surrounding environment. However, there are numerous projects in progress to counter the negative impacts on the environment. Regular surveys are conducted to measure the extent of the environmental impacts of Company Cu's operations in order to develop mitigation plan for its prevention. Nevertheless, the operations of Company Cu have a substantial negative impact on the surrounding environment, especially the ground water and soil. Therefore, the Slag Mill repair/replace decision environmental sustainability is assigned a weight factor of 0.2.

Table 5.7 illustrates a summary of the five identified influencing criteria and their respective assigned weight factors.

Table 5.7: Slag Mill Repair/Replace Decision Criteria Weight Factors

Criteria	**Weight Factor**
Slag Mill repair/replace decision IRR	0.35
Slag Mill repair/replace decision EVA	0.15
Slag Mill repair/replace decision FFF	0.1
Slag Mill repair/replace decision social sustainability	0.2
Slag Mill repair/replace decision environmental sustainability	0.2

According to Figure 4.1 and 4.2 following the identification of the criteria weight factors is the problem validation. During this stage in the application of the strategic physical asset repair/replace decision-making framework the identified influencing criteria scores are combined with their relevant weight factors and integrated into the calculation of the framework final score.

5.4 Interpretation of Strategic Physical Asset Repair/Replace Decision-Making Framework Results

The aim of the strategic physical asset repair/replace decision-making framework is to assist asset managers and decision-makers with the physical asset repair/replace decision-making process. This section therefore details the discussion of the results obtained throughout the application of the framework to the Slag Mill repair/replace decision. It focusses specifically on the validation stage illustrated in Figure 4.1. First, the strategic physical asset repair/replace decision-making framework final score is calculated. Thereafter, the final results and the option recommended by the application of the framework is compared to the existing practice at Company Cu, followed by the framework validation.

5.4.1 Slag Mill Repair/Replace Decision Final Score Calculation

This section details the combination of the influencing criteria scores determined in Sections 5.3.2.1 to 5.3.2.5 with their respective weight factors determined in Section 5.3.3. Thereafter these scores and weight factors are integrated into the calculation of the strategic physical asset repair/replace decision-making framework final score. It is thus necessary to summarize the identified influencing criteria, their assigned scores and respective weight factors, refer to Table 5.8.

Table 5.8: Slag Mill Repair/Replace Decision Criteria Score and Weight Factor Summary

Criteria	Repair Decision Score	Replace Decision Score	Weight Factor
Slag Mill repair/replace decision IRR	4	1	0.35
Slag Mill repair/replace decision EVA	0	0	0.15
Slag Mill repair/replace decision FFF	4	4	0.1
Slag Mill repair/replace decision social sustainability	3.5	4	0.2
Slag Mill repair/replace decision environmental sustainability	1.5	2	0.2

Using the information on Table 5.8 and the AUT technique discussed in Section 5.2.1, the strategic physical asset repair/replace decision-making framework final score can be calculated.

Firstly, the AUT equation is restated as follows:

$$\mathrm{V}(a) = \sum_{i=1}^{n} x_i y_i(a) \tag{5.4.1}$$

Where y_i represents the scores determined for the influencing criteria and x_i represents their respective weight factors. i is equal to five, corresponding to the five identified criteria that form part of the strategic physical asset repair/replace decision-making framework. The framework final score for the Slag Mill repair and replace decision is therefore calculated as follows:

$$\mathbf{V}(a)_{repair} = (4 \times 0.35) + (0 \times 0.15) + (4 \times 0.1) + (3.5 \times 0.2) + (1.5 \times 0.2)$$

Such that

$$\mathbf{V}(a)_{repair} = 2.8$$

And for the Slag Mill replace decision

$$\mathbf{V}(a)_{replace} = (4 \times 0.35) + (0 \times 0.15) + (4 \times 0.1) + (4 \times 0.2) + (2 \times 0.2)$$

Such that

$$\mathbf{V}(a)_{replace} = 1.95$$

From the strategic physical asset repair/replace decision-making framework final scores calculated above, the recommended option is to repair the major equipment and machinery in the Slag Mill. The calculated framework final score for the Slag Mill repair decision is higher than that of the Slag Mill replace decision and thus, even though the scores for the social and environmental sustainability were slightly higher for the replace decision, the significant difference in the calculated IRR's resulted in the higher score assigned to the Slag Mill repair option.

The aim of the Slag Mill repair/replace decision is to increase the throughput and increase the average availability of the plant, and thereby increase the copper recoveries from the slag. According to Company Cu's feasibility study for the Slag Mill repair/replace decision, the major equipment and machinery currently in the Slag Mill are able to accommodate higher production and throughput volumes. However, adequate maintenance, repair and continuous application of preventative maintenance procedures are to be implemented in order to ensure that the required plant availability is obtained.

It must however be noted that the recommended course of action suggested in this study is merely to serve as a guideline based on the evaluation of the identified influencing criteria. The scores calculated throughout the application of the framework can also serve as a benchmark against which Company Cu can measure its performance with regards to the criteria considered. In other words, the Slag Mill repair and replace decision environmental sustainability calculated scores are both relatively low, thus Company Cu can attempt to improve on its environmental impacts, after which it can again be evaluated and compared to the previous score. In this manner the company can track its progress. Also, the Slag Mill replace IRR is low compared to that of the repair decision, therefore Company Cu can go back and improve on the costs involved in the Slag Mill replace decision, recalculate the IRR and compare it to the previous value, as well as against the repair option for evaluation. Moreover, the weight factors assigned to the influencing criteria can also be adjusted to better represent the vision of the company and thereby alter the outcome of the final calculated framework score.

The following section details the validation of the strategic physical asset repair/replace decision-making framework.

5.4.2 Strategic Physical Asset Repair/Replace Decision-Making Framework Validation

This section discusses the validation of the strategic physical asset repair/replace decision-making framework developed and applied in this study. The purpose of this validation is to corroborate that the developed framework meets the objectives specified in Section 1.3 and adds value to the issue of the management of physical asset repair/replace decisions in practice.

The relevance and applicability of the strategic physical asset repair/replace decision-making framework is investigated based on theoretical considerations, thereby determining if practical application of the framework is possible. Furthermore, by means of a case study based on real-world company data and information, the practical application value of the framework is determined.

Company Cu provided the opportunity for the collection of the relevant data in order to apply the strategic physical asset repair/replace decision-making framework to a physical asset repair/replace decision in practice. As mentioned before, the aim of this framework is to assist asset managers and decision-makers with managing physical asset repair/replace decisions, based on multiple decision-influencing criteria. Physical asset intensive industries are regularly faced with the physical asset repair/replace decision and typically the outcome of these decisions are based on purely financial data. The data collected from Company Cu is specifically focused on the Slag Mill repair/replace decision, for this reason the results and recommendations from this case study in only applicable to the Slag Mill repair/replace decision.

As stated before, the application of the strategic physical asset repair/replace decision-making framework is dependent on the knowledge from respective individuals that have extensive knowledge in the areas concerning the identified criteria, as well as on the discretion of the decision-maker or decision-making team. Therefore, gathering the right information for the application of the framework is essential. Once all of the relevant information has been obtained, application of the framework is quick and can easily be implemented in practice.

After application of the framework, the outcome and recommended decision was compared to that of the decision taken by Company Cu's projects team. The outcome of the strategic physical asset repair/replace decision is to repair the major equipment and machinery in the Slag Mill, corresponding to the decision of the project's team after a lengthy pre-feasibility and feasibility study. At the time of the framework application, the first of numerous Slag Mill shut-downs were in progress to refurbish and repair the major machinery and equipment identified.

Furthermore, the results obtained through the implementation of this framework demonstrated the practical value of such a framework in practice, aiding in the management of physical asset repair/replace decisions. Not only does the application of the framework recommend the decision that is most advantageous to the company, it also identifies areas of shortcomings. Therefore, the company has the opportunity to act on these shortcomings and improve upon its performance in problem areas.

From the aforementioned information, the strategic physical asset repair/replace decision-making framework was applied successfully to Company Cu's Slag Mill repair/replace decision. The application of the framework in practice proved that, with the right information and knowledge, the application is easy, understandable, relatively quick to implement and a valuable tool to aid asset managers and decision-makers in managing physical asset repair/replace decisions.

5.5 Chapter Summary

This chapter details the application of the strategic physical asset repair/replace decision to Company Cu's Slag Mill repair/replace decision. A brief overview of the case study is provided, followed by detailed discussions regarding the various steps involved in preparing for the case study. The scope of the case study is defined as well as the data required for the evaluation of each of the criteria that forms part of the developed framework.

Current company practices with regards to the management of projects that are of significant investment are discussed. Also, the current Slag Mill practices are discussed, detailing the current capacity and possible cost savings if the process and major equipment and machinery were to be either repaired or replaced.

Furthermore, the application of the strategic physical asset repair/replace decision-making framework is discussed, detailing the data required as well as the data gathering techniques and sources used to obtain the relevant data for the analysis of the influencing criteria. Thereafter, the analysis and evaluation of each of the identified influencing criteria is discussed in detail, the relevant calculations are also discussed in the before mentioned analysis. Moreover, the weight factors for each of the influencing criteria are determined according to their relative importance to Company Cu.

Finally, the strategic physical asset repair/replace decision-making framework final scores are calculated from which the Slag Mill repair decision is recommended as the most advantageous option, based on the data evaluated. Thereafter, the strategic physical asset repair/replace decision-making framework is validated by comparing the recommended decision to that of the decision made by Company Cu, as well as placing emphasis on the practical applicability of the framework in real-world situations, given the recommended data.

This chapter therefore contributes to achieving the fifth and last research objective, achieving the following objectives and sub-objectives:

Validate the strategic decision-making framework

a) Validate the framework in accordance with the relevant framework features

b) Compare the outcome of the framework with that of actual industry results

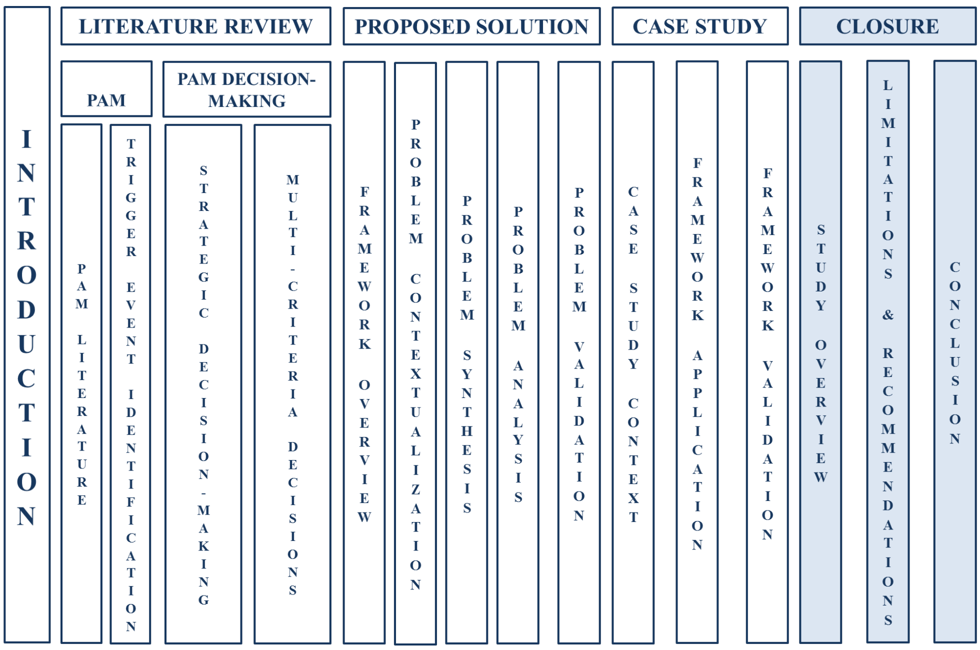
Furthermore, the developed framework also complies with the specified key characteristics: it is practical, flexible enough to be applied to different decisions in different industries, supplies the decision-maker with a structured guideline to follow throughout the decision-making process and enables a holistic approach to the problem.

The final chapter in this research study provides a summary of the main components and outcomes of the study, it also includes a discussion of the limitations of the framework as well as recommendations for possible future research.

Chapter 6

Closure

The purpose of this chapter is to provide a holistic overview of the study conducted and to conclude the study. In this chapter the research findings are consolidated with the initial research conducted, the research process used is discussed and reflected upon and finally, the outcome and results obtained are compared to that of the initial stated research study objectives. First, a brief overview of the various chapters that form part of the study is discussed. Followed by a discussion of the limitations experienced and discovered throughout the course of the study. Thereafter, recommendations for improvement and possible future research are provided. Lastly, the final section of the study details the conclusion of the study.



6.1 Research Study Overview

This study proposes a strategic physical asset repair/replace decision-making framework for the management of physical asset repair/replace decisions in physical asset intensive industries. The study consists of six chapters namely; Introduction, PAM, PAM Decision-Making, Proposed Solution, Case Study and Conclusion. This section therefore provides a brief overview of each of the before mentioned chapters that form part of the study.

Chapter one presents a overview and broad outline of the research study. Initially the chapter provides a background to the research study and research problem. Thereafter, the research objectives and research scope are discussed, specifying the goals of the study as well as the extent of the research area. Furthermore, the research design and methodology is discussed to act as a road map or guide to the research process.

Chapter two and three details the literature analysis relevant to the fields of study. Chapter two introduces the basic concepts of PAM, focusing on the physical asset life cycle as well as the identification of trigger events that result in the consideration of the physical asset repair/replace decision. Chapter three details the main categories that influence the strategic decision-making process. These categories include decision-specific characteristics, internal company characteristics, decision-making team's characteristics and external company characteristics. Also discussed in Chapter three are the various multiple criteria decision-making methods that are applicable to the physical asset repair/replace decision. The methods that were identified as most applicable to the physical asset repair/replace decision include; MAUT, AHP, fuzzy theory, CBR and DEA.

Chapter four proposes a strategic physical asset repair/replace decision-making framework for the management of physical asset repair/replace decisions in physical asset intensive industries. The chapter details the various steps involved in the development the framework as well as the intended area of application.

Chapter five discusses, in detail, the application of the strategic physical asset repair/replace decision-making framework to a real world physical asset repair/replace decision, by means of a case study in the Namibian mining industry. Firstly, an overview of the intended case study is given, followed by the preparation needed for the application of the framework to the case study. The preparation includes a discussion of the case study scope, data required as well as the company current practices. Moreover, the bulk of the chapter consists of the discussion of the application of the strategic physical asset repair/replace decision-making framework to the specific scenario. Finally, the chapter concludes with the validation of the framework by comparing the results obtained to the decision made by the company.

Recalling the research problem and null hypothesis:

H_0
It is possible to improve the outcome of current physical asset repair/replace decisions by developing a multi-criteria decision-making framework to assist the management of physical assets in physical asset intensive industries.

As well as the main research objective stated in Section 1.3

Develop a strategic decision-making framework for the management of physical asset repair/replace decisions in physical asset intensive industries.

The above mentioned main research objective is divided into five objectives, each with respective sub-criteria, refer to Section 1.3. Chapter 2 achieved the first and second objectives of mastering the fundamental principles and concepts in the relevant fields of PAM, as well as mastering the physical asset repair/replace decision. Chapter 3 achieved the third objectives of mastering the fundamental principles and concepts of strategic decision-making, and multiple criteria decision-making. Chapter 4 achieved the fourth criteria of developing a strategic decision-making framework for the management of physical asset repair/replace decisions, and Chapter 5 achieved the fifth and final criteria of validating the developed strategic decision-making framework by means of a case study.

The following section details the discussion of the limitations of the research study as well as the recommendations for improvement and possible future research. Thereafter, the final section details the concluding remarks of the study.

6.2 Limitations

As mentioned before, this section details the limitations experienced throughout the course of the research study. Identifying these limitations is an essential part of any research study in order to improve on the current information, as well as for the purposes of possible future research. Throughout the development and application of the strategic physical asset repair/replace decision-making framework, numerous limitations were identified and are listed below.

1. Nature of the case study selection - The physical asset repair/replace decision chosen for the case study did not allow the framework to evaluate accurate repair and replace decision alternatives, the information gathered were based on studies and financial information from periods that did not include the specific decision.

2. Data collection and gathered information - As mentioned in the previous limitation, the data and information gathered could not accurately reflect on the physical asset repair/replace decision under consideration as it was not available. As discussed in the case study, the company does keep records of its respective plants alone and could only provide overall financial statements and studies. Furthermore, the data collected did not yet include the costs associated with either the physical asset repair or replace decision, and thus needed adjustment to reflect on the decision under consideration.

3. Framework user - As mentioned multiple times throughout this study, the user of the framework is required to either have the required knowledge him/herself or has to consult the individuals or teams within the company that has the required knowledge regarding the physical asset and its operation.

4. Specificity of data - As mentioned before, the data required for ideal application of the proposed application of the framework is relatively specific to the physical asset repair/replace decision under consideration.

5. Framework recommendations - The results of the framework are merely to serve as a recommendation for the proposed course of action based on the criteria considered. The decision-maker or decision-making team is still required to use his/her/their judgement and discretion to determine the eventual course of action.

6. Industry - The developed framework is validated by means of a case study within the mining industry, a physical asset intensive industry. Therefore, the validation of the study does not necessarily prove that the developed framework is valid in other industries.

7. Significant Investment - The developed framework is based on the evaluation of physical asset repair/replace decisions that are of significant investment. Thus, the application of the framework to physical asset repair/replace decisions that are not of such high capital investment is not necessarily validated.

8. Data period relevance - As the case study and framework application is based on the data and costs obtained in the month of application, such an analysis is again required if the information and/or costs of considered machinery and equipment were to change. Also, the analysis is to be re-applied if the relevant importance of the influencing criteria were to change.

The before mentioned limitations should be addressed to improve the current framework as well as for further studies in the same field. Moreover, the next section details the discussion of recommendations for possible future research.

6.3 Recommendations

Throughout the application of the strategic physical asset repair/replace decision-making framework, areas of possible improvement were identified, following from the aforementioned limitations.

1. The strategic physical asset repair/replace decision-making framework can be applied to other, physical asset repair/replace decision-making case studies in order to develop a more comprehensive understanding of the relevant information required for the analysis.

2. Determining the most advantageous decision to the company can be improved if more accurate and relevant data is available.

3. The criteria identified in this study is based on the characteristics that influence strategic decisions, other criteria can also be included or substituted in order to more accurately represent the vision of the company under consideration.

4. This case study is performed in the mining industry, more insight into the physical asset repair/replace decision can be gained if the framework were to be applied to other physical asset intensive industries.

5. This framework is developed specifically for the consideration of physical asset repair/replace decisions that concern physical assets that are of significant investment, therefore further development can lead to its applicability to any physical asset repair/replace decision.

6. It is also recommended to incite the company of application to collect data according to its different sections in order to simplify and more accurately apply the strategic physical asset repair/replace decision-making framework.

The above mentioned recommendations are intended for further research into the application of a strategic physical asset repair/replace decision-making framework. The suggested improvements can not only improve the current framework, but also provides opportunities for future research into the physical asset repair/replace decision field of study.

The following section of this study comprises of the concluding remarks of this research study.

6.4 Conclusion

The physical asset repair/replace decision represents one of four stages within the life cycle of a physical asset. Therefore, the decision to either repair or replace a physical asset, especially those that are of a significant investment nature, requires considerable attention. The effective management of these decisions lead to only increased production, but also possible future economic value, returns and competitive advantage. Even though the decision to repair or replace a physical has historically been based on the economic life of the asset, other factors such as the sustainability and competitive advantage of the decision also have an effect on the outcome. Therefore, a method to evaluate these decisions with respect to additional factors, apart from finances, is required.

Physical asset repair/replace decisions are a common phenomenon in physical asset intensive industries and requires the decision-maker to determine the most advantageous decision for the company, based on the current and future state of the company. Therefore, long-term factors need to be incorporated into the decision.

This study therefore proposes a strategic physical asset repair/replace decision-making framework for the management of physical asset repair/replace decisions. The framework is specifically intended for physical asset repair/replace decisions in physical asset intensive industries that are of a significant capital investment nature. Application of the framework is specifically intended to aid asset managers and decision-makers with the management of physical asset repair/replace decisions. Furthermore, the framework also acts as a benchmark against which the company can measure its performance relevant to the influencing criteria considered.

This study is based on a holistic approach, supported by an extensive literature review. Firstly, the basic concepts of PAM and strategic decision-making are introduced, with specific focus on the physical asset life cycle, as well as the characteristics that from part of strategic decision-making. Thereafter, the proposed framework is developed based on the concepts of PAM and strategic decision-making, as well as that of multiple criteria decision-making methods. The extensive research in the literature review, as well as the holistic approach to PAM and strategic decision-making enables a comprehensive view on the physical asset repair/replace decision issue.

The literature review therefore consists of four different study fields namely; PAM, physical asset repair/replace decisions, strategic decision-making and multiple criteria decision-making. Furthermore, the development of the framework is divided into four main focus areas namely; problem contextualization, problem synthesis, problem analysis and problem validation. In each of the before mentioned focus areas the objective is clearly stated, as well as the output expected.

Moreover, the developed framework is unique in the sense that it incorporates multiple influencing criteria and provides the user with enough flexibility to apply it to his/her specific situation.

The proposed strategic physical asset repair/replace decision-making framework is validated through its application to a case study in the mining industry in Namibia. Particularly, the framework is applied to aid decision-makers with the issue of the Slag Mill repair/replace decision. The outcome of the application of the framework suggests that the current machinery and equipment in place should be repaired and refurbished, and not replaced. Even though the copper recoveries from the Slag Mill repair decision is slightly lower than that of the Slag Mill replace decision, the required throughput tonnage and availability is still satisfied. Thus, the social and environmental sustainability, as well as the IRR generated from the Slag Mill repair decision outweighs the slight increase in the copper recovery of the Slag Mill replace decision.

Furthermore, the outcome of the application of the framework to the Slag Mill repair/replace decision resulted in the same outcome as that determined by the company through lengthy feasibility studies and incurred consultation costs. Given the right information, the framework is practical and easy to apply to a specific physical asset repair/replace decision, and to accordingly determine the recommended most advantageous decision for the company. Also, as mentioned before, the framework can be adapted to include other influencing criteria that are more relevant to the company, as well as different weight factors depending on the vision of the company.

From the above information, as well as the application of the framework to a real world physical asset repair/replace decision, the null hypothesis is not rejected. It is therefore possible to develop a multiple-criteria decision-making framework that can improve the outcome of physical asset repair/replace decisions in physical asset intensive industries. Furthermore, as stated in Section 6.1, all of the research objectives are achieved.

Therefore, in conclusion, this study proposes a strategic physical asset repair/replace decision-making framework for the management of physical asset repair/replace decisions in physical asset intensive industries. The framework is validated through a practical case study, thereby confirming that it is binding, both from a practical and theoretical perspective. Thus, this study contributes towards a better understanding of the physical asset repair/replace decision within the physical asset life cycle and assists in the management of physical asset repair/replace decisions within PAM.

Appendices

Appendix A

Example Calculations

A.1 IRR Example Calculations

Cashflow Period (years)	Net Cash Flow Existing Physical Asset (xn)	Net Cash Flow of Physical Asset to be Acquired (xn)
0	-600000	-1200000
1	180000	240000
2	200000	290000
3	260000	340000
4	210000	310000
5	0	350000
	=IRR(B2:B7)	=IRR(C2:C7)

Figure A.1: IRR Example Calculation Excel Sheet Formulae

Table A.1: IRR Example Calculation

Cash Flow Period (years)	Net Cash Flow of Existing Asset (x_n)	Net Cash Flow of Physical Asset to be Acquired (x_n)
0	(600,000)	(1,200,000)
1	180,000	240,000
2	200,000	290,000
3	260,000	340,000
4	210,000	310,000
5	0	350,000
IRR	14.9%	8.2%

A.2 EVA Example Calculations

Income Statement of Company X		
Revenue		2436000
Less Cost of Goods Sold		=B7-B8
opening stock	1300000	
Add Purchases	1200000	
	=SUM(B5:B6)	
Less Closing Stock	800000	
Gross Profit		=C3-C4
Less SG&A expenses		220000
EBIT		=C9-C10
Less Depreciation		120000
Less interest expense		60000
Less tax allowance		=0.2*600000
ANOPBT		=C11-SUM(C12:C14)
Income Tax (40%)		=C15*0.4
NOPAT		=C15-C16

Figure A.2: Income Statement before physical asset acquisition Excel Sheet Formulae

Income Statement of Company X		
Revenue		2436000
Less Cost of Goods Sold		=B7-B8
opening stock	1300000	
Add Purchases	1200000	
	=SUM(B5:B6)	
Less Closing Stock	800000	
Gross Profit		=C3-C4
Less SG&A expenses		220000
EBIT		=C9-C10
Less Depreciation		120000
Less interest expense		60000
Less tax allowance		=0.2*600000
ANOPBT		=C11-SUM(C12:C14)
Income Tax (40%)		=C15*0.4
NOPAT		=C15-C16

Figure A.3: Income Statement after physical asset acquisition Excel Sheet Formulae

Table A.2: Income Statement before physical asset acquisition

Income Statement of Company X		
Revenue		2,436,000
Less Cost of Goods Sold		1,700,000
Opening Stock	1,300,000	
Add Purchases	1,200,000	
	2,500,000	
Less Closing Stock	800,000	
Gross Profit		736,000
Less SG&A Expenses		220,000
EBIT		516,000
Less Depreciation		120,000
Less Interest Expense		60,000
Less Tax Allowance		120,000
ANOPBT		216,000
Income Tax (40%)		86,400
NOPAT		129,600

Table A.3: Income Statement after physical asset acquisition

Income Statement of Company X		
Revenue		3,045,000
Less Cost of Goods Sold		2,640,000
Opening Stock	1,560,000	
Add Purchases	2,040,000	
	3,600,000	
Less Closing Stock	960,000	
Gross Profit		405,000
Less SG&A Expenses		242,000
EBIT		163,000
Less Depreciation		140,000
Less Interest Expense		60,000
Less Tax Allowance		480,000
ANOPBT		(517,000)
Income Tax (40%)		0
NOPAT		(517,000)

Balance Sheet of Company X		
ASSETS		=C21+C26
Current Assets		=SUM(B22:B25)
Cash	328000	
Accounts Receivable	15300	
Prepaid Expenses	2500	
Inventory	800000	
Fixed Assets		=SUM(B27:B29)
Equipment	1875000	
Premises	755500	
Accumulated depreciation	635000	
LIABILITIES		=SUM(C32,C35)
Current Liabilities		=SUM(B33:B34)
Accounts Payable	18200	
Accreud Expenses	3500	
Long-Term Liabilities		=B36
Long-Term Loan	3060000	
OWNERS EQUITY		
Owners Equity		=SUM(B40:B41)
Retained Earnings	129600	
Common Stock	1200000	
Total Liabilities and Owners Equity		=C31+C39

Figure A.4: Balance Sheet before physical asset acquisition Excel Sheet Formulae

Table A.4: Balance Sheet before physical asset acquisition

Balance Sheet of Company X		
ASSETS		4,411,300
Current Assets		1,145,800
Cash	328,000	
Accounts Receivable	15,300	
Prepaid Expenses	2,500	
Inventory	80,000	
Fixed Assets		3,256,500
Equipment	1,875,000	
Premises	755,500	
Accumulated Depreciation	635,000	
LIABILITIES		3,081,700
Current Liabilities		21,300
Accounts Payable	18,200	
Accrued Expenses	3,100	
Long-Term Liabilities		3,060,000
Long-Term Loan	3,060,000	
OWNERS EQUITY		
Owners Equity		1,329,600
Retained Earnings	129,600	
Common Stock	1,200,000	
Total Liabilities and Owners Equity		4,411,300

Balance Sheet of Company X		
ASSETS		=G21+G26
Current Assets		=SUM(F22:F25)
Cash	328000	
Accounts Receivable	15300	
Prepaid Expenses	2500	
Inventory	960000	
Fixed Assets		=SUM(F27:F29)
Equipment	3075000	
Premises	755500	
Accumulated depreciation	655000	
LIABILITIES		=SUM(G32,G35)
Current Liabilities		=SUM(F33:F34)
Accounts Payable	21500	
Accreud Expenses	6800	
Long-Term Liabilities		=F36
Long-Term Loan	5080000	
OWNERS EQUITY		
Owners Equity		=SUM(F40:F41)
Retained Earnings	-517000	
Common Stock	1200000	
Total Liabilities and Owners Equity		=G31+G39

Figure A.5: Balance Sheet after physical asset acquisition Excel Sheet Formulae

Table A.5: Balance Sheet after physical asset acquisition

Balance Sheet of Company X		
ASSETS		5,791,300
Current Assets		1,305,800
Cash	328,000	
Accounts Receivable	15,300	
Prepaid Expenses	2,500	
Inventory	96,000	
Fixed Assets		4,485,500
Equipment	3,075,000	
Premises	755,500	
Accumulated Depreciation	655,000	
LIABILITIES		5,108,300
Current Liabilities		28,300
Accounts Payable	21,500	
Accrued Expenses	6,800	
Long-Term Liabilities		5,080,000
Long-Term Loan	5,080,000	
OWNERS EQUITY		
Owners Equity		683,000
Retained Earnings	(517,000)	
Common Stock	1,200,000	
Total Liabilities and Owners Equity		5,791,300

Appendix B

Company Cu Data

B.1 Company Cu Income Statement for the year end 2014

Table B.1: Company Cu Income Statement for the year ended December 31, 2014

Revenue	**107,959,787**
Revenue Deductions	**(28,024,270)**
Interest	(11,383,179)
Exposure Movement	(16,641,091)
Net Revenue	**79,935,516**
Cost of Sales	**97,315,369**
Production Costs	**68,025,690**
Aministration	20,114,243
Smelting	6,501,035
Enriching	3,512,383
Materials Handling	2,223,078
By Products	2,318,227
HSEPS	5,126,561
Business Improvement	3,556,675
Slag Mill	1,500,519
Utilities	13,381,383
Maintenance (All Plant)	9,791,589
Other Costs	**29,289,679**
Other Costs	11,415,830
Depreciation	17,873,849
Gross Profit/(Loss)	**(17,379,853)**
G&A Expenses	842,704
Other operating (Income) / Loss	(4,063,430)
Interest Received	(204,122)
Finance Cost	2,993,314
Other (Income) / Expenses	168,174,601
Profit/(Loss) before Intercompany	**(185,122,919)**
Company Interest	11,783,245
Profit/(Loss)	**(196,906,164)**

B.2 Company Cu Balance Sheet for year end 2014

Table B.2: Company Cu Balance Sheet as at December 31, 2014

Current Assets	**121,316,443**
Cash and Cash Equivalents	15,917,788
Accounts Receivable	52,032,461
Inventory	47,971,715
Prepaid Expenses	5,394,480
Long-term Assets	**3,646,611,524**
Intangible Assets	1,520,290
Land	6,985,841
Buildings	105,987,453
Machinery and Equipment	1,282,076,472
Fixed Assets in Progress	2,223,919,965
Other Long-term Assets	22,107,000
Long-term Loan	4,014,503
Total Assets	**3,767,927,967**
Current Liabilities	**186,543,027**
Accounts Payable and Accrued Liabilities	180,950,440
Current Portion of Long-term Liabilities	5,592,587
Long-term Liabilities	**3,636,705,646**
Asset Retirement Obligation	266,131,239
Long-term Debt	122,502,327
Other Long-term Debt	3,248,072,080
Total Liabilities	**3,826,248,673**
Shareholders' Equity	
Share Capital	
Capital-Premium Allotment	1,194,564,370
Share Capital	1,300
Accumulated Profit/(Loss)	(1,249,886,377)
Equity	**(55,320,707)**

B.3 Adjusted Income Statement for Company Cu Slag Mill Repair Decision

Table B.3: Adjusted Income Statement for the Slag Mill Repair Decision

	Original	Adjusted
Revenue	**107,959,787**	**108,659,492**
Revenue Deductions	**(28,024,270)**	**(28,024,270)**
Interest	(11,383,179)	(11,383,179)
Exposure Movement	(16,641,091)	(16,641,091)
Net Revenue	**79,935,516**	**80,635,222**
Cost of Sales	**97,315,369**	**106,056,205**
Production Costs	**68,025,690**	**76,117,360**
Administration	20,114,243	20,114,243
Smelting	6,501,035	6,501,035
Enriching	3,512,383	3,512,383
Materials Handling	2,223,078	2,223,078
By Products	2,318,227	2,318,227
HSEPS	5,126,561	5,126,561
Business Improvement	3,556,675	3,556,675
Slag Mill	1,500,519	3,100,519
Utilities	13,381,383	13,381,383
Maintenance (All Plant)	9,791,589	16,283,256
Other Costs	**29,289,679**	**29,938,846**
Other Costs	29,289,679	11,415,830
Depreciation	17,873,849	18,523,016
Gross Profit/(Loss)	**(17,379,853)**	**(25,420,983)**
G&A Expenses	842,704	842,704
Other operating (Income) / Loss	(4,063,430)	(4,063,430)
Interest Received	(204,122)	(204,122)
Finance Cost	(2,993,314)	(3,065,154)
Other (Income) / Expenses	168,174,601	168,174,601
Tax Allowance	0	1,298,333
Profit/(Loss) before Intercompany	**(185,122,919)**	**(194,534,223)**
Company Interest	(11,783,245)	(11,783,245)
Profit/(Loss)	**(196,906,164)**	**(206,317,468)**

B.4 Adjusted Balance Sheet for Company Cu Slag Mill Repair Decision

Table B.4: Adjusted Balance Sheet for the Slag Mill Repair Decision

	Original	**Adjusted**
Current Asset	**121,316,443**	**114,824,777**
Cash and Cash Equivalents	15,917,788	9,426,121
Accounts Receivable	52,032,461	52,032,461
Inventory	47,971,715	47,971,715
Prepaid Expenses	5,394,480	5,394,480
Long-term Assets	**3,646,611,524**	**3,645,962357**
Intangible Assets	1,520,290	1,520,290
Land	6,985,841	6,985,841
Buildings	105,987,453	105,987,453
Machinery and Equipment	1,282,076,472	1,281,427,305
Fixed Assets in Progress	2,223,919,965	2,223,919,965
Other Long-term Assets	22,107,000	22,107,000
Long-term Loan	4,014,503	4,014,503
Total Assets	**3,767,927,967**	**3,760,787,135**
Current Liabilities	**186,543,027**	**186,543,027**
Accounts Payable and Accrued Liabilities	180,950,440	180,950,440
Current Portion of Long-term Liabilities	5,592,587	5,592,587
Long-term Liabilities	**3,636,705,646**	**3,638,945,918**
Asset Retirement Obligation	266,131,239	188,231,239
Long-term Debt	122,502,327	123,612,957
Other Long-term Debt	3,248,072,080	3,328,212,352
Total Liabilities	**3,823,248,673**	**3,825,518,945**
Shareholders' Equity		
Share Capital		
Capital-Premium Allotment	1,194,564,370	1,194,564,370
Share Capital	1300	1300
Accumulated Profit/(Loss)	(1,249,886,377)	(1,259,297,480)
Equity	**(55,320,707)**	**(64,731,810)**

B.5 Adjusted Income Statement for Company Cu Slag Mill Replace Decision

Table B.5: Adjusted Income Statement for Company Cu Slag Mill Replace Decision

	Original	Adjusted
Revenue	**107,959,787**	**108,888,005**
Revenue Deductions	**(28,024,270)**	**(28,024,270)**
Interest	(11,383,179)	(11,383,179)
Exposure Movement	(16,641,091)	(16,641,091)
Net Revenue	**79,935,516**	**80,863,735**
Cost of Sales	**97,315,369**	**100,052,872**
Production Costs	**68,025,690**	**69,925,693**
Administration	20,114,243	20,114,243
Smelting	6,501,035	6,501,035
Enriching	3,512,383	3,512,383
Materials Handling	2,223,078	2,223,078
By Products	2,318,227	2,318,227
HSEPS	5,126,561	5,126,561
Business Improvement	3,556,675	3,556,675
Slag Mill	1,500,519	3,100,519
Utilities	13,381,383	13,381,383
Maintenance (All Plant)	9,791,589	10,091,589
Other Costs	**29,289,679**	**30,271,179**
Other Costs	29,289,679	11,415,830
Depreciation	17,873,849	18,711,349
Gross Profit/(Loss)	**(17,379,853)**	**(19,189,137)**
G&A Expenses	842,704	842,704
Other operating (Income) / Loss	(4,063,430)	(4,063,430)
Interest Received	(204,122)	(204,122)
Finance Cost	(2,993,314)	(3,086,107)
Other (Income) / Expenses	168,174,601	168,174,601
Tax Allowance	0	3,350,000
Profit/(Loss) before Intercompany	**(185,122,919)**	**(190,374,997)**
Company Interest	(11,783,245)	(11,783,245)
Profit/(Loss)	**(196,906,164)**	**(202,158,242)**

B.6 Adjusted Balance Sheet for Company Cu Slag Mill Replace Decision

Table B.6: Adjusted Balance Sheet for Company Cu Slag Mill Replace Decision

	Original	Adjusted
Current Asset	**121,316,443**	**121,316,443**
Cash and Cash Equivalents	15,917,788	15,917,788
Accounts Receivable	52,032,461	52,032,461
Inventory	47,971,715	47,971,715
Prepaid Expenses	5,394,480	5,394,480
Long-term Assets	**3,646,611,524**	**3,745,624,857**
Intangible Assets	1,520,290	1,520,290
Land	6,985,841	6,985,841
Buildings	105,987,453	105,987,453
Machinery and Equipment	1,282,076,472	1,381,089,440
Fixed Assets in Progress	2,223,919,965	2,223,919,965
Other Long-term Assets	22,107,000	22,107,000
Long-term Loan	4,014,503	4,014,503
Total Assets	**3,767,927,967**	**3,866,941,301**
Current Liabilities	**186,543,027**	**186,543,027**
Accounts Payable and Accrued Liabilities	180,950,440	180,950,440
Current Portion of Long-term Liabilities	5,592,587	5,592,587
Long-term Liabilities	**3,636,705,646**	
Asset Retirement Obligation	266,131,239	266,131,239
Long-term Debt	122,502,327	106,135,227
Other Long-term Debt	3,248,072,080	3,352,307,490
Total Liabilities	**3,823,248,673**	**3,927,514,083**
Shareholders' Equity		
Share Capital		
Capital-Premium Allotment	1,194,564,370	1,194,564,370
Share Capital	1300	1300
Accumulated Profit/(Loss)	(1,249,886,377)	(1,255,138,452)
Equity	**(55,320,707)**	**(60,572,782)**

Bibliography

AAMCoG (2008). Best practice in integrated engineering asset management. Tech. Rep., Australian Asset Management Collaborative Group.

Aamodt, A. and Plaza, E. (1994). Case-based reasoning: Foundational issues, methodological variations, and system approaches. *AI communications*, vol. 7, no. 1, pp. 39–59.

Al-Tamimi, H.A.H. and Lootah, A.M. (2007). Evaluating the operational and profitability efficiency of a uae-based commercial bank. *Journal of Financial Services Marketing*, vol. 11, no. 4, pp. 333–348.

Alihodžić, A. and Erić, D. (2013). Calculation of average weighted cost of capital for induvidual shares of sarajevo and banja luka stock exchange.

Amadi-Echendu, J.E., Brown, K., Willett, R. and Mathew, J. (2010*a*). *Definitions, concepts and scope of engineering asset management*. Springer.

Amadi-Echendu, J.E., Willett, R., Brown, K., Hope, T., Lee, J., Mathew, J., Vyas, N. and Yang, B.-S. (2010*b*). What is engineering asset management? In: *Definitions, concepts and scope of engineering asset management*, pp. 3–16. Springer.

AMBoK (2014). Design out maintenance.

Ambrose, M., Burn, S., DeSilva, D. and Rahilly, M. (2010). Life cycle analysis of water networks. In: *Plastics Pipe XIV Conferences Association*.

Andrews, K.R. (1997). The concept of corporate strategy. *Resources, Firms, and Strategies: a reader in the resource-based perspective*, p. 52.

Assefa, G. and Frostell, B. (2007). Social sustainability and social acceptance in technology assessment: A case study of energy technologies. *Technology in Society*, vol. 29, no. 1, pp. 63–78.

Asselbergs, Karel; Dijk, J. (2013). Economic life of an asset. Tech. Rep., ACORDIO, Chemical Engineering Consultants.

Bacidore, J.M., Boquist, J.A., Milbourn, T.T. and Thakor, A.V. (1997). The search for the best financial performance measure. *Financial Analysts Journal*, pp. 11–20.

Balbach, E.D. (1999). Using case studies to do program evaluation. Tech. Rep., California Department of Health Services.

Balmat, J.-F., Lafont, F., Maifret, R. and Pessel, N. (2011). A decision-making system to maritime risk assessment. *Ocean Engineering*, vol. 38, no. 1, pp. 171–176.

Barabady, J. and Kumar, U. (2005). Maintenance schedule by using reliability analysis: A case study at jajarm bauxite mine of iran. In: *20th World Mining Congress, November 7-11, 2005, Tehran, Iran: Mining and sustainable development*. Teheran: Geological Survey of Iran.

Bashir, T., Javed, A., Butt, A.A., Azam, N., Tanveer, A. and Ansar, I. (2013). An assessment study on the "factors influencing the individual investor decision making behaviour". *Journal of Business and Management*, vol. 9, no. 5.

Belton, V. and Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach*. Springer Science & Business Media.

Benders, J. (2011). The business case for pas 55: An emerging global standard for asset management. Tech. Rep., Mincom.

Bergmann, R., Althoff, K.-D., Minor, M., Reichle, M. and Bach, K. (2009). Case-based reasoning: Introduction and recent developments. Tech. Rep., University of Trier, Department of Business Information Systems, 54286 Trier, Germany.

Bhushan, N. and Rai, K. (2004). *Strategic decision making: applying the analytic hierarchy process*. Springer Science & Business Media.

Bierman Jr, H. and Smidt, S. (2012). *The capital budgeting decision: economic analysis of investment projects*. 9th edn. Routledge.

Blees, J., Kemp, R., Maas, J., Mosselman, M. *et al.* (2003). *Barriers to entry: differences in barriers to entry for SMEs and large enterprises*. Scientific Analysis of Entrepreneurship and SMEs.

Boric, J. (2006). Investing in copper.
Available at: `dailyreckoning.com/investing-in-copper/`

BSi (2008). Publicly available specification 55 part 1: Specification for the optimized management of physical assets. Tech. Rep., The Institute of Asset Management (IAM) and British Standards Institute (BSi).

(BSI), B.S.I. (2008). Publicly available specification 55 part 2: Guidelines for the application of pas 55-1. Tech. Rep., The Institute of Asset Management (IAM).

Campbell, J.D., Jardine, A.K. and McGlynn, J. (2011). *Asset management excellence: optimizing equipment life-cycle decisions*. CRC Press.

Cesca, I.G. and Novaes, D.D. (2012). Physical assets replacement: an analytical approach. *arXiv preprint arXiv:1210.3678*.

Chan, F., Lau, H., Ip, R., Chan, H. and Kong, S. (2005). Implementation of total productive maintenance: A case study. *International Journal of Production Economics*, vol. 95, no. 1, pp. 71–94.

Chen, T.-Y. (2002). Measuring firm performance with dea and prior information in taiwan's banks. *Applied Economics Letters*, vol. 9, no. 3, pp. 201–204.

Cheng, D.S. (2013). Analyze the hotel industry in porter five competitive forces. *Journal of Global Business Management*, vol. 9, no. 3.

Commonwealth of Australia (2006 January). *Handbook of Cost-Benefit Analysis*. Departement of Finance and Administration.

Cooper, W.W., Seiford, L.M. and Zhu, J. (2011). Data envelopment analysis: History, models, and interpretations. In: *Handbook on data envelopment analysis*, pp. 1–39. Springer.

Costa Lima, G.A. and Fliho, A.M.T. (2014). Economic and risk replacement model for physical assets in the gas distribution's system. In: Steenbergen, R., van Gelder, P., Miraglia, S. and Vrouwenvelder, A. (eds.), *Safety, Reliability and Risk Analysis: Beyond the Horizon*, pp. 767–773. Tailor & Francis Group, London.

Cox, A. (2001). Understanding buyer and supplier power: a framework for procurement and supply competence. *Journal of Supply Chain Management*, vol. 37, no. 1, pp. 8–15.

Cruzan, R. (2009). *Manager's Guide to Preventive Building Maintenance*. The Fairmont Press, Inc.

Dälken, F. (2014). Are porter's five competitive forces still applicable? a critical examination concerning the relevance for today's business. In: *3rd IBA Bachelor Thesis Conference*. University of Twente.

Damodaran, A. (2007). Return on capital (roc), return on invested capital (roic) and return on equity (roe): Measurement and implications. *Return on Invested Capital (ROIC) and Return on Equity (ROE): Measurement and Implications (July 2007)*.

De Meel, H.W. (2008). Asset management: Deciding optimal timing for equipment rehab or replacement. *Hydro Review*, vol. 27, no. 2.

De Swaan Arons, H. and Waalewijn, P. (1999). A knowledge base representing porter's five forces model.

Dean, J.W. Jr; Sharfman, M. (1996). Does decision process matter? a study of strategic decision making effectiveness. *Academy of Management Journal*, vol. 39, pp. 368–396.

Dean, J.W; Sharfman, M. (1993). Procedural rationality in the strategic decision making process. *Journal of Management Studies*, vol. 30, pp. 587–611.

Deming, W.E. (1986). Out of the crisis, massachusetts institute of technology. *Center for advanced engineering study, Cambridge, MA*, vol. 510.

Department for Environment, F. and Affiars, R. (2006). Environmetal key performance indicators. Tech. Rep., Department for Environment, Food and Rural Affiars, Nobel House, 17 Smith Square, London.

Doane, D. and MacGillivray, A. (2011). Economic sustainability: The business of staying in business. Tech. Rep., The Sigma Project.

Dobbs, I.M. (2004). Replacement investment: Optimal economic life under uncertainty. *Journal of Business Finance & Accounting*, vol. 31, no. 5-6, pp. 729–757.

Dorfman, R. (1981). The meaning of internal rates of return. *The journal of Finance*, vol. 36, no. 5, pp. 1011–1021.

Drake, P.P. (2010 01). Value-added measures of performance and residual income valuation. Tech. Rep..

Duarte, E., Falla, D., Gavin, J., Lawrence, M., McGrail, T., Miller, D., Prout, P. and Rogan, B. (2010). A practical approach to condition and risk based power transformer asset replacement. In: *Electrical Insulation (ISEI), Conference Record of the 2010 IEEE International Symposium on*, pp. 1–4. IEEE.

Duhaime, I.M; Baird, I. (1987). Divestment decision-making: the role of business unit size. *Journal of Management*, vol. 13, pp. 483–499.

Dutton, J. (1993). Interpretations on automatic: a different view of strategic issue diagnosis. *Journal of Management Studies*, vol. 30, pp. 339–357.

Eakins, S.G. (2001). *Finance: Investments, Institutions, and Management*, vol. 2. Addison Wesley.

El-Wahed, W.F.A. (2008). Intelligent fuzzy multi-criteria decision making: review and analysis. In: *Fuzzy Multi-Criteria Decision Making*, pp. 19–50. Springer.

Elbanna, S. (2006). Strategic decision-making: Process perspectives. *International Journal of Management Reviews*, vol. 8, no. 1, pp. 1–20.

Encyclopedia of Management (2009). Finacial ratios.
Available at: `http://www.encyclopedia.com/doc/1G2-3273100106.html`

Engineering Economic Analysis (2014). Minimum attractive rate of return.
Available at: `http://engineeringandeconomicanalysis.blogspot.com/2013/12/minimum-attractive-rate-of-return.html`

Eti, M.C., Ogaji, S. and Probert, S. (2006). Reducing the cost of preventive maintenance (pm) through adopting a proactive reliability-focused culture. *Applied energy*, vol. 83, no. 11, pp. 1235–1248.

Exchange-Rates.org (2015). Convert usd to nad.
Available at: `http://www.exchange-rates.org/Rate/USD/NAD`

Fan, W.D., Gemar, M.D. and Machemehl, R. (2013). Equipment replacement decision making: Opportunities and challenges. In: *Journal of the Transportation Research Forum*, vol. 52, pp. 79–90.

Franceschini, F., Galetto, M., Collins, T.R., Rossetti, M.D., Nachtmann, H.L. and Oldham, J.R. (2006). The use of multi-attribute utility theory to determine the overall best-in-class performer in a benchmarking study. *Benchmarking: An International Journal*, vol. 13, no. 4, pp. 431–446.

Frank, A.G., Souza, D.V.S.d., Ribeiro, J.L.D. and Echeveste, M.E. (2013). A framework for decision-making in investment alternatives selection. *International Journal of Production Research*, vol. 51, no. 19, pp. 5866–5883.

Frank, M.Z. and Shen, T. (2014). Investment and the weighted average cost of capital. *Available at SSRN 2014367*.

Gamble, J. and Thompson Jr, A. (2014). *Essentials of strategic management*. Irwin Mcgraw-Hill.

Ghauri, P. (2004). *Handbook of qualitative research methods in international business*, pp. 109–124.

Gibson, R.B. (2006). Beyond the pillars: Sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making. *Journal of Environmental Assessment Policy and Management*, vol. 8, no. 3, pp. 259–280.

Gitman, J. and Forrester, J. (1977). A survey of capital budgeting techniques used by major u.s. firms. *Financial Management*, vol. 6, no. 3, pp. 66–71.

Gitman, L.J. and Zutter, C.J. (2012). *Principles of Managerial Finance*. Prentice Hall.

Gjerde, O. and Nordgard, D.E. (2009). Risk assessment as an integrated part of distribution system reinvestment analysis. In: *Electricity Distribution-Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on*, pp. 1–4. IET.

Gluch, P. and Baumann, H. (2004). The life cycle costing (lcc) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and environment*, vol. 39, no. 5, pp. 571–580.

Goodland, R. (2002). Sustainability: human, social, economic and environmental. *Encyclopedia of Global Environmental Change. John Wiley & Sons*.

Government Gazette of the Republic of Namibia (1998 9). Affirmative Action Act, 1998.

Grundy, T. (2006). Rethinking and reinventing michael porter's five forces model. *Strategic Change*, vol. 15, no. 5, pp. 213–229.

Hartman, J. and Schafrick, I. (2010*a*). The relevant internal rate of return. *Engineering Economist*, vol. 49, no. 2, pp. 139–158.

Hartman, J.C. (2001). An economic replacement model with probabilistic asset utilization. *IIE Transactions*, vol. 33, no. 9, pp. 717–727.

Hartman, J.C. and Schafrick, I.C. (2010*b*). The relevant internal rate of return. *The Engineering Economist*, vol. 49:2, pp. 139–157.

Hastings, N.A. (2010). *Physical Asset Management*. 1st edn. Springer.

Hastings, N.A.J. (2009). *Physical asset management*. Springer Science & Business Media.

Heger, D. and Kraft, K. (2008). Barriers to entry and profitability. *ZEW-Centre for European Economic Research Discussion Paper*, , no. 08-071.

Hitt, M.A; Tyler, B. (1991). Strategic decision models: integrating different perspectives. *Strategic Management Journal*, vol. 12, pp. 327–351.

Howe, K.M. and McCabe, G.M. (1983). On optimal asset abandonment and replacement. *Journal of Financial and Quantitative Analysis*, vol. 18, no. 03, pp. 295–305.

IBM (2009). Enabling the benefits of pas 55: The new standard for asset management in the industry. Tech. Rep., IBM.

International Organization for Standardization (ISO) (2010). Iso 26000: Guidance on social responsibility. Tech. Rep., ISO.

Iskandar, B.P., Murthy, D.P. and Jack, N. (2005). A new repair–replace strategy for items sold with a two-dimensional warranty. *Computers & Operations Research*, vol. 32, no. 3, pp. 669–682.

ISSD, D..T. (1992). Business strategy for sustainable development: leadership and accountability for the 90s. Tech. Rep..

Jack, N. and Van der Duyn Schouten, F. (2000). Optimal repair–replace strategies for a warranted product. *International Journal of Production Economics*, vol. 67, no. 1, pp. 95–100.

Jaffe, A.B., Newell, R.G. and Stavins, R.N. (2003). Technological change and the environment. *Handbook of environmental economics*, vol. 1, pp. 461–516.

Jardine, A.K. and Tsang, A.H. (2013). *Maintenance, replacement, and reliability: theory and applications*. CRC press.

Javaherdashti, R., Nwaoha, C. and Tan, H. (2013). *Corrosion and materials in the oil and gas industries*. CRC Press.

Johnson, A., Strachan, S. and Ault, G. (2011). A methodology for risk based asset replacement and investment planning. In: *Universities' Power Engineering Conference (UPEC), Proceedings of 2011 46th International*, pp. 1–5. VDE.

Kaiser, D., Christensen, I., Foust, J. and Davidian, K. (2011). An industry structural analysis and strategy insights for the commercial crew transportation industry. In: *AIAA Space Conference*.

Karabakal, N., Lohmann, J.R. and Bean, J.C. (1994). Parallel replacement under capital rationing constraints. *Management Science*, vol. 40, no. 3, pp. 305–319.

Katkamwar, S.G., Wadatkar, S.K. and Paropate, R.V. (2013). Study of total productive maintenance & its implementing approach in spinning industries. *International Journal of Engineering Trends and Technology (IJETT)*, vol. 4, no. 5, pp. 1750–1754.

Keeble, J., Topiol, S. and Berkeley, S. (2003). Using indicators to measure sustainability performance at corporate and project level. *Journal of Business Ethics*, vol. 44, pp. 149–158.

Khan, F.I. and Haddara, M. (2004). Risk-based maintenance (rbm): A new approach for process plant inspection and maintenance. *Process Safety Progress*, vol. 23, no. 4, pp. 252–265.

Khan, F.I. and Haddara, M.M. (2003). Risk-based maintenance (rbm): a quantitative approach for maintenance/inspection scheduling and planning. *Journal of Loss Prevention in the Process Industries*, vol. 16, no. 6, pp. 561–573.

Kirby, L. (2012 5). Maintaining data center performance. Tech. Rep., SKANSKA.

Kolodner, J.L. (1992). An introduction to case-based reasoning. *Artificial Intelligence Review*, vol. 6, no. 1, pp. 3–34.

Konrad Adenauer Stiftung, (KAS) (2015 4). Republic of namibia kas factbook. Tech. Rep., KAS.

Koronios, A., Nastasie, D., Chanana, V. and Haider, A. (2007). Integration through standards–an overview of international standards for engineering asset management. In: *Fourth International Conference on Condition Monitoring, Harrogate, United Kingdom*.

Kothari, C. (2004). *Research Methodology: Methods and Techniques*. 2nd edn. New Age International.

Labib, A.W. (2004). A decision analysis model for maintenance policy selection using a cmms. *Journal of Quality in Maintenance Engineering*, vol. 10, no. 3, pp. 191–202.

Labuschagne, C., Brent, A.C. and Van Erck, R.P. (2005). Assessing the sustainability performances of industries. *Journal of cleaner production*, vol. 13, no. 4, pp. 373–385.

Lavelle, J.P., Liggett, H.R. and Parsaei, H.R. (2001). *Economic Evaluation of Advance Technologies: Techniques and Case Studies*. CRC Press.

Lee, J., Lee, J. and Feick, L. (2001). The impact of switching costs on the customer satisfaction-loyalty link: mobile phone service in france. *Journal of services marketing*, vol. 15, no. 1, pp. 35–48.

Li, W., Vaahedi, E. and Choudhury, P. (2006). Power system equipment aging. *Power and Energy Magazine, IEEE*, vol. 4, no. 3, pp. 52–58.

Liebert (2003). Lifecycle costing for data centers: Determining the true cost of data center cooling. Tech. Rep., Emerson.

Lilian Chan, Y.-C. (2004). Use of capital budgeting techniques and an analytic approach to capital investment decisions in canadian municipal governments. *Public Budgeting & Finance*, vol. 24, no. 2, pp. 40–58.

Littig, B. and Griessler, E. (2005). Social sustainability: a catchword between political pragmatism and social theory. *International Journal of Sustainable Development*, vol. 8, no. 1, pp. 65–79.

Løken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews*, vol. 11, no. 7, pp. 1584–1595.

Love, C., Zhang, Z.G., Zitron, M. and Guo, R. (2000). A discrete semi-markov decision model to determine the optimal repair/replacement policy under general repairs. *European journal of operational research*, vol. 125, no. 2, pp. 398–409.

Luecke, R. (2002). *Finance for Managers*, vol. 1. Harvard Business Press.

Ma, Z., Zhou, L. and Sheng, W. (2014). Analysis of the new asset management standard iso 55000 and pas 55. In: *Electricity Distribution (CICED), 2014 China International Conference on*, pp. 1668–1674. IEEE.

Magni, C.A. (2010). Average internal rate of return and investment decisions: a new perspective. *The Engineering Economist*, vol. 55, no. 2, pp. 150–180.

Mardin, F. and Arai, T. (2012). Capital equipment replacement under technological change. *The Engineering Economist*, vol. 57, no. 2, pp. 119–129.

Martić, M., Novaković, M. and Baggia, A. (2009). Data envelopment analysis-basic models and their utilization. *Organizacija*, vol. 42, no. 2, pp. 37–43.

Masomi, S. and Ghayekhloo, S. (2011). Consequences of human behaviours' in economics: The effects of behavioural factors in investment decision making at tehran stock exchange. In: *International Conference on Business and Economics Research*, vol. 1.

Mateo, J.R.S.C. (2012). Multi-criteria analysis. In: *Multi Criteria Analysis in the Renewable Energy Industry*, pp. 7–10. Springer.

Mauer, D.C. and Ott, S.H. (1995). Investment under uncertainty: The case of replacement investment decisions. *Journal of Financial and Quantitative Analysis*, vol. 30, no. 04, pp. 581–605.

McElroy, R.S. (1999). Update on national asset management initiatives: facilitating investment decision-making. In: *Innovations in Urban Infrastructure Seminar of the APWA International Public Works Congress*, pp. 1–10. Citeseer.

McKone, K.E., Schroeder, R.G. and Cua, K.O. (1999). Total productive maintenance: a contextual view. *Journal of Operations Management*, vol. 17, no. 2, pp. 123–144.

Melvin, Gordon J; Benders, J. (2012). A capital asset. Tech. Rep., ABB.

Misumi, J., Miller, R. and Wilpert, B. (2003). *Nuclear safety: a human factors perspective*. CRC Press.

Mitchell, J. and Carlson, J. (2001). Equipment asset management–what are the real requirements. *Reliability Magazine*, vol. 4, p. 14.

Montibeller, G. and Franco, A. (2010). Multi-criteria decision analysis for strategic decision making. In: *Handbook of multicriteria analysis*, pp. 25–48. Springer.

Moubray, J. and Lanthier, J. (1991). *Reliability-centred maintenance*. Butterworth-Heinemann Oxford.

Muchiri, P. and Pintelon, L. (2008). Performance measurement using overall equipment effectiveness (oee): literature review and practical application discussion. *International Journal of Production Research*, vol. 46, no. 13, pp. 3517–3535.

Muchiri, P., Pintelon, L., Gelders, L. and Martin, H. (2011). Development of maintenance function performance measurement framework and indicators. *International Journal of Production Economics*, vol. 131, no. 1, pp. 295–302.

Narayanan, V. and Fahey, L. (2005). The relevance of the institutional underpinnings of porter's five forces framework to emerging economies: An epistemological analysis. *Journal of Management Studies*, vol. 42, no. 1, pp. 207–223.

Nelson, T. (2009). Physical asset management background. Tech. Rep., The Nexus Approach to Physical Asset Management (NAPAM).

Noll, R.G. (2005). " buyer power" and economic policy. *Antitrust Law Journal*, pp. 589–624.

Nooraie, M. (2011). Decision's familiarity and strategic decision-making process output: the mediating impact of rationality of the decision-making process. *International Journal of Applied Decision Sciences*, vol. 4, pp. 385–400.

Nooraie, M. (2012). Factors influencing strategic decision-making process. *International Journal of Academic Research in Business and Social Sciences*, vol. 2, no. 7.

Obermatt (2014). Value driver trees.
Available at: `http://www.obermatt.com/products/knowledge/value-management/value-driver-tree`

O'Hanlon, John; Peasnell, K. (1998). Wall street's contribution to management accounting: the stern steward eva ® financial management system. *Management Accounting Research*, vol. 9, pp. 421–444.

Ouertani, M.-Z., Parlikad, A.K. and McFarlane, D.C. (2008). Towards an approach to select an asset information management strategy. *IJCSA*, vol. 5, no. 3b, pp. 25–44.

Papadakis, V.M., Lioukas, S. and Chambers, D. (1998). Strategic decision-making processes: The role of management and context. *Strategic Management Journal*, vol. 19, pp. 115–147.

Perold, A.F. (2004). The capital asset pricing model. *The Journal of Economic Perspectives*, vol. 18, no. 3, pp. 3–24.

Pintelon, L. and Parodi-Herz, A. (2008). Maintenance: an evolutionary perspective. In: *Complex system maintenance handbook*, pp. 21–48. Springer.

Pojasek, R.B. (2011). Iso 26000 guidance on social responsibility. *Environmental Quality Management*, vol. 20, no. 3, pp. 85–93.

Ponce-Cruz, P. and Ramírez-Figueroa, F.D. (2010). Fuzzy logic. *Intelligent Control Systems with LabVIEW?*, pp. 9–46.

Porter, M.E. (1991). Towards a dynamic theory of strategy. *Strategic Management Journal*, vol. 12, pp. 95–117.

Porter, M.E. (2008). The five forces that shape strategy. *Harward Business Reveiew*, vol. Reprint 96608, pp. 23–41.

Pratt, S.P. (2003). *Cost of capital: estimation and applications*. John Wiley & Sons.

Priem, R., Rasheed, A. and Kotulic, A. (1995). Rationality in strategic decision proceses, environmental dynamism and firm performance. *Journal of Management*, vol. 21, pp. 913–929.

PWC (2014). *Namibia Tax Reference and Rate Card*. Pricewaterhouse Coopers.

Quertani, M.Z., Parlikad, A.K. and Mcfarlane, D. (2008). Towards an approach to select an asset information management strategy. *International Journal of Computer Science and Applications*, vol. 8, no. 3b, pp. 25–44.

Rausand, M. (1998). Reliability centered maintenance. *Reliability Engineering & System Safety*, vol. 60, no. 2, pp. 121–132.

Ray, S.C. (2004). *Data envelopment analysis: theory and techniques for economics and operations research*. Cambridge University Press.

Richard, P.J., Devinney, T.M., Yip, G.S. and Johnson, G. (2009). Measuring organizational performance as a dependent variable: Towards methodological best practice. *Journal of Management*.

Ricke, M. and Pfingsten, A. (2002). The economic life of industrial equipment reconsidered. *Available at SSRN 812864*.

Rogers, J.L. and Hartman, J.C. (2005). Equipment replacement under continuous and discontinuous technological change. *IMA Journal of Management Mathematics*, vol. 16, no. 1, pp. 23–36.

Rooney, J.J. and Heuvel, L.N.V. (2004). Root cause analysis for beginners. *Quality progress*, vol. 37, no. 7, pp. 45–56.

Rowley, J. (2002). Using case studies in research. *Management research news*, vol. 25, no. 1, pp. 16–27.

Saaty, T.L. (2000). *Fundamentals of decision making and priority theory with the analytic hierarchy process*, vol. 6. Rws Publications.

Sandborn, P. (2007). Software obsolescence-complicating the part and technology obsolescence management problem. *IEEE Transactions on Components and Packaging Technologies*, vol. 30, no. 4, pp. 886–888.

SARS (2014/2015). *Taxation in South Africa*. South African Revenue Service.

Scall, L., Sundem, G. and Geijsbeek, W. (1978). Survey and analysis of capital budgeting methods. *The Journal of Finance*, vol. 33, no. 1, pp. 281–287.

Schafrick, I.C. (2003). *Analyzing multiple internal rates of return*. Master's thesis.

Schlit, W.K; Paine, F. (1987). An examination of the underlying dynamics of strategic decisions subject to upward influence activity. *Journal of Management*, vol. 24, pp. 161–175.

Schneider, J., Gaul, A.J., Neumann, C., Hogräfer, J., Wellßow, W., Schwan, M. and Schnettler, A. (2006). Asset management techniques. *International Journal of Electrical Power & Energy Systems*, vol. 28, no. 9, pp. 643–654.

Schwenk, C.R. (1995). Strategic decision making. *Journal of Management*, vol. 21, no. 3, pp. 471–493.

Sharpe, W.F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk*. *The journal of finance*, vol. 19, no. 3, pp. 425–442.

Shepherd, W.G. and Shepherd, J.M. (2003). *The economics of industrial organization*. Waveland Press.

Shil, N.C. (2009). Performance measures: An application of economic value added. *International Journal of business and Management*, vol. 4, no. 3, p. p169.

Sigman, K. (2005). Capital asset procong model (capm).
Available at: `http://www.columbia.edu/~ks20/FE-Notes/4700-07-Notes-CAPM.pdf`

Singh, R.K., Murty, H., Gupta, S. and Dikshit, A. (2007). Development of composite sustainability performance index for steel industry. *Ecological Indicators*, vol. 7, no. 3, pp. 565–588.

Sinha, D. (1990). The contribution of formal planning to decisions. *Strategic Management Journal*, vol. 11, no. 6, pp. 479–492.

Slaper, T.F. and Hall, T.J. (2011). The triple bottom line: what is it and how does it work. *Indiana Business Review*, vol. 86, no. 1, pp. 4–8.

Smith, A.M. (1993). *Reliability-centered maintenance*. McGraw-Hill New York, NY.

Sporleder, T.L., Bailey, M.D., Association, A.A.E. *et al.* (2001). *Using Real Options to Evaluate Producer Investment in New Generation Cooperatives*. American Agricultural Economics Association.

Starovic, D., Cooper, S. and Davis, M. (2004). Maximizing shareholder value. Tech. Rep..

Stewart, D., Kennedy, B., Norton, L., Byrne, R. and Rose, D. (2003). Strategic asset management planning: How the orange county sanitation district adopted the team approach. *Water environment & technology*, vol. 15, no. 3, pp. 34–40.

Sullivan, W.G., McDonald, T.N. and Van Aken, E.M. (2002). Equipment replacement decisions and lean manufacturing. *Robotics and Computer-Integrated Manufacturing*, vol. 18, no. 3, pp. 255–265.

Szekely, F. and Knirsch, M. (2005). Leadership and corporate responsibility: Metrics for sustainable corporate performance. *Center for responsible leadership and sustainable Futures, European School of Management and Technology, Berlin pp3*, vol. 54.

Szopa, P. and Pękała, W. (2012). Distribution channels and their roles in the enterprise. *Polish Journal of Management Studies*, vol. 6, pp. 143–150.

Tam, A.S. and Gordon, I. (2009). Clarification of failure terminology by examining a generic failure development process. *International Journal of Engineering Business Management*, vol. 1, no. 1, pp. 33–36.

Thanassoulis, E., Kortelainen, M. and Allen, R. (2012). Improving envelopment in data envelopment analysis under variable returns to scale. *European journal of operational research*, vol. 218, no. 1, pp. 175–185.

The Economist (2009). Triple bottom line.
Available at: `http://www.economist.com/node/14301663/print`

Thomas, J. and Evanson, R.V. (1987). An empirical investigation of association between financial ratio use and small business success. *Journal of Business Finance & Accounting*, vol. 14, no. 4, pp. 555–571.

Torres, D., Usandizaga, M., Casoldi, P., Bolla, R., Scheck, H.O. and Kallio, S. (2012). General specifications and kpis. Tech. Rep., International Telecommunications Union (ITU).

Triantaphyllou, E. and Mann, S.H. (1995). Using the analytic hierarchy process for decision making in engineering applications: some challenges. *International Journal of Industrial Engineering: Applications and Practice*, vol. 2, no. 1, pp. 35–44.

Trinh, J. and Ly, D. (2013 12). Fit data and mttf/mtbf. Tech. Rep., TDK.

Turbit, N. (2005 6). Defining the scope of a project. The Project Perfect White Paper Collection.

Van den Honert, A., Schoeman, J. and Vlok, P. (2013). Correlating the content and context of pas 55 with the iso 55000 series. *South African Journal of Industrial Engineering*, vol. 24, no. 2, pp. 24–32.

Van der Poll, H.M., Booyse, N.J., Pienaar, A., Büchner, S. and Foot, J. (2011). An overview of the implementation of economic value added (eva?) performance measures in south africa. *Southern African Business Review*, vol. 15, no. 3, pp. 122–141.

Van Heerden, R.E. (2003). *The performance of different asset classes during the stages of the investment cycle.* Ph.D. thesis, Rand Afrikaans University.

Velasquez, M. and Hester, P.T. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research*, vol. 10, no. 2, pp. 56–66.

Venkatraman, N. and Ramanujam, V. (1986). Measurement of business performance in strategy research: a comparison of approaches. *Academy of management review*, vol. 11, no. 4, pp. 801–814.

Ventyx (2012). A pas 55 approach to asset management. A ventyx whitepaper, ABB.

Wallingford, E. and Sticklen, J. (1992). Selecting plans for capital asset acquisition through classification problem solving. *Expert Systems in Finance*, pp. 19–36.

Wally, S; Baum, J. (1994). Personal and structural determinants of the pace of strategic decision making. *Academy of Management Journal*, vol. 37, pp. 932–956.

Welman, C., Kruger, F. and Mitchell, B. (2005). *Research Methodology.* Oxford University Press.

Wendling, T.E. (2011*a*). A life contingency approach for physical assets: Create volatility to create value. In: *Society of Actuaries 2011 ERM Symposium Monograph.*

Wendling, T.E. (2011*b*). A life contingency approach for physical assets: Create volatility to create value. In: *Society of Actuaries 2011 ERM Symposium Monograph.*

Werden, G.J. (2001). Network effects and conditions of entry: Lessons from the microsoft case. *Antitrust Law Journal*, pp. 87–111.

Wernetfelt, Birger; Karnani, A. (1987). Competitive strategy under uncertainty. *Strategic Management Journal*, vol. 8, pp. 187–194.

Whitelaw, K. (2004). *ISO 14001 environmental systems handbook.* Routledge.

Winsor, G. and Buncombe, S. (2007). Repair/replace decision making practices. 25. Energy Australia, ICOMS Asset Management Conference.

Woodhouse, J. (1997). What is asset management? *Maintenance and Asset Management*, vol. 12, pp. 26–28.

Woodhouse, J. (2006). Putting the total jigsaw puzzle together: Pas 55 standard for the integrated, optimized management of assets. In: *International Maintenance Conference*.

Woodhouse, J. (2014). Briefing: Standards in asset management: Pas 55 to iso 55000. *Infrastructure Asset Management*, vol. 1, no. 3, pp. 57–59.

Xu, L. and Yang, J.-B. (2001). *Introduction to multi-criteria decision making and the evidential reasoning approach*. Manchester School of Managment, University of Manchester Institute of Science and Technology.

Xu, L.D. (1994). Case based reasoning. *Potentials, IEEE*, vol. 13, no. 5, pp. 10–13.

Yatsenko, Y. and Hritonenko, N. (2008*a*). The dynamics of asset lifetime under technological change. *Operations Research Letters*, vol. 36, no. 5, pp. 565–568.

Yatsenko, Y. and Hritonenko, N. (2008*b*). Properties of optimal service life under technological change. *International Journal of Production Economics*, vol. 114, no. 1, pp. 230–238.

Yatsenko, Y. and Hritonenko, N. (2009). Technological breakthroughs and asset replacement. *The Engineering Economist*, vol. 54, no. 2, pp. 81–100.

Zimmermann, H.-J. (2010). Fuzzy set theory. *Wiley Interdisciplinary Reviews: Computational Statistics*, vol. 2, no. 3, pp. 317–332.