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UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

ANALYSES OF SOUTH AFRICAN MINING PROJECTS: TECHNICAL VARIANCES AND IMPACT OF THESE ON PROJECT SUCCESS.

Ipelo Gasela

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering.

Johannesburg, 19 October 2018

CONTENTS

CONTENTS 2
DECLARATION 5
ABSTRACT 6
DEDICATION 7
ACKNOWLEDGEMENTS 8
LIST OF FIGURES 9
LIST OF TABLES 12
LIST OF SYMBOLS 13
1 INTRODUCTION 14
1.1 Chapter overview 14
1.2 Background 14
1.3 Purpose of the Study 16
1.4 Research Motivation 16
1.5 Problem Statement 17
1.6 Chapter summary 17
2 LITERATURE REVIEW 18
2.1 Chapter overview 18
2.2 What is project success? 18
2.3 Project risk in the minerals industry 20
2.4 Reporting codes background 25
2.4.1 JORC 25
2.4.2 SAMREC 25
2.4.3 CRIRSCO 26
2.5 Mineral Resource 27
2.6 Mineral Reserve 30
2.6.1 Mining 31
2.6.2 Geotechnical 34
2.6.3 Ventilation and refrigeration requirements 35
2.6.4 Metallurgy 35
2.6.5 Cost estimation 37
2.7 The economic viability of a project 38
2.7.1 Discounted Cash Flows 38

2.8 Technical risk 39
2.9 Project success model for construction projects 40
2.10 Chapter summary 42
3 SOUTH AFRICAN MINING INDUSTRY 44
3.1 Chapter overview 44
3.2 Mining history in South Africa 44
3.3 The economic significance of the mining industry 45
3.4 Operating mines in South Africa 47
3.5 Chapter summary 48
4 METHODOLOGY AND DATA SOURCE ..... **Error! Bookmark not defined.**
4.1 Chapter overview ..... **Error! Bookmark not defined.**
4.2 Target population ..... **Error! Bookmark not defined.**
4.3 Research design and methods ..... **Error! Bookmark not defined.**
4.3.1 Limitations of the study 57
4.4 Chapter summary 58
5 SOUTH AFRICAN EXAMPLES 59
5.1 Chapter overview 59
5.2 Gold industry 59
5.2.1 Burnstone Gold Mine 59
5.2.2 Kusasalethu Gold Mine 64
5.2.3 Phakisa Gold Mine 69
5.3 Platinum projects 71
5.3.1 Bokoni Platinum Mine 71
5.3.2 Modikwa Platinum Mine 78
5.3.3 Crocodile River Platinum Mine 83
5.3.4 Marula Platinum Mine 88
5.3.5 Two Rivers Platinum Mine 90
5.3.6 Leeuwkop Platinum Mine 94
5.3.7 Platinum Price 94
5.4 Coal projects 96
5.4.1 Mooiplaats Colliery 96
5.4.2 Isibonelo Colliery 99
5.5 Chapter summary 100
6 PROJECT SUCCESS EQUATION 103

6.1 Chapter overview 103
6.2 Background 103
6.3 Analyses of results 103
6.4 Applying the equation to South African examples 112
6.4.1 Burnstone Gold Mine 112
6.4.2 Kusasalethu Gold Mine 114
6.4.3 Bokoni Platinum Mine 116
6.4.4 Modikwa Platinum Mine 118
6.4.5 Crocodile River Platinum Mine 120
6.5 Chapter summary 124
7 CONCLUSION 125
8 RECOMMENDATIONS 129
9 REFERENCES 130
10 APPENDIX 149
10.1 Response1 149
10.2 Response2 150
10.3 Response3 151
10.4 Response4 152
10.5 Response5 153
10.6 Response6 154
10.7 Response7 155
10.8 Response8 156
10.9 Response9 157
10.10 Response10 158
10.11 Response11 159
10.12 Response12 160

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University

Signed:

_____

Ipelo Gasela

_____day of_____year_____

ABSTRACT

Mining projects are known for having a poor success rate. The purpose of this study is to assess the impact of technical shortcomings on the value of mining projects and define success in mining projects, using an empirical equation. This study was focused on South African mining projects, due to the uncertainty of how successful South African mining projects are.

A total of 11 projects were reviewed. Six from the platinum, three from the gold and two projects from the coal industry were selected due to the importance of these commodities in the South African economy. Actual technical and cost parameters were analysed and compared against the initially planned values. Financial comparisons were carried out in similar money terms. An impact of the planned NPV by actual performance was also analysed. This was only undertaken for projects whose DCF was published in the public domain.

Most of the projects reviewed in this study did not reach the planned production, exceeded operating costs and/or capital expenditure. Technical factors contributing to this, included change in design during development, additional water handling, ageing infrastructure, lack of mining flexibility, and geological difficulties being the most common factor. The most common non-technical factors included community and labour unrest.

Following the approach developed by Khosravi and Afshari (2011) in the construction industry, an empirical equation was formulated based on success criteria identified by McCarthy (2014), which were rated by mining professionals, in a survey, according to their sensitivity to the success or failure of mining projects. Capital cost overrun was rated the most sensitive criterion to project failure, while schedule overrun was deemed to be the least sensitive to project success by mining professionals.

Only five projects, out of the 11 selected for this study, were assessed using this equation, due to insufficient data on other projects in the public domain. The results of this assessment enabled the projects to be ranked according to their relative success. The results of this assessment demonstrated that a project can still be in operation although it is performing far below its original design criteria.

DEDICATION

This research report is dedicated to my family. To my hubby, Lance Gasela, thanks for your encouragement and your unwavering support on this adventure. To my two beautiful daughters, Lethiwe Oreratile Gasela and Nkanyezi Peo Gasela, I love you and thank you for being understanding and patient with me during this demanding time.

XOXO Mama

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- My former colleagues at Snowden Mining Industry Consultants (Pty) Ltd

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LIST OF FIGURES

Figure 1-1 Project evaluation studies as project development progresses (after Hanson et. al., 2005) 15
Figure 2-1 Hypothetical root cause analysis for a project (after De-Vitry, 2014) 22
Figure 2-2 Mineral Resource and Mineral Reserve classifications (after Committee for Mineral Reserves International Reporting Standards, 2012) 29
Figure 2-3 A simple 2D pit limit analysis (after Thorley, 2012) 33
Figure 3-1 Contribution to the Q1 2017 GDP by sector (after StatsSA, 2017a)..... 46
Figure 3-2 Percentage contribution of mineral production to the South African mining industry (after StatsSA, 2015)..... 46
Figure 3-3 Percentage contribution of job employment in the South African mining industry in 2012 (after StatsSA, 2015)..... 47
Figure 3-4 Number of operating mines in South Africa over time. (Data was sourced from Department of Mineral Resources, 2004-2014)..... 48
Figure 5-1 Burnstone Gold Mine locality map (after Great Basin Gold, 2012a)..... 59
Figure 5-2 Feasibility study versus actual cumulative CAPEX. (Sourced from the Great Basin Gold, 2007 – 2012) 61
Figure 5-3 Feasibility study vs actual milled tonnes profile (Data sourced from the Great Basin Gold, 2007 – 2012) 62
Figure 5-4 Feasibility study vs actual milled grade profile (Data sourced from the Great Basin Gold, 2007 – 2012) 62
Figure 5-5 Feasibility study vs actual unit operating cost (Data sourced from the Great Basin Gold, 2007 – 2012) 63
Figure 5-6 Change in NPV due to actual values at Burnstone (Data sourced from the Great Basin Gold, 2007 – 2011) 64
Figure 5-7 Locality map for Kusasalethu Gold Mine (after Harmony Gold Mining Company Limited, 2009) 65
Figure 5-8 Planned peak annual gold ounces predicted in 2001 and 2005, and actual gold produced over time at Kusasalethu Gold Mine. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2002 - 2016). 67
Figure 5-9 Average Reserve grade vs actual recovered grade. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2002 - 2016). 68
Figure 5-10 Annual gold ounces planned vs actual for Phakisa Mine. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2003 – 2017)..... 70
Figure 5-11 Total planned vs actual cumulative CAPEX for Phakisa Mine. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2003 – 2017)..... 70
Figure 5-12 Locality map for Bokoni Platinum Mine (after Atlatsa Resources Corporation, 2018)..... 71
Figure 5-13 Produced tonnes at Bokoni versus planned tonnes between 2009 and 2015. (Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015)..... 74
Figure 5-14 Produced 4E ounces at Bokoni versus planned 4E production between 2009 and 2015. (Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa

Resources Corporation, 2012 - 2015) 75
Figure 5-15 Actual unit cash cost at Bokoni measured in ZAR/tonne. (Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015) 76
Figure 5-16 Rand basket price for PGM from 2009 to 2015. Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015 77
Figure 5-17 Change in NPV due to actual values at Bokoni 77
Figure 5-18 Produced tonnes at Modikwa versus planned tonnes between 2004 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)..... 79
Figure 5-19 Achieved head grade at Modikwa versus planned head grade between 2005 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)..... 80
Figure 5-20 Produced 4E ounces at Modikwa versus planned 4E production between 2005 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)... 81
Figure 5-21 Actual vs planned cash costs at Modikwa between 2005 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015) 81
Figure 5-22 Locality map for Crocodile River Platinum Mine (after Eastern Platinum Limited, 2007)..... 83
Figure 5-23 Produced tonnes at Crocodile River Platinum Mine versus planned tonnes between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2008 – 2014) ... 85
Figure 5-24 Produced 4E PGM ounces at Crocodile River Platinum Mine versus planned 4E production between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014) 85
Figure 5-25 Actual head grade at Crocodile River Platinum Mine versus planned head grade between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014) 86
Figure 5-26 Actual unit cash cost versus planned unit cash cost between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014) 86
Figure 5-27 Actual CAPEX versus planned CAPEX between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014)..... 87
Figure 5-28 Change in NPV due to actual values at the Crocodile River Platinum Mine (Data sourced from Eastern Platinum Limited, 2008 – 2014) 88
Figure 5-29 Marula Platinum Mine locality map (Impala Platinum Limited, 2009)..... 89
Figure 5-30 Produced tonnes at Marula versus planned tonnes between 2004 and 2017 (Data sourced from Impala Platinum Limited, 2003 - 2017)..... 89
Figure 5-31 Gross operating profit/loss at Marula between 2004 and 2017 (Data sourced from Impala Platinum Limited, 2003 - 2017) 90
Figure 5-32 Produced tonnes versus planned tonnes at Two Rivers between 2007 and 2017 (Data sourced from Impala Platinum Limited, 2005 - 2017)..... 92
Figure 5-33 Produced Pt ounces versus planned Pt ounces at Two Rivers between 2007 and 2017 (Data sourced from Impala Platinum Limited, 2005 - 2017) 92
Figure 5-34 Gross profit/loss at Two Rivers between 2008 and 2017 (Data sourced from Impala Platinum Limited, 2005 - 2017)..... 92
Figure 5-35 US dollar platinum price per ounce between 2000 and 2018 (after InfoMine.com, 2018) 95
Figure 5-36 South African Rand platinum price per ounce between 2000 and 2018 (after

InfoMine.com, 2018 95
Figure 5-37 Locality map for Mooiplaats Colliery (after Mindset Mining Consultants (Pty) Ltd, 2013) 97
Figure 5-38 Forecast versus actual ROM tonnes per annum over time (Data sourced from Coal of Africa, 2009 - 2013) 98
Figure 5-39 Coal production yield over time (Data sourced from Coal of Africa, 2009 - 2013) 98
Figure 5-40 Forecast versus actual ROM tonnes per annum over time (Data sourced from Anglo American, 2005 – 2017) 100
Figure 6-1 Rankings by respondents of technical criteria in project failure 104
Figure 6-2 Sum of rankings from respondents per criterion 107

LIST OF TABLES

Table 2-1 Success criteria weighting based on a survey (after de Wit, 1988) 20
Table 2-2 Areas of risk in the minerals industry and relevant rankings according to finance entities (after Simonsen & Perry, 1999) 23
Table 2-3 Ranked mining project risks in Mongolia based on the consequences of project success (after Chinbat, 2011) 24
Table 2-4 Weight factors for the final project success criteria (after Khosravi & Afshari, 2011) 41
Table 4-1 A list of mine projects analysed in this study 56
Table 5-1 Technical performance indicators anticipated at full production (after African Rainbow Minerals Limited, 2004) 79
Table 5-2 Mine performance information provided per project 102
Table 6-1 Ratings per criterion 105
Table 6-2 Ratings per criterion weighted by the respondent's experience 106
Table 6-3 Total ratings and the total number of responses per criterion 107
Table 6-4 Weight factors for mining project success/failure criteria 108
Table 6-5 Ranked ratings and mean rankings per criterion 111
Table 6-6 Burnstone performance measurement 113
Table 6-7 Kusasalethu performance measurement 115
Table 6-8 Bokoni performance measurement 117
Table 6-9 Modikwa performance measurement 119
Table 6-10 Crocodile River Platinum Mine performance measurement 121
Table 6-11 Summarised PSI for assessed mines 123

LIST OF SYMBOLS

£	British pound
%	Percent
g/t	Grams per tonne, same as parts per million
DCF	Discount cash flow
Kt	Kilo tonnes
NPT	Net present value
Mt	Million tonnes
oz	Troy ounce = 31.1034768 grams
Tonne	1,000 kilograms
tpm	Tonne per month
US$	United States Dollar
ZAR	South African Rand

1 INTRODUCTION

1.1 Chapter overview

This chapter discusses the role of feasibility studies on a mining project, looks at the overview on the success of mining projects, the purpose of the study, research motivation and the problem statement for this research.

1.2 Background

Feasibility studies for mining projects provide plans for construction and operation of a mine. Feasibility studies need to disclose the technical and economic inputs that form the basis of the plans for development and mining (Mackenzie & Cusworth, 2007). It is recommended that input into the feasibility studies be based on preceding pre-feasibility studies, where trade-off studies are undertaken to investigate and determine the most optimal options for mining (Kühn & Visser, 2014; Mackenzie & Cusworth, 2007). In-depth investigation of these options and knowledgeable judgment by experts is important to ensure that the parameters used in a feasibility study are viable and will yield the highest possible value for the project. Once a feasibility study has been approved and construction commenced, very little can be done to add value to the project. Feasibility studies are thus expected to have a high level of accuracy (Mackenzie & Cusworth, 2007) (Figure 1-1).

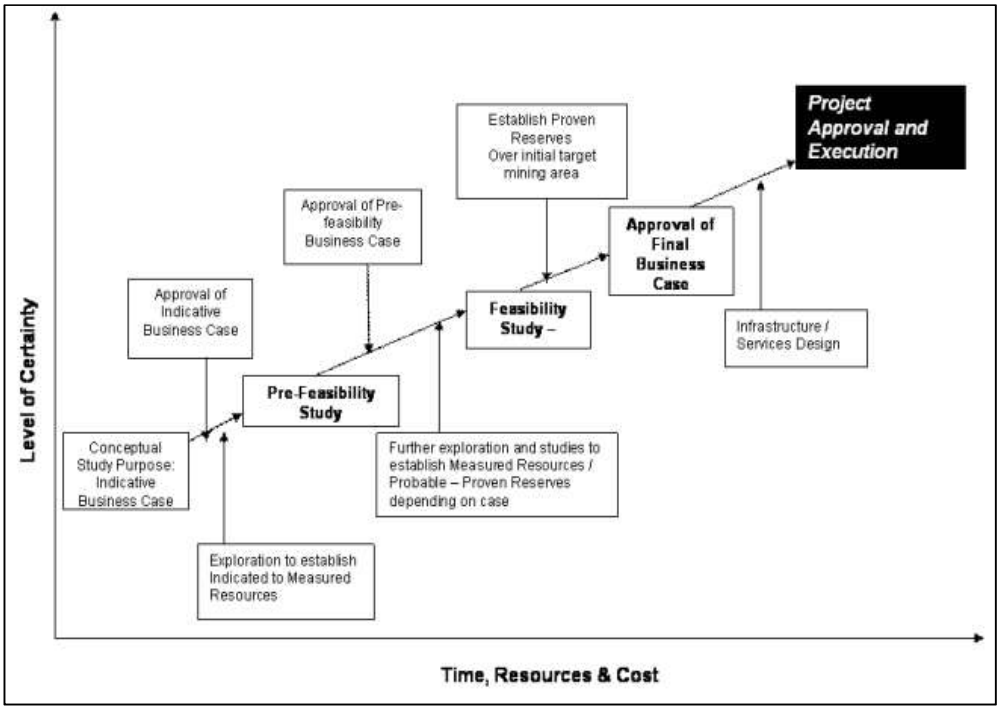

Figure 1-1 Project evaluation studies as project development progresses (after Hanson et. al., 2005)

Despite the preparation of feasibility studies, the mining industry has been historically reported to perform poorly on projects globally, and these have been due to an array of factors. The following studies demonstrate poor performance of mining projects in history (McCarthy, 2013):

- "A Master's research studied 35 Australian gold mines. The research found that 68 percent (%) of the mines failed to deliver the planned head grade to the respective plants. Excessive dilution, inappropriate planning methods, inappropriate geological interpretation, insufficient chemical analysis and probing in the project study phase were reasons provided for this shortfall (Burmeister, 1988)."
- "A review of approximately 50 North American gold projects found that only 10% of the projects achieved their commercial objectives, and 38% failed within the first year. Most of the failure was attributed to not achieving planned production levels and/or inappropriate processing methods, which led to high operational costs (Harquail, 1991)."
- "A study of the start-up performance of nine Australian underground base metal mines

found that only 50% achieved design throughput by year three, and 25% never achieved their planned production level at all (McCarthy & Ward, 1999)."

- "A study in the US comparing the final feasibility study production rate with the average sustained production rate from 60 steeply-dipping tabular deposits found that 35% of the mines did not achieve their planned production rate. The study found that the production rate in the feasibility study was based on general input requirements and economic optimisation that suggested production rates that were not always sustainable (Tatman, 2001)."
- Gypton (2002) observed in the 1980s that out of a sample of 60 mining projects developed in the Americas, only 40% had project costs within 15% accuracy claimed in the feasibility studies. The failed projects were irrespective of orebody, location, project size and company size. According to the author, although some of the project failures have been caused by technical risks and other unforeseeable circumstances such as "acts of God" or unexpected change in legislation, project management has the highest impact in the success or failure of a project. Project management, especially the owner project management, must be experienced and skilled enough to ask relevant, specific questions to address the risks in the project.

1.3 Purpose of the Study

The purpose of this study is to assess the impact of the technical shortcomings on the value of mining projects. Due to limited studies of this nature being undertaken in South Africa, this study will focus on South African mining projects.

The study also aims to define failure in mining projects, based on technical factors. Failure of a project is commonly understood as a significant, negative deviation of the actual achievements of a project, against the plan set out. Since a project is made up of several components, all the components do not carry the same impact in assessing a success or failure of a project. For example, great deviations between the plan and the actual construction do not necessarily conclude that the project has failed (Lim & Zain Mohamed, 1999). In this study, an equation will be developed aimed to determine project success/failure based on the actual performance compared to the planned technical parameters.

1.4 Research Motivation

This research aims to contribute to the existing body of knowledge by investigating the

impact of technical shortcomings on the value of projects. This study will be undertaken on mining projects in South Africa, due to limited studies of such nature in South Africa.

The study will also formulate an empirical equation, which will be aimed to determine success or failure of a mining project based on technical criteria identified by McCarthy (2014) and the perceived influence each of these criteria has towards determining the project as a success or failure.

1.5 Problem Statement

There is uncertainty as to how successful South African mining projects are. This study seeks to identify if South African projects are successful with regards to value and the technical impact thereof.

1.6 Chapter summary

Feasibility studies are the basis for decision making in terms of developing a mining project. Therefore, the accuracy of a feasibility study has a direct influence on the success of mining projects. Globally, the mining industry has not had a good track record with the development of mining projects. The purpose of this study is to assess the impact of the technical shortcomings on the value of mining projects, with a focus on South African projects. The study also aims to define failure in mining projects, based on technical factors.

2 LITERATURE REVIEW

2.1 Chapter overview

This chapter discusses the definition of project success according to different researchers. This is followed by a discussion on the lists of project risks in the mining industry. Codes for reporting Mineral Resource and Mineral Reserves are then discussed, followed by an in-depth discussion defining Mineral Resource and Mineral Reserve and the technical inputs thereto. Since project viability is dependent on technical and economic viability, the discount cash flow (DCF) is discussed, with inputs to the DCF. Finally, a project success model is discussed that was developed for the construction industry. The approach of this model is adopted to develop the success equation for the mining industry, in this study.

2.2 What is project success?

Project success has traditionally been based on time, cost and quality, known as the Iron Triangle (Lim & Zain Mohamed, 1999). However, these criteria do not measure the overall success of a project. Thus, an additional criterion has been added to the assessment of project success. Project success is also deemed to depend on stakeholder satisfaction or stakeholder benefits arising from the project (Atkinson, 1999; Lim & Zain Mohamed, 1999).

According to Lim and Zain Mohamed (1999), project success criteria can be classified into a micro and macro perspective. Micro success is concerned with achieving components of project implementation. It is usually evaluated on the basis of time, cost, quality and safety against the construction plan.

While the macro view of a project's success assesses whether a project's original concept has been achieved. This can only be assessed at the operational phase of the project, by evaluating the achievement of the operation against the major objectives of the project. Macro success is determined by two factors, completion and satisfaction. The time a project is completed will influence the project's macro success assessment. Once a project has been completed, it can then be assessed for satisfaction. In terms of mining, satisfaction would be whether the mine is able to produce the quantities, qualities of the product and generate the cash flows set out in the feasibility study (Kühn & Visser, 2014). Therefore, a project that operates at a profit can still be rendered unsuccessful by stakeholders if it operates significantly below the economic target set out in the feasibility study. Satisfaction, based on achieving or exceeding the set-out objectives of the project, generally holds more weight

in the assessment of success for a project, than the implementation of a project (de Wit, 1988; Lim & Zain Mohamed, 1999). It is also acknowledged in the mining industry that excellent construction of a project only maintains the value of a project, but it is during the operation that this value is delivered (Mackenzie & Cusworth, 2007).

Merrow (2011) considered the following failure criteria for industrial megaprojects, which include mining, petroleum and chemical projects:

- Will it be built and started up without injury to anyone involved, or will there be some casualties?
- Will the total cost be in line with the amount authorised, or will it exceed the estimate by more than 25%?
- Will it be completed on the original schedule, or will it slip by more than 25%?
- Will it start up and deliver the promised production, or will there be an initial or permanent shortfall?

Ferguson, et. al. (2011) considered the following definitions, within five years of completing a feasibility study, to be appropriate for defining failure of a developing mine:

- Unable to secure mine financing,
- The project is sold off,
- The project postponed or production suspended, or
- The company declares insolvency.

According to McCarthy (2014), the following criteria may result in the failure of mining projects.

- "The capital cost of the project is higher than expected.
- The project takes longer to build and ramp up than expected, affecting costs and delaying cash flow.
- Initial performance cannot be sustained, though it may take several years for the failure to become evident. This is where the project's initial production performance is lower than planned and cannot sustain the operation.
- The operating cost is higher than expected.

- The recovered grade is lower than expected, affecting revenue.
- The project incurs unforeseen negative environmental, social and political impacts."

This study will not assess the last criterion listed by McCarthy (2014), which is the impact of environmental, social and political factors as these are external to the project and are often out of the control of project owners. The above criteria by McCarthy (2014) are assessed in this study because in the opinion of the author are inclusive of most internal technical factors that may affect the success of a project.

Defining success is not easy. Success varies because stakeholders do not consider the criteria, used to determine project success, at the same level of importance. This was the case with the respondents to a mail survey undertaken on 103 development projects, which were mostly sponsored by the Department of Defense in the United States of America and National Aeronautics and Space Administration (NASA). The respondents indicated that the following contributions would be relevant for a weighted success criterion (Table 2-1) (de Wit, 1988):

Table 2-1 Success criteria weighting based on a survey (after de Wit, 1988)

Success criteria	***Relative weight (%)**
Technical performance	54
Cost performance	23
Schedule performance	22

*It has been noted that these figures do not add up to 100 but have been reported exactly as they are from the source.

Due to the different levels of importance different stakeholders consider of criteria, this study will attempt to measure mining projects success according to the criteria recognised by McCarthy (2014). These criteria will be rated by mining professional for the level of sensitivity towards project success, and the ratings will be used to establish a weighted formula for defining project success.

2.3 Project risk in the minerals industry

Risk is defined as an uncertain event or the variance between anticipated and actual outcomes, which can have a positive or negative impact on at least one of the project

objectives (Chartered Institute of Management Accountants, 2005; Project Management Institute, 2004). Mining projects inherently have high risk because of their size, uncertainty, complexity, high costs and prolonged time they take before generating an income (Baurens, 2010; Chinbat, 2011; Kühn & Visser, 2014). As much as mining is characterised by high risk for failure, it also presents an opportunity for high returns (Miller & Lessard, 2001).

Kühn and Visser (2014) identified risks or uncertainties by determining the project requirement first. The common requirement for projects in the minerals industry is to maximise the net present value (NPV) and the internal rate of return (IRR). Thereafter, assumptions and constraints that can impact the requirement are identified as follows:

- Assumptions;
- Physical constraints;
- Imposed constraints; and
- Technical constraints

These constraints should be tested in a financial model pertaining to the project to determine the impact of the identified constraints and assumptions. According to Kühn and Visser (2014), this assessment should help the project team prioritise its efforts to areas that carry the highest uncertainty and the highest catastrophic impact on the value of the project.

According to De-Vitry (2014) risk in mining projects can be classified into three broad categories, namely:

- Technical risk, associated with sample quality, Mineral Resource estimation, pit optimisation, mine equipment selection, metallurgical processing, cost estimation, geotechnical modelling;
- Non-technical risk which includes exchange rates, metal prices and country risk; and
- People risk, which includes turnover, skills shortage, fraudulent behaviour.

De-Vitry (2014) states that these risks are often interlinked and cannot always be separated. For example, risks that appear to be technical in nature may have a non-technical root cause (Figure 2-1) (De-Vitry, 2014).

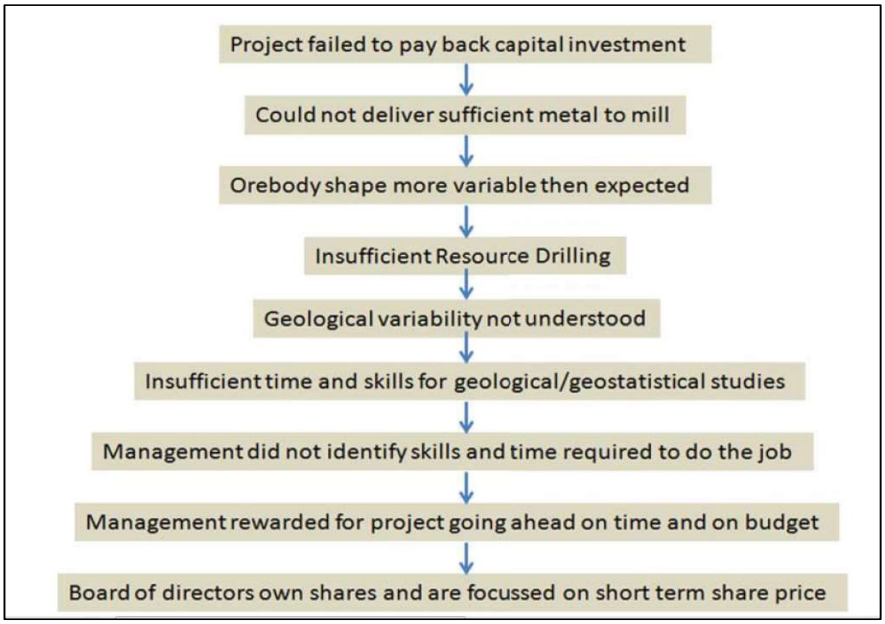

Figure 2-1 Hypothetical root cause analysis for a project (after De-Vitry, 2014)

According to 11 finance entities, areas of risk in the minerals industry carry different levels of significance as per the ranking below (Simonsen & Perry, 1999). The highest ranking risks include Reserve estimation, technical factors, market as well as completion time (Table 2-2).

Table 2-2 Areas of risk in the minerals industry and relevant rankings according to finance entities (after Simonsen & Perry, 1999)

Areas of risk	Risk ranking
Reserves	1
Technical	1
Market	1
Completion	1
Political	0.91
Cost	0.64
Force majeure	0.55
Foreign exchange	0.55
Participants	0.45
Management	0.27
Infrastructure	0.27
Syndication	0.09

In another study, Chinbat (2011) requested mining engineers and project managers working in the mining industry in Mongolia to identify and rank risks based on the impact these risks would have on project success in Mongolia (Table 2-3).

The studies mentioned in this section are consistent in identifying technical factors, including Mineral Resource estimation to bear the majority of the risk in the success of mining projects.

Table 2-3 Ranked mining project risks in Mongolia based on the consequences of project success (after Chinbat, 2011)

1	Incorrect mineral resource calculation
2	Incorrect financial resource calculation
3	Owner's financial difficulties
4	Diesel shortage in the country
5	Price fluctuation of minerals (negative effect case only)
6	Changes in laws and regulations (negative effect case only)
7	Poor management
8	Technical problem (breakdown)
9	Railway transportation delay
10	Shortage of skilled manpower for the mining machinery
11	Demand fall of the mineral
12	Insufficient skills of the project managers
13	Shortage of equipment
14	The irresponsibility of the workers
15	Shortage of machinery
16	Foreign exchange rate fluctuation (negative effect case only)
17	Accidents during construction and operation
18	Government bureaucracy for obtaining licenses
19	Boycotting
20	Unpredicted environmental damages
21	Poor infrastructure
22	Not enough fund for the environmental recovery
23	Political instability
24	Insufficient employment safety substances
25	Pressure from the government inspectors
26	Employee strike
27	Poor internal communication
28	Increase of competition
29	Shortage of experts
30	Shortage of local manpower

2.4 Reporting codes background

The development of Mineral Resource and Mineral Reserve reporting codes for investment purposes received great attention in the 1990s. Though the first publication of this kind of codes was written in 1556 by Georgius Agricola, known as 'De Re Metallica'; they became popular in the 1990's triggered by mining scandals, in particular, the BreX Scandal (Camisani-Calzolari, 2004).

2.4.1 JORC

The Australian reporting code was a reaction to an earlier mining scandal that took place in Australia between 1969 and 1970 known as the Poseidon scandal. This took place when the price of nickel increased significantly due to the Vietnamese war and a shortage in the supply of nickel. Around the same time, a company called Poseidon NL (Poseidon) discovered the Windarra deposit, in Western Australia. This company became overvalued because of the price of nickel and the Mineral Resource declared to the market. As a result, properties around Windarra raised their values by association. Consequently, money was raised on the stock market on properties with little or no mineralisation. The decline in the nickel price led to a crash in the stock market and a write off on companies that had no real value. A commission of enquiry instated to investigate the crash in the stock market reported that the stock market was poorly regulated and that much of the information relied upon by investors was based on rumours (Simon, 2003).

Subsequently, the Australian government warned the mining industry to develop reporting standards or it will impose regulations on it. This led to the creation of the Joint Ore Reserves Committee (JORC) and the release of the first edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (the 'JORC Code') in 1989 (Camisani-Calzolari, 2004). Subsequent editions of the 'JORC Code'were released in 1992, 1996, 1999, 2004 and the current edition in 2012. The Australian Stock Exchange (ASX) requires the reporting of exploration results, Mineral Resource and Ore Reserve to be compliant to the JORC Code (Joint Ore Reserves Committee of The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia, 2012). Most of the current investor focused Mineral Resource and Mineral Reserve reporting codes are based on the JORC code (Camisani-Calzolari, 2004).

2.4.2 SAMREC

South Africa's first attempt to develop a Mineral Resource and Mineral Reserves reporting code was in 1992 as a response to a request by the Council of Mining and Metallurgical

Institutes (CMMI). The Geological Society of South Africa (GSSA) and Geostatistical Association of South Africa (GASA) worked on this, and together with the South African Institute for Mining and Metallurgy (SAIMM) presented 'Draft 6' at the CMMI's 15th Congress at Sun City, South Africa, in 1994. The first official working committee was formed in 1998, and it released the first edition of the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (the SAMREC Code) in March 2000. The code was revised in 2007, with some added amendments released in 2009. The code was subsequently updated in 2016, which is the current applicable edition (Samcodes Standards Committee, 2017).

2.4.3 CRIRSCO

The 15th Congress of the CMMI, at Sun City, was attended by representatives from organisations that were responsible for developing existing Mineral Resources and Mineral Reserves reporting codes for their respective countries and formed a working group. This working group was later called Committee for Mineral Reserves International Reporting Standards (CRIRSCO). Countries, and reporting codes, who form part of the CRIRSCO membership include South Africa (SAMREC), Australasia (JORC), Brazil (CBRR), Canada (CIM), Europe (PERC), Kazakhstan (KAZRCA), Mongolia (MPIGM), Russia (NAEN), the USA (SME) and Chile (National Committee) (Committee for Mineral Reserves International Reporting Standards, 2017).

CRIRSCO was formed with the intent to standardise definitions in the reporting of Mineral Resource and Mineral Reserves for its participants. In 1997, five CRIRSCO participants agreed on definitions of Mineral Resource and Mineral Reserve, as well as the definitions of the respective sub-categories for Mineral Resource and Mineral Reserve at a meeting in Denver, which was named the Denver Accord (Committee for Mineral Reserves International Reporting Standards, 2017).

In 2012, CRIRSCO agreed in principle to definitions of 15 terms. These standard terms and definitions are also incorporated in the latest CRIRSCO related codes (Committee for Mineral Reserves International Reporting Standards, 2012). Consistent terms and definitions help investors to understand and compare projects.

2.5 Mineral Resource

A Mineral Resource as defined by CRIRSCO is “a concentration or occurrence of solid material of economic interest in or on the Earth’s crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction” (Committee for Mineral Reserves International Reporting Standards, 2012). A Mineral Resource is then an estimate of grade and tonnage of mineralisation in or on the Earth’s crust that has the potential for eventual economic extraction.

The level of accuracy in a Mineral Resource estimate is based on the understanding of the underlying geology represented as a geology model, the level of quality and quantity of the information used and the estimation techniques used (Stephenson & Vann, 2001). The inputs into the Mineral Resource and Mineral Reserve are very important, that is why some of the latest CRIRSCO related codes, such as the JORC Code and the SAMREC Code, require a discussion on inputs on an ‘if not, why not’ basis (Joint Ore Reserves Committee of The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia, 2012; Samcodes Standards Committee, 2016).

A geology model is a diagram representing the interpretation of the underlying geology from available data. Such a model must be tested and updated when new information becomes available. A model should also be changed if the available information is not consistent with it. Available information must be used to model and not force the information to fit a model. It is also good practice to test more than one interpretation. The extent of differences in the interpretations gives an indication of the level of risk in a geology model (Jackson, et. al., 2003).

According to Stephenson and Vann (2001), different drilling methods are inherently associated with different levels of quality. In terms of the theory of sampling, bigger samples are more representative. Smaller samples lead to higher fundamental sampling error, which is dependent on the size of the sample as well as the shape and size of the particles sampled, liberation size, mineralogy and density of the critical component. The higher the sampling error is the less representative a sample is (Abzalov, 2011). In light of this, reverse circulation (RC) drilling should be considered more desirable than diamond drilling. However, due to the inability to preserve geological structures, lithological contacts and probability of downhole smearing or contamination in RC holes, RC drilling is considered of an inferior quality to diamond drilling. Hence the practice in the mining industry is to twin RC holes with diamond core especially for the purpose of Resource estimation. When undertaking the comparison between the two drilling methods the effect

of volume on the results must be taken into consideration, where bigger samples will lead to more averaged values than smaller volume samples (Stephenson & Vann, 2001).

Unrepresentative data leads to unreliable interpretations and estimated results. Errors may occur during drilling, sampling and assaying. Therefore, attempts need to be made to minimise such errors (Abzalov, 2011, Méndez, 2011). Data collection and analyses should be subjected to rigorous systematic checks for representivity, precision and accuracy (Stephenson & Vann, 2001). Hence, sampling should entail processes using tools and procedures that allow all particles to have an equal opportunity of being sampled, without being bias (Abzalov, 2011; Wagner & Esbensen, 2012).

A quality assurance and quality control (QAQC) programme are essential in ensuring the quality of the collected data. This includes quality assurance which comprises of setting up standard operating procedures (SOPs) and systematic processes to ensure quality samples are collected. Systematic processes help to limit random errors that may be difficult to trace and rectify. Quality Control entails the insertion of special samples, namely blanks, reference material (RM) and duplicates to measure contamination, accuracy and precision, respectively, during sampling and sample analyses (Abzalov, 2011; Canadian Institute of Mining, Metallurgy and Petroleum, 2007).

Data collected through exploration activities, including but not limited to geology logs, grade assays, collar and down-hole surveys, is captured and best stored in an electronic, relational database. This data is retrieved from the database at the time of Mineral Resource estimation. It is therefore vital to undertake a database validation to ensure that the database is accurate in terms of correctness of the data collected (Stephenson & Vann, 2001; Stoker & Gilfillan, 2001).

Estimated tonnes are determined by multiplying volume and bulk density. Bulk density measurements are often neglected in the exploration stages. A small change in bulk density values can have a detrimental effect on the estimated tonnes and contained metal or mineral that a project is based on. In-situ bulk density is affected by in-situ voids or porosity, mineral grain density and the in-situ moisture content. Mineral Resource and Reserves are reported on a dry bulk density basis, therefore, the effect of moisture when reporting Resource and Reserves must be deducted from in-situ bulk density measurements. It is also important to note that different density descriptions can mean different things, for example, specific gravity is the density of the minerals making up the rock without taking in-situ voids into consideration. The use of specific gravity in rocks with significant porosity will

lead to over-estimation of tonnes (Lipton, 2014; Stephenson & Vann, 2001).

The choice of the geostatistical method and estimation parameters is another important attribute to the accuracy of a Mineral Resource estimate. The geostatistical method of choice should be suitable to the geology, available data, as well as the possible mining method where possible. It is also recommended to use more than one estimation method when preparing a Mineral Resource estimate as a check, especially when using a complex estimation method as the primary method. The estimates of the two methods should compare well if both are suitable to the Mineral Resource being estimated (Carras, 2001; Stephenson & Vann, 2001).

According to CRIRSCO and its associated reporting codes, Mineral Resource can only be classified into Inferred, Indicated and/or Measured based on an increasing level of geoscientific knowledge and confidence (Figure 2-2). This confidence is underpinned by the quality of data, the understanding of geology, grade continuity and the quantity and distribution of the samples (Committee for Mineral Reserves International Reporting Standards, 2012; Stephenson & Vann, 2001).

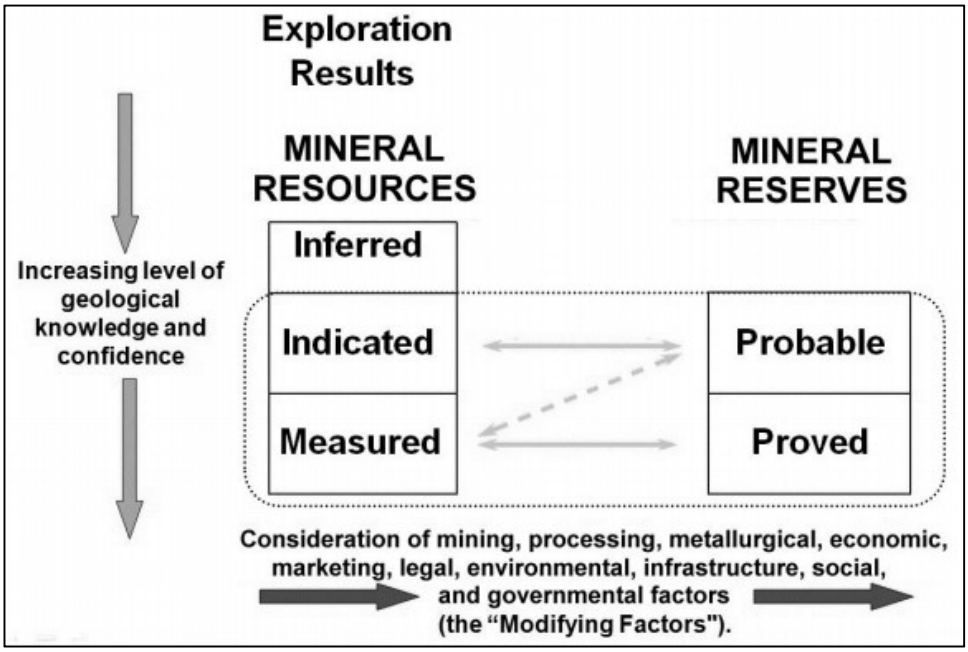

Figure 2-2 Mineral Resource and Mineral Reserve classifications (after Committee for Mineral Reserves International Reporting Standards, 2012)

Communication amongst the project team is imperative. Interpretation of geology needs to

be discussed with the mining engineer to keep in mind when choosing an appropriate mining method. The mining engineer must communicate the proposed mining method and mine design, for example, bench height, to the Resource geologist to keep in mind when preparing the Resource model. The metallurgist should also be taken through the geology model and the planned drilling programme, to evaluate whether the planned samples would be representative for mineralogical and metallurgical tests and to ensure they will be collected in time (Stephenson & Vann, 2001). The geotechnical engineer needs to also be involved in the planning of drillholes to ensure that the geotechnical information required will be acquired during drilling (Hanson, et. al., 2005). While resource geology drilling is focused on the orebody, the geotechnical assessment is more focused on the waste, the development to access the orebody takes place in the waste (Hanson, et. al., 2005; Sullivan, 2014).

2.6 Mineral Reserve

CRIRSCO defines a Mineral or Ore Reserve as "the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at pre-feasibility or feasibility level as appropriate that include the application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified" (Committee for Mineral Reserves International Reporting Standards, 2012; Whitham, 2014).

Ore Reserves should be classified either as Probable and/or Proved, depending on the confidence in the Mineral Resource and the Modifying Factors. For example, Indicated Resource can only be classified as Probable Reserve if found to be economically mineable. Measured Resource can be classified as Proved, or Probable if confidence on the Modifying Factors is low, for example, if using new technology (Figure 2-2) (Committee for Mineral Reserves International Reporting Standards, 2012; Whitham, 2014).

CRIRSCO and its associated codes prohibit the application of numerical factors in the conversion of Mineral Resource to Ore Reserve. Instead, they require pre-feasibility or feasibility study for a project to demonstrate that extraction is economical at the time of reporting (Committee for Mineral Reserves International Reporting Standards, 2012; JORC, 2012, Canadian Institute of Mining, Metallurgy and Petroleum, 2014); in addition, the SAMREC code requests a life of mine plan for an operating mine to declare a Mineral Reserve (Samcodes Standards Committee, 2016).

Modifying factors are inputs from a number of interdisciplinary components required to show that extraction is economical. Modifying factors include mining, geotechnical, metallurgy, economic, marketing, legal, environmental, infrastructure, social and governmental factors (Figure 2-2) (Committee for Mineral Reserves International Reporting Standards , 2012; Joint Ore Reserves Committee of The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia, 2012, Canadian Institute of Mining, Metallurgy and Petroleum, 2014; Samcodes Standards Committee, 2016). Though this study recognises that all Modifying factors are important to the success of a project, only the first four modifying factors listed above are discussed in detail below. This is because they are technical in nature and are therefore applicable to this research. Economic factors are not technical but are driven by technical factors, and hence they are also discussed below.

2.6.1 Mining

The two most common mining methods are either surface mining methods and underground mining methods; each of which has several types of mining methods. The choice of mining method is undertaken in consideration to geometry, depth, mineralisation style, geotechnical characteristics, skills availability, social and economic considerations, and available technology.

South Africa mostly uses underground mining methods due to the type of mineralisation and depth, thus the discussion will focus on a general method followed for underground mine planning. Generally, the underground mine plan consists of the following key areas (Little, et. al., 2013):

- Stope layouts;
- Ventilation layouts;
- Development;
- Production scheduling, and
- Equipment selection and utilisation (Musingwini, 2016).

There are numerous design mining software products in the market. These include the Floating Stope Algorithm, Multiple Pass Floating Stope Process, Vulcan Stope Optimiser and Snowden Stope Sizer. Generally, these methods determine a cutoff grade based on commodity price and costs, and identify areas or volumes above this cutoff grade, while

keeping practical and safe mineable sizes. Some of the challenges with this approach is overlapping stope envelopes which had to be resolved manually. However, this limitation has been an area of improvement that mine planning development has focused on to optimise the stope layout (Little, et. al., 2013; Musingwini, 2016).

Once economic stopes have been identified and the layout thereof decided on, the subsequent stage in mine planning includes scheduling. Scheduling includes the sequence of how the stopes will be mined to achieve maximum return or NPV while obeying technical rules, such as geotechnical and ventilation constraints (Kruger, et. al., 2003), to fulfil the requirements the Occupational Hygiene Measurements in the Mine Health and Safety Act No. 29 of 1996. The timing of mining of stopes is also dependent on the availability of access, namely development, mining capacity, milling capacity, required grade and geo-metallurgical limitations (Musingwini, 2016).

One of the aims of scheduling is to ensure that the broken material reaches the mill at a planned rate, thus to achieve this the infrastructure should be sufficient to enable this. This will depend on the amount of development available. The more the stope development or face development, the easier it is to transport broken material as well as man and material to workplaces. Further, the more stope development is available the more points of attack there is on the orebody. Leading to a more flexible mine plan or operation. The downside with development is that it is capital intensive, however, it offers mining flexibility. Thus, the number of development desire and cost should be balanced to get the most economic outcome (Musingwini, 2016).

Equipment size is determined by the stope size recommended by geotechnical engineers and signed-off by the competent mining engineers. Mine planning process focuses on the selection of fleet size and on the utilisation of equipment to enable optimum production and equipment usage (Musingwini, 2016).

According to Musingwini (2016) and Little, et. al. (2013), the current, sequential underground planning process is sub-optimal; the process needs to integrate the identified key areas and simultaneously assess them to achieve an optimal mining plan.

Open pit mine planning generally follows the following sequence in the assessment of the deposit (Rickus & Northcote, 2001):

- Ultimate pit determination including cut-off grade estimation;

- Pushback design; and
- Scheduling.

The mining process starts by determining the mining limit, or pit limit, in terms of open pit mining. Pit limit or mining limit is basically the maximum limit at which mining can take place without making a loss (Thorley, 2012). An optimal cut-off grade needs to be calculated to determine the minimum grade the material needs to be, for the mine to be economical. This calculation needs to take commodity price, metallurgical recovery, realisation cost and operating cost into account (Rickus & Northcote, 2001). Therefore, the economic blocks within the pit limit need to have a value that exceeds the cost of being removed and processed, it must also cover the cost of removing the blocks with sub-economic or no value to access them (Figure 2-3) (Thorley, 2012).

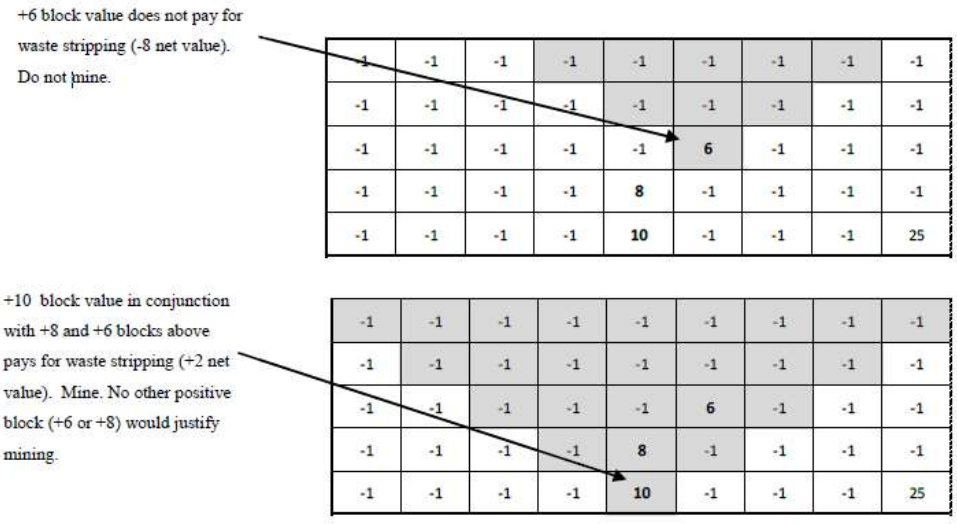

Figure 2-3 A simple 2D pit limit analysis (after Thorley, 2012)

A pit limit has to be determined within the recommended range of pit slope angles. The ultimate pit limit is commonly undertaken using the Lerchs-Grossmann or the floating cone algorithm (Thomas, 2001; Thorley, 2012).

Once mining limits have been set, scheduling can commence. Mine scheduling is a mine planning process that determines the specific time at which blocks are mined. It is aimed at maximising the net present value (NPV) (Rickus & Northcote, 2001; Thorley, 2012). Therefore, the highest value ore is planned to be mined earliest, while delaying waste

stripping as much as possible. The lower grade material may be planned to be stockpiled and processed towards the end of the operation. In this way, maximum return is ensured on the mined material (Navarrete and Varas. 2011). Other stockpiles may be created or planned for blending to achieve a consistent feed to the plant and/or storing excess material (Topal, et. al., 2010). Different mining sequences are tested, considering stockpile management, to determine the one that provides the highest NPV (Thorley, 2012).

One of the inputs into mine scheduling is production rate. According to McCarthy (2003), this is one of the major risk factors in mine planning. Initial production rates can be determined based on empirical equations such as Taylor's rule, which is based on open-pit porphyry copper mines. It is, therefore, not always applicable. The use of economic criteria or maximum physical capacity may result in high production rates. High production rates may appear to be the best option because they decrease the investment, for example, capital per unit, but they carry a high risk of production and economic failure. High production rates require more equipment, and therefore high total capital. High production rates are more difficult to achieve. While lower production rates may carry higher costs per unit, but they are predictable and carry lower capital and technical risk (McCarthy, 2003).

Dilution and ore loss are other factors that need to be considered when determining the production rate. Dilution and ore loss reflect mining selectivity, which depends on orebody geometry, the variability of the mineralisation, mining method, and geotechnical considerations. Dilution translates into a cost, and ore loss translates into a loss of revenue and therefore the aim of any mine plan is to keep these two factors at a minimum. Dilution and ore loss in practice may be high due to unrealistic planning parameters or bad mining practices (Appleyard & Smith, 2001). Dilution is also affected by production rate, thus, the higher the production rate is the more likely dilution will increase. Therefore, dilution needs to be considered in terms of production rate as well (McCarthy, 2013).

2.6.2 Geotechnical

Geotechnical engineering is an important input into mine planning, which involves pit slope stability for an open pit operation (Grenon & Hadjigeorgiou, 2010). Pits with competent lithologies can carry steeper slopes. Pit slopes with loose or friable material have much gentler slopes. The gentler the pit slope the higher the stripping ratio will be and the higher the cost of mining (Mathews & Rosengren, 1986; Sullivan, 2006).

In underground operations, geotechnical investigation is concerned with how the rock mass will react to the development of excavations. Geotechnical investigations contribute to the

underground mine design in terms of support, caving characteristics, dilution and ore recovery (Whitham, 2014).

The collection of geotechnical data needs to be planned early in the project development cycle (Stephenson & Vann, 2001; Whitham, 2014), to ensure that adequate and appropriate data is collected for geotechnical assessment. One of the shortfalls with geotechnical data collection is that most of the drilling is aimed at Mineral Resource development, thus geotechnical drilling ends up being insufficient (McCarthy, 2014). It is also essential to have some of the geotechnical drillhole core orientated to identify areas of similar structural orientations. Bye and Bell (2001) states that inadequate geotechnical data during mining, whether open pit or underground, pose a safety risk and the consequence thereof will also impede on the project schedule and budget.

2.6.3 Ventilation and refrigeration requirements

Mining in South Africa needs to fulfil the requirements of the Occupational Hygiene Measurements in the Mine Health and Safety Act No. 29 of 1996. These requirements request that workplaces comply with the following limits:

- airborne pollutants
    - particulates >= 1/10 of the occupational exposure limit;
    - gases and vapours >= 1/2 of the occupational exposure limit;
- thermal stress
    - heat >25,0°C wet bulb and/or >32,0°C dry bulb and/or >32,0"C mean radiant temperature
    - cold <10 °C equivalent chill temperature; and
- noise - >= 82dBL AEq.8h

The first two conditions speak to the ventilation and refrigeration requirements in a mining workplace, especially underground workings as it is confined, constraining ventilation, and tends to get hot especially with increasing depths.

2.6.4 Metallurgy

Metallurgy is one of the more important modifying factors that need to be applied to

convert a Mineral Resource toa Mineral Reserve because most of the ores need metallurgical processing to attain marketable products. Metallurgical test work often includes the following processes (Lewis, 2014):

- Delineate the different ore types or zones. It is recommended that this is done in close collaboration with a geologist, as certain characteristics of ore are affected by geological processes.
- Select representative samples of different ore types that will be mined. For this process, the involvement of a geologist and mining engineer will be beneficial.
- Detailed assaying of the composites for the element(s) of economic interest, as well as elements for environmental investigation.
- Mineralogical examinations to test different minerals of interest present, mode of occurrence of the element of interest, grain size, degree of interlocking between economic minerals and gangue minerals
- Test different processing methods.
- Select a processing method, through the consideration of capital and operating costs required, and revenue generated by the method.
- Confirmatory test work where lesser ore types and ore beyond the current mining limit are tested, for possible mining in future.
- Further test work to provide criteria for the plant design, for environmental studies, tailings dam design, marketing studies and pilot plant.

The objective of the metallurgical evaluation is to (Lewis, 2014):

- Select a combination of the most economic metallurgical processes;
- Establish the extent to which the processes will be viable;
- Determine the metallurgical performance and operating costs;
- Determine the value of products produced by the metallurgical processes; and
- Provide the design principles for the proposed processing plant.

Revenue calculation needs to take into consideration accurate estimates of ore grade, recovery, smelter terms, and realisation costs. It is important to demonstrate at feasibility study that the product has a market.

2.6.5 Cost estimation

Economic viability or financial evaluation of any project or business depends on the balance between revenue and cost; these are based on technical and financial inputs. The accuracy of costs depends on the accuracy of both the technical assessments from the mining plan, as well as the financial estimates (Cusworth, 2008; Kühn & Visser, 2014; McCarthy, 2012).

Cost estimates include both capital and operating cost estimates. Capital costs include start-up, working and reclamation capital. It is recommended that capital costs be allocated according to a work breakdown structure (WBS) to ensure that all the elements of the project scope have been considered in the capital cost estimation (Cusworth, 2008).

Operating costs must be estimated based on the scale and schedule of mining. The costs should be broken down into an organisational breakdown structure (OBS); the OBS must be in line with the WBS used for capital cost estimation. Schedules of physical mining activities, such as the following, are required to estimate operating costs accurately (McCarthy, 2012):

- Operating hours of machinery such as pumps and ventilating fans, and fuel and energy consumption.
- Operating hours for drilling, blasting, loading, haulage and associated equipment.
- Personnel schedules for each category using the proposed roster. A distinction between on- and off-site personnel, management and technical support would be required.
- In open pits, ore and waste movement schedule, including rock properties, dewatering requirements and slope support activities.
- In underground operations, production schedules distinguishing between ore and waste tonnage and the source of the material.
- Stockpile movements.
- Processing schedule.

The accuracy of a cost estimate depends on the confidence of the quantity estimates as well as the accuracy of the cost price per quantity. It is preferable that cost estimates for a feasibility study are based on direct quotes from suppliers, according to detailed design and estimates, and firm bids or awarded contracts. Most recent cost estimates must be used for a feasibility study as costs are subjected to the time value of money (McCarthy, 2012).

Caution must be exercised when using the manufacturer's estimates in determining maintenance intervals, as they tend to be optimistic about ideal conditions (McCarthy, 2003). It is better to use an extensive historical cost and performance database (McCarthy, 2012).

2.7 The economic viability of a project

A feasibility study should demonstrate that the project is technically possible and economically viable. The assessment of technical plausibility is undertaken through the assessment of realistic Modifying Factors and applying those modifying factors to determine probable extraction. Economic viability is undertaken through financial analysis by varying technical and financial inputs to attain an optimal value for the project (Csiminga & Iloiu, 2007; Iloiu & Iloiu, 2008; Kühn & Visser, 2014).

2.7.1 Discounted Cash Flows

Future cash flows of a project are commonly used in determining the expected return on the projects. Due to these cash flows being received in the future, a discount rate is applied to determine their current value. Thus, these are known as discount cash flows (DCFs) (Nhleko & Musingwini, 2016).

The most important inputs in calculating a DCF is net revenue, cost of sales, tax, capital expenditure (CAPEX), working capital and discount rate. Revenue is calculated by multiplying the amount of product and the commodity price (Baurens, 2010). Commodity prices depend on supply and demand as well as numerous industries and macroeconomic factors and are often beyond the control of project owners; and project owners are therefore "price takers" (Gentry, 1988). Since most of the commodity prices are quoted in United States dollars (US$), South African operations are further influenced by exchange rates between the South African Rand (ZAR) and US$. Project owners further have no control over this, unless they hedge their products (Gleason, 2012).

Since project owners are "price takers", they can only increase revenue by increasing their mineral produced. Mineral produced is calculated by multiplying tonnes produced and recovery grade. Recovery grade is calculated by multiplying the head grade and the recovery factor (Carrasco, et. al., 2008). Therefore, the project owner has to keep these parameters in mind when working towards a product target (Maxwell, 2012).

The second important parameter in the DCF is operating cost, which includes the cost of mining, processing, general and administration, stockpiles movement and product-in-

circuit, and is adjusted with by-product credits to calculate the net cash cost (McCarthy, 2012). Though total cost includes depreciation and amortisation these are not real cash deductions and are therefore not considered in a cash flow model (Tholana, 2012). Other deductions incurred in mining may include realisation costs, which include freight, insurance, marketing and other selling costs deducted against the revenue (Maxwell, 2012).

The discount rate is another vital input in the DCF as it can significantly sway the outcome of a project value. The choice of discount rates is subjective, but the utilised discount rate needs to account for the risk and stage of development of the mineral project (Nhleko & Musingwini, 2016).

Although profitability is very important in project appraisal, it is not the only factor considered by potential lenders. Financial institutions may take into account the triple bottom line, which includes the economic, environmental and social outcomes of a project (Hendrickson, 2008). For example, 48 project-finance banks were reported to have signed the Equator Principles that commits them to fund projects that are environmentally and socially responsible according to the guidelines of the International Finance Corp., World Bank Group (Tinsley, 2007).

2.8 Technical risk

Castle (1985) undertook a study on the performance of 18 mines, spanning different commodities, including open pit and underground mines. The performance of these mines was assessed against four questions:

- Was the project constructed on time?
- Did the project experience any overrun in costs?
- Was the mine ultimately able to achieve the design production level?
- Has the actual cash flow generated by the project measured up to the original forecast?

The study found that only four projects out of 18 achieved the targets set out in the feasibility studies. Out of that 14 projects experienced at least one of the challenges set out in the questions above, and 13 projects experience major problems. It was further observed that 11 out of these 14 projects experienced all four challenges. Castle (1985) drew conclusions from this study that variances are inter-dependent, therefore variance in one aspect can lead to a variance in another aspect of the project; and that most of the variances were due to technical factors such as geologic complexity, product quality and equipment.

People performance was the only non-technical factor that was identified as a cause for the poor performance. This demonstrates that technical risk plays a vital role in the performance of a mining project.

Due to the high failure rate of mining projects, researchers recommended that feasibility studies ought to undertake risk assessments on the Mineral Resource and Modifying Factors to evaluate the likelihood and impact of the overall risk in the project and make an assessment whether or not the project has a feasible business case (Mackenzie & Cusworth, 2007). Several authors also highlight the importance of early identification of critical Modifying Factors that will most likely impact the project so that these receive adequate attention, as well as monitoring of the interaction between different Modifying Factors (Kühn & Visser, 2014, Whitham, 2014).

2.9 Project success model for construction projects

The construction industry, similar to the mining industry, is capital intensive and face challenges of project failure. One of the challenges in the construction industry is that the definition of success is different from person to person (de Wit, 1988). Thus, Khosravi and Afshari (2011) pursued to derive a success measurement model for construction projects. This aims to provide a project success index for completed projects that will enable comparison between projects as well as to establish a benchmark for future project execution in the construction industry. The model was based on project success criteria (Khosravi & Afshari, 2011).

A two-round Delphi survey and a questionnaire survey were used as input to the model. The two-round Delphi survey was aimed at narrowing down the initially proposed list of 10 project success criteria to five. In the first round of the Delphi survey, 21 experts were asked to what extent they agreed with the listed project success criteria. The respondents were also asked to suggest additional criteria that should be included in the initial list of criteria. In the second round of the Delphi, the survey included the average score of the top six criteria and the score of the respondents. The respondents were asked if they would like to change their score from their first-round score, in light of the provided information. The top five success criteria were statistically determined by using the mean rank method and Kendall's Coefficient of Concordance, (Khosravi & Afshari, 2011).

The subsequent questionnaire survey was sent to 150 respondents, of those 74 completed the questionnaire. The aim of this questionnaire was to determine a weight factor for the five shortlisted project success criteria. In this questionnaire, respondents were asked to

indicate the degree of importance of each of the shortlisted criteria by rating them between 0 and 10, with 0 demonstrating not important and 10 indicating very important. A mean rank method was used to determine the weighting of each of the success criteria for the project success index. (Table 2-4 and Equation 1) (Khosravi & Afshari, 2011).

Table 2-4 Weight factors for the final project success criteria (after Khosravi & Afshari, 2011)

Project Success criteria	**Mean Rank**	**Corresponding Weighting**
Time Performance (PTP)	3.141	0.209
Cost Performance (PCP)	3.5	0.233
Quality Performance (PQP)	2.986	0.199
Project HSE performance (PHP)	2.587	0.173
Client Satisfaction (PCS)	2.783	0.186
Number of respondents	74	
Sum		1

The project success measurement model was presented as:

Equation 1: PSI = 0.209PTP + 0.233PCP + 0.199PQP + 0.173PHP + 0.186PCS.

Where:

PSI: Project Success Index

PTP: Project time performance

PCP: Project cost performance

PQP: Project quality performance

PHP: Project HSE performance

PCS: Project Client's Satisfaction (Khosravi & Afshari, 2011)

The purpose of this success measurement model was to provide a project success index for comparing finished projects against each other and to establish a benchmark for future improvement for construction projects (Khosravi & Afshari, 2011).

This process was adopted by the author to develop an empirical equation, which is aimed at measuring projects success against each, and ultimately establish a benchmark for project success in the mining industry.

2.10 Chapter summary

Literature recognises that different stakeholders define project success differently. Lim and Zain Mohamed (1999) proposed that project success is divided into micro and macro perspectives; with the macro addressing the objective of the project instead of just looking at the time, budget and quality of the project, which is the micro perspective.

Researchers identified Mineral Resources as the most consistent risk in mineral projects, hence the development of reporting codes to limit this risk. The mining industry previously experienced reckless and fraudulent reporting of projects that led to investors losing large amounts of money on stock exchanges. This led to the development of reporting codes, most of which are part of an international body called CRIRSCO. The reporting codes define and guide the reporting of Mineral Resource and Reserves. Mineral Resource and Reserves depend on a number of technical inputs, and the accuracy and interpretation of these inputs determine the level of accuracy of the Mineral Resources and Mineral Reserves. The Mineral Resource and Mineral Reserves must be reported accordingly into different categories. Since a feasibility study of the project needs to show economic viability, this normally includes the use of discounted cash flows which depend on net revenue, cost of sales, tax, CAPEX, working capital and discount rate.

Literature (Mackenzie & Cusworth, 2007; Kühn & Visser, 2014, Whitham, 2014) recommends that feasibility studies ought to undertake risk assessments on the Mineral Resource and Modifying Factors, especially the most critical Modifying Factors as well as the interaction between the different Modifying Factors.

The construction industry also has challenges on agreeing on the definition of success for its

projects, hence Khosravi and Afshari (2011) proposed a success measurement equation for the construction projects. The weights of the success criteria were determined from the Mean Rank method from a rated survey. This model together with the criteria identified by McCarthy (2014) was used in determining the proposed success equation in this study.

McCarthy (2014) identified technical criteria that have been previously observed to lead to failure in mining projects. The criteria included environmental and social impact criterion, which is not considered to be technical by this study, thus was not included in the proposed success equation for mining projects in this study. These criteria listed by McCarthy (2014) were selected for this study because they were considered to be inclusive of most of the mining technical factors and relevant to the scope of this study, which analyses the impact of the technical variance of mining projects in South Africa.

3 SOUTH AFRICAN MINING INDUSTRY

3.1 Chapter overview

This chapter discusses the history and economic impact of the South African mining industry, over time; as well as the number of operating mines in South Africa between 2003 and 2014 – this is the period to which applicable data was available.

3.2 Mining history in South Africa

South Africa has a noteworthy mining industry, with historical impact locally and internationally. Mining by European Settlers in South Africa started in 1852 in Namaqualand for copper, after seeing the copper ornaments made by the indigenous people; but due to lack of water, it did not continue for too long. Diamonds were discovered 16 years later, on the bank of the Orange River on a farm near Hopetown. These discoveries led to the diamond rush and later to the discovery of kimberlite pipes including the Great Kimberley pipe, which resulted in the development of the city of Kimberley and the creation of the De Beers mining company by Cecil John Rhodes. In 1917, Anglo American was established through the purchase of diamond rights off the coast of South West Africa (currently Namibia), from the German owners. The company was founded by Ernest Oppenheimer, an English businessman, with the assistance of Herbert Hoover, an American mining engineer who later became the president of the United States of America (USA) in 1929. Hoover helped Oppenheimer to secure a loan from House of Morgan in the USA to purchase the rights, hence the company is called Anglo American (Habashi, 2010). In 1926, Anglo American became the biggest shareholder in De Beers Consolidated Mines (Anglo American, 2017).

In 1886 gold was discovered in the Witwatersrand basin, near Johannesburg, by George Harrison, an Australian gold miner. This led to a gold rush in the Witwatersrand gold region. Within 10 years, Johannesburg became the largest settlement in South Africa (Habashi, 2010). The Witwatersrand is the largest gold deposit to be discovered (Robb & Meyer, 1995), and according to Handley (1990), the Witwatersrand basin had single-handedly produced 35% of the world's gold then.

The earliest recorded exploitation of coal was in the Eastern Cape, near Molteno, in 1864. The demand for coal increased after the discovery of diamonds and gold, which used coal as a source of power. This demand for coal led to the discovery of other coalfields, including the Witbank coalfields in the 1890s. The demand for coal also increased as the country was

getting more industrialised. South Africa began producing oil from coal in 1955, and this gained momentum during the 1973 oil crisis. The 1973 oil crisis was due to a ban by members of the Organization of Arab Petroleum Exporting Countries (OAPEC) to stop selling oil to countries, including South Africa, perceived to support Israel during the Yom Kippur War. The war was between Israel and a coalition of Arab states led by Egypt and Syria (Wikipedia, 2018).

The establishment of Iron and Steel Corporation's (Iscor) led to the development of the Natal and Waterberg coalfields for the supply of coking coal, an essential ingredient in the production of steel (Peatfield, 2003).

Another dominant mineral deposit in South Africa is the Bushveld Igneous Complex (BIC), which is estimated to have 90% of the world's known platinum group element (PGE) Reserves, and extensive deposits of iron, tin, chromium, titanium and vanadium. The BIC was discovered in 1930 by Hans Merensky but was only significantly mined from the 1950s when the use of PGE in the petroleum industry increased to transform crude naphtha to high octane and a range of aromatics (Habashi, 2010; McDonald & Hunt, 1982).

3.3 The economic significance of the mining industry

The mining industry has been and is still a significant contributor to the South African economy. Mining in South Africa has been responsible for the development of several cities, such as Johannesburg, Kimberley, Klerksdorp, Welkom, Rustenburg and several smaller towns. Furthermore, mining contributes significantly to the gross domestic product (GDP) of the country. In the first quarter of 2017, mining was the sixth highest contributor to the GDP, at 7% of the GDP (Figure 3-1) (StatsSA, 2017a). Platinum, gold and coal mining are the most significant contributors to the South African economy in terms of sales revenue and export earnings (Figure 3-2) (StatsSA, 2015).

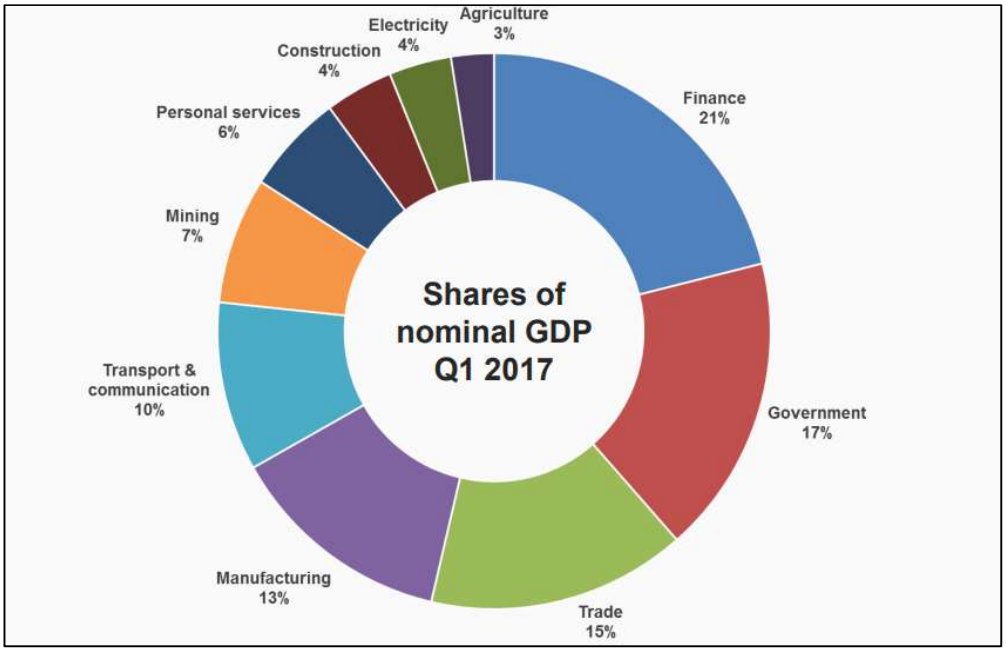

Figure 3-1 Contribution to the Q1 2017 GDP by sector (after StatsSA, 2017a)

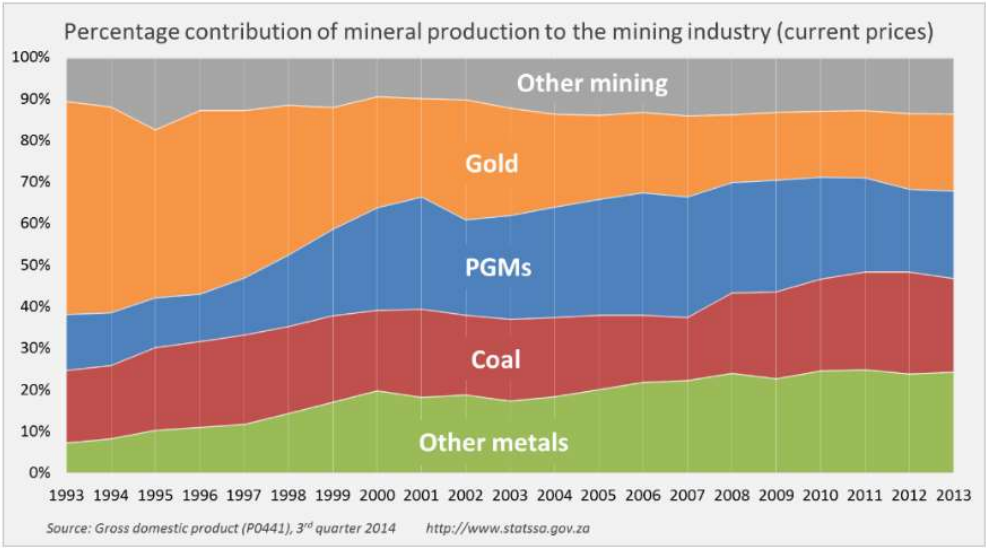

Figure 3-2 Percentage contribution of mineral production to the South African mining industry (after StatsSA, 2015)

In addition, mining is also an important source of employment. StatsSA (2017b) estimated that the mining industry employed 490,146 people in 2015, which equated to 5% of the workforce. The platinum group metals (PGM), gold and coal industry are the major

contributors of employment in the mining industry (Figure 3-3) (StatsSA, 2015).

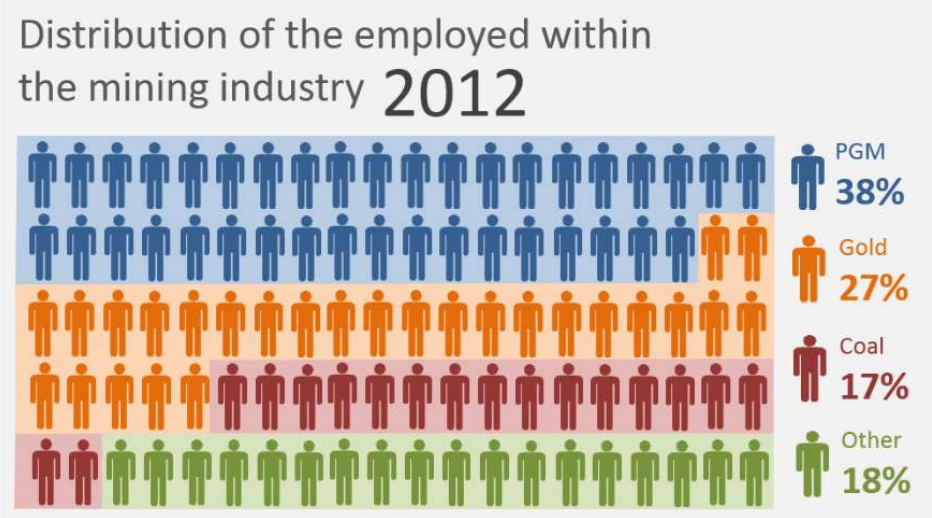

Figure 3-3 Percentage contribution of job employment in the South African mining industry in 2012 (after StatsSA, 2015)

3.4 Operating mines in South Africa

Since South Africa mines an array of minerals, it was decided that this study focuses on the performance of mines that extracted minerals identified to be the highest contributors to the South African economy.

The number of operating mines or mining sites in South Africa increased from 1,004 to 1,712 between 2004 and 2014, with most of the mines in the diamond sector, followed by coal, gold and PGM sector (Figure 3-4) (Department of Mineral Resources, 2004-2014). The diamond sector is dominated by small-scale mining, hence the significant number of mines in this sector. Therefore, though the diamond sector has more mines, the extent of the contribution of the diamond sector to the economy is not as extensive. Hence mines from the diamond sector were not selected as part of the study.

The coal industry had 69 operating mines in 2004, which increased to 137 mines in 2014. This is almost a 100% increase in the number of mines in the coal industry during this period. The platinum industry had 26 mines in 2004, and 43 mines in 2014, which equates to 65% increase over the time interval. In 2004, there were 44 gold operating mines which increased to 52 in 2014. This is an increase of 18% in operating mines in the gold mining industry over the same period (Figure 3-4) (Department of Mineral Resources, 2004-2014).

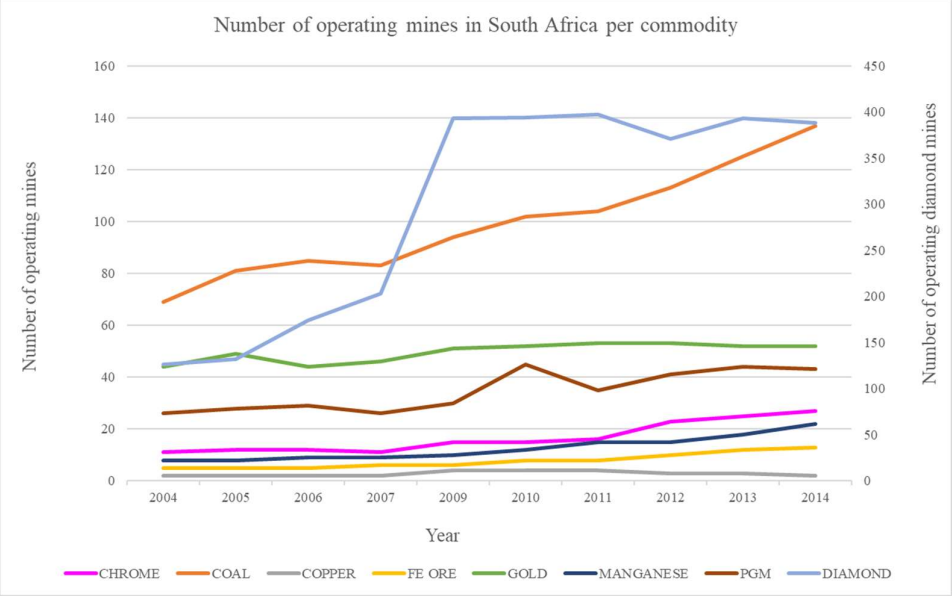

Figure 3-4 Number of operating mines in South Africa over time. (Data was sourced from Department of Mineral Resources, 2004-2014).

3.5 Chapter summary

South Africa was, and remains, significantly endowed with mineral wealth. Mining by European Settlers in South Africa started in 1852 in the copper deposits of Namaqualand (Northern Cape), after seeing the copper ornaments by the indigenous people. Significant mining activity did not take place until the discovery of diamonds. Thereafter, gold was discovered in the Witwatersrand, and later platinum in the Bushveld Igneous complex. Although coal was discovered in 1864, it was not until the diamond and gold rush that the demand for coal significantly increased which led to the discovery of the significant coalfields in South Africa.

The importance of the mining industry to the economy of South Africa is inarguable; being the sixth highest contributor to the GDP of the first quarter of 2017, with gold, coal and PGM being the highest contributors. Furthermore, the mining industry employed 5% of the South African labour in 2015, with gold, coal and platinum sector being the major employers in the mining industry.

South Africa saw an increase in operating mines between 2003 and 2014, with most of the mines in the diamond industry followed by coal, gold and platinum. The diamond industry is dominated by small-scale miners hence the significant number of mines.

The importance of gold, coal and platinum industry is significant in South Africa, especially with their contribution to the economy, and thus the study analysed mining projects in these industries.

4 METHODOLOGY AND DATA SOURCE

4.1 Chapter overview

This chapter discusses the target population and the sample of mining projects selected for analysis of this study. This is followed by a discussion on the research design and methods employed in this study, including how the information derived was analysed. This chapter also looked at an overview of the development of the success equation and the survey it was based on, and lastly the limitation of the study.

4.2 Target population

The scope of this study is limited to South African mining projects, owned by public companies. Studies assessing the performance of mining projects against their feasibility studies have been carried out around the world, but such studies are limited for South African mines.

Further, the study focused on projects in the coal, gold and platinum industry because of the importance of these commodities in the South African economy as discussed in Section 3. Reviewed projects were sampled from projects that were developed after the year 2000, as there is limited information on the internet on mining projects in prior years. According to DMR records, the number of projects increased by 93 in the gold, coal and platinum industries between 2004 and 2014, with about half of the projects owned by non-public companies.

Further, the study aimed to select projects with comprehensive planned and actual project performance information. Therefore, selected projects were based on the availability of project information in the public domain. Only projects that were considered to have had enough time to achieve steady state at the time of this study, from the initial project development announcement, were selected. Thus, 11 projects were selected as a sample for this study, which includes six platinum, three gold and two coal projects. The selected projects included:

- Burnstone Gold Mine;
- Kusasalethu Gold Mine;
- Phakisa Gold Mine;
- Bokoni Platinum Mine;

- Modikwa Platinum Mine;
- Crocodile River Platinum Mine;
- Marula Platinum Mine;
- Two Rivers Platinum Mine;
- Leeuwkop Platinum Mine;
- Mooiplats Colliery; and
- Isibonelo Colliery.

The study looked at both greenfields and brownfields projects. Greenfields projects are projects developed where there has not been mining before, and brownfields projects are projects that are developed around where there is or was mining previously.

4.3 Research design and methods

The research employed both qualitative and quantitative methodologies. Reviews were undertaken on the selected projects based on the projects' available information (Table 4-2) in the public domain, such as project owners' websites and reports submitted to various stock exchanges.

The plan information provided in the public domain for the project development was assumed to be based on feasibility studies, if not clearly stated in the reports. This research has two major objectives, the first being to assess the impact of the technical shortcomings on the value of mining projects. To address this objective the following analyses on the results of the project were undertaken:

- A comparison of the planned and actual technical and cost parameters disclosed in the public documents for a project
- The impact of the actual production, cost, commodity price and the exchange rate on the original value of the project calculated using a DCF.

Actual costs and production were plotted as bar charts benchmarked against planned parameters that were plotted as a line, where the relevant planned information was available.

In determining the impact of actual production, cost, commodity price and the exchange rate on the planned value, the plan NPVs were first re-calculated based on the published

DCFs. This was done to derive working financial models since these were not available to the author. The re-calculated NPVs were comparable to the reported plan NPVs. The author acknowledges that achieving the same NPV as has been reported in the feasibility study is not conclusive that the re-calculated DCFs are correct, but this was the only way of getting a DCF model for these projects. Companies approached were not willing to disclose their DCF models for this study.

The achieved production, costs, commodity prices and exchange rates were substituted into the plan DCF one at a time to see how each factor impacted the plan DCF. A waterfall graph was completed to show the impact of the achieved production, capital and operating costs and commodity prices on the plan NPV. This analysis was not done for projects, where a DCF was not available in the public domain. Where a DCF was not published for a project, a comment on whether the planned value of the project was achieved based on the judgement of the author was provided. The opinion of the author hinged on a project's performance on parameters that affect value namely revenue and costs. The performance needs to show an increase in parameters that have a positive correlation to revenue, such as increase in production tonnes and head grade; and a decrease in capital costs and operating costs for the value of the project to increase compared to the plan.

The second objective of this study was to develop an equation to determine project success/failure based on the actual performance compared to planned technical parameters observed in the samples. Since project criteria do not carry the same impact in determining a project as a success or failure, a survey was undertaken. The following technical criteria identified by McCarthy (2014) were sent out to mining professionals for rating in a questionnaire:

- Capital cost overruns
- Schedule overruns
- Lower head grade
- Lower recovery
- High operating costs
- Unsustainable initial performance

Table 4-1 A list of mine projects analysed in this study

Mine	Commodity mined	Capital cost	Schedule	Head grade[1]	Recovery	Operating costs	Production tonnes	DCF
Burnstone Gold Mine	Gold	✓	✓	✓	✓	✓	✓	✓
Kusasalethu Gold Mine	Gold	✓	✓	✓	X	X	X	X
Phakisa Gold Mine	Gold	✓	✓	X	X	X	X	X
Bokoni Platinum Mine	Platinum	✓	✓	✓	X	✓	✓	✓
Modikwa Platinum Mine	Platinum	✓	X	✓	X	✓	✓	X
Crocodile River Platinum Mine	Platinum	✓	✓	✓	✓	✓	✓	✓
Marula Platinum Mine	Platinum	X	X	✓	X	X	X	X
Two Rivers Platinum Mine	Platinum	X	X	X	X	X	✓	X
Leeuwkop Platinum Mine	Platinum	X	X	X	X	X	X	X
Mooiplats Colliery	Coal	X	X	X	X	X	✓	X
Isibonelo Colliery	Coal	X	X	X	X	X	✓	X

[1] Recovered grade or planned yield were also considered were head grade was not reported

The questionnaire enquired about the respondents' technical background as well as the number of years they had been involved in feasibility studies and due diligence work. This was requested to ascertain the familiarity of the respondents with feasibility studies.

Respondents were asked to rate each criterion ranging from 0 to 10, indicating the sensitivity of each criterion towards the success or failure of a project. Respondents were also requested to provide additional criteria they thought would lead to project failure.

The ratings were weighted on experience. The weighting used was in proportion to the longest experience of 20 years. This was done to take into consideration that experienced respondents have a far better understanding of mining projects and project development than less experienced respondents.

The weighted ratings were ranked, similar to Khosravi and Afshari (2011). Rankings convert a set of numbers into ranks through re-coding the numbers into rank ordering in ascending or descending order. The ranks for the survey ratings were calculated in Microsoft Excel, using the RANK() equation, in ascending order. The rankings were then averaged per criterion to calculate the mean ranking for each criterion.

The mean rankings were used to calculate a relative factor using Equation 3, to determine the weight of each criterion in the success equation.

Equation 2: Weight i = Mean ranking i / $\sum$Mean ranking

Where i refers to each criterion

Each weight was assigned to the applicable criteria to formulate the equation.

4.3.1 Limitations of the study

Planned and actual detailed production data, capital costs and operating costs were not always reported across projects. Therefore, not all performance indicators were assessed against plan for all projects. This led to the measure of performance of projects not being standardised. Parameters that were not measured due to lack of information did not give a complete picture of the performance of the mine or project, and the assessment thereof was not conclusive as a number of assumptions had to be made for the assessment of these projects, especially on the impact on value (Table 4-2).

Discounted cash flows were not often available in the public domain, therefore the

quantitative impact of actual performance on the planned project value could not be calculated for all the projects reviewed. Only projects owned by companies listed on the Toronto Stock Exchange (TSX) had cash flows pertaining to the projects included in the projects' technical reports because it is a requirement for that stock exchange. The disclosure of DCF in technical reports enables investors and potential investors easy and open access to information required to make an investment. It is thus the author's opinion that DCF's and full disclosure of project information, similar to the requirements of the National Instrument (NI) 43 101, should be requested for listing on other stock exchanges to further assist the public with their investment decisions.

The lack of information on some projects presented a limitation on fully assessing a project's success using the proposed success index equation. Some of the projects assessed using the index equation still had missing information, and this presented difficulty in comparing the projects' indices against each other.

4.4 Chapter summary

The research is based on projects from the gold, platinum and coal industry - the most important mining sectors in the South African economy. Projects selected for analyses in this study had to be developed after the year 2000 and owned by a public company to be considered for this study because the information on the analysed projects was derived from the public domain. A total of 11 projects were sampled for this study. Comparisons of the planned and actual technical and cost parameters were analysed, as well as the impact these parameters had on the original value of the project from DCFs. Not all the information required to do the intended analyses were available, therefore not all performance indicators were measured for all projects. Only projects with owners listed on the TSX disclosed more comprehensive information, including the DCFs for the projects. This study recommends that other stock exchanges require the same level of disclosure as the TSX for their listing requirements.

To develop the mining project success equation, a questionnaire was sent out to mining professionals. Respondents were asked to rate the technical criteria provided by McCarthy (2014) on sensitivity to the failure of mining projects. Mean rankings were calculated from the ratings, which were first weighted on experience. These mean rankings were used to calculate the weights assigned to each criterion in the equation. The weights calculated assign the relative impact of each criterion on the success of a project. The higher a weight is for a criterion, the higher the impact that criterion has on the perceived success of a project.

Table 4-2 A list of mine projects analysed in this study

Mine	Commodity mined	Capital cost	Schedule	Head grade[1]	Recovery	Operating costs	Production tonnes	DCF
Burnstone Gold Mine	Gold	✓	✓	✓	✓	✓	✓	✓
Kusasalethu Gold Mine	Gold	✓	✓	✓	X	X	X	X
Phakisa Gold Mine	Gold	✓	✓	X	X	X	X	X
Bokoni Platinum Mine	Platinum	✓	✓	✓	X	✓	✓	✓
Modikwa Platinum Mine	Platinum	✓	X	✓	X	✓	✓	X
Crocodile River Platinum Mine	Platinum	✓	✓	✓	✓	✓	✓	✓
Marula Platinum Mine	Platinum	X	X	✓	X	X	X	X
Two Rivers Platinum Mine	Platinum	X	X	X	X	X	✓	X
Leeuwkop Platinum Mine	Platinum	X	X	X	X	X	X	X
Mooiplats Colliery	Coal	X	X	X	X	X	✓	X
Isibonelo Colliery	Coal	X	X	X	X	X	✓	X

[1] Recovered grade or planned yield were also considered were head grade was not reported

The questionnaire enquired about the respondents' technical background as well as the number of years they had been involved in feasibility studies and due diligence work. This was requested to ascertain the familiarity of the respondents with feasibility studies.

Respondents were asked to rate each criterion ranging from 0 to 10, indicating the sensitivity of each criterion towards the success or failure of a project. Respondents were also requested to provide additional criteria they thought would lead to project failure.

The ratings were weighted on experience. The weighting used was a proportion of the longest experience, of 20 years. This was done to take into account that experienced professionals have a far better understanding of mining projects and project development than less experienced ones.

The weighted ratings were ranked, similar to methodology in Khosravi and Afshari (2011). Rankings convert a set of numbers into ranks through re-coding the numbers into rank ordering in ascending or descending order. The ranks for the survey ratings were calculated in Microsoft Excel, using the RANK() equation, in ascending order. The rankings were then averaged per criterion to calculate the mean ranking for each criterion.

The mean rankings were used to calculate a relative factor using Equation 3, to determine the weight in the success equation for each criterion.

Equation 3: Weight i = Mean ranking i / $\sum$Mean ranking

Where i refers to each criterion

Each weight was assigned to the applicable criteria to formulate the equation.

4.4.1 Limitations of the study

Planned and actual detailed production data, capital costs and operating costs were not always reported across the selected projects. Therefore, not all performance indicators were measured for all projects, therefore the measure of performance for each project was not carried out the same. Parameters that were not measured due to lack of information did not give a complete picture of the performance of the mine or project, and the assessment thereof was not conclusive as a number of assumptions had to be made for the assessment of these projects (Table 4-2).

Discounted cash flows were not often available in the public domain, therefore the

quantitative impact of actual performance on the planned project value could not be calculated for all the projects reviewed. Only projects owned by companies listed on the Toronto Stock Exchange (TSX) reported cash flows pertaining to the projects in the projects' technical reports because it is a requirement for that stock exchange. The disclosure of DCF in technical reports enables investors and potential investors easy and open access to information required to make an investment. It is thus the author's opinion that DCF's and full disclosure of project information, similar to the requirements of the National Instrument (NI) 43 101, should be requested for listing on other stock exchanges to further assist the public with their investment decisions.

The lack of information on some projects prohibited the assessment of performance against the planned values, this further had a limitation on assessing these projects' success using the proposed success index equation.

4.5 Chapter summary

The research is based on projects from the gold, platinum and coal industry - the most important mining sectors in the South African economy. Projects selected for analyses in this study had to be developed after the year 2000 and owned by a public company to be considered for this study because the information on the analysed projects was derived from the public domain. A total of 11 projects were sampled for this study. Comparisons of the planned and actual technical and cost parameters were analysed, as well as the impact these parameters had on the original value of the project from DCFs. Not all the information required to do the intended analyses were available, therefore not all performance indicators were measured for all projects. Projects with owners listed on the TSX disclosed more comprehensive information, including the DCFs for the projects. This study recommends that other stock exchanges require the same level of disclosure as the TSX for their listing requirements.

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5 SOUTH AFRICAN EXAMPLES

5.1 Chapter overview

This chapter includes the analyses of the selected South African projects. The analyses include the comparison of actual performance against planned parameters as well the impact of actual performance on the planned value or NPV derived from the public domain. The selected projects for analyses include three from the gold industry, six from the platinum industry and two from the coal industry (Table 4-2).

5.2 Gold industry

5.2.1 Burnstone Gold Mine

The Burnstone Gold Mine (Burnstone) was developed by Great Basin Gold Limited (GBG) from 2006 to 2012. Burnstone is located in the South Rand Goldfield of the Witwatersrand Basin, near the town of Balfour (Figure 5-1). GBG was listed on the New York Stock Exchange (NYSE), TSX and Johannesburg Stock Exchange (JSE). The information used to do the analyses for this project was derived from the System for Electronic Document Analysis and Retrieval (SEDAR), an electronic database with filed documents by public companies and investment funds listed in Canada (Ontario Securities Commission, 2017).

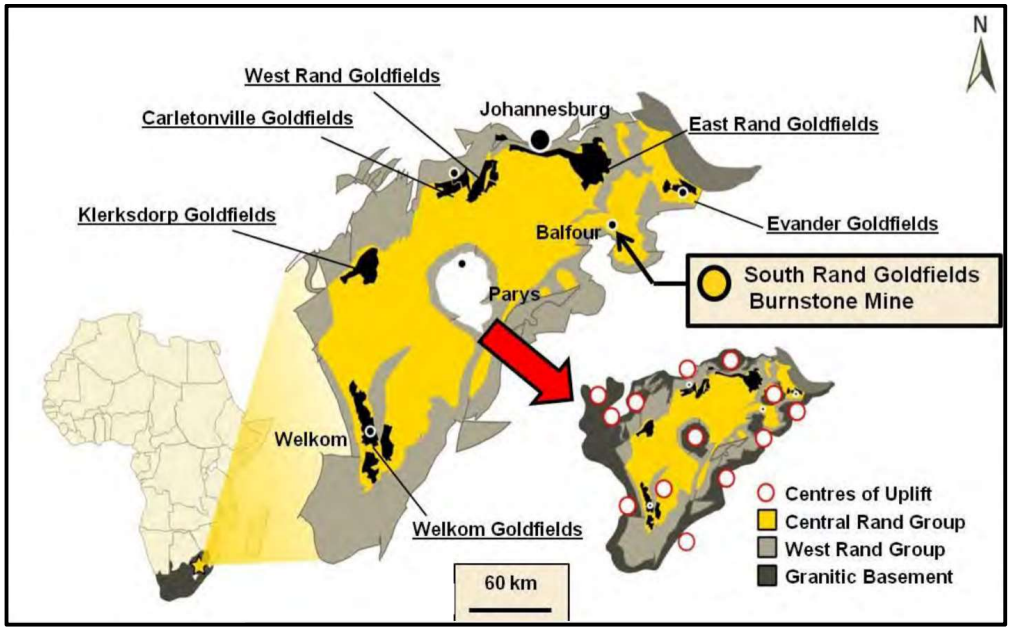

Figure 5-1 Burnstone Gold Mine locality map (after Great Basin Gold, 2012a)

GBG prepared a feasibility study for the project in 2006. Subsequently, in 2007, an update of the 2006 feasibility study was released, which aimed to inform and document the results and the overall economics of the project. The 2007 feasibility update report (Great Basin Gold Limited, 2007) is regarded by this research as the base feasibility plan report for this project. This is because the 2006 feasibility report was not available on SEDAR. Two further updates on the feasibility study were released during project construction, one in 2009 (Great Basin Gold Limited, 2009) and another in 2011 (Great Basin Gold Limited, 2011).

Plan

Development at Burnstone started in May 2006. According to the 2007 report, Burnstone was planned to be an underground operation, with primary access through a shaft and a twin decline system. The decline was to transport men and material and the shaft was to hoist rock. The mining method of choice was to be a hybrid mining method, which entailed trackless access to the stopes and the use of conventional breast stoping of the reef. Construction and development were expected to take four years to full production. First reef intersection was expected in 2008, with milling commencing in 2010. Total planned CAPEX was at US238 million (Figure 5-2) (Great Basin Gold Limited, 2007).

Reported costs were in 2007 money terms (Great Basin Gold Limited, 2007).

Actual performance

The actual performance information on Burnstone was retrieved from the Management discussion and analysis (MD&A) reports from 2007. All costs were adjusted to 2007 money terms using the consumer price index (CPI) tables (StatsSA, 2018).

CAPEX accumulated to US$325 by end of 2011. The working capital intended to bring up production to steady state was not reported separately for Burnstone in 2012, instead, it was reported collectively with the rest of the projects owned by GBG thus, could not be added to the accumulated CAPEX. The cumulative CAPEX at 2011 exceeded the planned CAPEX by 79% (Figure 5-2).

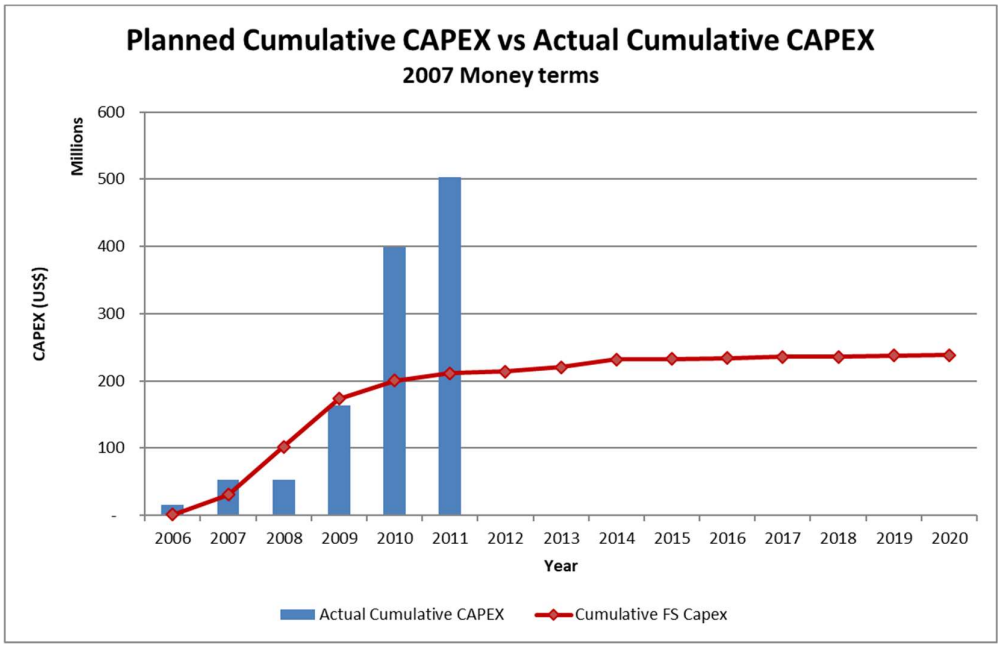

Figure 5-2 Feasibility study versus actual cumulative CAPEX. (Sourced from the Great Basin Gold, 2007 – 2012)

The reef was intersected in the second quarter of 2009 (Great Basin Gold Limited, 2011a) and processing started in 2011 (Great Basin Gold Limited, 2011b). The milled tonnes, milled grades (Figure 5-3 and Figure 5-4) and therefore produced gold ounces were far less than what was planned in the feasibility study. This did not exceed the planned unit cash cost of operation in 2011; however, 2012 saw higher operating costs than planned (Figure 5-5).

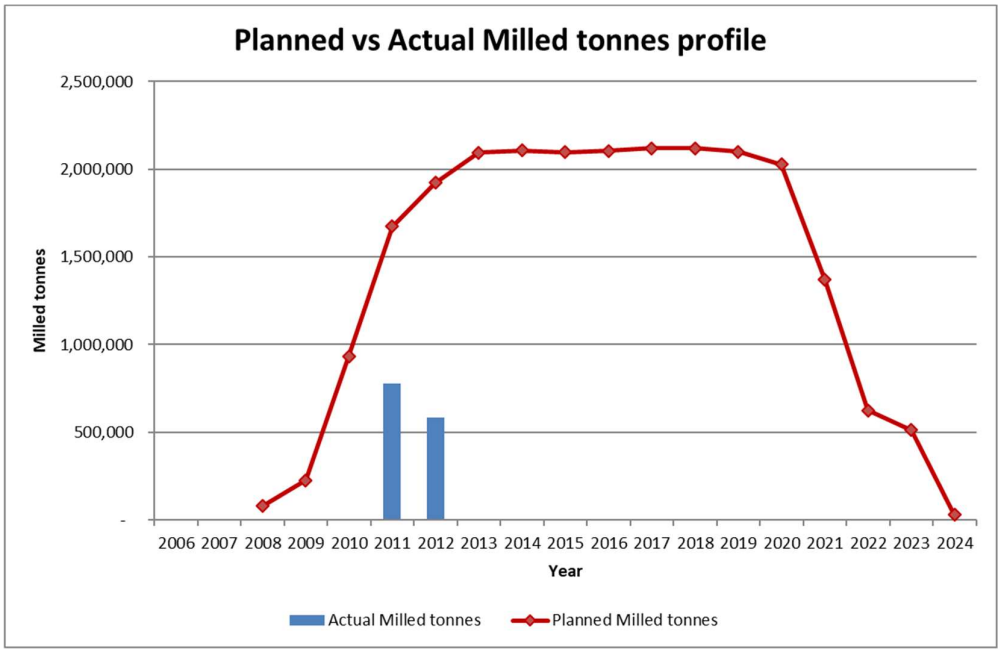

Figure 5-3 Feasibility study vs actual milled tonnes profile (Data sourced from the Great Basin Gold, 2007 – 2012)

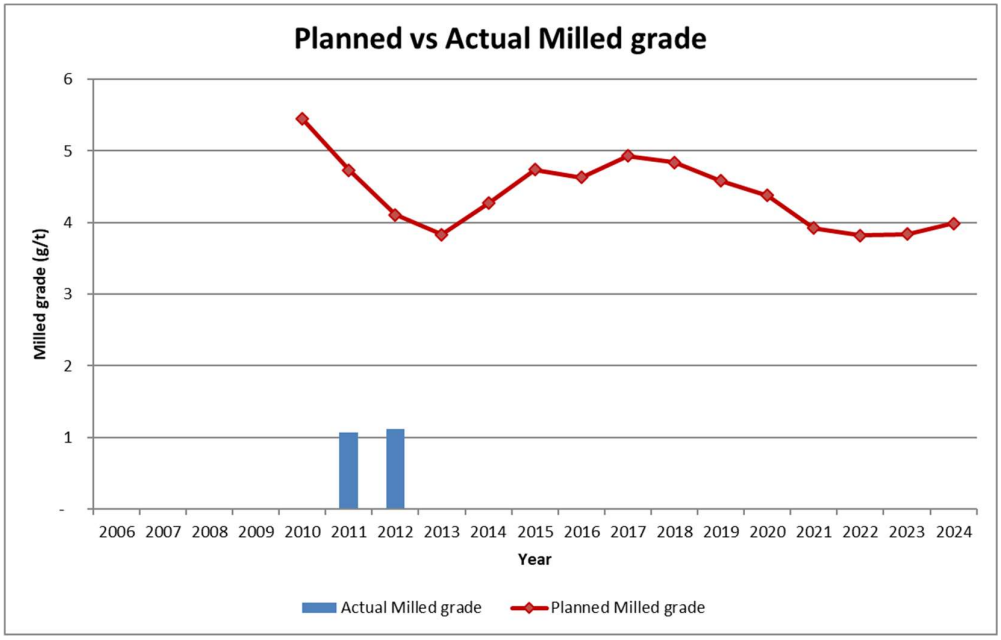

Figure 5-4 Feasibility study vs actual milled grade profile (Data sourced from the Great Basin Gold, 2007 – 2012)

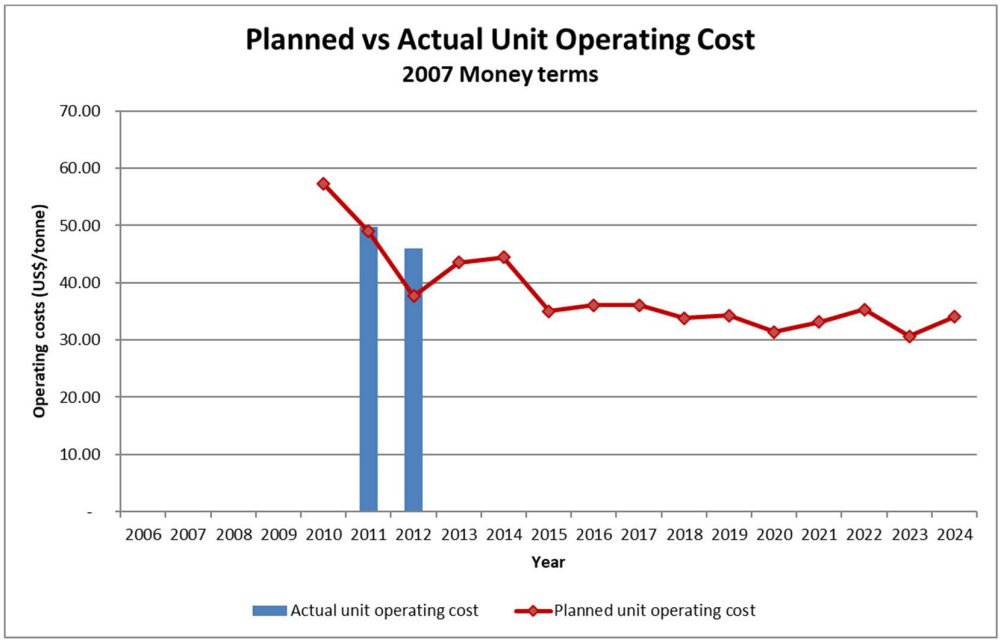

Figure 5-5 Feasibility study vs actual unit operating cost (Data sourced from the Great Basin Gold, 2007 – 2012)

Burnstone did not reach steady state production, instead, it suspended all its development and production activities on the 11th September 2012. Technical difficulties, such as poor ground conditions due to an unanticipated fault and excessive water handling, were attributed to the development challenges experienced at Burnstone during ramp up (Great Basin Gold Limited, 2012c).

Burnstone also applied a number of design changes to the original feasibility study, which contributed to an increase in CAPEX. The design changes applied included change in mining equipment due to change in mining method from hybrid to fully mechanised long hole stoping, electrical design changes to the processing plant to comply with Eskom initiatives, upgrading of some plant equipment, an additional fan was added to the shaft for ventilation. Fast tracking of the construction and commissioning of the plant also incurred additional capital costs (Great Basin Gold Limited, 2011a).

Impact on value

The plan NPV was recalculated using the reported DCF to get a financial model. Thereafter, the actual performance values were substituted into the plan DCF one at a time to see how each factor impacts the plan DCF. All monetary value was expressed in 2007 money terms. NPV calculated for the 2007 update was at US$328 million; 2% higher than the reported

NPV of US$322 million. Further, the calculated values into the DCF were similar to the reported values in the report that feed into the DCF. The author acknowledges that there may be unnoticeable errors between the DCF used for this research and the actual DCF model by Burnstone. Because the project duration was up to 2012, the plan NPV was re-stated to the end of 2012 at -US$ 51 million. The NPV calculated using actual performance was - US$279 million. The main decrease to the NPV over the active project life was due to the reduced production scale, which was very limited in 2011 and 2012. Capital expenditure was the next factor leading to a decrease in NPV which was significantly higher than the plan. Operating costs, which was slightly lower than plan, had the least impact on the decrease in NPV. The increase in commodity price and exchange rate over the period the project operated in contributed positively to the NPV (Figure 5-6). This indicates that Burnstone achieved a decrease in value from what was planned in the feasibility study.

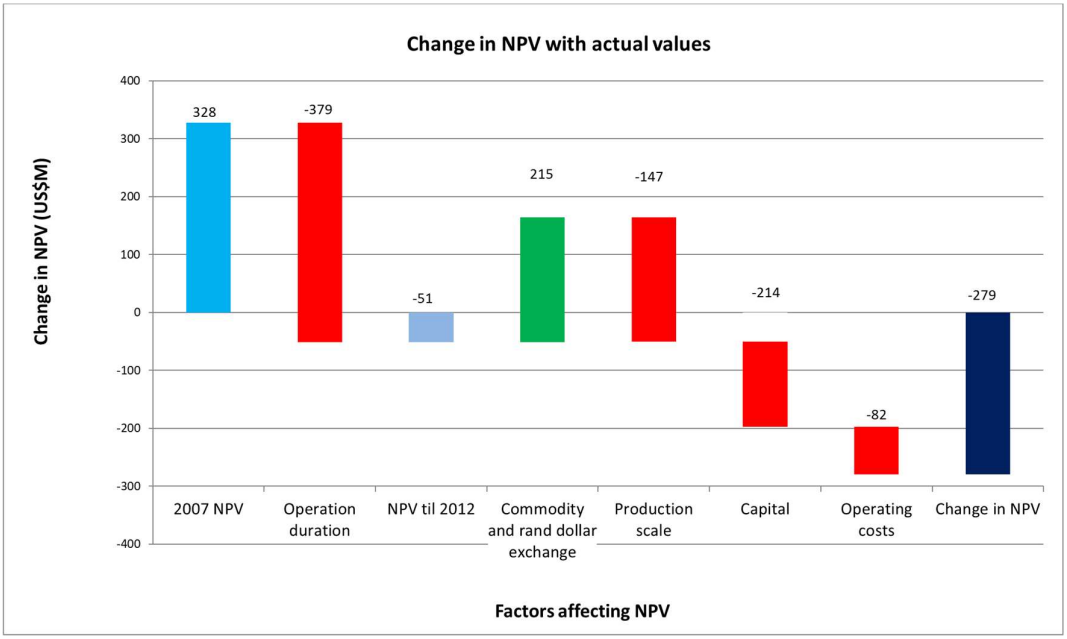

Figure 5-6 Change in NPV due to actual values at Burnstone (Data sourced from the Great Basin Gold, 2007 – 2011)

5.2.2 Kusasalethu Gold Mine

Harmony Gold Mining Company Limited (Harmony) purchased the Elandsrand Gold Mine (Elandsrand) and the Deelkraal Gold Mine (Deelkraal), together referred to as Elandskraal, from AngloGold Ashanti Limited (AngloGold) in 2001 for approximately ZAR1 billion for both operations (Mining Weekly, 2005). Kusasalethu is located in the West Rand

Goldfields, between Carletonville and Potchefstroom (Figure 5-7). Upon acquiring the mines, Harmony commenced with a deepening project to the south of the Elandsrand to increase output. Deelkraal closed down in 2004 (Fin24, 2004). Elandsrand was later renamed Kusasalethu Gold Mine (Harmony Gold Mining Company Limited, 2010).

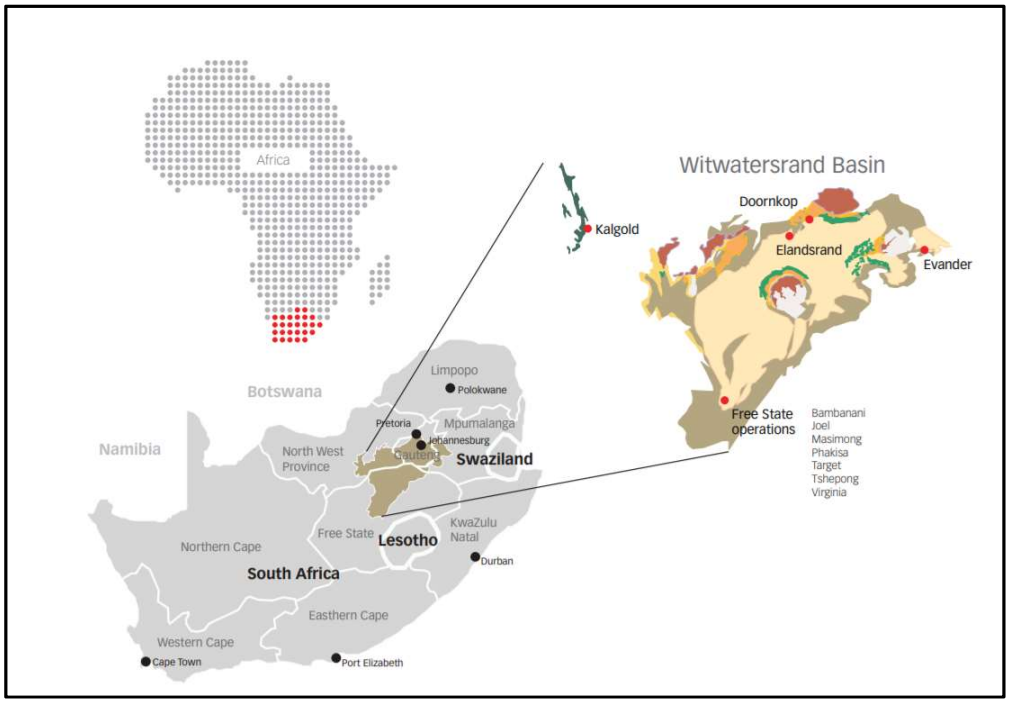

Figure 5-7 Locality map for Kusasalethu Gold Mine (after Harmony Gold Mining Company Limited, 2009)

The deepening project was aimed at mining the high-grade VCR payshoot below the infrastructure then, at depths of 3,000 to 3,600 m below surface. This project involved the deepening of the sub-vertical and vertical shafts (Mining Weekly, 2005).

Plan

The planned performance of the deepening project at Kusasalethu was reported in annual reports from 2001. The following plan parameters were reported for the project between 2001 and 2009; subsequent to 2009, this information was not reported at the same level of detail:

- Peak annual gold ounces (in ounces);
- Average Reserve grade (in g/t);

- Development capital required (in ZAR million);
- Life of Mine (LOM) ounces (in million ounces); and
- Expected completion date.

The total required CAPEX was reported until 2009. The planned CAPEX increased from ZAR 864 million in 2001 to ZAR 1,435 million in 2009, both reported in 2016 money terms. It was predicted in the 2001 annual report that Kusasalethu would produce a total of 7.2 million ounces over 15 years, which translates to approximately 480,000 ounces (oz) per annum at steady state, this prediction declined to 450,000 ounces a year in the 2005 report (Figure 5-8). The planned gold production continued to decrease to between 270,000 and 310,000 ounces a year, predicted in the 2011 report. The Reserve grade, namely the mined grade over the LOM, was planned at 6.7g/t in 2001; the plan Reserve grade peaked at 8.8g/t in 2005 and steadily decreased thereafter (Figure 5-9). The ramp-up period was planned to be three years in 2001. The planned LOM was announced at 15 years in the 2001- 2009, Harmony Gold Mining Company Limited, 2011).

Actual performance

The gold production reported between 2001 and 2003 included Deelkraal but was mostly from Elandsrand. Gold production at Elandskraal increased from 122,880 oz in 2001 to 476,059 oz in 2002. This was followed by a decrease over time (Figure 5-8) (Harmony Gold Limited, 2002-2016).

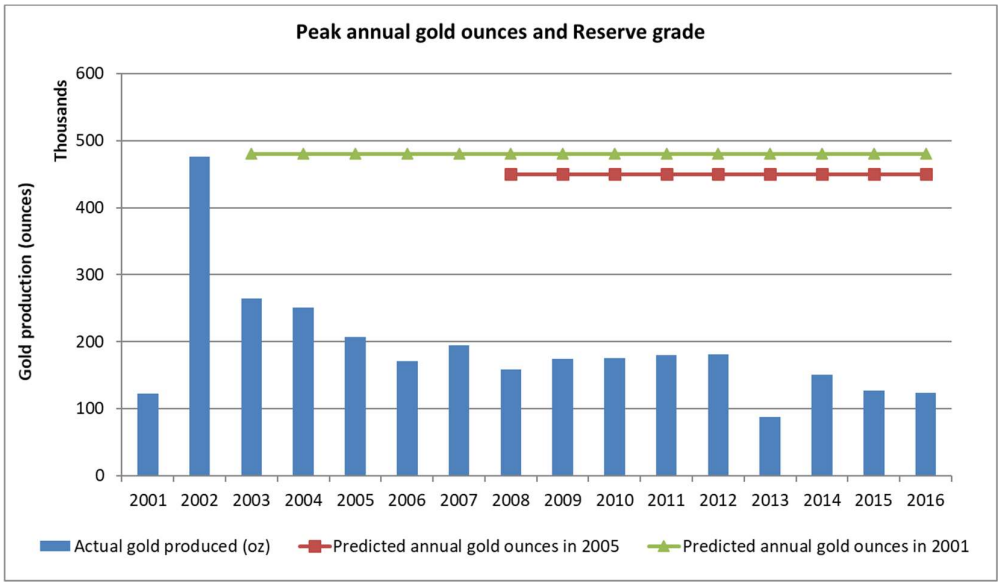

Figure 5-8 Planned peak annual gold ounces predicted in 2001 and 2005, and actual gold produced over time at Kusasalethu Gold Mine. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2002 - 2016).

A declining trend was also observed in the Reserve grade. Though Reserve grade is calculated over a much longer period, namely the life of mine, compared to the mined grade, it was worth noting that Reserve grade was consistently higher than the reported mined grade and that both were steadily decreasing over time (Figure 5-9). Efforts were taken by Kusasalethu to achieve the Reserve grade during mining (Harmony Gold Mining Company, 2015), but had not been achieved at the time of the reporting.

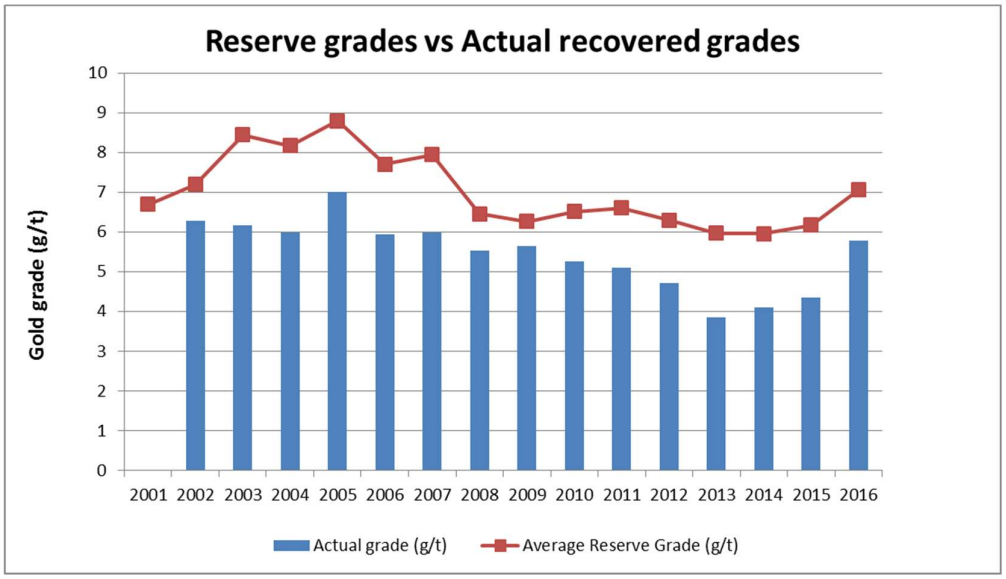

Figure 5-9 Average Reserve grade vs actual recovered grade. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2002 - 2016).

In 2015, mine plans for Kusasalethu were revised to increase profitability. This revision included mining higher grade areas over a shorter life of five years (Harmony Gold Mining Company Limited, 2015). In 2016, Kusasalethu management announced that it plans to mine high-grade material over a shorter LOM period of five years (Miningmx, 2016).

Since 2001, approximately ZAR5.59 billion of capital, in 2016 money terms, was spent at Kusasalethu, over and above the purchase price of ZAR1 billion in the year 2001, which equates to ZAR 2.33 billion in 2016 money terms. The actual CAPEX include capital for growth, on-going and maintenance capital. The cumulative operating profit at Kusasalethu from 2001 to 2016 is approximately ZAR 4.13 billion, in 2016 terms.

Over a number of years, Kusasalethu cited difficulty with infrastructure, including scaling orepasses (Harmony Gold Mining Company Limited, 2003; Harmony Gold Mining Company Limited, 2010), unavailability of compressor and refrigeration plants (Harmony Gold Mining Company Limited, 2007) ageing engineering equipment. The 2005 annual report mentioned slow advances due to mining through the Cobra Dyke (Harmony Gold Mining Company Limited, 2005). Kusasalethu also experienced a number of accidents and labour strikes, which hampered production.

The planned NPV for Kusasalethu reported in the Harmony Gold Mining Company Limited annual report (2002) was ZAR 163 million, money terms for this is not clear. Due to the

unavailable plan DCF for Kusasalethu in the public domain, the impact of actual performance on the initial value of this project could not be assessed quantitatively. A qualitative assessment of this project by this study indicates the value of this project was not achieved because:

- Actual gold production was less than the plan, therefore revenue was less;
- Actual recovered grades were less than the Reserve grades, further lowering the revenue; and
- Accumulated profit was less than the total CAPEX, this therefore cannot result in a positive NPV, which was planned for this project.

5.2.3 Phakisa Gold Mine

Phakisa Gold Mine is located in the Free State Goldfields in the Witwatersrand basin (Figure 5-7).

Plan

In 2003, Harmony announced the commencement of construction of the Phakisa Shaft. The Phakisa Shaft was planned to be a mine with a shaft sunk from the surface to 2,421 m below surface. The development of the mine was estimated at a cost of R550 million and was expected to reach full production in 2010. The project was planned to produce 280,000 ounces of gold per year. It was predicted that the mine will return a NPV of ZAR 900 million and an IRR of 32% (Harmony Gold Mining Company Limited, 2003). It is assumed that these values are in 2003 money terms.

Actual performance

The actual production of the mine over time, from 2008 to 2017, has not reached the planned levels of full production of 280,000 ounces per year. The most ounces produced in a year at the mine to date are 155,000 ounces in 2017 (Figure 5-10). The cumulative CAPEX from 2004 to 2017 was at R2,897 million, in 2003 money terms (Figure 5-11). Harmony wrote off R1,400 million from the project value in 2014, after a change in the life of mine plan (Mining Weekly, 2014b). The write off was made up of R1,310 million goodwill and R75 million mining assets (Harmony Gold Mining Company Limited, 2014).

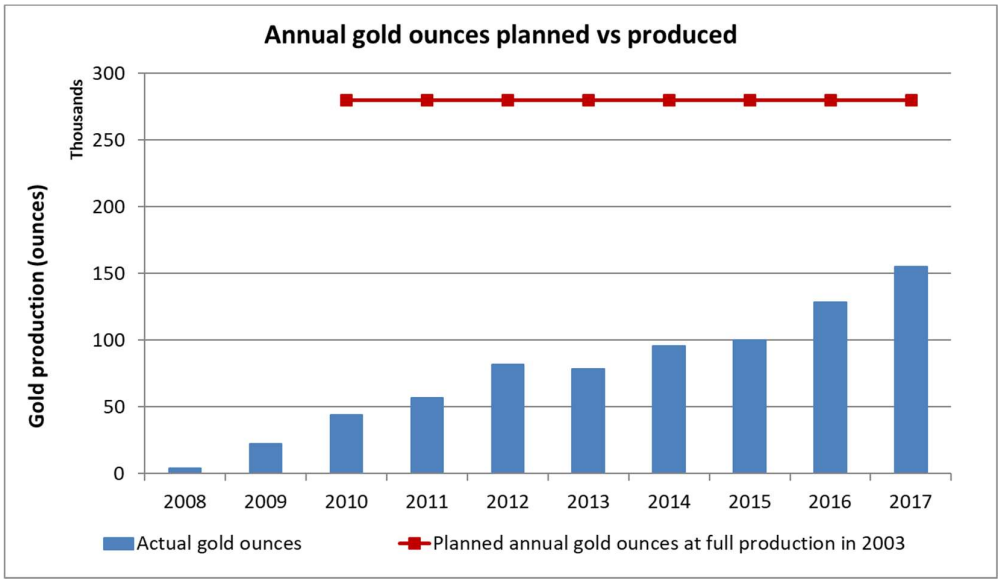

Figure 5-10 Annual gold ounces planned vs actual for Phakisa Mine. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2003 – 2017)

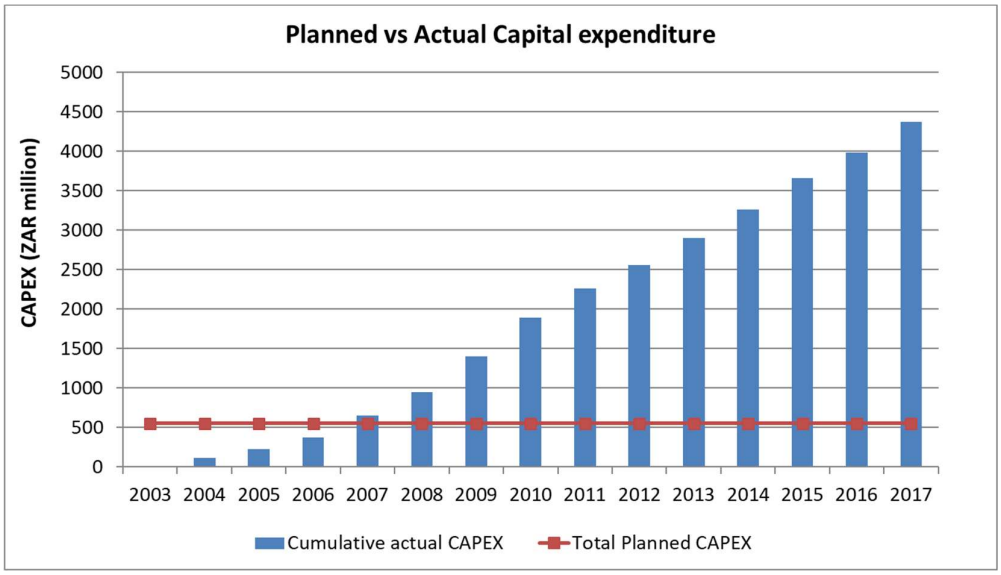

Figure 5-11 Total planned vs actual cumulative CAPEX for Phakisa Mine, in 2003 money terms. (Data sourced from Harmony Gold Mining Company Limited annual reports, 2003 – 2017)

Since the Phakisa DCF was not published in the public domain, it was not possible for this study to quantitatively assess the impact of the actual performance on the planned value of the project. The CAPEX spent at Phakisa between 2004 and 2017, in 2003 money terms, is

R2,897 million. This exceeds the total planned CAPEX for the project of ZAR 500 million, announced in 2003. It is thus clear that the actual CAPEX is excessively high compared to what the planned CAPEX was.

The actual gold produced at Phakisa, from 2008 to 2017, is 739,755 oz, compared to an expected production of 2.24 million ounces over the same period, which is 67% lower than plan (Harmony Gold Mining Company Limited annual reports, 2003 – 2017). A qualitative assessment of this project indicates the value of this project was not achieved because:

- Actual gold production was 67% lower than plan; and
- Actual CAPEX was excessively higher than total plan CAPEX.

5.3 Platinum projects

5.3.1 Bokoni Platinum Mine

Bokoni Platinum Mine (Bokoni) is located in the north of the Eastern limb of the Bushveld Igneous Complex (BIC) (Figure 5-12). The mine was wholly owned by Anglo American Platinum Limited (Amplats) prior to 2009.

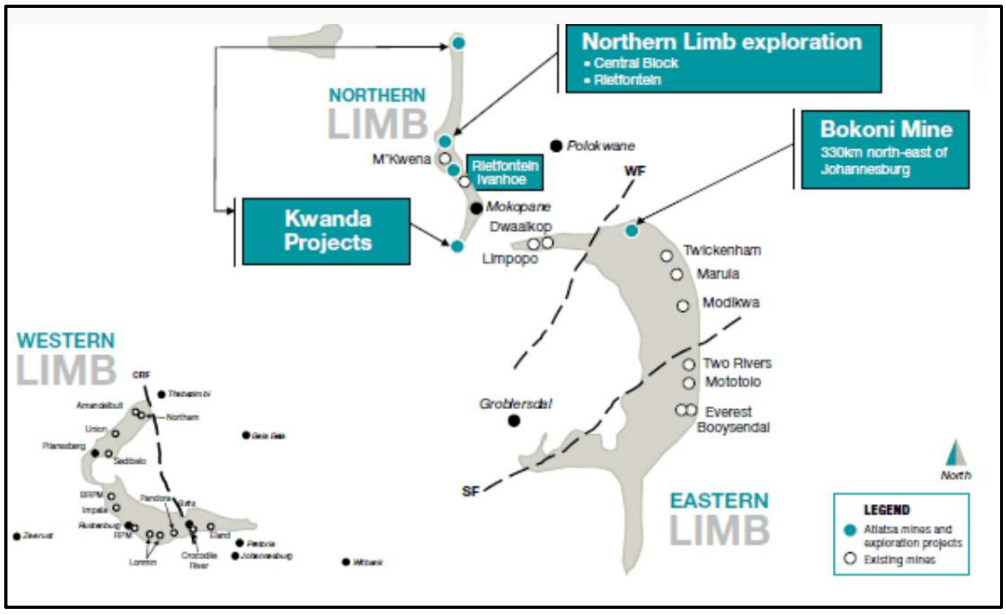

Figure 5-12 Locality map for Bokoni Platinum Mine (after Atlatsa Resources Corporation, 2018)

In 2009, Atlatsa Resources (Atlatsa), formerly called Anooraq Resources Corporation

(Anooraq), gained an indirect controlling share of 51% in Bokoni mine (then called Lebowa Platinum mine. Amplats owns the remainder of the shares in the mine (Anooraq Resources Corporation, 2011).

Bokoni predominantly mined the Merensky Reef (Merensky), with some Upper Group 2 Reef (UG2) horizons. The UG2 was extracted exclusively from the Middelpunt Shaft, which employed a hybrid, mechanized mining method. The Merensky was mined from three shafts, namely the Vertical Shaft, UM2 Shaft and Brakfontein Shaft. The Vertical Shaft and the UM2 Shaft were expected to close down in 2013 because they were old and used conventional mining methods, which incurred high operating costs. The Brakfontein Shaft was developed on a semi-mechanised, hybrid mining method, and was expected to have lower operating costs and replace production at the Vertical and the UM2 Shafts in 2013 (Anooraq Resources Corporation, 2011).

Plan

In 2009, Atlatsa released a technical report on Bokoni as a "statement of strategic intent" (Anooraq Resources Corporation, 2009a). As stated by the report, Atlatsa intended to expand Bokoni from 92,000 tonnes per month (tpm) production through a two-phase expansion project. The first phase of expansion was intended to increase production to a steady-state production of 160,000 tpm between 2011 and 2015; then ramp up again to 245,000 tpm from 2020 to 2043. According to the 2009 Anooraq report, this report was not released as a feasibility study and the reported financial model was not based on a recent LOM plan but rather on a previous LOM prepared by Amplats (Anooraq Resources Corporation, 2009a), for the purpose of this research the 2009 technical report is considered a feasibility study report.

In a presentation to analysts in 2009, Bokoni had a production guideline of 80,000 tpm for 2009 and 2010, yielding 150,000 4E ounces (oz) (Anooraq Resources Corporation, 2009b). At the end of 2010, Bokoni revised its plan to reach its first phase steady-state of 160,000 tpm yielding 240,000 PGM ounces per annum, by 2014. This steady state production was to be made up of 120,000 tpm from Merensky reef and 40,000 tpm from UG2 (Anooraq Resources Corporation, 2011).

In 2012, Brakfontein was planned to reach a steady state of 110,000 tpm in 2020, a six-year delay from the previous plan due to changes in the LOM plan. Middelpunt was reported to produce 30,000 tpm and was planned to reach 40,000 tpm in the medium term and reach 60,000 tpm at steady state in 2020 (Atlatsa Resources Corporation, 2013).

Limited surface exploration was undertaken on the Klipfontein and Zeegoegat mineral properties in 2012, to evaluate opencast potential (Atlatsa Resources Corporation, 2013). In the second quarter of 2013, an opencast operation was commissioned at Klipfontein. The opencast operation is expected to contribute to the reduction of costs. This was expected to produce 40,000 tpm at steady state over a LOM of 10 years, but LOM was revised to four years in 2014 (Atlatsa Resources Corporation, 2015).

The planned cash unit averaged ZAR703/t over the planned LOM, with an average planned head grade of 5.06g/t. The average recovered grade was calculated at 4.6g/t (Anooraq Resources Corporation, 2009a).

Actual performance

The performance information for Bokoni was derived from the MD&A reports filed on SEDAR. Bokoni achieved the planned production for the 2009 and 2010 financial year, it treated 79,000 tpm and 87,000 tpm of ore, respectively, from both Merensky and UG2 (Anooraq Resources Corporation, 2011).

The production at Bokoni was consistent in 2011 at 87,000 tpm, but decreased to 72,000 tpm, in 2012 (Figure 5-13) (Atlatsa Resources Corporation, 2012a). This was the same year the platinum industry experienced long strikes, which claimed 45 lives (IOL, 2012). Bokoni was impacted by the strike in quarter four of that year, where 35,500 4E PGM ounces were estimated to have been lost (Atlatsa Resources Corporation, 2013).

Production increased significantly in 2013 to 127,000 tpm (Figure 5-13). This included ore from the Klipfontein opencast. Production further increased in 2014 to 145,000 tpm (Atlatsa Resources Corporation, 2015) but decreased slightly to 140,000 tpm in 2015 (Atlatsa Resources Corporation, 2016). This production fell short against the early plan announced, where the steady state of 160,000 tpm was planned to be achieved by 2014 (Anooraq Resources Corporation, 2009a).

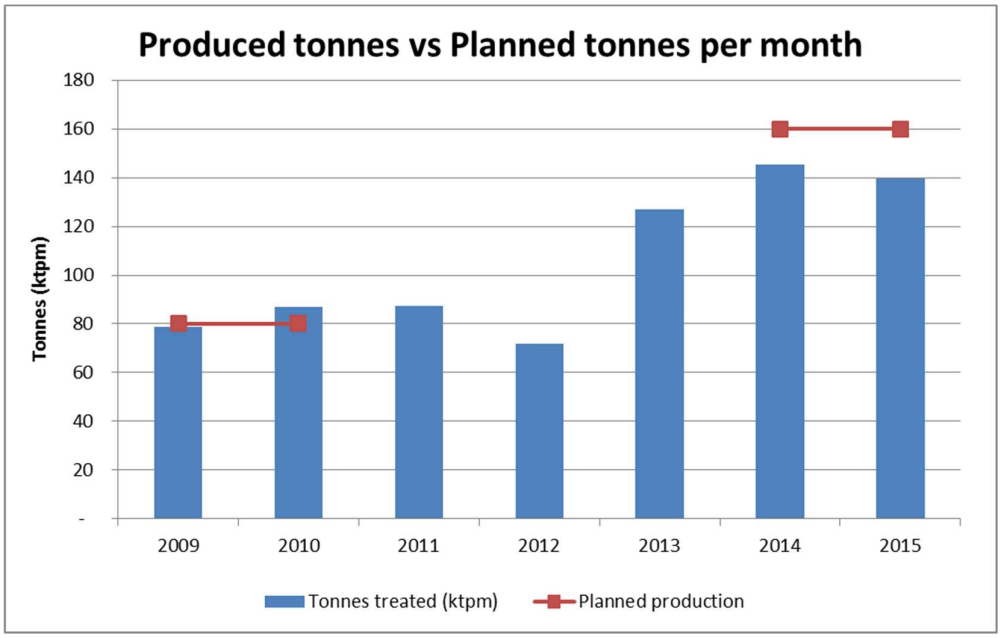

Figure 5-13 Produced tonnes at Bokoni versus planned tonnes between 2009 and 2015. (Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015)

The produced metals did not reach the planned targets in all the years analysed, even in years where the produced tonnes exceeded the planned tonnes (Figure 5-14). This indicates that the recovered grade was lower than planned. This could have been due to a lower head grade and/or lower recovery.

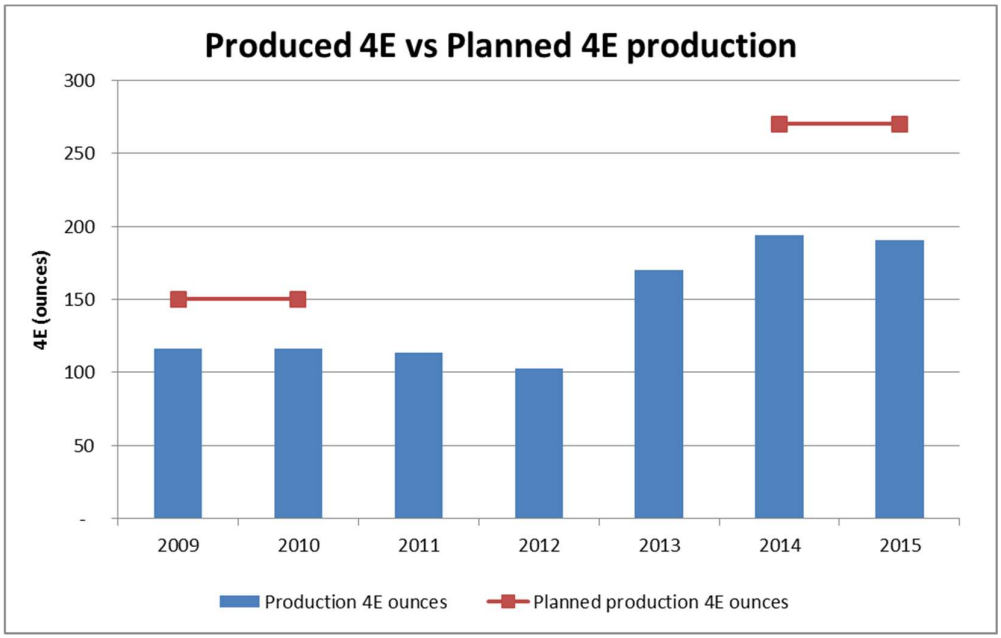

Figure 5-14 Produced 4E ounces at Bokoni versus planned 4E production between 2009 and 2015. (Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015)

The unit cash cost at Bokoni averaged ZAR1,033/t between 2009 and 2015, in 2009 money terms, this was higher than the average planned cash cost of ZAR829/t over LOM, in 2009 money terms (Figure 5-15). This cost ranged from ZAR1,061/t in 2009 to ZAR975/t in 2015, in 2009 money terms, with a peak in 2012 due to the strike, which saw a significant decrease in the tonnes produced. Labour contributed significantly to the cost of mining, due to the yearly increase in the numbers of employees, as well as an increase in remuneration. South Africa also experienced a significant increase in electricity tariffs and was 7% of the operating costs at Bokoni in 2015 (Atlatsa Resources Corporation, 2016).

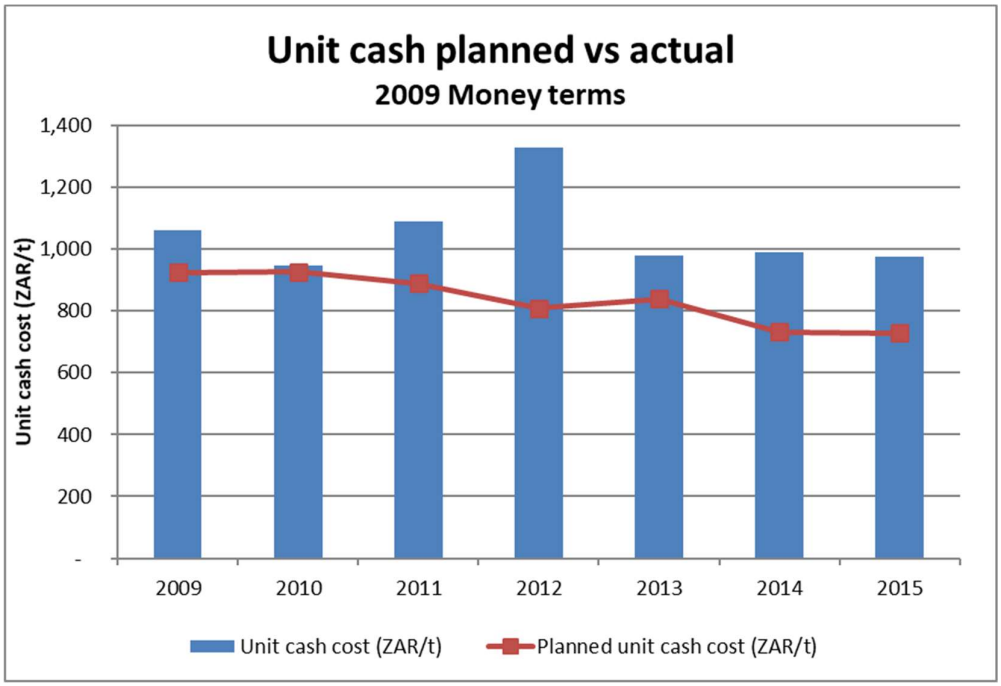

Figure 5-15 Actual unit cash cost at Bokoni measured in ZAR/tonne. (Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015)

Impact on value

The DCF published in the 2009 technical report and the annual cashflows recorded from the financial and MD&A reports were used to analyse the impact of actual production on planned value. The re-calculated NPV over the planned life of the project was ZAR 7,841 million, which was 15% lower than the reported NPV. The re-calculated NPV was further re-stated at ZAR2,805 million only for the period between 2009 and 2015 because it was the period in which the mine operated. Meanwhile, the DCF based on actual performance between 2009 and 2015 had an NPV of - ZAR399 million. This shows a decrease in value between the plan and actual performance (Figure 5-17) (Anooraq Resources Corporation, 2009-2011; Atlatsa Resources Corporation, 2012-2015).

The rand basket price for PGM improved over the stated period (Figure 5-16), and CAPEX was lower than planned between 2009 and 2015, thus increasing value in the cash flows. On the other hand, the scale of production and the operating costs contributed negatively to the cash flows (Figure 5-17).

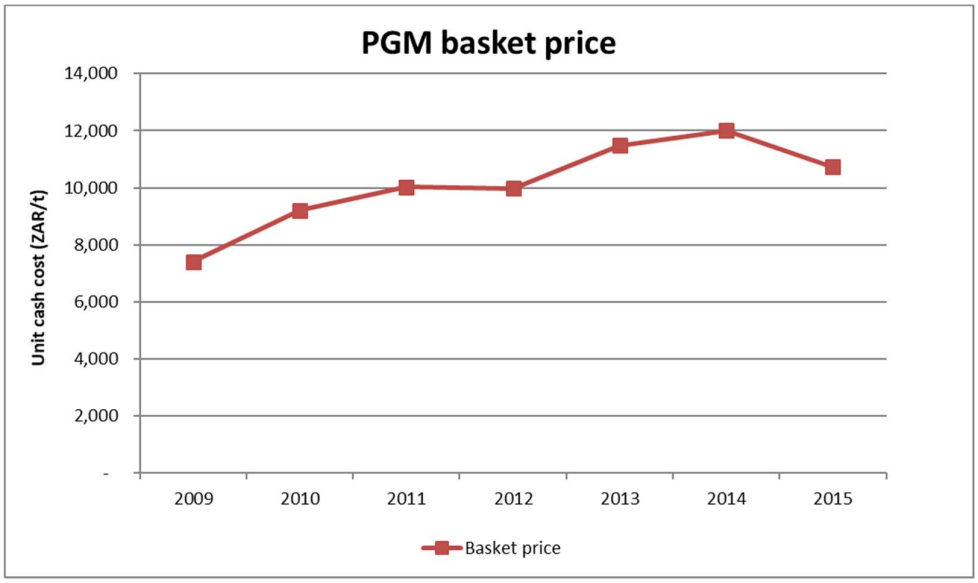

Figure 5-16 Rand basket price for PGM from 2009 to 2015. Data sourced from Anooraq Resources Corporation, 2009 - 2011; Atlatsa Resources Corporation, 2012 - 2015

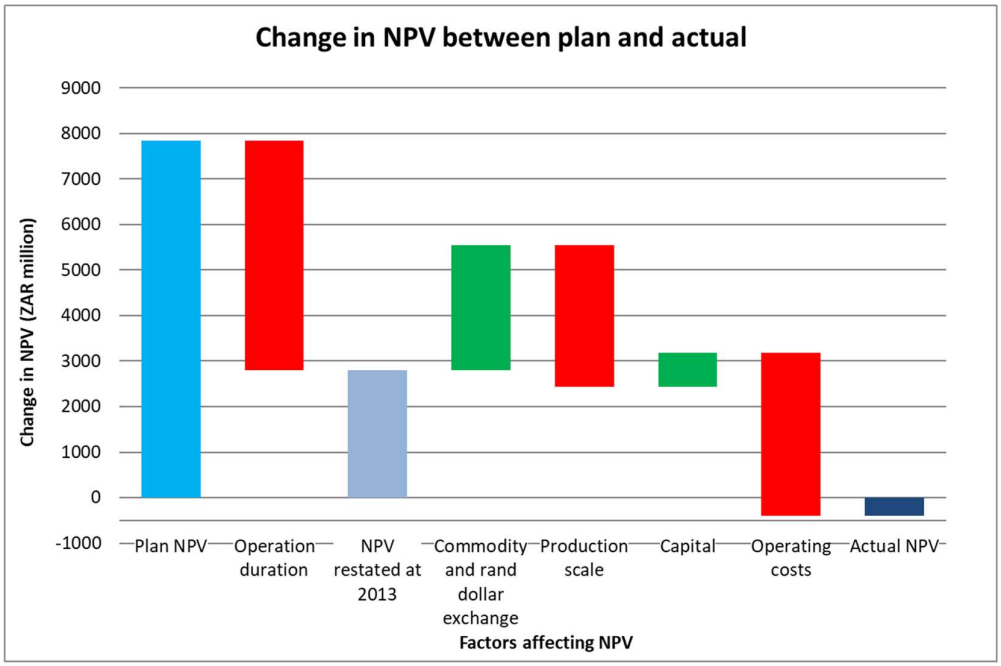

Figure 5-17 Change in NPV due to actual values at Bokoni

The major concern at Bokoni is the high operating cost while producing low volumes at low grades (Atlatsa Resources Corporation, 2016). Most of the mines on the Eastern Bushveld

Limb mine the UG2 Reef. Jarman (2012) in her Master's research undertook a financial evaluation of the UG2 and Merensky Reef at Twickenham mine, which is also on the northern part of the Eastern limb like Bokoni. In her research, she mentions that Bokoni has historically had difficulties with mining the Merensky, due to the abundance of potholes in the orebody, which are a geological loss. Therefore, mining through potholes leads to high costs and lower grades because they represent the absence of reef. Further, Jarman (2012) concluded that the Merensky was not viable to mine at Twickenham as a standalone ore, due to lower Reserve grades. It is thus the opinion of this study that the indicated high number of potholes encountered during mining could have contributed to the high operating costs.

This study concludes that Bokoni did not achieve the value it set out to achieve, starting off with a re-calculated plan NPV of ZAR 2,805 million in 2008, the operation ended up with NPV of ZAR -399 million in 2015.

5.3.2 Modikwa Platinum Mine

Modikwa Platinum Mine (Modikwa) is an underground mine, located on the Eastern limb of the BIC. It is a joint venture (JV) owned between African Rainbow Minerals (ARM) and Amplats. It is located 55 km south of Bokoni (Figure 5-12). The mine is 450m deep, with three decline shafts and a concentrator. The mine is a hybrid operation using conventional stoping methods with trackless development (African Rainbow Minerals Limited, 2006). Modikwa mostly mines UG2 (African Rainbow Minerals Limited, 2007).

Plan

It is not clear when the construction of the mine commenced. According to a 2004 media report, the planned capital cost of the mine was estimated at ZAR1.6 billion, this is assumed to be at 2004 money terms (IOL, 2004). The 2004 ARM annual report stated the planned full production of the mine as shown in Table 5-1 for mid-2005 (African Rainbow Minerals Limited, 2004).

Table 5-1 Technical performance indicators anticipated at full production (after African Rainbow Minerals Limited, 2004)

Annual Performance Indicators	Projected at full production per year
Tons milled (000)	2,880
Head grade 4 E (g/t)	4.50
Pt Production (oz)	160,000
PGM production (oz)	366,000

Actual performance

Modikwa has not been able to achieve the steady state production planned; and has seen a further decline in production in the recent years, namely 2014 and 2015 (Figure 5-18) (African Rainbow Minerals Limited, 2004-2015).

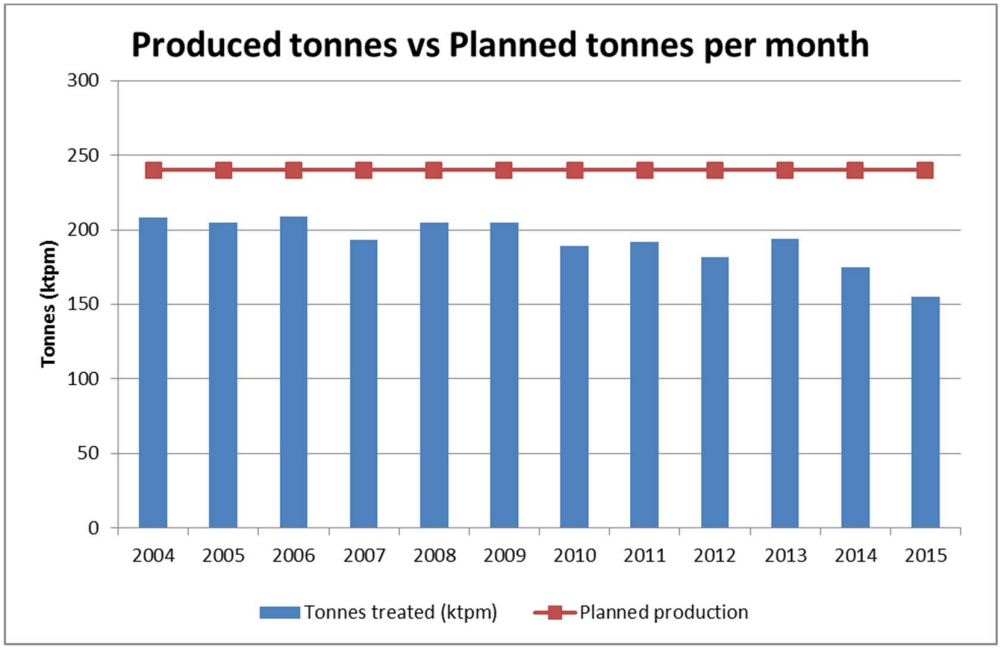

Figure 5-18 Produced tonnes at Modikwa versus planned tonnes between 2004 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)

The reported, achieved head grade was lower than the planned head grade between 2004 and 2008. In 2009, the actual head grade increased but this was due to the reported head grade including 6E PGM instead of 4E. The change in the reported head grades was because Modikwa renewed its offtake agreement to include 6E PGM (Figure 5-19) (African

Rainbow Minerals Limited, 2009). The 4E PGM grade was deduced not to have increased much beyond 2008, because the produced 4E PGM never achieved its target after 2008 (Figure 5-20) (African Rainbow Minerals Limited, 2004-2015).

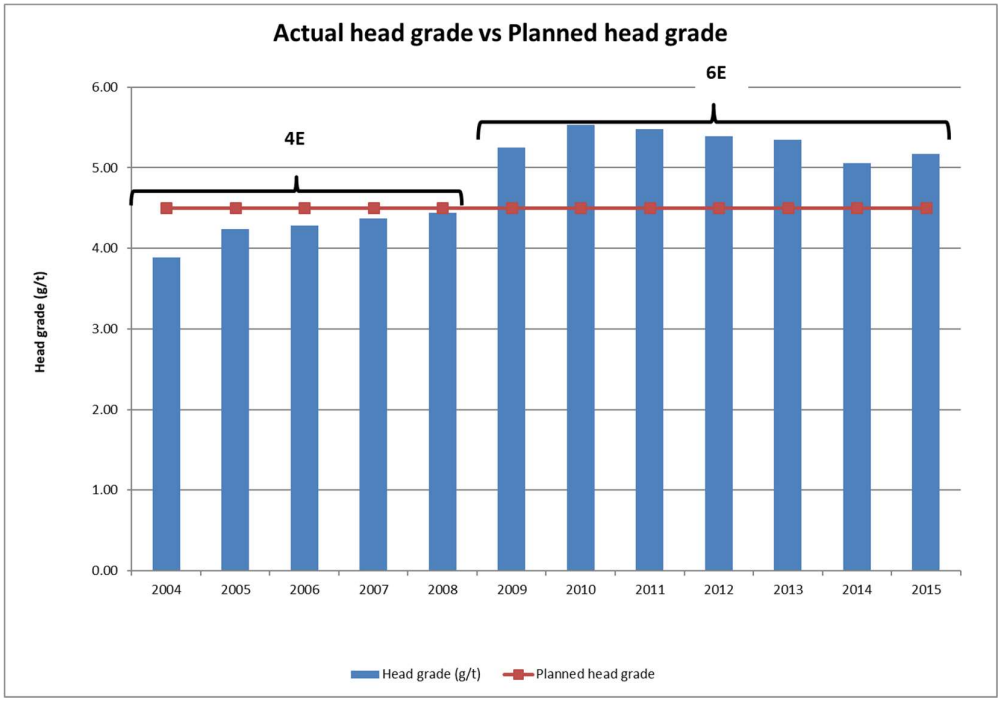

Figure 5-19 Achieved head grade at Modikwa versus planned head grade between 2005 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)

The metal in concentrate between 2004 and 2015 at Modikwa never met the steady state level stated in the initial plan of 366,000 oz 4E PGM per annum (Figure 5-20). This was due to both the tonnes and head grade being lower than planned (African Rainbow Minerals Limited, 2004-2015).

Operating cost at Modikwa was planned at ZAR300/t, assumed to be in 2004 money terms, but the actual unit cash cost exceeded the target on a yearly basis, while continuously increasing. The average unit cash cost between 2005 and 2015 averaged ZAR467/t, which is 56% higher than the planned costs (Figure 5-21) (African Rainbow Minerals Limited, 2004-2015).

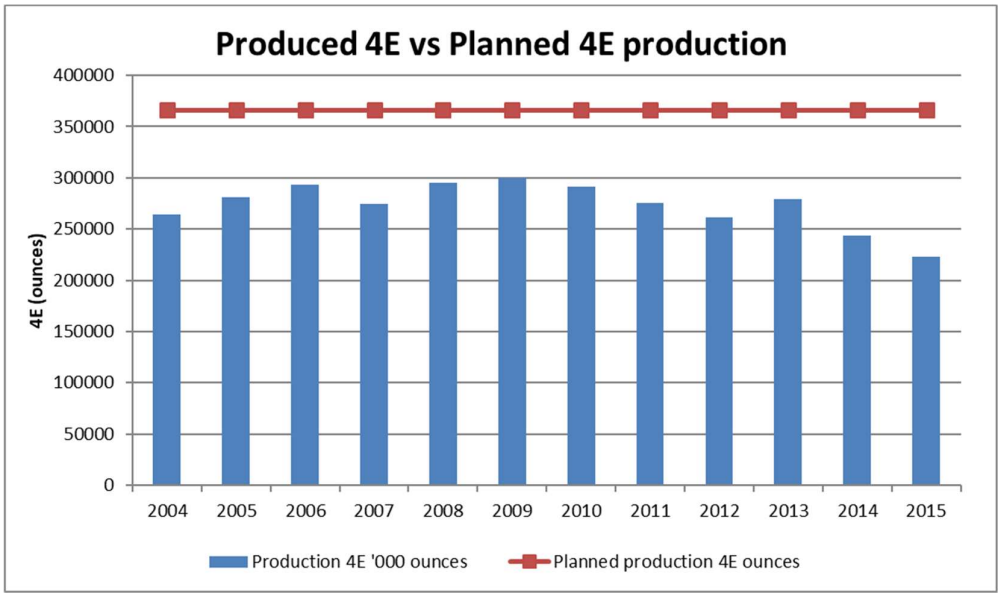

Figure 5-20 Produced 4E ounces at Modikwa versus planned 4E production between 2005 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)

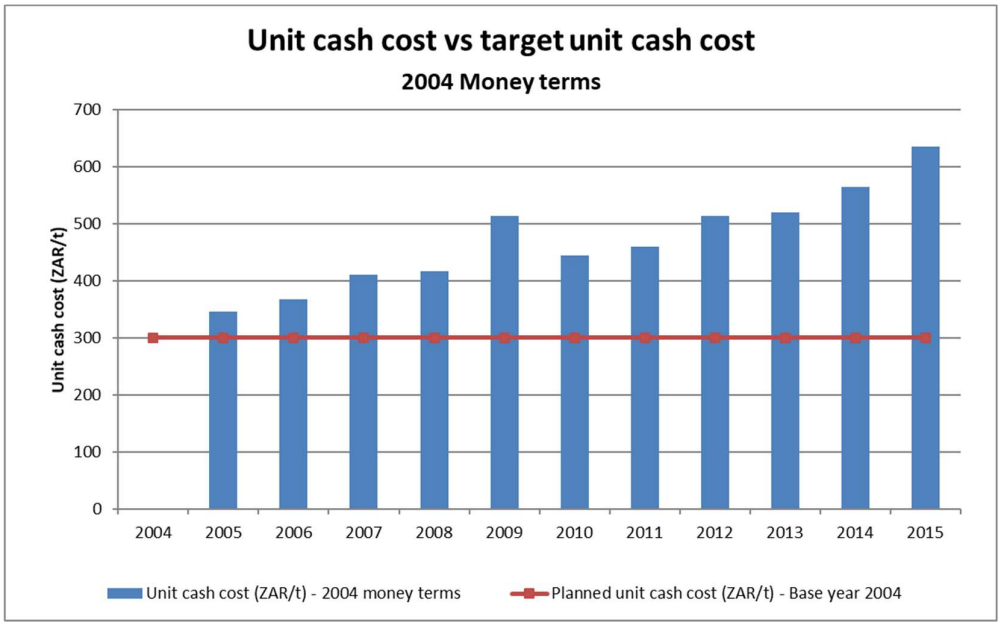

Figure 5-21 Actual vs planned cash costs at Modikwa between 2005 and 2015 (Data sourced from African Rainbow Minerals Limited, 2004 - 2015)

Modikwa recorded an operating profit 8 out of the 11 years from 2005 to 2015. In 2008, Modikwa's operating profit was ZAR1.5 billion, which was mainly due to a significant

increase in commodity prices in that year. This enabled ARM Mining Consortium to settle the project debt for Modikwa in full on the 31st December 2008, 18 months earlier than the intended date of settlement (African Rainbow Minerals Limited, 2009). Though Modikwa has shown good profit margins it has not been able to operate at the level it was intended to operate at in the initial plans. The good profits received at Modikwa have largely been due to the commodity prices, supported by a weaker rand. Total operating profit from 2005 to 2015 is ZAR3,618, in 2004 terms. CAPEX is ZAR1,043, in 2004 terms, between 2005 and 2011, after which an expansion project was mentioned in the annual reports and it is thought that is what the CAPEX was used for (African Rainbow Minerals Limited, 2004-2015). The information reported excludes the years prior to 2005 as the cost and revenue information for this mine was not available.

The reasons provided by ARM for not achieving steady state included unexpected geological disturbances, lower labour efficiencies and strained relations between management and employees, in 2005 and 2006. The JV partners changed the mining method from down dip to breast mining (African Rainbow Minerals Limited, 2005), which was considered to be more cost-effective. African Rainbow Minerals Limited (2015) reported that a decrease in production was due to safety stoppages, a lack of mining flexibility resulting in labour inefficiencies and some concentrator inefficiencies. It is clear that a number of technical and non-technical factors have played a role in the negative impact on production. The technical factors included geotechnical, mine design and mining rate, and metallurgical (African Rainbow Minerals Limited, 2004-2015).

Due to the cash flow model for Modikwa being unavailable, a quantitative assessment of the actual performance on the initial value of this project could not be assessed. A qualitative assessment of this project indicates that profit has been achieved at Modikwa, but this study is unable to conclude whether the initial value of the project was achieved. It is clear though that the commodity price has had a positive contribution to the achieved value at Modikwa. Based on technical parameters and operating costs only, it is not clear whether Modikwa reached its planned value based on:

- Production was lower than planned. Lower production means lower revenue, and lower revenue also has a direct impact on project value.
- Operating costs negatively impacted the value since the steady state had not been achieved as fixed costs had to be spread over lower production levels.
- CAPEX at Modikwa was lower than planned.

5.3.3 Crocodile River Platinum Mine

Crocodile River Platinum Mine (Crocodile River) is an underground mine in the Western Bushveld Limb. The mine is situated on the Brits Graben, which is structurally complex (Figure 5-22). Crocodile River Platinum Mine mined the UG2. The mine was previously owned by Impala Platinum Limited (Implats) through its subsidiary Barplats. Impala shut the mine down because of the high dilution and difficult ground conditions; that were placing it at a loss. Eastern Platinum Limited (Eastplats) acquired 69% shareholding in Barplats in 2006 (Eastern Platinum Limited, 2007, Eastern Platinum Limited, 2010a). Later, Eastplats shut operations in 2013 citing low commodity prices. The mine is in the process of being acquired by Hebei Zhongheng Tianda Platinum Co. Limited (Mining Technology, 2016). All monetary values are in 2007 money terms.

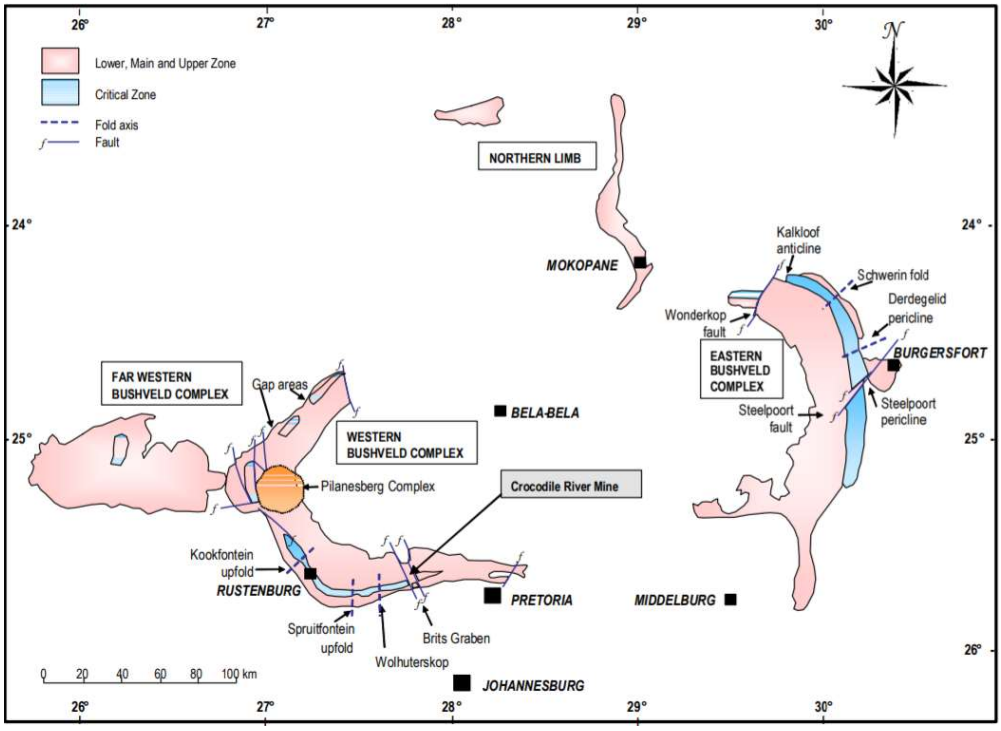

Figure 5-22 Locality map for Crocodile River Platinum Mine (after Eastern Platinum Limited, 2007)

Plan

The technical report for Crocodile River Platinum Mine prepared in 2007 was aimed at raising funds for the mine extension and working capital. For the purpose of this research, the 2007 report was considered as a feasibility study report for the extension project at

Crocodile River Platinum Mine. The base case pre-tax cash flow model for the Crocodile River Platinum Mine operations calculated at a discount rate of 10% over a 9½ year period resulted in an NPV of ZAR4,064 million for the mine, in 2007 money terms. The cash flow model was used to demonstrate that the operation is economically viable with the payback period estimated at less than one year (Eastern Platinum Limited, 2007).

CRM was planned to mine the UG2, dipping between 15º and 25º, at a thickness ranging between 1.2 m and 1.6 m. Eastplats's plan was to use a hybrid mining method, where handheld machinery would be used in the stopes, and the broken stock would be transported using diesel equipment to a conveyor belt that would take the rock to the surface (Eastern Platinum Limited, 2007).

Ramp up was planned to take four years from 2007, and at steady state, the mine was to produce 2.5 Mt per annum yielding 245,125 ounces of 4E (Figure 5-23 & Figure 5-24). The operating cash cost was planned at less than ZAR300/tonne (Eastern Platinum Limited, 2007).

Actual performance

Production targets for tonnes and metal were exceeded in 2007 and 2008. Subsequent to 2008, production was far below target for both tonnes and PGM produced in concentrate (Figure 5-23 & Figure 5-24) (Eastern Platinum Limited, 2007 - 2014).

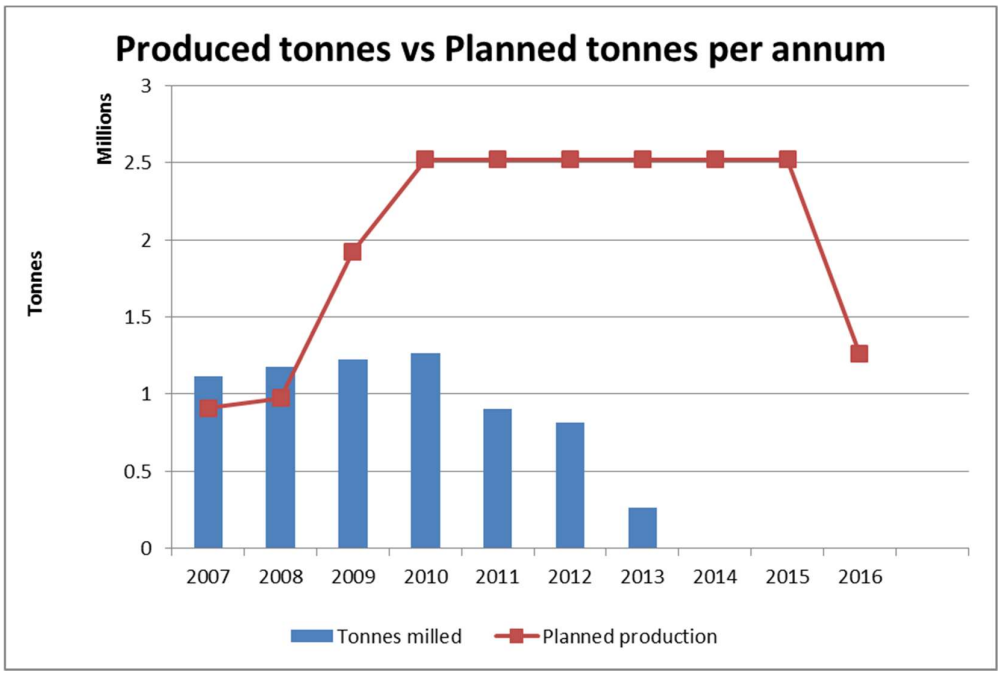

Figure 5-23 Produced tonnes at Crocodile River Platinum Mine versus planned tonnes between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2008 – 2014)

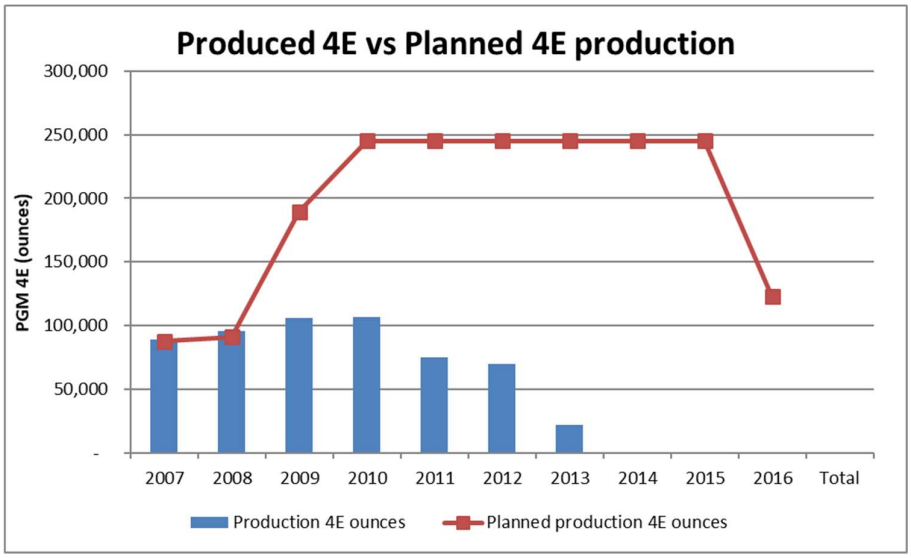

Figure 5-24 Produced 4E PGM ounces at Crocodile River Platinum Mine versus planned 4E production between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014)

The head grade however at Crocodile River Platinum Mine was higher than what was in the plan. The head grade at Crocodile River Platinum Mine was planned at 3.47g/t 4E, and the mined head grade was reported in 4E at 3.39g/t on average (Figure 5-25) (Eastern Platinum Limited, 2007 - 2014). The head grade difference was only -2%, which means Crocodile Platinum Mine achieved its head grade target.

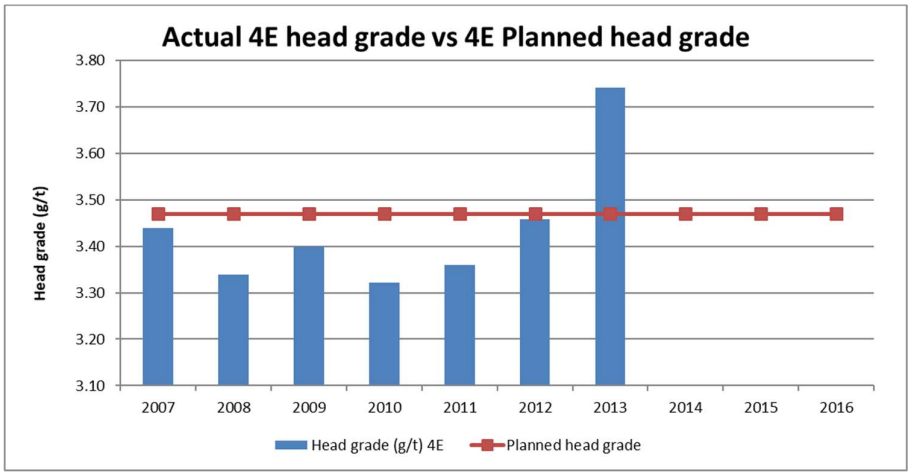

Figure 5-25 Actual head grade at Crocodile River Platinum Mine versus planned head grade between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014)

Operating cash costs were also compared. The actual unit costs averaged ZAR486/tonne, in 2007 money terms, over the operation of the mine, which was higher than the planned unit costs of ZAR286/tonne, in 2007 money terms (Figure 5-26) (Eastern Platinum Limited, 2007 - 2014).

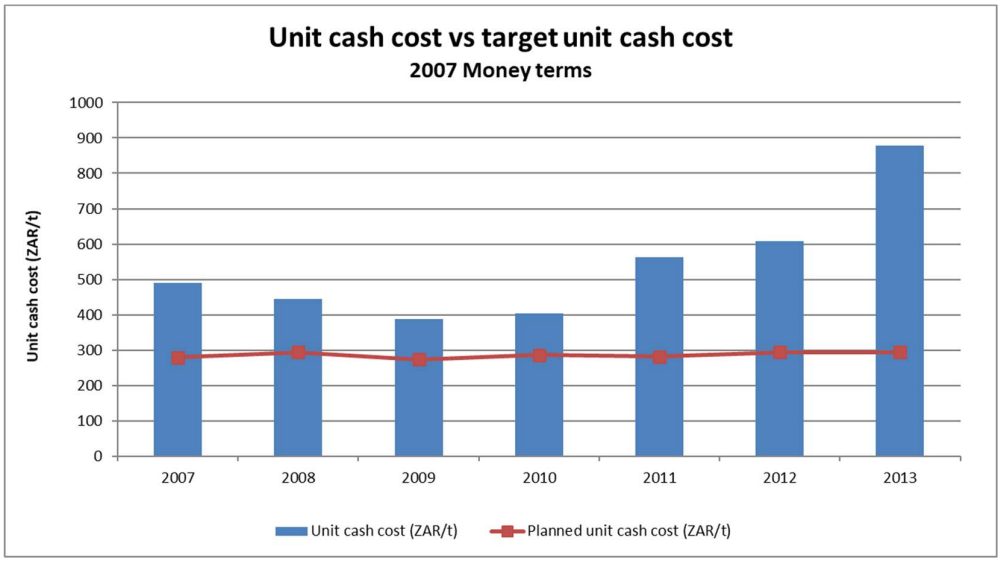

Figure 5-26 Actual unit cash cost versus planned unit cash cost between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014)

The actual CAPEX was higher than planned. The capital expenditure in 2008 was approximately ZAR 931 million, in 2007 money terms (Eastern Platinum Limited, 2008). This one year's capital expenditure exceeded the total planned capital expenditure for the entire project, of ZAR 907 million, from 2007 and 2016. The total actual CAPEX was ZAR 2,139 million, which was 139% higher than the planned CAPEX of ZAR 895 million between 2007 and 2013 (Figure 5-27) (Eastern Platinum Limited, 2007 - 2014).

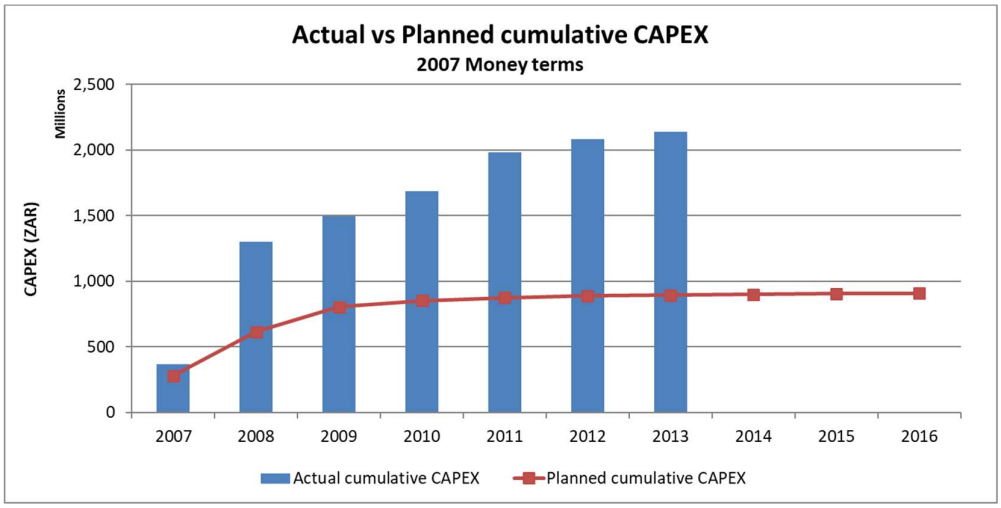

Figure 5-27 Actual CAPEX versus planned CAPEX between 2007 and 2016 (Data sourced from Eastern Platinum Limited, 2007 – 2014)

Impact on value

The DCF published in the 2007 technical report and the recorded performance from MD&A reports were used to carry out a quantitative evaluation of the actual performance on the initial value. Data used for this analysis was sourced from the Eastern Platinum Limited MD&A reports between 2007 and 2014.

The re-calculated NPV from the cashflow published in the 2007 feasibility study was at ZAR4,605 million, which is 13% higher the reported NPV of ZAR4,064 million. The re-calculated NPV excluded penalties and royalties. The original NPV re-stated to 2013 since that was the year CRM stopped operating was ZAR3,400 million. Actual CAPEX and operating costs were also restated to 2007 money terms. The working DCF was used to calculate a NPV from actual operation; this resulted in a NPV of ZAR-561 million. The biggest contributor to the decrease in value was operating costs, followed by production scale and then CAPEX (Figure 5-27 & Figure 5-28).

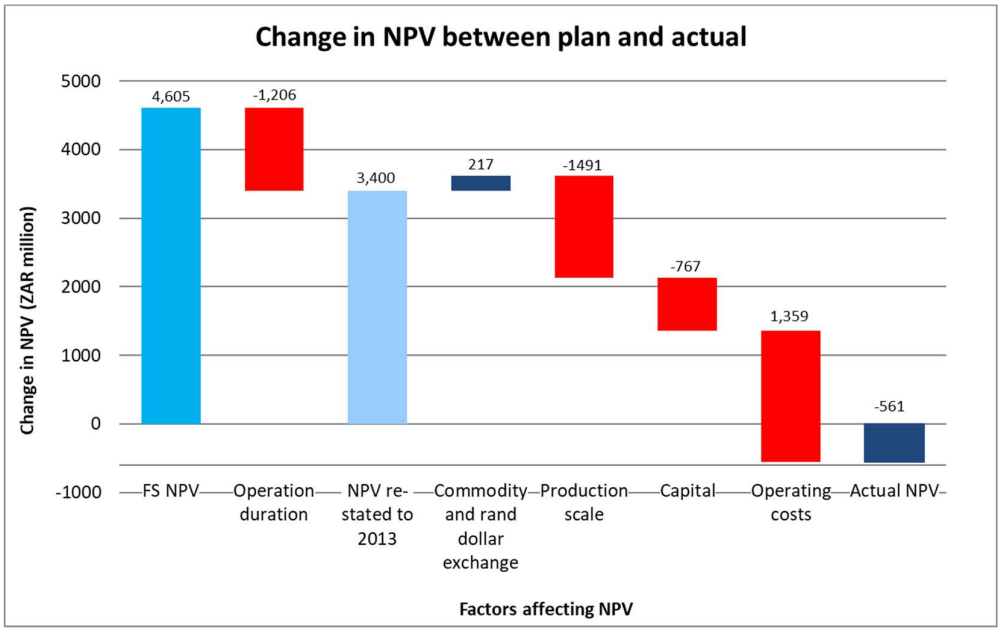

Figure 5-28 Change in NPV due to actual values at the Crocodile River Platinum Mine (Data sourced from Eastern Platinum Limited, 2008 – 2014)

5.3.4 Marula Platinum Mine

Plan

Marula Platinum Mine (Marula) is located in the Eastern Bushveld Limb (Figure 5-29). It started development in 2002 and had planned to reach full production in January 2005, producing 270,000 PGE ounces and 100,000 ounces of platinum. The mine was initially planned to use a trackless semi-mechanised room and pillar mining method, with a mining height of 1.6m. (Impala Platinum Limited, 2003).

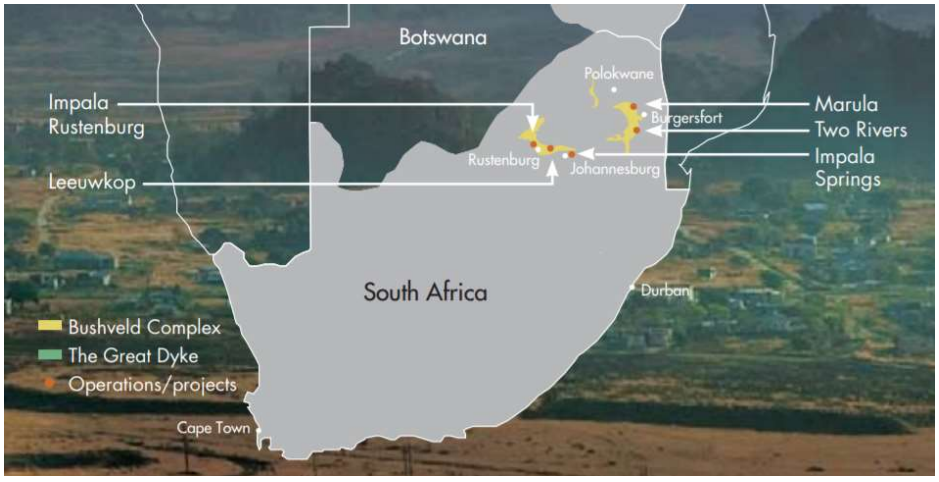

Figure 5-29 Marula Platinum Mine locality map (Impala Platinum Limited, 2009)

Actual performance

It was reported that development at Marula encountered difficulties, due to the result of poor hanging-wall conditions and potholes. Further, the mining method was changed to a hybrid method, which entailed mechanised development and conventional stoping, due to steeper, more variable dips in the orebody than initially thought. Marula started processing in 2004 but has not reached the full production targets it initially set out (Figure 5-30). The total PGM production over time was 33% less than the accumulated planned PGM production (Impala Platinum Limited, 2003-2017).

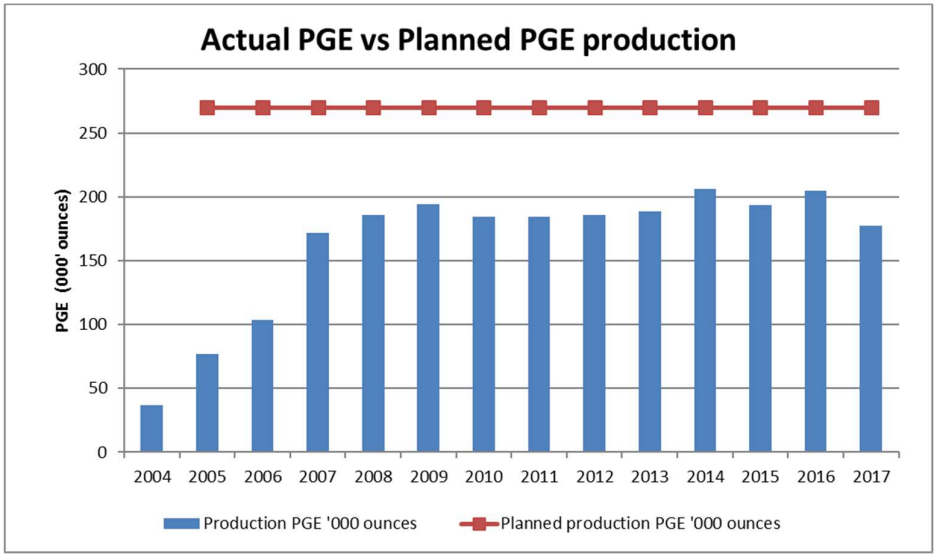

Figure 5-30 Produced tonnes at Marula versus planned tonnes between 2004 and 2017 (Data sourced from Impala Platinum Limited, 2003 - 2017)

Marula has also recorded numerous gross operating losses over the years. In total 9 out of 14 years have recorded a gross operating loss, since 2004. Cumulatively, the reported gross operating loss is ZAR64million, in 2017 money terms (Figure 5-31) (Impala Platinum Limited, 2003-2017). The shortfall in PGE production would have impacted negatively on the initial value planned. A media report, in 2004, indicated that operating costs at Marula were higher than plan. The reason provided by management for the high operating costs at Marula included high inflation and lower-than-planned throughput, due to strikes, accidents

and lack of mining flexibility (Mining Weekly, 2009). The mine has also experienced community protest as well as employees' strikes, which would have impacted on productivity (Impala Platinum Limited, 2003-2017).

Since it is believed Marula would have presented a business case before embarking on mine construction, this study can therefore deduce that Marula has not met its initial value due to:

- Lower production;
- Higher operating costs; and
- Recurring operating losses in 9 out of 14 years.

Beyond technical factors, other factors outside of the mine's control also impacted on the performance of this mine.

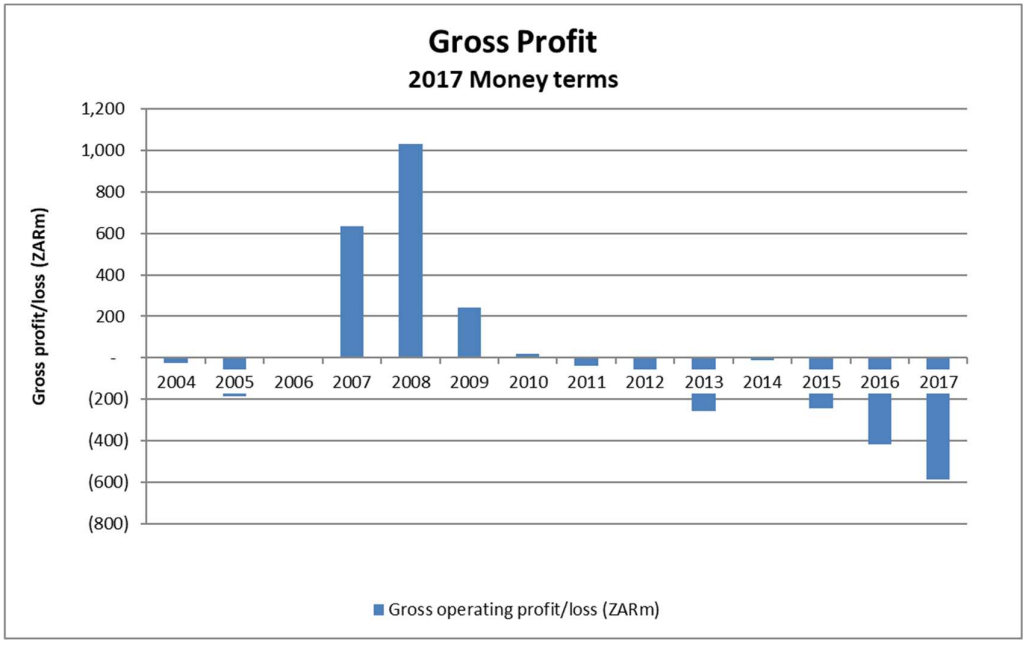

Figure 5-31 Gross operating profit/loss at Marula between 2004 and 2017 (Data sourced from Impala Platinum Limited, 2003 - 2017)

5.3.5 Two Rivers Platinum Mine

Plan

The Impala and ARM (then Anglovaal Mining Limited) joint venture purchased the PGM mineral rights to the Dwarsrivier property, which was later known as Two Rivers, in 2001

(Impala Platinum Limited, 2002). Two Rivers is also located in the Eastern Bushveld, 67km south of Marula (Figure 5-29).

A feasibility study and trial mining were undertaken after purchasing the property, before a decision to develop was taken. The JV decided to develop a mine at the property in June 2005. The project was expected to be developed for a total of ZAR1.2 billion CAPEX, and reach steady production in 2008. The mine was planned to mine only UG2 and expected to produce 120,000 oz of platinum and 220,000 PGM ounces a year at steady state. The mine was planned to be a fully mechanised underground mine (Impala Platinum Limited, 2005).

Actual performance

Two Rivers achieved its planned throughput in 2009 and thereafter exceeded the plan by optimising the plant and testing the mining method before the project commenced (Figure 5-32 and Figure 5-33). The mine has generally been profitable over time, (Figure 5-34). Impala attributes the successful implementation of the mechanised mining method to the pre-production trial mining (Impala Platinum Limited, 2007).

It is not possible to deduce whether Two River has met its initial value or not. The operation met its production targets in 2008 and exceeded these targets thereafter. Since the NPV for Two Rivers is not known and other information such as planned total CAPEX, plan operating costs, the study cannot make any conclusions with regards to initial value. The author has observed that there has been consistent gross profit over time at Two Rivers (Figure 5-34), which indicates a positive contribution towards current value.

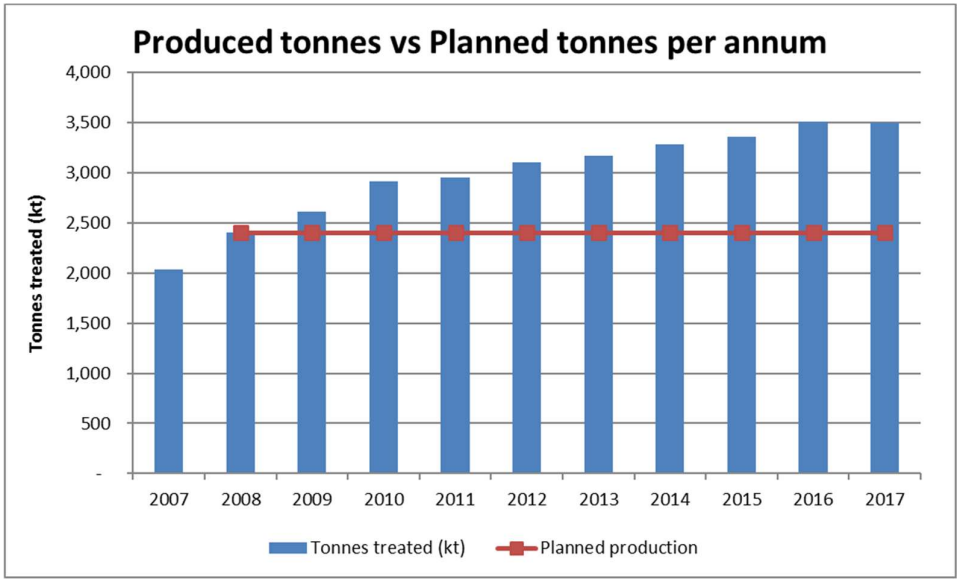

Figure 5-32 Produced tonnes versus planned tonnes at Two Rivers between 2007 and 2017 (Data sourced from Impala Platinum Limited, 2005 - 2017)

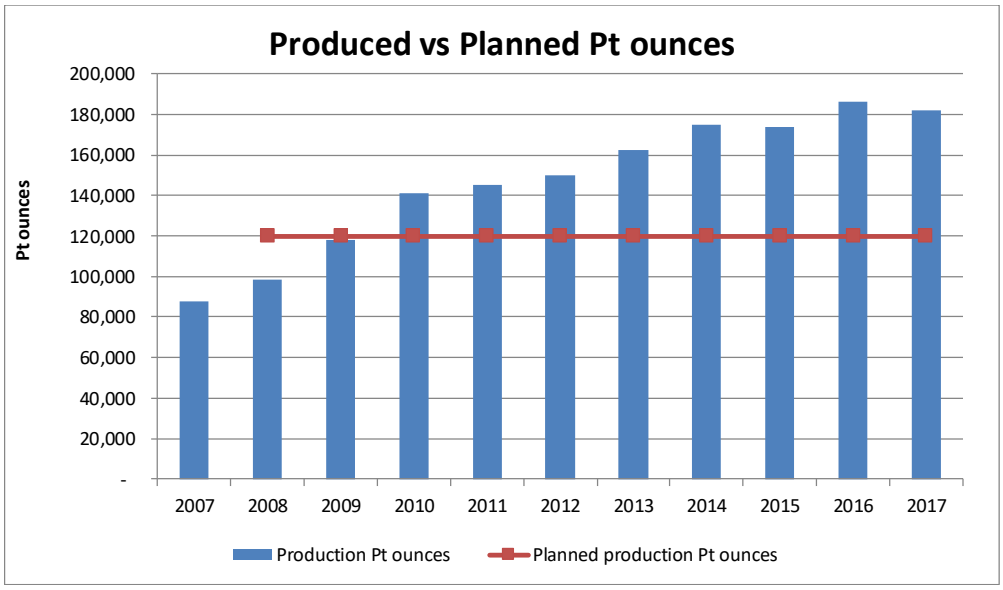

Figure 5-33 Produced Pt ounces versus planned Pt ounces at Two Rivers between 2007 and 2017 (Data sourced from Impala Platinum Limited, 2005 - 2017)

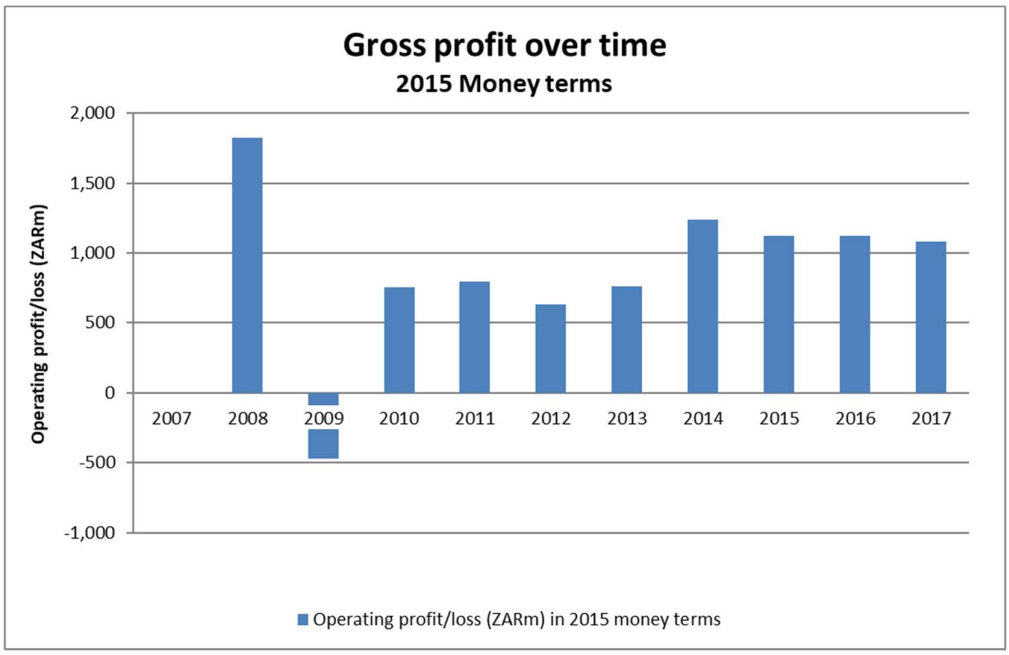

Figure 5-34 Gross profit/loss at Two Rivers between 2008 and 2017 (Data sourced from Impala Platinum Limited, 2005 - 2017)

5.3.6 Leeuwkop Platinum Mine

Impala Platinum bought 100% shareholding in African Platinum (Afplats) in 2007, and acquired the Leeuwkop platinum project, located in the Western Bushveld next to Brits (Figure 5-29). This transaction cost Impala ZAR4.2 billion. The mine was anticipated to be an underground mechanized mine, producing 160,000 ounces of platinum in concentrate per annum (Impala Platinum Limited, 2007). In 2009, Impala announced the decision to defer Leeuwkop (Impala Platinum Limited, 2009), after it was previously envisaged that the development at Leeuwkop was going to start in 2009 (Impala Platinum Limited, 2008). Development at Leeuwkop commenced in 2012 (Mining Weekly, 2014a). In the 2015 annual report, Impala announced the decision to postpone the project by four years to preserve cash (Impala Platinum Limited, 2015). The early closure of the mine did not allow the mine to realise value from what it had anticipated when the decision was taken to develop the mine.

5.3.7 Platinum Price

It is interesting to observe the trend of the Rand platinum price over time, as it is different to the US dollar platinum price. The US platinum price has seen a general decline over from 2011 to current (Figure 5-35). However, the South African Rand platinum price has shown an increase from mid-2008 to current (Figure 5-36).

All the platinum projects reviewed above, except for Leeuwkop, were approved before the peak price period of 2008. Thus, the projects could have not been planned at that peak price. Instead, all the projects, except for Leeuwkop, received higher South African Rand platinum prices than what they started off with. Whether a project received a higher price or not also depends on the projected commodity price that the project was planned at. An unrealistically high platinum price may result in project failure.



Figure 5-35 US dollar platinum price per ounce between 2000 and 2018 (after InfoMine.com, 2018)

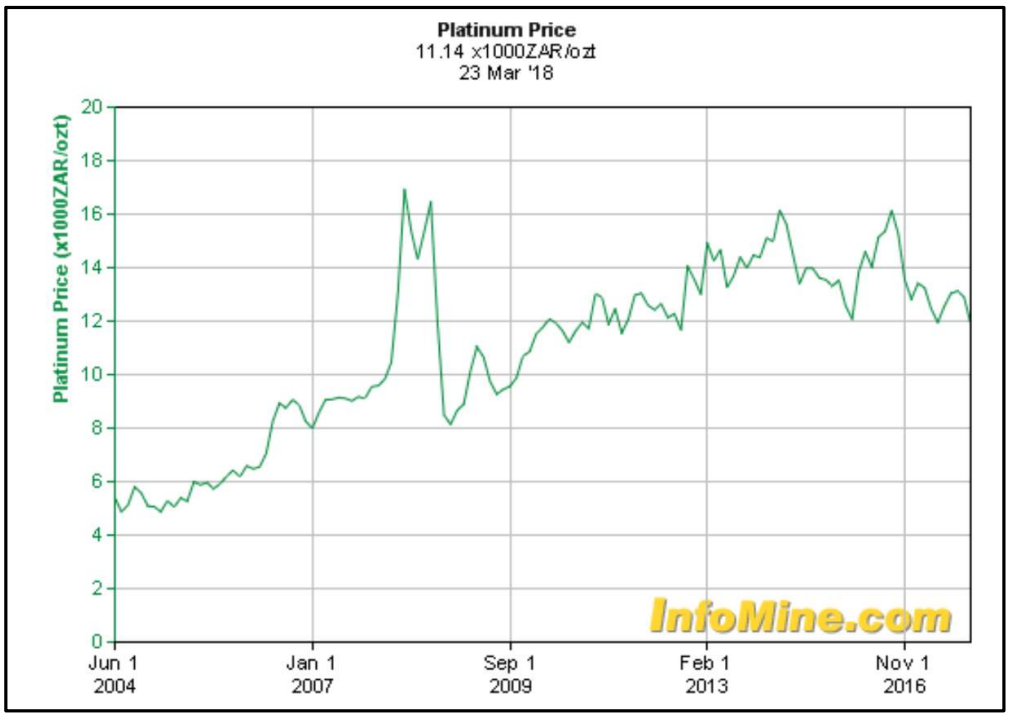

Figure 5-36 South African Rand platinum price per ounce between 2000 and 2018 (after InfoMine.com, 2018

5.4 Coal projects

5.4.1 Mooiplaats Colliery

Plan

Mooiplaats Colliery (Mooiplaats) was purchased by Coal of Africa in 2008 for of $125 million. Mooiplaats is located in the Ermelo Coalfield in Mpumalanga Province (Figure 5-37). Adverse geological conditions led to an extensive re-evaluation of the existing mine plan. The subsequently revised mine plan was finalised in July 2009. According to the mine plan, the run of mine (ROM) production was expected to increase from 1.7 million tonnes in 2010 to 3.2 million tonnes in 2014 (Coal of Africa, 2009). Mooiplaats was planned to have a life of mine of 12 years (Coal of Africa, 2012). Other planned production statistics were not mentioned.

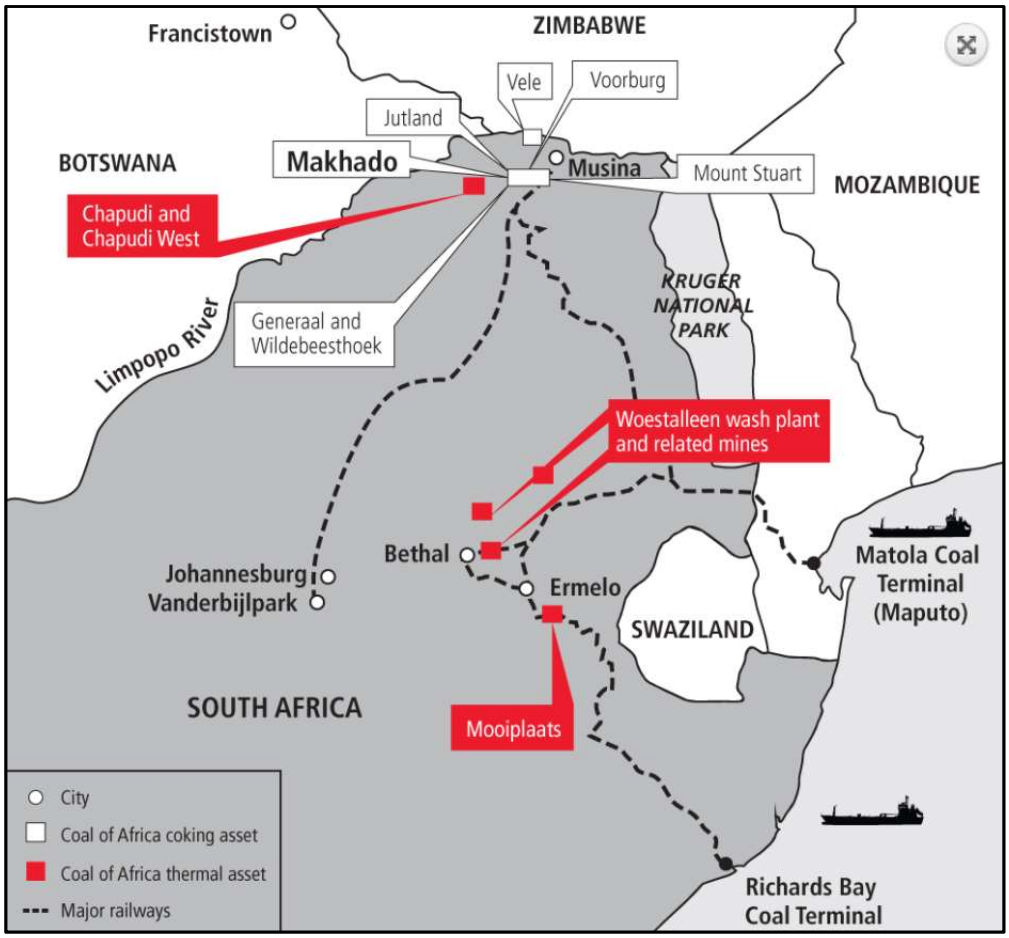

Figure 5-37 Locality map for Mooiplaats Colliery (after Mindset Mining Consultants (Pty) Ltd, 2013)

Actual performance

Development at Mooiplaats started in 2008. The mine required dewatering, de-silting and deepening of the box-cut to the bottom contact of the coal horizon for it to be operational. The operation started in November 2008. A coal handling and preparation plant commissioned in May 2009 (Coal of Africa, 2009). In the 2010 financial year, the second module of the wash plant was commissioned, the Mooiplaats Colliery's north shaft developments and the rest of the surface infrastructure also got completed (Coal of Africa, 2010).

The production reported from 2010 to 2013 was lower than the forecast production in the 2009 mine plan (Figure 5-38). This shortfall in production was attributed to difficult mining conditions, because of poor geological conditions mentioned in previous years. Production

yield at Mooiplaats saw a steady improvement from 2010 to 2013 (Figure 5-39).

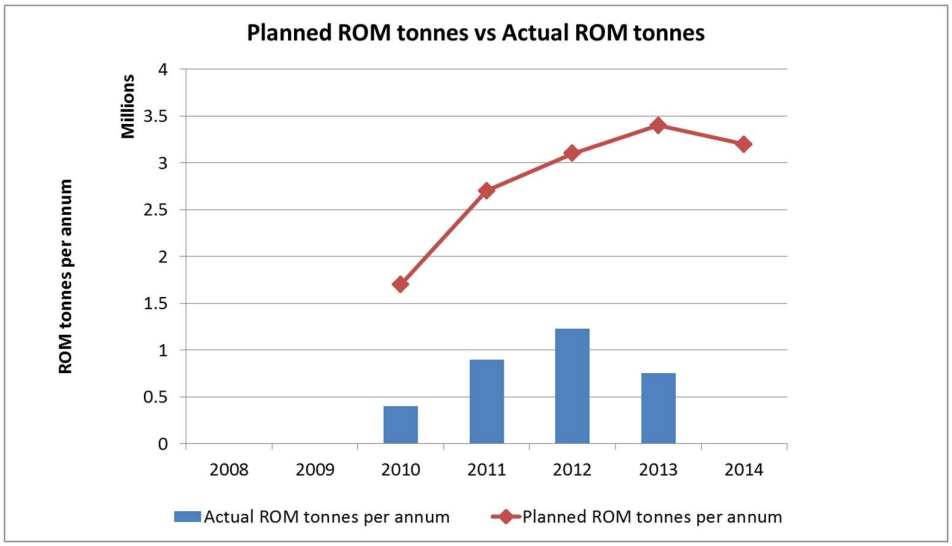

Figure 5-38 Forecast versus actual ROM tonnes per annum over time (Data sourced from Coal of Africa, 2009 - 2013)

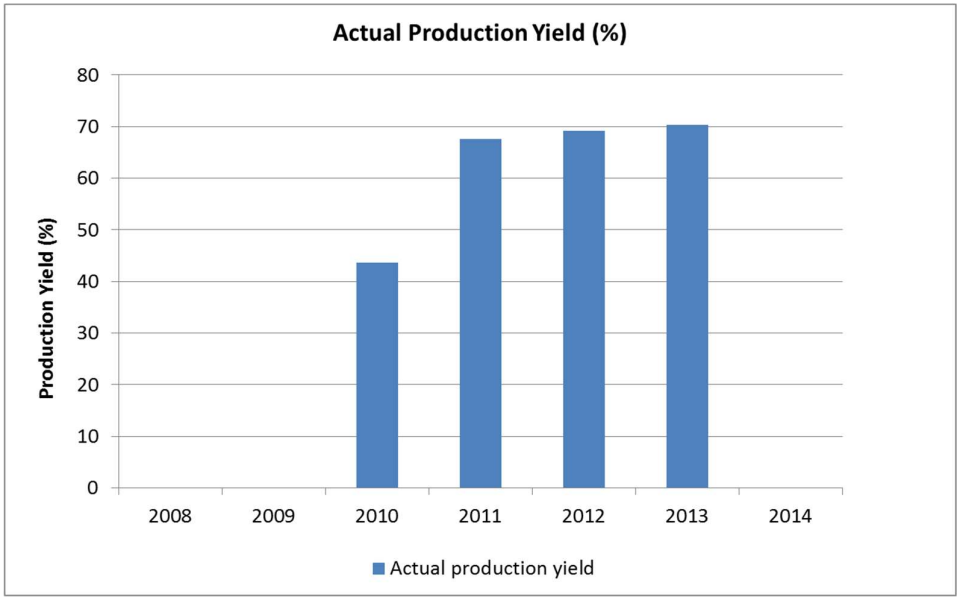

Figure 5-39 Coal production yield over time (Data sourced from Coal of Africa, 2009 - 2013)

In the 2011 Coal of Africa financial year, Mooiplaats incurred an impairment of US$88.5 million due to:

- Lower steady state production tonnes than predicted, from 2.28 - 3.36Mtpa to a revised level of 1.18 - 1.70Mtpa
- Revised coal qualities in some areas
- Increase in the mining cut which resulted in a lower Coal Resource from 41.8 million ROM to 32.0 million ROM tonnes; and
- Significantly higher rail and port costs than originally projected

The project was also impaired with US$46.7 million in 2010 and US48.5 million in 2013 (Coal of Africa, 2013).

Mooiplaats was put on care and maintenance in October 2013. Subsequently, Coal of Africa entered into a sale and purchase agreement (SPA) with Blackspear Capital over Mooiplaats for R250 million, in September 2014. The SPA lapsed on 30 June 2015 and was not renewed (Mining Africa Review, 2016).

A qualitative assessment of the delivered value compared to the project's initial value indicates that the initial value was not reached, due to production falling short of the planned production. Further, the difference in the amount the project was purchased for plus the added costs incurred during the development of the project, compared to the price the project was intended to sell for, indicates that the project had decreased in value.

5.4.2 Isibonelo Colliery

Isibonelo Colliery (Isibonelo), previously known as Kriel South, is an open cast mine developed and operated based on an agreement, reached in 2003, between Anglo American Coal and Sasol Mining, which entailed that the mine would supply coal to Sasol Synthetic Fuel (SSF) plant. Construction began in 2003 and coal was supplied to SSF for the first time in July 2005 (Mining Weekly, 2006). According to a report update by Anglo American Coal, the project was delivered on time and within budget (Anglo American, 2005).

Plan

Isibonelo was planned to deliver 5 Mt/year, at full production, to the SSF for over 20 years (Mining Weekly, 2006). It was planned, to reach this full production state in 2006.

Actual performance

Isibonelo reached full production in 2007. Since then, the mine has consistently been producing approximately 5 Mt/year, as planned (Figure 5-40). Unfortunately, other production parameters were not reported in the annual reports, therefore, there is no measure of the quality of the reported tonnes (Anglo American, 2005 – 2017). Based on this limited information, it is not possible to comment on the actual value of the mine compared to the planned value.

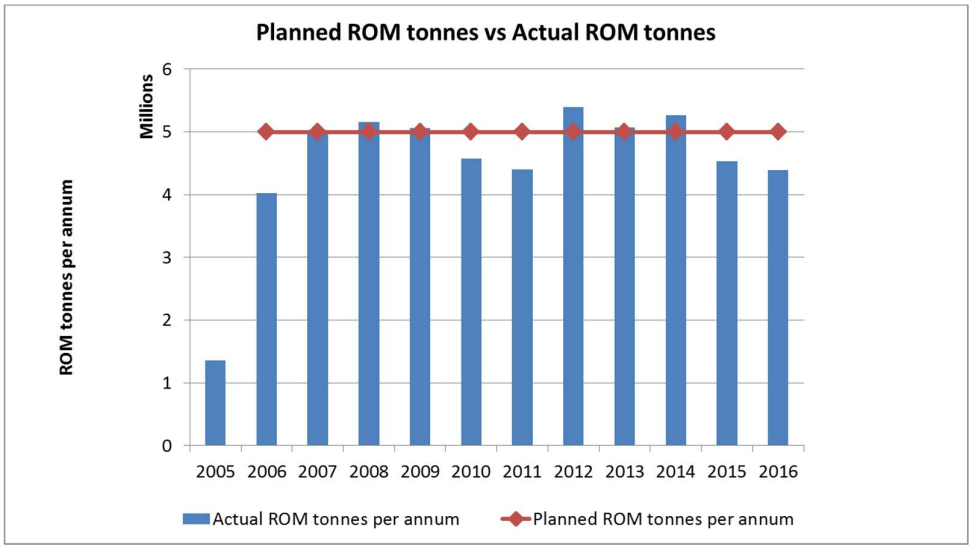

Figure 5-40 Forecast versus actual ROM tonnes per annum over time (Data sourced from Anglo American, 2005 – 2017)

5.5 Chapter summary

The amount of project information reported in the public domain varies vastly, especially for projects not reported on the TSX. Projects reported on the TSX provide more comprehensive information. This limited the study to analyse the performance of projects consistently, and therefore had to make several assumptions (Table 5-2).

Nonetheless, this study shows that South African mining projects have a low success rate in comparison to their initial plans. From the reviewed projects only two projects, namely Two Rivers and Isibonelo, achieved their production tonnes targets. The rest fell short of the

planned steady state production tonnes, CAPEX, head or recovery grade and operating costs initially announced for the projects. Five out of the nine mines that did not meet the production tonnes ended up on care and maintenance prematurely.

Table 5-2 Mine performance information provided per project

Mine	Commodity mined	Tonnes mined	Produced metal	Head grade1	Operating cost	CAPEX	Gross profit	DCF
Burnstone Gold Mine	Gold	✓	✓	✓	✓	✓	X	✓
Kusasalethu Gold Mine	Gold	X	✓	✓	X	✓	✓	X
Phakisa Gold Mine	Gold	X	✓	X	X	✓	X	X
Bokoni Platinum Mine	Platinum	✓	✓	✓	✓	✓	✓	✓
Modikwa Platinum Mine	Platinum	✓	✓	✓	✓	✓	✓	X
Crocodile River Platinum Mine	Platinum	✓	✓	✓	✓	✓	✓	✓
Marula Platinum Mine	Platinum	✓	✓	X	X	X	X	X
Two Rivers Platinum Mine	Platinum	✓	✓	X	X	X	X	X
Leeuwkop Platinum Mine	Platinum	X	✓	X	X	X	X	X
Mooiplats Colliery	Coal	✓	X	✓	X	X	X	X
Isibonelo Colliery	Coal	✓	X	X	X	X	X	X

6 PROJECT SUCCESS EQUATION

6.1 Chapter overview

This chapter discusses how the project success equation was formulated, including how the survey was carried out, the background qualifications of the respondents, analysis of the responses and how ratings were used to derive weights for the equation. Five out of the eleven projects assessed in Section 5 were analysed using the formulated equation to measure their relative success.

6.2 Background

Part of the research objectives for this study was to formulate an equation for defining success, based on ratings of technical performance criteria from a survey. The survey was sent to 17 mining professionals, out of those 13 responded. One of the respondents to the survey rated some of the criteria beyond 10; this survey was therefore not used, giving a response rate of 71%. Out of the 12 responded surveys, one did not have a rating for one of the success criteria due to not understanding what the criteria meant.

The respondents had at least five years' experience working with feasibility studies and due diligence for project development, thus were well acquainted with them. The respondents came from varied technical backgrounds, with four having more than one technical background. The technical backgrounds for the respondents included the following:

- Six mining engineering;
- Five geology;
- One metallurgy; and
- Three techno-financial/financial analyst/corporate advisory.

The respondents were based in South Africa and Australia. The responses to the survey are included in the APPENDIX.

6.3 Analyses of results

The questionnaire requested the respondents to rate the technical criteria listed by McCarthy (2014) from 0 to 10 according to the sensitivity of the criteria towards project failure. A ranking of 0 reflects that the criteria is not sensitive or have much impact on project failure and 10 means that the criteria are highly sensitive to project failure.

The respondents rated all criteria between 2 and 10, with most of the criteria rated at 8 (Table 6-1 and Figure 6-1). This indicates that generally, the respondents thought that the selected criteria were sensitive to project failure.

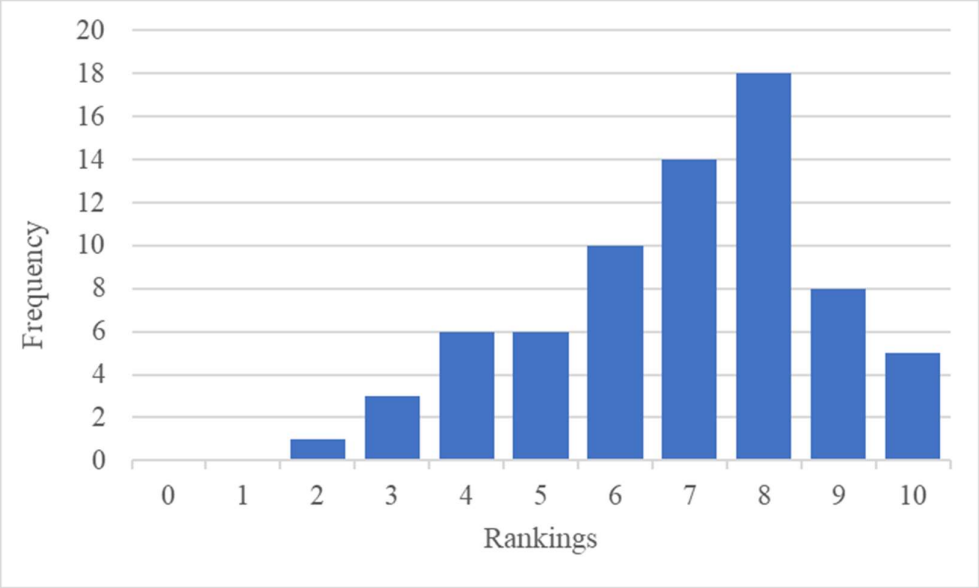

Figure 6-1 Rankings by respondents of technical criteria in project failure

The ratings were weighted on the responder's experience on feasibility studies and due diligence that they indicated in the questionnaire. The longest experience the responders have was 20 years, while the shortest was five years. Each of the responder's experience was calculated as a proportion of 20 years, as it was the longest experience. Each of these proportions was used to weight the respondents' rankings (Table 6-2).

The weight ratings of the criteria assessed were similar, with some slight difference. The criterion that had the highest weight ratings was capital cost overruns with a sum rating of 41. The highest weight rated criterion was perceived to have the highest sensitivity towards project failure. The criterion that was perceived to have the least impact on project failure was schedule overrun, with a sum weight rating of 33 (Table 6-3 and Figure 6-2).

Table 6-1 Ratings per criterion

Rated criteria	Response1 Ratings	Response2 Ratings	Response3 Ratings	Response4 Ratings	Response5 Ratings	Response6 Ratings	Response7 Ratings	Response8 Ratings	Response9 Ratings	Response10 Ratings	Response11 Ratings	Response12 Ratings	Sum of ratings
Capital cost overruns	9	8	6	10	3	10	6	8	4	8	10	8	90
Lower head grade	7	9	8	7	4	5	8	9	7	8	8	8	88
Lower recovered grade	6	8	8	9	6	5	10	5	8	7	8	6	86
High operating costs	8	10	6	5	7	4	4	7	7	7	9	8	82
Unsustainable initial performance	7	6	5	6	7	3	9	8		6	7	9	73
Schedule overruns	3	6	4	8	2	7	7	7	4	5	9	8	70
Sum of ratings per response	40	47	37	45	29	34	44	44	30	41	51	47	

Table 6-2 Ratings per criterion weighted by the **respondent's experience**

Rated criteria	Weighted Ratings 1	Weighted Ratings 2	Weighted Ratings 3	Weighted Ratings 4	Weighted Ratings 5	Weighted Ratings 6	Weighted Ratings 7	Weighted Ratings 8	Weighted Ratings 9	Weighted Ratings 10	Weighted Ratings 11	Weighted Ratings 12	Sum of weighted ratings
Years of experience	**6.5**	**10**	**12**	**6**	**10**	**10**	**6**	**10**	**5**	**10**	**5**	**20**	
Weighting based on experience	**0.325**	**0.5**	**0.6**	**0.3**	**0.5**	**0.5**	**0.3**	**0.5**	**0.25**	**0.5**	**0.25**	**1**	
Capital cost overruns	3	4	4	3	2	5	2	4	1	4	3	8	41
Lower head grade	2	5	5	2	2	3	2	5	2	4	2	8	41
Lower recovered grade	2	4	5	3	3	3	3	3	2	4	2	6	38
High operating costs	3	5	4	2	4	2	1	4	2	4	2	8	38
Unsustainable initial performance	2	3	3	2	4	2	3	4	0	3	2	9	36
Schedule overruns	1	3	2	2	1	4	2	4	1	3	2	8	33
Sum of weighted ratings per respondent	13	24	22	14	15	17	13	22	8	21	13	47	

Table 6-3 Total ratings and the total number of responses per criterion

Failure criteria	Sum of weight ratings	Total responses	Average score
Capital cost overruns	41	12	3.44
Lower head grade	41	12	3.40
Lower recovered grade	38	12	3.16
High operating costs	38	12	3.20
*Unsustainable initial performance	36	11	2.96
Schedule overruns	33	12	2.72

*One of the respondents did not rank this criterion due to not understanding the criterion

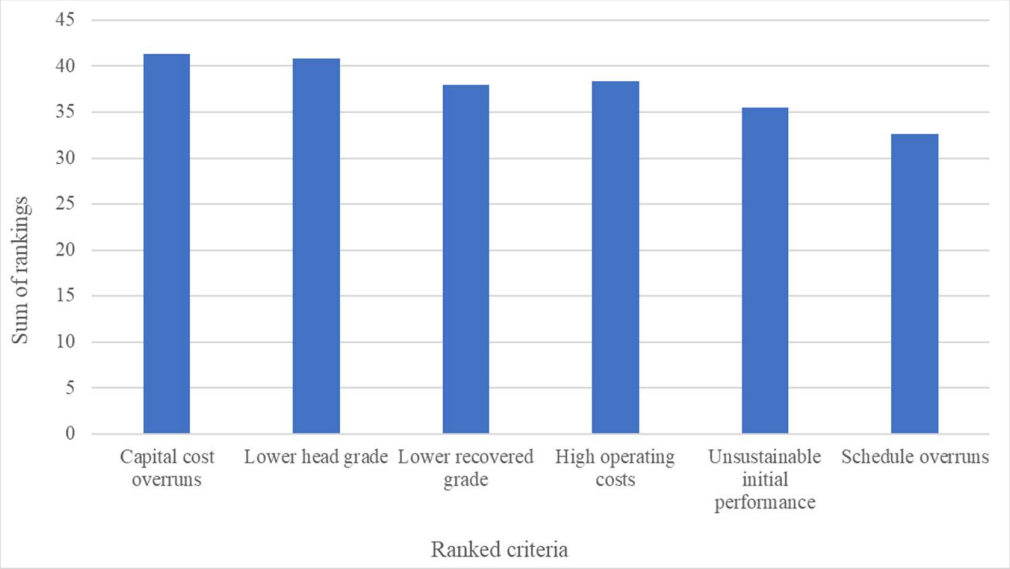

Figure 6-2 Sum of rankings from respondents per criterion

The weighted ratings were ranked in ascending order and the average of the ranks within each criterion was calculated to obtain a mean rank for that criterion (Table 6-5). The higher the mean ranking the more significant that criterion was deemed to be towards the failure of mining projects. The mean ranking values were in alignment with the average scores, which were calculated from dividing the total ratings of each criterion by the number of responses for that criterion. Therefore, the criterion with the highest average score also had the highest mean ranking (Table 6-4). The corresponding weights were calculated as discussed in Section 4.3 using Equation 3. Thus, the criterion with the highest mean rank also had the

highest weight in the equation. The calculated weights were assigned to Equation 4 to determine a project success index for mining projects. Head grade and recovery were subtracted from the equation because these criteria have an indirect relationship with project failure. This means the lower these values are the higher the chances of failure and vice versa.

Table 6-4 Weight factors for mining project success/failure criteria

Technical criteria	Average score	Mean rank	Weights
Capital cost overruns (CCO)	3.44	40.08	0.19
Lower head grade (LHG)	3.40	37.75	0.18
Lower recovery (LR)	3.16	37.67	0.18
High operating costs (HOP)	2.96	35.08	0.17
Unsustainable initial performance (UIP)	2.72	31.83	0.15
Schedule overruns (SO)	3.44	27.92	0.13
Sum		210.33	1

Equation 4: PSI = 0.19CCO + 0.13SO - 0.18LHG - 0.18LR + 0.17HOP - 0.15UIP

Where CCO: Capital cost overruns = (actual capex- planned capex)/ planned capex

SO: Schedule overruns = (actual – planned period to reach steady state)/planned period to reach steady state

LHG: Lower head grade = (actual – planned head grade)/planned head grade

LR: Lower recovery = (actual – planned recovery)/planned recovery

HOC: High operating costs = (actual – planned operating costs)/ planned operating costs

UIP: Unsustainable initial performance. = (actual – planned tonnes output)/planned tonnes output over the period analysed or to the year the mine

ceased operating

The following criteria are pre-production based:

- Capital cost overruns;
- Schedule overruns; and
- Unsustainable initial performance.

The following criteria are production or operation based:

- Lower head grade;
- Lower recovery; and
- High operating costs.

A number of studies (de Wit, 1988; Lim & Zain Mohamed, 1999; Mackenzie and Cusworth; 2007) stated that construction or implementation of a project has a lesser impact on the value of a project than the operation of a project. The ratings do not seem to agree with this view, as the weightings for the pre-production criteria and the post-production calculated from the ratings are almost the same, with a slight leaning to the pre-production criteria being more sensitive to failure. The weightings for the pre-production criteria add up to 0.503 a and 0.497 for the production criteria.

The purpose of this project success equation is to provide an index for comparing mining projects against each other and to establish a benchmark of a successful project in the mining industry. The lower the index value for a project, the more successful that project is perceived to be relative to another.

The respondents were further asked to list other criteria not listed in the survey that could lead to project failure. Below are the most common additional criteria that were listed:

- Commodity price;
- Unreliable Resource estimate;
- Aggressive development and ramp up rates;
- Poor metallurgical design;
- Incorrect financial modelling;

- Incompetent owners team;
- Change in country regulations;
- Country infrastructure; and
- Poor community relations.

Table 6-5 Ranked ratings and mean rankings per criterion

Rated criteria	Response 1 Ranks	Response 2 Ranks	Response 3 Ranks	Response 4 Ranks	Response 5 Ranks	Response 6 Ranks	Response 7 Ranks	Response 8 Ranks	Response 9 Ranks	Response10 Ranks	Response11 Ranks	Response12 Ranks	Mean rakings
Capital cost overruns	38	55	53	39	7	65	13	55	3	55	30	68	40.08
Lower head grade	25	61	63	21	16	30	27	61	10	55	16	68	37.75
Lower recovered grade	15	55	63	36	39	30	39	30	16	46	16	67	37.67
High operating costs	35	65	53	7	46	16	6	46	10	46	23	68	35.08
Unsustainable initial performance	25	39	39	13	46	7	36	55	1	39	10	72	31.83
Schedule overruns	2	39	27	27	3	46	21	46	3	30	23	68	27.92

6.4 Applying the equation to South African examples

The project success equation was used to assess the relative success of Burnstone, Kusasalethu, Bokoni, Modikwa and Crocodile River Platinum Mine, (Table 6-6 to Table 6-10). These projects were chosen because they have more information than the rest of the projects reviewed in Section 5. This application was done on data and information discussed in Section 5. The other projects have missing information for more than three criteria.

6.4.1 Burnstone Gold Mine

The data used in the PSI calculation and the resulting PSI for Burnstone is in Table 6-6. The data used in the application of the equation was derived from the Great Basin Gold Limited MD&A reports between 2007 and 2012, as well as the 2007 feasibility update report (Great Basin Gold Limited, 2007). The development of Burnstone is discussed in detail in Section 5.2.1.

Burnstone planned to spend US$238 million in CAPEX for developing the mine but ended up spending US$325 at the end of 2011, in 2007 money terms. It was planned that the mine would take six years to reach steady state. Unfortunately, the mine development and minor operation took eight years. Over the eight years, Burnstone was planned to produce a total of 5 Mt at an average recovery grade of 4.48g/, but instead, Burnstone only produced 1 Mt at an average recovery grade of 1.09g/t. The actual unit cost did not exceed the planned unit costs significantly over the two years it operated. Burnstone planned to operate at a recovery of 90% but ended up operating at a recovery of 88% (Great Basin Gold, 2007 – 2012).

Upon applying this data to the mining project success equation, Burnstone resulted in a project success index (PSI) of 0.412. The PSI for Burnstone was mostly impacted by the lower head grade, followed by the CAPEX overrun at -76% and 54%, respectively compared to planned parameters. The head grade values used were recovered grade instead since actual head grade was not reported. The planned values indicated in the table are for the first eight years of the Burnstone plan because the mine only operated for eight years before its activities were suspended on the 11th September 2012 (Great Basin Gold, 2012) (Table 6-6).

Table 6-6 Burnstone performance measurement

	Sum of actuals	**Sum of planned**	**Percentage difference**	**Weights**	**Weighted % difference**
CCO	US$ 325 M	US$ 214 M	54%	0.191	0.103
SO	8 years	6 years	33%	0.179	0.059
LHG	1.09 g/t	4.48 g/t	-76%	-0.179	0.136
LR	88%	95%	-7%	-0.167	0.012
HOC	US$ 48/t	US$ 46/t	4%	0.151	0.007
UIP	1 Mt	5 Mt	-72%	-0.133	0.096
SUM					**0.412**

Note: Calculated percentage differences and PSI may differ from the reported values above due to rounding off

6.4.2 Kusasalethu Gold Mine

Kusasalethu was also assessed through the mining success equation. The data used in the equation and the results of the equation are in Table 6-7. The data was sourced from Harmony annual reports from 2002 to 2016. A more detailed discussion of the Kusasalethu deepening project is in Section 5.2.2.

Harmony purchased Kusasalethu in 2001 from AngloGold Ashanti when it was called the Elandsrand Gold Mine. It was purchased with Deelkraal Gold Mine, an adjacent mine to it. Harmony planned to deepen Kusasalethu to 3,600 m below surface, to mine high-grade ore below the infrastructure (Mining Weekly, 2005). In 2001, the project was planned to require CAPEX of ZAR 550 million to bring it to steady state production. Instead, the total CAPEX spent at Kusasalethu between 2001 and 2016 was about ZAR 4.5 billion. The project was expected to produce 450,000 ounces per year, which equates to 7.2 Moz over 15 years. The actual total gold produced between 2001 and 2016 was 3.04 Moz. Kusasalethu has not achieved the peak production that was initially announced in 2001. From 2001 to 2016, over 15 years, Kusasalethu has produced 3.05 Moz. The actual recovery grade has also decreased from the planned recovery grade of 7.03 g/t to an average grade of 5.33 g/t between 2001 and 2016 (Harmony Gold Mining Company Limited annual reports, 2002-2016).

Kusasalethu was analysed with only three criteria. Exclusion of criteria in the equation negatively biases the PSI, which means the PSI is underestimated. The criteria used in the Kusasalethu PSI calculation include CAPEX, head grade and unsustainable initial performance. Kusasalethu had a PSI of 0.839. The highest contributor to this value was the capital cost overrun. Kusasalethu in 2001 was planned at a total CAPEX of ZAR 550 million but had an accumulated capital cost of ZAR 2,651 million, in 2001 money terms, at the end of 2016. The unsustainable production was the next highest contributor to PSI at 0.077. This research used gold production to calculate unsustainable production since planned tonnes were not reported. The actual gold production, 3.04 Moz, was less than half of the planned gold production, 7.2 Moz. The head grade percentage difference was based on actual recovery grade and planned reserve grade (Table 6-7).

Table 6-7 Kusasalethu performance measurement

	Sum of actuals	**Sum of planned**	**Percentage difference**	**Weights**	**Weighted % difference**
CCO	ZAR 2,651 million	ZAR 550 million	382%	0.191	0.728
SO				0.179	
LHG	5.66	7.03	-20%	-0.179	0.035
LR				-0.167	
HOC				0.151	
UIP	3.04 Moz	7.2 Moz	-58%	-0.133	0.077
SUM					**0.839**

Note: Calculated percentage differences and PSI may differ from the reported values above due to rounding off

6.4.3 Bokoni Platinum Mine

Data used in the application of the mining success equation and the results thereof are in Table 6-8. Bokoni was planned to increase production from 2009, through a two-phase expansion project, which entailed production of 160,000 tpm between 2011 and 2015; then another ramp up to 245,000 tpm from 2020 to 2043. The application of the success equation only considered data between 2009 and 2015. Bokoni was planned to produce a total of 12 Mt between 2009 and 2015, but only produced 8 Mt. Bokoni expansion was planned at a recovery grade of 4.42g/t 4E between 2009 and 2015, but only achieved 3.80g/t 4E over the same period. The project was expected to take four years, from 2009 to 2011, to achieve steady state. Over the period analysed, Bokoni did not achieve steady state. Operating costs were planned at ZAR829/t, but was exceeded during the operation of the mine to ZAR1,033/t. The CAPEX at Bokoni was planned at ZAR 2,187 million between 2009 and 2015, and only spent ZAR 1,876 million in the same period (Anooraq Resources Corporation, 2009-2011; Atlatsa Resources Corporation, 2012-2015).

The PSI for Bokoni mine was 0.291. The highest contributor to the Bokoni PSI was the schedule overrun. Bokoni was planned to reach steady state in three years, instead, it never reached the initial steady state production planned in the seven years it was analysed in. By 2016 the Bokoni ramping up phase had already been in progress for seven years and counting. In 2017, the mine was put on care and maintenance. Because the mine had not reached a steady state, it also had not reached the total CAPEX it indicated in the 2009 technical report. The head grade calculation used recovery grade. Recovery was not taken into consideration because it was not reported (Table 6-8).

Table 6-8 Bokoni performance measurement

	Sum of actuals	**Sum of planned**	**Percentage difference**	**Weights**	**Weighted % difference**
CCO	ZAR 1,556 M	ZAR 2,187 M	-29%	0.191	-0.055
SO	7 years	3 years	133%	0.179	0.239
LHG	3.80 g/t	4.42 g/t	-14%	-0.179	0.025
LR	-	-		-0.167	-
HOC	ZAR 1,033/t	ZAR 836/t	25%	0.151	0.037
UIP	8 Mt	12 Mt	-33%	-0.133	0.044
SUM					**0.291**

Note: Calculated percentage differences and PSI may differ from the reported values above due to rounding off

6.4.4 Modikwa Platinum Mine

The input and results of the success equation for Modikwa are in Table 6-9. The planned values for Modikwa were reported in the African Rainbow Minerals annual report of 2004, and the actual performance values were retrieved from the African Rainbow Minerals annual reports from 2004 to 2016. Modikwa was planned to spend ZAR 1.6 billion CAPEX for construction and development of the mine but only spent ZAR 1.0 billion CAPEX, in 2003 money terms. Modikwa planned to produce 2.9 Mt of ore each year during steady state, which equates to 34.56 Mt over 12 years from 2004 to 2016. Instead, Modikwa produced a total of 27.75 Mt over the same period. Modikwa was planned to mine at a 4E head grade of 4.50g/t, but the actual head grade was at 4.2g/t. Operations at Modikwa were planned to take place at a cost of ZAR300/t, the actual production cost at Modikwa from 2004 to 2016 averaged ZAR683/t, which is 128% higher than the planned cost (African Rainbow Minerals Limited, 2004-2015). The planned recovery percentage was not reported, therefore could not be included in the mining success equation. It is not clear when Modikwa started construction, and how long the ramp up was supposed to be, thus the schedule overrun in the mining equation success was not included in the Modikwa assessment.

Due to the lack of comprehensive information, Modikwa was analysed with four criteria. The criteria that were excluded from the Modikwa PSI calculation include recovery and schedule overrun. The PSI for Modikwa was 0.054. The criteria that contributed the most to this value was operating cost, which was 56% higher than planned. On its own, operating costs had a contributing value of 0.084, while head grade and unsustainable production together had a contributing value of 0.036. Due to actual cost expenditure at Modikwa being lower than plan, the CAPEX reduced PSI by 0.066 (Table 6-9). CAPEX for Modikwa reported from 2012 was not regarded as part of the original mine development but as CAPEX for a subsequent expansion project.

Table 6-9 Modikwa performance measurement

	Sum of actuals	**Sum of planned**	**Percentage difference**	**Weights**	**Weighted % difference**
CCO	ZAR 1.0 billion	ZAR 1.6 billion	-35%	0.191	-0.066
SO				0.179	
LHG	4.2 g/t	4.5 g/t	-6%	-0.179	0.010
LR				-0.167	
HOC	ZAR 467/t	ZAR 300/t	56%	0.151	0.084
UIP	27.75 Mt	34.56 Mt	-20%	-0.133	0.026
SUM					**0.054**

Note: Calculated percentage differences and PSI may differ from the reported values above due to rounding off

6.4.5 Crocodile River Platinum Mine

The data used and results of the mining success equation for the Crocodile River Platinum Mine, under the operation of Eastern Platinum Limited, is in Table 6-10. Eastern Platinum Limited purchased a majority holding into Crocodile River Platinum Mine from Impala Platinum in 2006. Eastern Platinum Limited, subsequently, planned to expand operations at the Crocodile River Platinum Mine. Crocodile River Mine closed early in 2013. The planning and actual data used in the mining success equation is from 2007 to 2013.

The expansion development was planned to take four years to reach steady state, but the mine never reached a steady state when it went on care and maintenance in 2013, which meant the schedule overrun for the mine was at 75%. The Crocodile River Platinum Mine was planned to produce 2.5 Mt per annum at steady state starting from 2010. The mine was planned to mine a total of 14 Mt from 2007 to 2013. The actual production between 2007 and 2013 was approximately 7 Mt, which was materially lower than the planned production by 51%. The production was planned at a 4E head grade of 3.47g/t, and the actual mining head grade was 3.39g/t 4E, which is 2% lower than the planned head grade. The planned operating cash cost had an average of ZAR283/t, but the actual operating cost was ZAR486/tonne, which is 70% above the planned costs. The expansion project was planned at a total CAPEX of 896 million, but the project ended up spending CAPEX of ZAR 2,139 million.

The PSI for Crocodile River Platinum Mine was 0.577. CRM was worst impacted by the CAPEX, which was higher by 139% and by schedule overrun that was at 75% over the original plan at the time the mine closed (Table 6-10).

Table 6-10 Crocodile River Platinum Mine performance measurement

	Sum of actuals	**Sum of planned**	**Percentage difference**	**Weights**	**Weighted % difference**
CCO	ZAR 2,139 M	ZAR 896 M	139%	0.191	0.265
SO	7 years	4 years	75%	0.179	0.135
LHG	3.39 g/t	3.47 g/t	-2%	-0.179	0.004
LR			0%	-0.167	
HOC	ZAR 486/t	ZAR 286/t	70%	0.151	0.105
UIP	7 Mt	14 Mt	-51%	-0.133	0.068
SUM					**0.577**

Note: Calculated percentage differences and PSI may differ from the reported values above due to rounding off

The PSI results of the mine success equation for Burnstone Gold Mine, Kusasalethu Gold Mine, Modikwa Platinum Mine, Bokoni Platinum Mine and Crocodile River Platinum Mine are summarised in Table 6-11. From the analysed projects, the projects ranking from the most successful, relatively speaking, are Modikwa Platinum Mine, Bokoni Platinum Mine, Burnstone Gold Mine, Crocodile River Platinum Mine then Kusasalethu Gold Mine. The criteria contributing the least towards PSI was head grade and capital expenditure. Three out of the five analysed projects; these projects had head grade relative difference ranging from -2% to -20%. Modikwa's, the most successful of the projects, lowest contributing criterion was the capital cost, where the actual CAPEX was lower than the planned CAPEX by 35%, in the same money terms (Table 6-11).

The performance of the two least successful projects according to the equation was impacted the most by the capital cost overrun. The impact of this criterion was further compounded by the fact that the capital cost overrun carries the highest weight in the project success index. Capital expenditure is the least contributing criterion to PSI for some projects, and the worst contributing criterion for other projects indicates the sensitivity of capital expenditure on the perception of project success.

Modikwa scored the lowest PSI and therefore can be deduced that Modikwa was more successful than all the projects analysed using the mine project success equation. From all these projects, Modikwa is the only one that has not been put on care and maintenance or had a drastic shortening of the life of mine, and thus validates this equation. Kusasalethu had the highest PSI value. This is due to the extensive capital overrun that Kusasalethu incurred over time. Projects like Burnstone, Bokoni and Crocodile River were mostly dependent on lenders to fund the development and were the only or main producers for their respective holding companies. They were, therefore, depended on the lenders' ability to keep on extending loans to keep them alive. Meanwhile, Harmony has a lot more options on funding, including other producing mines, to keep projects going.

Table 6-11 Summarised PSI for assessed mines

Mines	PSI	Lowest Contributing factor to PSI	Relative difference of lowest contributing factor	Relative Success
Modikwa Platinum Mine	0.05	CCO	-35%	1
Bokoni Platinum Mine	0.29	CCO	-14%	2
Burnstone Gold Mine	0.41	HOC	-2%	3
Crocodile River Platinum Mine	0.58	LHG	-2%	4
Kusasalethu Gold Mine	0.84	LHG	-20%	5

6.5 Chapter summary

The formulated equation for defining success was based on ratings of technical performance criteria from a survey undertaken. The survey was sent out to 17 mining professionals, including six mining engineers, five geologists, one metallurgist and three professionals from techno-financial/financial analyst/corporate advisory background. The response rate for this survey was 71%.

The criterion that was deemed to be most sensitive to project failure was capital cost overruns. The criterion that was perceived to have the least impact on project failure was schedule overrun. The survey ratings were ranked before mean rankings were calculated per criterion and these mean rankings were used to determine weights for the criterion in the success equation. The output value of the equation referred to as the project success index, is used to compare projects to determine relative success. The lower the PSI the more successful a project is deemed to be compared to others.

The following projects, Burnstone, Kusasalethu, Bokoni, Modikwa and Crocodile River Platinum Mine, were analysed using the equation. Other projects were not analysed using the success equation due to missing information for more than three criteria, because this will significantly bias the PSI. Bokoni and Crocodile River Platinum Mine were analysed with one less criterion, while Kusasalethu and Modikwa had missing information for three and two criteria, respectively. This is an indication of how sensitive capital expenditure is on the perception of project success.

From the analysed projects, the projects ranking from the relatively successful, based on the success equation, were Modikwa, Bokoni, Burnstone, Crocodile River Platinum Mine and Kusasalethu. Interestingly, the most successful projects had lower capital expenditure than planned, and the least successful projects, according to the equation, had a high capital cost overrun.

Modikwa being the most successful of the five projects is still operational with an expansion project on the go. Bokoni, Burnstone and Crocodile River Platinum Mine have been put on care and maintenance. Although Kusasalethu is still operating, it has a much shorter LOM than what was initially planned with a strategy to mine high-grade areas only.

7 CONCLUSION

Mining projects are known for poor success rate. This study reviewed South African mining projects to assess their technical performance against feasibility studies, which are supposed to have an accuracy of 10 to 15% on costs (Samcodes Standards Committee, 2016). Technical performance was reviewed because the owners of the project have control over these parameters and they play a significant role in the value of the project (Baurens, 2010).

The study reviewed the following 11 projects comprising of six from platinum, three from gold and two from the coal industries.

- Burnstone Gold Mine;
- Kusasalethu Gold Mine;
- Phakisa Gold Mine;
- Bokoni Platinum Mine;
- Modikwa Platinum Mine;
- Crocodile River Platinum Mine;
- Marula Platinum Mine;
- Two Rivers Platinum Mine;
- Leeuwkop Platinum Mine;
- Mooiplats Colliery; and
- Isibonelo Colliery.

Projects from these industries were selected because of the importance of these commodities on the economy of South Africa. The choice of projects to analyse were limited by the availability of comprehensive information in the public domain.

Out of the projects reviewed, only Isibonelo Colliery produced tonnes at the planned level of production, and Two Rivers Platinum Mine's actual production tonnes and metal produced exceeded the planned tonnes and planned produced metal. The rest fell short of the steady state production level that was initially announced for the projects. From the nine mines that did not meet steady state, five, including Burnstone, Bokoni, Crocodile River, Leeuwkop and Mooiplaats, ended up on care and maintenance before the intended time.

Further, one out of the three that are currently operational, namely Kusasalethu Gold Mine announced a high grading strategy and a shortened life of mine compared to what was initially announced.

Change in mine design is also a prevailing characteristic in the assessed projects. The following projects Burnstone, Kusasalethu, Phakisa and Marula stated a change in mine design and mining method. These changes were as a result of uncertainty in geological information, including reef orientation, in-situ grade and geological structure. Uncertainty in the abovementioned variables could be due to poor information collected, poor judgement of information and/or related to emotions such as optimism, preconceptions and/or anchored believes about a project. Change in design is so significant to a project that it impacts other aspects of the project plan and execution, namely CAPEX, schedule overrun, head grade, recovery, revenue and ultimately value.

In terms of grade, the research found that all projects with reported grade did not achieve their planned head or recovery grade, except for Crocodile River Platinum Mine. This could either be due to the inaccuracy of the Mineral Resource estimate, poor dilution control or poor recovery at the plant.

CAPEX was another aspect that was reviewed for projects. Projects that had CAPEX information disclosed in the public domain showed two projects that did not exceed the CAPEX, namely Modikwa and Bokoni Platinum Mines. Meanwhile, the rest of the projects reported overrun of capital up to 382%, as in the case of Phakisa. Operating costs were reported, were consistently higher against plan costs.

The study was able to compare the planned NPV to the NPV calculated with actual performances for three projects only, namely Burnstone, Bokoni and Crocodile River, while others had a qualitative assessment of the actual performance against the planned NPV. The author acknowledges that the recalculated DCF although resulted in similar NPVs to what was reported they may have errors but were used in the absence of the original DCFs.

Nine out of the 11 projects reviewed did not reach the intended values, while it was not clear if the other two, namely Two Rivers and Isibonelo, reached the initial value. This was because these two had recorded profits or achieved production tonnes target over the period analysed but did not disclose other information needed to calculate the planned NPV and achieved NPV.

The most common cause for the poor performance of the reviewed projects was poor

ground conditions and geological structures that were not anticipated. Other technical reasons included a change in design during development, which was the next most common reason, excessive water handling, ageing infrastructure and lack of mining flexibility. Other causes for poor performance that was non-technical included labour and community unrest.

McCarthy (2014) identified a list of technical criteria, including an enviro-socio criterion, that was deemed to lead to project failure. This study selected these criteria, excluding the enviro-socio criterion, due to the comprehensiveness of these criteria on technical performances for determining a project success index equation for the mining industry. These criteria were rated in a survey by mining professionals, in terms of the sensitivity of these criteria to the failure of mining projects. Capital cost overrun was rated the most sensitive criteria to project failure, while schedule overrun was rated the least sensitive criteria to project failure. The output value of the equation referred to as the project success index, is used to compare projects to determine relative success.

Out of the 11 projects selected for analyses, five projects, namely Burnstone, Kusasalethu, Bokoni, Modikwa and Crocodile River, were assessed using the equation, due to lack of detailed information for other projects. Data availability was a major limitation in this study, which resulted in restricted projects being chosen, and further incomplete conclusions drawn mainly due to the limitation in the number of projects reviewed. The varying availability of project information in the public domain for the selected projects also added a further limitation in the research, which led to assumptions made to enable some assessments, especially on qualitative impact of projects' performance on value and establishing a project success index.

Project success index or PSI determines an index value for a project based on the project's performance against its plan. Each of the chosen performance criteria was weighted on the perceived impact these criteria have on the success of a project, by mining professionals. Since commodity prices are not within the control of the project team, commodity price was not included in the calculation of the PSI.

From the analysed projects, the projects ranking from the most successful, relatively speaking to the least, are Modikwa, Bokoni, Burnstone, Crocodile River and then Kusasalethu. It was observed that the most successful and the least successful projects were due to capital expenditure. Where capital expenditure was lower than planned the projects had the lowest PSI score, meaning they were successful as seen for Modikwa and Bokoni. Where the capital expenditure was higher than planned the projects had the highest score, as

was the case with Kusasalethu and Crocodile River Mine. It can be agreed that Modikwa is the more successful project of the five because it is still operational and planning an extension project. Bokoni, Burnstone and Crocodile River Platinum Mine are on care and maintenance. Kusasalethu although still operational, ended up with a much shorter LOM than initially planned with a strategy to focus mining on high-grade areas. Further, projects that have limited sources of capital will generally cease operations shortly after the funds made available runout.

The study recognises that the number of projects used to determine a benchmark for success using the PSI equation was limited, due to limited data or information on projects available in the public domain. This study thus recommends that more projects are assessed with this equation to determine a robust benchmark of success in the mining industry. This would enable the industry clear and consistent examples it can learn from and benchmark itself against. More application of this equation would also further test the validity and applicability thereof.

8 RECOMMENDATIONS

This study showed geology as a common risk factor in South African mining projects. It is therefore recommended that geology aspects of every project be thoroughly investigated. It is the author's opinion that geology needs to be the foundation of every mining project, and for project owners to put more time and effort in understanding geological controls of their projects' mineralisation and geological structures.

Another project shortfall observed in some of the projects analysed in this study is change in mine design during construction or ramp up. It is recommended that project development carry out scoping and pre-feasibility studies before embarking on a feasibility study. Scoping studies should be carried out as an early stage assessment of the project to determine viability as well, and pre-feasibility undertaken to evaluate different modifying factors options. This can help reduce the chances of changing the mine design during construction or operation, which is normally accompanied by hefty costs that were not anticipated – thus leading to lower achieved value compared to plan. Change in mine design should be an exception, if at all occur.

Since it is not possible for all the project's Modifying Factors to receive the same level of attention during feasibility or prior study investigations, the study agrees with the recommendation made by Kühn & Visser (2014) that an impact assessment of the Modifying Factors on the net present value needs to be undertaken, and then focus investigations or studies on those Modifying Factors that are more sensitive to the project's NPV.

It is also recommended that project planning use Monte Carlo simulation, which estimates a distribution of values (instead of a single value) that reflect the uncertainty in each of the estimated planning parameters. Further, a range of outputs will help the investor get an indication of the financial risk associated due to the cumulative uncertainty.

This study believes that as more and more projects are assessed using the success equation, the industry will start to be more conscious about what a successful project looks like and have a more focused view of achieving this success. It is clear that an operating mine does not necessarily mean it is successful.

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10 APPENDIX

10.1 Response1

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (i.e. Geology, Metallurgy, Mining, etc)

Mining

2. Number of years involved in due diligence/feasibility studies

6.5 Years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	9
Schedule overruns	3
Lower head grade	7
Lower recovered grade	6
High operating costs	8
Unsustainable initial performance	7

4. Please any additional significant criteria that can result in project failure. List five at most

Capital constraints with regards to the project.

The unrealistic timeline given in terms of the project study phase, resulting in suboptimum study work or option analysis.

10.2 Response2

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Degree in Civil Engineering / Finance

PhD in Mine optimisation

Ten years of experience in mine planning

2. Number of years involved in due diligence/feasibility studies

10

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	8
Schedule overruns	6
Lower head grade	9
Lower recovered grade	8
High operating costs	10
Unsustainable initial performance	6

4. Please any additional significant criteria that can result in project failure. List five at most

Commodity price

Less tonnes

10.3 Response3

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Mining Engineer

2. Number of years involved in due diligence/feasibility studies

12 Years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	6
Schedule overruns	4
Lower head grade	8
Lower recovered grade	8
High operating costs	6
Unsustainable initial performance	5

4. Please any additional significant criteria that can result in project failure. List five at most

Permits and Licensing

Country Infrastructure (roads, power, rail, port, water etc)

Environmental / Rehabilitation requirements not suitable

Militant / unproductive human resources

Employee and local community development expectations (housing, SSD programmes etc)

10.4 Response4

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Geology

2. Number of years involved in due diligence/feasibility studies

6

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	10
Schedule overruns	8
Lower head grade	7
Lower recovered grade	9
High operating costs	5
Unsustainable initial performance	6

4. Please any additional significant criteria that can result in project failure. List five at most

10.5 Response5

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Geology and corporate advisory

2. Number of years involved in due diligence/feasibility studies

10 years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	3
Schedule overruns	2
Lower head grade	4
Lower recovered grade	6
High operating costs	7
Unsustainable initial performance	7

4. Please any additional significant criteria that can result in project failure. List five at most

- Incompetent owners team
- Weak commodity prices once project executed – affects reserving, ore depletion strategy, high margin areas.
- Government or union interference and community issues

10.6 Response6

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Mechanical Engineer (M.Sc. (Eng.), Pr.Eng., C.Eng.)

Techno-Financial Analyst (M.Eng. (MRM))

2. Number of years involved in due diligence/feasibility studies
16 years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	10
Schedule overruns	7
Lower head grade	5
Lower recovered grade	5
High operating costs	4
Unsustainable initial performance	3

3. Please any additional significant criteria that can result in project failure. List five at most

a. Discount rate
b. Incorrect financial modelling resulting in incorrect financial parameters
c. Insufficient attention to infrastructural requirements

10.7 Response7

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Dual qualified geologist and mining engineer

2. Number of years involved in due diligence/feasibility studies

20

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	6
Schedule overruns	7
Lower head grade	8
Lower recovered grade	10
High operating costs	4
Unsustainable initial performance	9

4. Please any additional significant criteria that can result in project failure. List five at most

Unreliable Resource estimate

Unreliable geotechnical engineering

Unreliable processing equipment

10.8 Response8

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Mining

2. Number of years involved in due diligence/feasibility studies

More than 10 years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	8
Schedule overruns	7
Lower head grade	9
Lower recovered grade	5
High operating costs	7
Unsustainable initial performance	8

4. Please any additional significant criteria that can result in project failure. List five at most

- Lower project budget
- Not fully understanding the mining assets i.e. the orebody
- Cutting corners to meet the un-tested milestone dates
- The mine value chain not integrated e.g. the plant design leading the orebody instead of the plant being design to meet the orebody
- Starting a mining project without a proper Mineral Resource Management department

10.9 Response9

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc

Metallurgy

2. Number of years involved in due diligence/feasibility studies

5 years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	4
Schedule overruns	4
Lower head grade	7
Lower recovered grade	8
High operating costs	7
Unsustainable initial performance	Not sure what his means

4. Please any additional significant criteria that can result in project failure. List five at most

One of the main causes of mining project failure is inadequate/insufficient work completed at the Resource definition phase.

Inadequate/incomplete metallurgical testwork, or poor geometallurgical understanding of the orebody.

10.10 Response10

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc)

Geology

2. Number of years involved in due diligence/feasibility studies

10

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	8
Schedule overruns	5
Lower head grade	8
Lower recovered grade	7
High operating costs	7
Unsustainable initial performance	6

4. Please any additional significant criteria that can result in project failure. List five at mos

- Commodity price cycles, e.g. Uranium projects in Namibia

- Type of Financial Valuation methodology, e.g. DCF vs. no escalation

- Increase in country risk, e.g. Ebola halted MANY West African projects

- Agreement with JV partners, e.g. JV parners disagreed on Fin Val methodology and so interpreted project differently)

10.11 Response11

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (ie. Geology, Metallurgy, Mining, etc

Geology

2. Number of years involved in due diligence/feasibility studies

5

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	10
Schedule overruns	9
Lower head grade	8
Lower recovered grade	8
High operating costs	9
Unsustainable initial performance	7

4. Please any additional significant criteria that can result in project failure. List five at most

Poor Management

Commodity prices

Exchange rate

Change in regulatory requirements e.g tax regime, ownership

10.12 Response12

Masters Research Questionnaire: Analyses of South African mining projects: technical variances and impact of these on project success

Please note that you are not obliged to respond to this questionnaire. Pressing 'send' or returning the completed form is taken to mean consent.

1. Kindly state your technical background (i.e. Geology, Metallurgy, Mining, etc.)

Mining Engineering

2. Number of years involved in due diligence/feasibility studies

20 years

3. Below is a list of success criteria adopted from McCarthy (2014). Based on your perception, please assign a value ranging from 0 to 10, reflecting the sensitivity of these criteria resulting in project failure. 0 = not sensitive, 10 = highly sensitive

Failure criteria	**Weight**
Capital cost overruns	8
Schedule overruns	8
Lower head grade	8
Lower recovered grade	6
High operating costs	8
Unsustainable initial performance	9

4. Please any additional significant criteria that can result in project failure. List five at most

Not meeting the production ramp up and steady state production profile
Operating cost overruns during ramp up and steady state
Studies not passing through the required scoping, pre-feasibility and feasibility project stages
Not complying with standards and codes etc. during scoping, pre-feasibility and feasibility project stages
Poor project design, planning and scheduling, and project execution