RANKING OF BROWNFIELD MINING INVESTMENT OPPORTUNITIES USING THE ANALYTIC HIERARCHY PROCESS.

Neil Eric Hamilton

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DECLARATION

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

Neil Eric Hamilton

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Contents

ABSTRACT

As the shareholders of mining companies have become increasingly informed and active, the corporate values of companies have had to evolve to remain relevant and maintain shareholder confidence. It is no longer acceptable to deliver only good financial results, as such results must be obtained in an ethical and socially responsible manner. Traditional project valuation and ranking techniques, typically a discounted cash flow (DCF) styled approach, deliver traditional financial metrics such as net present value. A DCF approach however fails to account for changing shareholder values such as safety and social responsibility. This requires other approaches such as the Analytic Hierarchy Process (AHP) which has the potential to be a more inclusive tool in the ranking of mining projects.

The ranking of Brownfield mining projects is complex, with varied and often competing priorities in the evaluation process. AHP is one of several multiple criteria decision making approaches that can be applied to such complex problems. AHP is a relatively simple process which breaks the complex decision into a hierarchal approach, with criteria given a weighting according to their relative importance while assessing several options or solutions to the overall goal. The aim of this research is to apply AHP to the ranking of Brownfield mining projects to provide an alternative and potentially more inclusive project ranking than that provided through a DCF approach.

Three projects from a leading gold mining company were identified, analysed and ranked using the traditional metrics of NPV, IRR and Capital developed from project specific DCF models. The corporate values as presented in the vision / mission statements of the three largest gold mining companies were analysed for commonality. Common values within the mission statements were used to populate the AHP. The various criteria within the AHP were ranked against each other through the use of pairwise comparison. Data available through the DCF models as well as data available in public annual reports was used to populate the AHP.

The outcomes of the study found that traditional DCF based metrics (values) are heavily favoured over the newer corporate values. As such the rankings of the AHP mirrored the ranking based on the DCF, however, the AHP is an inclusive process. As shown through the hypothetical scenarios presented, if there is a shift in the weighting of the corporate values, the AHP ranking will differ from the DCF rankings.

With more inclusive corporate value systems as shareholder demands evolve, the traditional DCF approach to Brownfield project ranking is no longer inclusive of all corporate values. Additionally, the traditional DCF approach is unable to account for shifting priorities within established corporate values. An AHP approach not only allows the end user to include all corporate values but also allows the user to adapt to additional corporate values or a shift in the prioritisation of values. The research, through the scenarios considered, demonstrates the usefulness of using AHP under various conditions. AHP provides a viable and useful tool for the ranking of Brownfield projects.

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Finally, to Keren and Oliver, the light of my life, one day when you read this page and ask mommy or daddy what this means, know that it means that anything is possible. Stay centred, stay kind, work hard and dream big for anything is truly possible.

To all those who have impacted my career in mining, I thank you and leave you with the immortal words of Johnny Clegg:

‘The warrior's now a worker and his war is underground

With cordite in the darkness he milks the bleeding veins of gold

When the smoking rock face murmurs, he always thinks of you

African sky blue, will you see him through?’ Johnny Clegg

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

°C	Degrees Centigrade
AISC	All in Sustaining Cost
AHP	Analytic Hierarchy Process
CI	Consistency Index
CIL	Carbon in Leach
CP	Compromise Programming
CR	Consistency Ratio
DCF	Discounted Cash Flow
ELECTRE	The elimination and choice translating reality
g/t	Grams per tonne
IRR	Internal Rate of Return
JV	Joint Venture
km	Kilometers
LOM	Life Of Mine
M	Million
MCDM	Multiple Criteria Decision Making
MAUT	Multi-attribute utility theory
mm	millimetre
Moz	Million Ounces
Mt	Million tonnes
Mtpa	Million tons per annum
MW	Mega Watt
NPV	Net Present Value
PI	Profitability Index
PROMETHEE	The technique for order preference by similarity to ideal solutions
PV	Present Value
RI	Random Index

TM	Traditional Metrics
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TSF	Tailings Storage Facility
USD	United States Dollar
US$ or $	United States Dollar
WACC	Weighted Average Cost of Capital
WPM	Weighted Product Method
WSM	Weighted Sum Method

1 INTRODUCTION

1.1 Background

Mining projects can be categorised as either Greenfield or Brownfield projects. Greenfield projects are projects where no previous mining related infrastructure is present, while Brownfield projects are projects where mining related infrastructure in some form is present.

Brownfield mining projects are fundamentally different to other classes of mining projects. There is almost always a wealth of data available on the operation, data that includes safety, production, geology and taxation. Such data is only reliably gathered during the operation of an asset. For example, safety performance is greatly influenced by company culture, while productivity is largely management driven (Koch & McGrath, 1996). True understanding of the Mineral Resources and Mineral Reserves of an asset is gained only through operation of the asset. In the case of a Brownfield investment opportunity, the investor as the operator has access to a unique, accurate and varied set of data. This data is not readily available in the case of other major mining investment opportunities such as merger and acquisition activity and Greenfield investments.

Brownfield investment opportunities that include plant expansions, plant conversions, plant additions, mine pushbacks and mine deepening are typical examples of mining investment opportunities. Despite the wealth of data available from the operation, Brownfield investment opportunities much like most corporate investment decisions are usually evaluated and ranked using traditional investment criteria, most notably Net Present Value (NPV) and Internal Rate of Return (IRR) based on a discounted cash flow (DCF) model (Moyen *et al.*, 1996).

In major mining companies with multiple operations in a variety of jurisdictions, it is commonplace for Brownfield investment opportunities to compete against one another for the available investment capital as noted in the platinum industry by Smith *et al.* (2007). In such cases, project ranking utilising only traditional investment criteria such as DCF with NPV and IRR miss the opportunity to utilise all of the available information.

With the changing face of corporate responsibilities spearheaded in South Africa by the updated versions of the King Report on Corporate Governance commencing in 1994, the value system of mining companies has been forced to evolve (Humphreys, 2000). Esteves (2008) argued that the long term success of mining companies is *"their ability to align their interests with the values of society".* Companies now incorporate issues such as corporate social responsibility, safety and the environment into their value systems (Jenkins & Yakovleva, 2006). Mining companies worldwide routinely publish their corporate strategies which are now based on a value system inclusive of the evolved corporate social responsibilities.

The application of traditional DCF based evaluation and ranking of projects satisfies risk and financial considerations found in almost all mining company strategies. However, this does little to address other elements of mining corporate strategy, safety, social responsibility, operating performance and geology. These additional elements are non-traditional investment criteria.

The ranking of Brownfield projects when considering all company values is therefore a multiple criteria decision. Within the suite of multiple criteria decision making (MCDM) approaches the Analytic Hierarchy Process (AHP) provides a potential solution. Utilising AHP in the ranking of Brownfield investment opportunities potentially provides a mechanism for the ranking of projects utilising traditional and non-traditional investment criteria. Such an approach would utilise the available operational information to augment traditional investment criteria in line with stated corporate strategy. The research question to be addressed in this research report is therefore *"Can the AHP be used for ranking of Brownfield mining investments in order to account for non-traditional investment criteria?"*

1.2 Aim of research

Large mining companies are routinely faced with multiple Brownfield investment opportunities and are required to rank these opportunities for selective investment. Traditional rankings based on a DCF (and associated decision making parameters such as IRR and NPV) generally address risk and financial considerations but do not address changing corporate values, strategies or objectives. Other tools are required to address this shortcoming through the incorporation of these non-traditional investment criteria. The AHP can potentially be used for such a purpose.

The application of AHP to Brownfield mining project investment ranking has not been noted in the reviewed literature. AHP has however been widely applied to understand and add value to an array of decisions since it was first published by Saaty (1980). Such applications include:

- Decision making in engineering applications (Triantaphyllou & Mann, 1995);
- Evaluating fisheries management options (Leung *et al.,* 1998);
- Safety risk assessment during planning and budgeting of construction projects (Aminbakhsh *et al.*, 2013);
- Evaluation of domestic solar water heating system in Jordan (Mohsen & Akash 1997); and
- Selection of electric power plants (Akash *et al.,* 1999).

The aim of the research project is to evaluate the use of AHP as a tool to apply updated corporate values and objectives to the ranking of Brownfield investment opportunities, thereafter undertaking a comparison of the new ranking against traditional ranking methods. The research steps that were taken include the following:

- Gather and analyse data for three unique Brownfield mining projects in different jurisdictions (the data from projects in varying stages of study from the author's employer has been made available, however the projects were named Project A, B and C to ensure company data confidentiality was maintained);
- Analyse the mining company strategies for three major (comparable) companies with at least 10 operations worldwide to determine common corporate values and strategy parameters;
- Application of the Analytic Hierarchy Process incorporating traditional and non-traditional investment criteria based on the common corporate strategies;
- Rank the investment opportunities utilising traditional investment criteria and compare this to the ranking of the projects utilising the Analytic Hierarchy Process; and

- Analyse the resulting rankings and propose opportunities for further research.

The study is of value as it tests a method of Brownfield mining project ranking on a basis that is more inclusive of revised corporate strategy, potentially providing an additional tool for the ranking of Brownfield mining projects. If a method can be proven to be more inclusive and deliver a quantitative ranking, company management will be able to demonstrate that shareholder values are truly being incorporated into the decision-making process.

The study does not attempt to provide an alternative evaluation tool for Brownfield mining projects. The study focuses on the ranking of Brownfield projects through AHP once an evaluation has been undertaken. As such it does not attempt to compete with evaluation techniques but provides a different view on the ranking of projects.

It is noted that the research does not suggest that companies ignore non-traditional criteria (such as safety performance), rather it assumes that the projects meet all criteria. The research project attempts to value one criteria against another in a complex decision-making process. The relative score of one project against another in the evaluation of the criteria then influences the ranking of that project.

1.3 Specific research problems

The research applied AHP to the ranking of Brownfield investment opportunities to establish if there is a difference in the ranking of Brownfield investment opportunities under two sets of evaluation criteria:

1. Traditional discounted cash flow analysis of the projects; and
2. Application of the Analytic Hierarchy Process where non-traditional investment criteria are considered in conjunction with traditional criteria.

The non-traditional criteria were selected on the basis of common elements in publicly available corporate strategies of three major mining companies. The projects that were analysed in this study are all gold projects as such gold mining companies were selected for the analysis.

1.4 Report structure

This report followed a structured approach to the investigation of the research question. The report structure is as follows:

- Review of relevant literature;
- Description of three gold mining projects that were ranked utilising the AHP;
- Analysis of the three gold mining projects through a discounted cash flow model;
- Application of AHP to the projects; and
    - Selection of Level 1 and sub-criteria;
    - Development of the AHP model with pairwise comparison;
    - Application of data to AHP;
    - Research results; and
    - Additional scenarios.
- Discussion, conclusions and recommendations.

2 RELEVANT LITERATURE

The primary value in mining companies lies in their opportunity to extract their Mineral Reserves and Mineral Resources (Rudenno, 2012). Opportunities identified to increase, prolong or improve production at existing operations (termed Brownfield opportunities) add value to a company's portfolio of assets. Brownfield mining projects are investment opportunities where the parent entity has the opportunity to invest in a modification or addition to an operating or previously operating mine site. Such opportunities are generally presented as growth or sustaining projects within an existing portfolio of assets. Brownfield projects generally enjoy a wealth of information that is not formally utilised in project evaluations and the subsequent rankings.

The literature review therefore focused on four key areas:

1. Traditional project valuation techniques;
2. Changing corporate values and responsibilities in industry;
3. Multiple Criteria Decision Making Methods; and
4. Analytic Hierarchy Process.

2.1 Traditional valuation techniques

Projects in the mining industry are typically capital intensive, often have a long project life and normally take several years before positive cash flows are realised (Topal, 2008). Shafiee *et al*. (2009) noted that mining investments are "*partially or completely irreversible"* and therefore pose a unique valuation problem. The use of appropriate project evaluation techniques is critical (Topal, 2008). The valuation of mining opportunities can be undertaken through a variety of methods and techniques. The method or technique applied is highly dependent on the available data. Certain methods such as the cost approach are more appropriate to early stage projects while methods such as a DCF approach are more appropriate for late stage projects or operating entities (Brownfield) opportunities. At a high level the methods for the valuation of mining projects can be divided into three major categories (Njowa *et al*. 2014):

- Sales or market method;

- Cost method; and
- Income method.

2.1.1 Sales or market comparison methods

The sales or market comparison method is generally applied in the early stages of a mining project where data is limited and the more detailed income methods cannot be applied. The comparison method is based on comparing the project in question with market transactions for similar assets then modifying the value of the project based on differing parameters. Roberts (2000) applied the sales comparison method for the valuation of advanced projects and operating mines where he argued that price is only assigned during a sale and that all valuation methods estimate value only.

The combination of geology, political climate, infrastructure and additional technical and socio-economic parameters almost always result in a unique project. The greatest downfall of the comparison method therefore is the identification of truly comparable projects that have recently been transacted (Roberts, 2000). Although simple in nature, the cost approach method as a result of its simplicity, tends to ignore many of the details that are value drivers from an operation (Lilford & Minnitt, 2005).

A second form of project valuation in early stage projects falling under the sales or market comparison method is the options agreement for the valuation of a project. As noted by Macfarlane (2002) the use of options agreement valuation is not widespread and *“reserved for valuations where information is scarce, as in the case of exploration properties”.* Utilising this approach, the value of the project is determined by the sum of 100% of the options agreement at the time of forging the initial agreement. Additional buy-in options are then viewed as value addition or recognised potential. The use of options agreements as a valuation technique for sales is infrequently used due to poor understanding of the methodology (Lilford, 2011).

The sales comparison method and options method are generally used in early stage projects where the available data does not support a more detailed approach such as the discounted cash flow (DCF) method (Lilford & Minnitt 2002). In the case of Brownfield mining projects, the data is generally sufficient to support more detailed valuation approaches such as DCF.

2.1.2 Cost approach methods

As noted in the case of the sales or market comparison method, cost approach methods are almost exclusively utilised in the valuation of early stage projects where insufficient data is available to estimate future income and therefore income methods. Within the class of cost approach methods, the historic cost approach is commonly utilised (Macfarlane, 2002).

The cost approach method determines the value of the project through the sum of the historic costs incurred while developing the project. The costs included in the valuation are costs which resulted in generating value to the project. Most importantly this method of valuation does not assign any value to the future potential of the property or project. The method does allow for the application of inflation onto the historic costs to bring these costs to today’s terms. This valuation method is advantageous in that it is relatively simple, is understood without difficulty and easily applicable, but loses favour as future potential is ignored.

The rural cost approach is a second valuation methodology applied to early stage projects or resource opportunities. In this approach a value per unit area (such as per hectare) is determined and then applied to the total project area, resulting in the total project value. While this method is relatively simple, as with many early stage valuation methodologies, it fails to accurately value future potential.

Cost approach methods are generally used in early stage projects and are predominantly concerned with the sale or purchase of such projects. These approaches are designed to function with minimal baseline information, where it is not feasible to develop a more detailed valuation of the project such as a DCF approach. These methods of project valuation have little application in the valuation of Brownfield projects, where considerably more data is available to formulate an evaluation, and are therefore unsuitable as a technique for the ranking of Brownfield mining projects within an asset portfolio.

2.1.3 Income methods

The valuation of a mining project based on the income approach is possible only when the appropriate level of data is available. The essence of the income approach is the application of forward looking methods to generate an estimate of cash inflow and outflow from the operation in the future. As such the income approach is dependent on the estimates of such parameters as reasonable future expenses, productivity and commodity price (Macfarlane, 2002). There are several different approaches in the income approach method for mining project valuations including:

i. Discounted Cash Flow (DCF);
ii. Accumulated cash flow;
iii. Probabilistic NPV; and
iv. Options Pricing.

The most commonly used income approach method is the use of a discounted cash flow model and the associated output parameters such as Net Present Value and Internal Rate of Return. NPV is recognised as the most appropriate method for the representation of sequential incomes from a non-renewable Mineral Resource (Minnitt, 2004). DCF is widely accepted and understood, as such it is widely utilised in project valuations and subsequent rankings (Ellis, 2000).

Perhaps the most widely quoted economic parameter in mining projects is the NPV. The NPV requires the determination of the sum of the present values of future cash flows over the useful life of the project through the use of an appropriate discount rate (SAMVAL, 2009). If the value is positive, the investment adds value and if it is negative, the investment destroys value.

The utilisation of a form of a DCF model is accepted as the standard project valuation technique across industry. Keck, Levengood, & Longfield (1998) noted that 95% of professionals surveyed evaluating international investments utilise a form of DCF for valuation purposes. Not surprisingly therefore, DCF is commonly used as the primary valuation method and therefore its outputs are used as the primary ranking metrics within mining projects inclusive of Brownfield mining projects. NPV is viewed as an incorporation of many risks and financial considerations and therefore an important all-inclusive metric for valuing mining projects. However an analyst's inability to accurately predict future costs and commodity prices is recognised as the cause of many challenges within DCF modelling (Kelly, 1998). Additionally, Guj & Garzon (2007) reported that difficulties with a DCF are noted as a result of utilising a single risk-adjusted discount rate.

The inputs into a DCF model are forecasts from a variety of methods. As such each forecast has associated risk and risk in DCF modelling is therefore a compound of these risks. A single discount factor is then applied to determine a NPV in today's terms. The concept that underpins DCF analysis is that time has value, as such cash flows that occur today are more valuable than those that occur in the future (Moyen *et al*., 1996), hence the use of a discount factor. There are two ways of addressing the risk in forecasting and discount rates. The first is an increase in the confidence of the data as additional work is undertaken on the project. This is usually in the form of the natural transition of the project from concept to pre-feasibility and feasibility. The second technique is the use of NPV range or best case / worst case NPV scenarios.

Once a project has progressed to feasibility level, a significant improvement in the forecast risk is unlikely with additional study. In recognition of this cumulative risk, the resource industry has turned to the application of models which give a range of results based on probabilistic techniques such as Monte Carlo analysis. In such cases the key elements of the model are assigned best case and worst-case ranges (or confidence / risk levels) and using mathematical iterations, thousands of possible combinations are tested within the assigned parameter ranges. A probabilistic result is then calculated for the DCF outputs. These relatively complex models determine a range of DCF results and a confidence factor associated with achieving the results.

As with all models, the confidence values applied to the key elements ultimately determine the confidence in the range of results.

The use of a DCF model is appropriate when the level of data supports the determination of future cost and future income. The confidence in the inputs determines the confidence in the outputs such as NPV and IRR. Almost without exception for Brownfield mining projects it is possible to determine future cost and income, usually at a very high level of confidence due to operational knowledge. As a result, the use of an income approach to the valuation of these projects is the best possible approach to utilise. Perhaps as a result of the highly suitable nature of this method to many mining projects, the income approach has become entrenched into the resource industry over several decades.

A ranking system for Brownfield projects inclusive of non-traditional criteria i.e. criteria not reviewed above has not been noted in most available literature. The following sections of this literature review discuss the changes in corporate value systems and propose a method for a more inclusive ranking system.

2.2 Corporate values and responsibilities

The way that business is conducted has changed dramatically over the last few decades. Until relatively recently big companies did well operating under a set of country and company regulations. Many changes in society have impacted this. The advent of such innovations as mass communication, international news networks, email, the internet, smart phones and social media have made the distance between people “smaller” and the world has become a global village. Kolk (2008) noted that companies have seen a rapid increase in pressure in corporate accountability, particularly in large companies. The recent changes in the understanding of corporate social responsibility and citizenship are driven by greater demands for transparency. Indeed Michnik & Lo (2005) recognised the increasing interest shareholders have in the manner in which business is conducted.

There has been a recognition that companies do not operate outside of society, rather they are part of society. Slowly, companies have recognised the need for a social licence to operate. Companies have recognised that conforming to the governing laws and regulations is simply no longer enough. As corporate citizens they have additional responsibilities.

Internationally, corporate values have evolved dramatically, and in the resource industry this evolution has taken place as well. In reviewing almost any recent annual report for a resource company one will be presented first not with the financial performance, but rather a performance across safety, the environment and the communities in which the company operates. Indeed, there has been an emergence of sustainability reporting as a separate annual report, focusing initially on the environment. The reporting scope has increased to include issues such as ethical and social sustainability (Kolk, 2008). This reflects the changing values of resource companies. It reflects the company's desire to be recognised as a good corporate citizen. A positive correlation between companies that demonstrate a total commitment to sustainability and shareholder valuation of such companies is noted (Lo & Sheu, 2007).

In addition to the move towards being good corporate citizens and members of society, shareholders have become increasingly powerful. With increased company transparency and tools of modern society, information is readily available and company boards are held to account for decisions and performance. Shareholder value has risen as a principle in corporate governance. In the United States of America (USA) for example there has been a transition in major companies from retention of corporate earnings and subsequent reinvestment in growth to downsizing of corporate labour complement as well as a distribution of corporate earnings to shareholders (Lazonick & O'Sullivan, 2000).

Although there have been significant steps in the formalisation of corporate responsibilities, most notably in a South African context through the King Report on Corporate Governance in 1994 (King I), 2002 (King II), 2009 (King III), and 2016 (King IV), there is no worldwide reporting standard for corporate governance. Additionally, the concept of sustainability is relatively vague and although many authors, politicians and policy makers have attempted a universal definition, there is no singular standard accepted for the reporting and definition of sustainability. In many jurisdictions companies have the luxury of choosing the reporting standard against which they report. The inherent ambiguity in definition especially of the term sustainable development lends itself to corporate manipulation. Critical analysis of such reporting is therefore key in determining a company's true commitment to such initiatives.

As noted, corporate value systems, reporting and strategy have changed dramatically over the course of the last few decades. Project valuation and ranking methods have not evolved at the same pace, to the extent that the ranking of projects in the resource industry is no longer representative of changed corporate values. A new ranking approach is required, and this research study proposes a possible solution.

2.3 Multiple criteria decision making methods

Mining investments are complex capital projects. Ultimately the decision to invest is based on several criteria. Multiple criteria decision making (MCDM) methods are analytical methods designed to aid in the decision-making process when a multitude of competing and sometimes opposing criteria must be considered. MCDM methods are applied in an array of fields such as water resources (Özelkan & Duckstein, 1996) and landslide mapping (Yalcin, 2008). Some of the better known MCDM methods along with relevant examples in academic literature include:

- Weighted sum method (WSM)

In the WSM method multiple alternatives are assessed against multiple criteria. Each criterion has a weight and the alternative with the highest aggregate score is deemed the best option. The WSM has been applied by Vuji & Karaba (2016) in the selection of leaders in the mining industry.

- Weighted product method (WPM)

  WPM works in a very similar way to WSM. However, in WPM the model uses multiplication and not addition, and the highest value is deemed the best option. While there are many potential applications of the WPM method, Mazziotta & Pareto (2016) apply the WPM in an attempt to develop a well-being index as an alternative to existing well-being measures such as gross domestic product (GDP) per capita.

- ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality) (ELECTRE)

  In this method a decision alternative is selected based on its superior ranking over the majority of the criteria and where remaining criteria do not breach unacceptable limits. The ELECTRE method was applied by Fahliani *et al*. (2011) in their selection of optimum support system for a tunnel.

- Compromise programming (CP)

  In the CP method, the criteria are assigned maximum values of compliance. Each alternative is measured against the maximum. Each criteria has a weighting and the alternative with the lowest score (i.e. closest to the desired criteria value) is deemed the best alternative. Strager (1995), applied the CP methodology to prioritise acid mine drainage affected watersheds.

- Preference ranking organization method for enrichment evaluation (PROMETHEE)

  This method performs a pairwise comparison of the decision alternatives against a number of criteria. The decision alternatives are then ranked. The highest ranking option is deemed the best alternative. PROMETHEE methods have been utilised widely, including application within the mining industry, such as the selection of ore transport systems (Elevli & Demirci, 2004).

- Analytical hierarchy process (AHP)

  AHP was developed by Thomas Saaty in the mid-1970's with publication in 1980. In AHP the decision is broken down in a hierarchical approach with the decision on the top with subsequent layers of criteria, sub-criteria and then the alternatives at the bottom of the hierarchy. Pairwise comparison of criteria is used to weight the importance of each criterion in the overall decision making process. Examples of the use of AHP in the mining industry are widespread and include applications such as equipment selection (Başçetin, 2003) and mining method selection (Gupta & Kumar, 2012).

There remain several additional MCDM methods which may be utilised such as:

- Multi-attribute utility theory (MAUT); and
- The technique for order preference by similarity to ideal solutions (TOPSIS).

2.4 Analytic Hierarchy Process

AHP has been successfully applied in the mining industry to provide guidance in the selection of optimal solutions to a number of problems. Examples of AHP application in the mining industry include:

- Ranking the efficiency of selected platinum mining methods (Musingwini & Minnitt, 2008);
- Techno-economic optimization of level and raise spacing in Bushveld Complex platinum reef conventional breast mining (Musingwini, 2010);
- Selecting a site for limestone quarry expansion in Barbados (Kumar & Ramcharan, 2008);
- Selection of an appropriate fan for an underground coal mine (Kursunoglu & Onder, 2015);
- Selecting the best energy-delivery system for hand-held stope drilling and associated equipment in narrow-reef hard rock mines (Petit & Fraser, 2013); and
- Selection of mineral processing plant location (Safari *et al*. 2010).

In a review of more than 90 published papers utilising MCDM methods Pohekar & Ramachandran (2004) noted that the Analytical Hierarchy Process (AHP) is the most commonly used MCDM method. A more recent review of the use of MCDM methods in literature by Mahase *et al.* (2016) found that 45 of the 150 cases assessed utilised AHP exclusively, significantly more than the second ranked Fuzzy set theory with 8 instances. Ataei *et al.* (2008) argued that AHP provides both flexibility and an easy to understand method of analysing complex problems. The very nature of complex multiple criteria decision making often encounters conflicting priorities. Başçetin (2007) noted the usefulness of AHP to arrive at a consensus decision.

As a result of its common application and its flexibility, the AHP method has been selected for application in the ranking of Brownfield mining projects in this research project. Elkarmi & Mustafa (1993) argued that AHP is widely accepted by the global scientific community as a robust and flexible MCDM tool, further supporting the selection of AHP to Brownfield mining project ranking. Coyle (2004) argued that one of the key attributes of AHP is its ability to *“detect inconsistent judgements and provide an estimate of the degree of inconsistency in the judgements”.*

The AHP method provides a solution to problems where the selection criteria are in conflict with one another and multiple alternatives are available (Pohekar & Ramachandran, 2004). AHP applies a hierarchy methodology to the MCDM analysis as illustrated in Figure 2-1. The hierarchy represents a decomposition of the focus or overall objective (Cheng & Li 2001). The process is adaptable to many problems because the method is flexible, there is no set number of criteria, and the selected criteria are customisable to a specific problem. One of its key features is its mathematical approach to the consistency of the ranking of multiple criteria (Saaty, 1987).

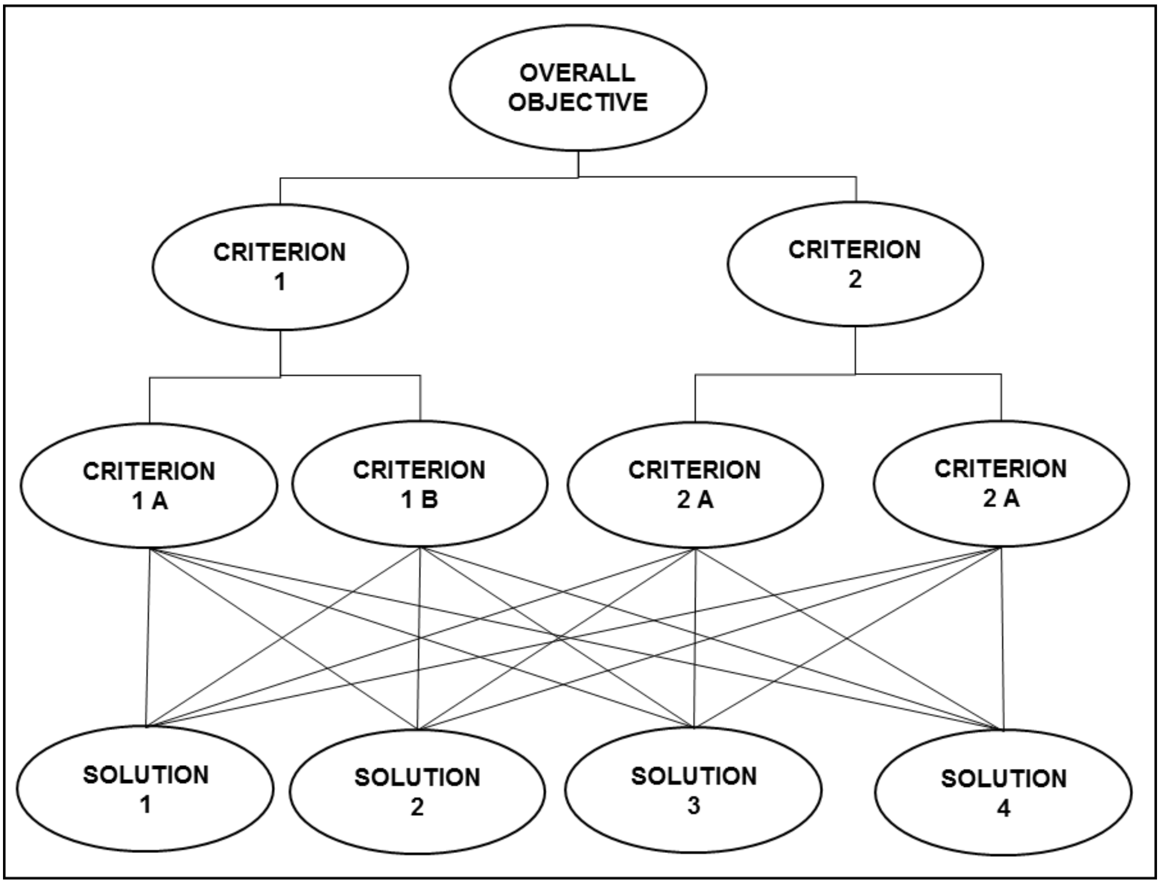


Figure 2-1 AHP overview

The AHP process commences with the identification of an overall objective. The overall objective could be any objective with multiple criteria. An example of an overall objective could be the identification of a new house for purchase in a new city. The house selection is dependent on multiple criteria (the next level of the hierarchy). Such criteria could be location (distance to desired amenities), cost and crime. The next level of the hierarchy is the sub-criteria under each main criterion. Utilising the house selection example, under the location criterion, there would be differing considerations (sub-criteria) for proximity to hospitals, schools, shops and work. The lowest level of the hierarchy is composed of the potential solutions for the overall objective. In the example given, the fourth level would therefore be the houses under consideration. In summary therefore once an overall goal is set, criteria, sub-criteria (if required) and alternatives (solutions) are placed in a successive hierarchical structure (Saaty, 1980).

Once the basic hierarchy has been established there is a need to determine the relative importance of each criterion either per level as is the case for the first level of the hierarchy or the case of subsequent levels, the relative importance to its parent criterion. This process is undertaken through a pairwise comparison where the individual or team must determine which criterion is more important in light of the overall goal and additionally by what scale (1-9), (Bogdanovic *et al.,* 2012). Once the pairwise comparison is complete, a mathematical analysis is undertaken to determine the consistency of the relative criteria weighting. The pairwise comparison weighting is done on the criteria level where each criterion is measured against other criteria. Subsequently, the pairwise comparison is then undertaken on the sub-criteria level, and in this case sub-criteria within a single criterion are compared against one another again through the use of pairwise comparison incorporating a statistical check for consistency to minimise personal bias.

Through the application of the process outlined above, the decision maker can effectively place a consistent and therefore valid weighting to a series of criteria that are important to determining the best alternative for the decision. In addition, sub-criteria have been identified and given statistically valid weightings for each of the criteria. The remaining step is then to assess each alternative solution against the sub-criteria. The scores may be qualitative or quantitative. However, a value within a range is required. Using linear transformation, the number is then converted to a range consistent across the model. In general, the number is reduced to a value between 0 and 1. Linear transformation is used to ensure the value range of criteria is consistent in order that the magnitude of a criterion value does not influence the weighted value of the criteria (i.e. if all criteria are scored between 0 and 1, the weightings can then be applied correctly). Utilising the housing example, the absolute scores of the sub-criterion “Hospital location”, may be on a scale of 0km to 100km while the “school” criterion may be scored on a scale of 0km to 10km. Having previously determined that school location had a higher weighting than the hospital location, it is imperative that the values of both criteria are reduced to a common scale in order that the multiplication of the score with the weighting reflects the pairwise comparison results (criteria weighting).

2.4.1 Mathematical framework for AHP

Saaty (1980) developed the AHP methodology. Matrix and vector algebra form the backbone of the mathematical framework of the AHP methodology (Musingwini, 2009) as such, Microsoft Excel® provides an appropriate and easy to use platform for AHP calculations. The mathematical theory of AHP has been explained by a number of authors including Saaty (1980), Coyle (2004) and Musingwini (2009). This section of the report serves as a brief summary of the AHP theory.

Harker & Vargas (1987) defined the AHP methodology as being premised on four key axioms:

1. **The reciprocity axiom.**

   Given any two criteria C_i and C_j, the magnitude of preference of C_i over C_j is an inverse of the complementary preference decision of C_j over C_i.

2. **The homogeneity axiom.**

   When comparing two alternatives, two criteria or sub-criteria, the scale of the ratio of comparison is restricted (one item cannot be infinitely better than the second item under comparison).

3. **The dependence axiom.**

   The alternatives are dependent on the set of criteria if a scale can be defined to measure each alternative against each criterion (this is a fundamental principle in AHP that the decision or problem can be decomposed into a hierarchy).

4. **The expectations axiom.**

   All alternatives and criteria (and sub-criteria if required) which impact a decision-making problem are represented in the hierarchy and assigned priorities compatible with the expectations.

As will be demonstrated through the course of this report, the problem assessed in this study (Brownfield project ranking) satisfies all four axioms and thus the AHP is an appropriate methodology for the research.

Once the problem has been decomposed into a hierarchy, the mathematical procedure commences with a pair-wise comparison of the relative importance (weight) of each criterion over another using the reciprocity axiom. The relative weight of C_i over C_j is denoted by w_{ij} such that, $w_{ij} = \frac{1}{w_{ji}}$, $\forall\, i \neq j$, and $w_{ij}=1$, $\forall i=j$, since a criterion is as important as itself (Musingwini, 2009). The weights derived from the pairwise comparisons are then used to form a square matrix (termed a reciprocal matrix) W = (w_{ij}), of the order n, where n is the number of criteria in the specific pairwise comparison. The matrix is termed a reciprocal matrix because the inverse of the weight of one criterion over another is equal to the weight of the second criterion over the first one (Musingwini, 2009).

The next step in solving the AHP from a mathematical perspective, is the assessment of the matrix of weights, **W**, for transitivity. A relationship is termed transitive if the relative importance is multiplicative. For example, if criterion $\boldsymbol{C_b}$ is twice as important as criterion $\boldsymbol{C_a}$ and criterion $\boldsymbol{C_c}$ is three times as important as $\boldsymbol{C_b}$, then logically criterion $\boldsymbol{C_c}$ should be six times as important as $\boldsymbol{C_a}$ (Musingwini, 2009). A matrix satisfying the transitive axiom represents consistent judgements. One of the strengths of the AHP methodology is that it provides a way of measuring the magnitude of inconsistency in judgements.

The transitive relationship can be articulated mathematically as $w_{ik} = w_{ij}w_{jk}$, $\forall i,j,k$. A vector, $\boldsymbol{w}$, of order $\boldsymbol{n}$ can be established such that $\mathbf{W}\boldsymbol{w} = \lambda \boldsymbol{w}$. The vector, $\boldsymbol{w}$, is termed an eigenvector of the matrix **W** and the constant λ is its matching eigenvalue (Musingwini, 2009). If the matrix, **W**, is consistent then $\boldsymbol{\lambda = n}$. For inconsistent human judgements, the eigenvector, $\boldsymbol{w}$, cannot satisfy the condition $\boldsymbol{\lambda = n}$ but will satisfy the condition $\mathbf{W}\boldsymbol{w} = \lambda_{max}\boldsymbol{w}$ such that $\lambda_{max} \geq \boldsymbol{n}$. The difference if any between λ_{max} and $\boldsymbol{n}$ is an indication of the inconsistency in the judgements but, if $\lambda_{max} = \boldsymbol{n}$ then the judgements were consistent (Coyle, 2004).

There are several methods that can be used to estimate the eigenvector (Coyle, 2004). Of the methods available, a close estimate of the eigenvector is gained when geometric means are used to estimate the eigenvector elements (Musingwini, 2009). If a scale of 1 to 10 is used to represent the relative weights, then the reciprocity axiom dictates that the reciprocal weights 0.1 and 10 will vary by an order of magnitude (100). The geometric means are meaningful when evaluating data that differs by several orders of magnitude, the minimum order being three (Costa, 2007).

The next step in the mathematical process to solve the AHP is the calculation of the Consistency Index, CI, which is calculated from λ_{max} and n using the relationship outlined in Equation 2-1

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)}$$

Equation 2-1 (Musingwini 2009)

In order to determine if the judgements that have been made are reasonably consistent a Consistency Ratio (CR) is calculated. This is done by measuring the calculated CI against judgements that have been made completely at random. Saaty (1980) simulated large samples of random matrices of increasing order and calculated their corresponding CIs. The CIs which were based on judgements made at random are therefore random indices (RIs). Saaty (1980) published RIs for matrices of the order 1 through 15 as shown in Table 2-1

Table 2-1 Random Index (RI) for 1 through 15 ordered matrix
Adapted from Saaty (1980)

Matrix Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The CR is attained by dividing the CI by its matching RI. Saaty (1980) argued that should the CR exceed 0.1 then the judgements are probably too inconsistent to be reliable, and the pairwise comparison should be redone. Coyle (2004) however argued that when there is sufficient justification for the acceptance of a greater CR value, CR’s of greater than 0.1 can still hold valid in a AHP analysis.

Once the CR requirement has been met, the next phase of the mathematical process is the elimination of the effects of different units of measure for each criterion. Efficiencies of all possible solutions on a criterion, O_{ij}, are normalised. The matrix of normalised efficiency outcomes is then multiplied by the calculated eigenvector to obtain the aggregated AHP priority score. The ranking of the solutions is then completed based on the logic that the higher the AHP priority score, the more desirable the alternative (Musingwini, 2009).

The AHP methodology has three key limitations (Musingwini, 2009):

1) The AHP only works if the matrix for the criteria weights is a positive reciprocal matrix (Coyle, 2004)
2) When the scale for measuring the relative importance of criteria with respect to each other is changed, say from a scale of 1 to 9 to a scale of 1 to 20, the weight vector will also change and this may impact the final decision (Coyle, 2004)
3) If the number of criteria to be compared increases, the number of pair-wise comparisons that must be done increases significantly (for the recommended maximum number of criteria of 9, a total of 36 comparisons have to be made). Musingwini (2009) argued that this clouds the judgement and makes the calculations more complex.

2.5 Chapter Summary

The valuation of a mining investment is traditionally carried out using one or more of three types of valuation methods. The applicable valuation technique is predominantly determined by the type of data available on the project. In early stage projects where the determination of future income is problematic, the sales or market comparison method is commonly applied. The method is based on comparing the project in question with market transactions for similar assets, then modifying the value of the project based on the differing parameters. Due to project specific parameters such as grade, tonnage and locality, the challenge in the application of this method is finding a truly comparable project.

A second class of valuation used primarily in early stage projects is the cost method. This method determines the value of the project through the sum of the historic costs (usually escalated) incurred while developing the project. This method of valuation does not assign any value to the future potential of the property or project. The method is relatively simple to apply and understand, but loses favour as future potential is ignored.

Valuation using an income method is possible only when the appropriate level of data is available. The income approach applies forward looking methods to generate an estimate of cash inflow and outflow from the future operation. There are several different approaches in the income method for the valuation of mining projects including: Discounted Cash Flow (DCF), Accumulated cash flow, Probabilistic NPV, and Options Pricing. The most commonly used income approach method is the DCF method.

Corporate value systems, reporting and strategy have changed dramatically over the course of the last few decades. Companies have recognised the need for a social licence to operate. Companies have acknowledged that conforming to the governing laws and regulations is simply no longer enough. As corporate citizens, they have additional responsibilities. Project valuation and ranking methods have not evolved at the same pace. The ranking of projects in the resource industry is no longer representative of changed corporate values.

Multiple criteria decision making (MCDM) methods are analytical methods designed to aid in the decision-making process when a multitude of competing and sometimes opposing criteria must be considered. While a number of MCDM methods exist, the AHP is the most commonly used. It is flexible in its application and has been applied to a vast array of problems. The consistency of pairwise comparison is a significant feature of the approach and particularly suited to the often conflicting criteria used in the ranking of Brownfield mining projects.

The AHP is the most commonly used MCDM mathematical tool available. It is flexible in its application and has been applied to a vast array of problems. The focus on the consistency of pairwise comparison is a significant feature of the approach and particularly suited to the often conflicting criteria used in the ranking of Brownfield mining projects. AHP provides a well-tested analysis tool capable of providing a non-traditional ranking of Brownfield mining projects through incorporation of multiple, conflicting criteria.

As identified by Musingwini & Minnitt (2008) AHP has several possible applications within the mining industry such as the ranking of projects competing for funding. Although this was suggested in the context of the South African platinum industry, the potential application holds true for the gold mining industry as applied in this body of research.

AHP provides a well-tested analysis tool capable of providing a non-traditional ranking of Brownfield mining projects through incorporation of multiple, conflicting criteria. As such the AHP was selected for application in this research project.

3 PROJECTS

3.1 Introduction

In this chapter the three Brownfield projects selected for analysis and ranking are presented. The projects are referred to as Projects A, B and C for proprietary reasons. The background and scope of each project is discussed in some detail. Each project is modelled in a discounted cash flow model, delivering traditional metric outputs (TM) such as NPV, IRR and Capital. The three projects are ranked against each other on the basis of their scoring on traditional metrics.

3.2 Project A

3.2.1 Background

Project A creates sulphide ore (hard ore) processing capacity at an existing mine. It involves mining the hard sulphide ore of the orebody that lies below the existing oxide pit. The processing of hard rock ore requires additional tailings storage capacity and an alternative power supply sought through the national power grid.

The project is a joint venture (JV) between the country's government and two multinational companies. The mine is located in West Africa. The country where the mine is located, is a landlocked nation in West Africa, and is dependent on its neighbours for ocean-borne inbound materials and supplies.

The mine lies within a subtropical-to-arid climatic zone between the 700 mm and 900 mm isohyets. The climate is subtropical to arid with a dry and a rainy season. The dry season is from November to February with temperatures ranging from 15°C to 30°C. From March to June, temperatures range from 25°C to 45°C. The rainy season lasts from July to October.

Rainfall, in the form of high intensity convectional thunderstorms, commonly accompanied by strong winds, occurs in summer. Annual rainfall exceeds 1,000 mm, and evaporation is twice the precipitation rate. Periods of water surplus and shortage occur in the wet and dry seasons, respectively.

Project A is situated proximal to 46 officially recognised villages and several hamlets. A mine village has been established to the northeast and provides housing, a medical clinic, a park and recreation facilities for mine employees and dependants. Other facilities include guest accommodation, a post office, a supermarket, sewage treatment facilities and other amenities.

The existing mine employs more than 1,000 people, including those employed by outside contractors. The majority of personnel are nationals (~93%), with the remainder being expatriates from South Africa (~7%). The majority of the unskilled labour is sourced from the nearby towns and neighbouring villages.

While the thickened tailings approach of Project A will result in significant process water recovery, the primary source of make-up water is a 55 km pipeline from the nearest River. This is the only reliable source of surface water in the region and was built to provide approximately 8 million cubic metres per year of process water in order to ensure that the existing mine does not impact on local water resources. Potable water for both the mine operation and the mine town site and local villages are supplied from the pipeline, as well as local boreholes (treated prior to distribution).

The existing mine began commercial production in 1996 and is scheduled to cease mining of the soft oxide and soft sulphide ore from nearby satellite pits and existing stockpiles in 2019. The operation has processed over 81.2 Mt of ore averaging 3.05 g/t gold and has produced some 7.5 Moz of gold as of the end of July 2016. The existing processing facility was designed for the processing of soft ore and can only introduce a small percentage of hard ore in the mill feed.

3.2.2 Scope of work

The current processing facility is capable of processing only soft ore and requires crushing, additional grinding, tankage and re-handling capacity to process hard ore from Project A. The upgraded processing plant which includes current and new equipment was designed to process 900 tonnes per hour based on 92% operating time for an annual throughput of 7.2 Mtpa of hard ore. The existing plant will continue to process soft material during the construction phase of Project A. Once the construction works are complete, the plant will transition to processing hard ore at a rate of 7.2Mtpa.

The hard rock processing facility will be constructed adjacent to the old plant. The existing plant will be modified and both plants will be connected to process 7.2 Mtpa of sulphide ore as illustrated in Figure 3-1.

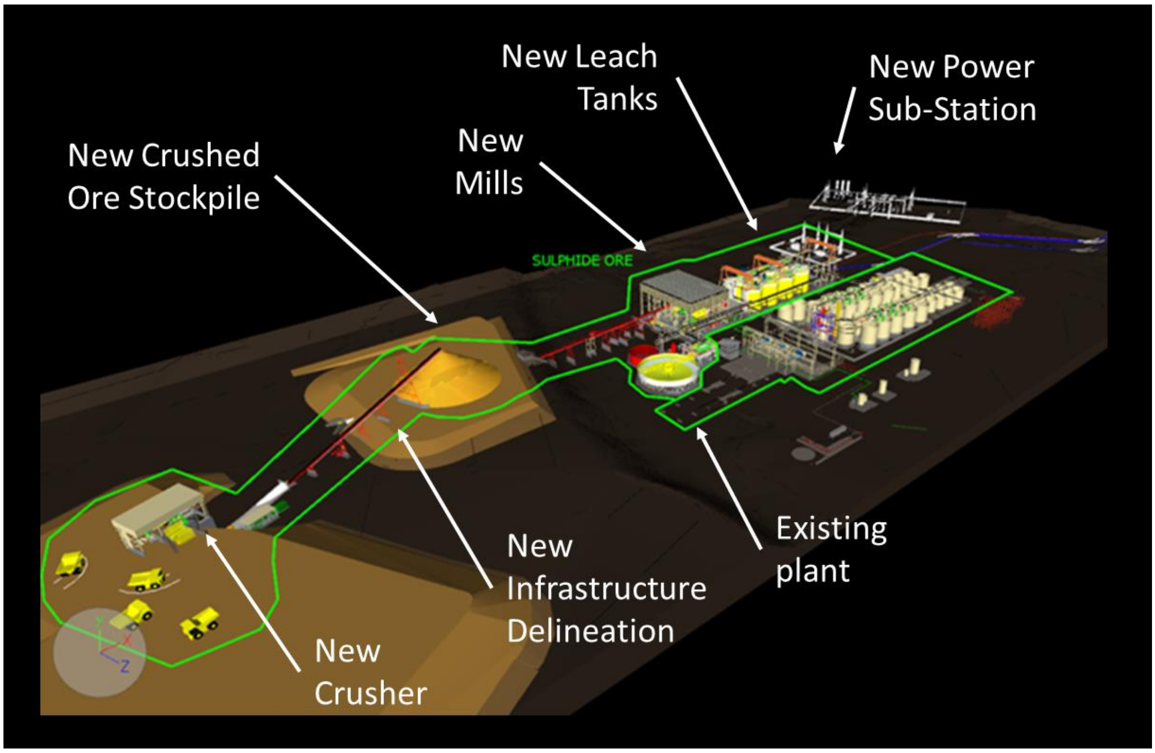


Figure 3-1 Project A plant general arrangement (processing 7.2 Mtpa of sulphide ore)

Project A will construct a new power line, a 225 kV single-circuit, three-phase transmission line. A power purchase agreement is in place with the government for the supply of power for the project.

This is a significant change from the current mine setup which utilises a fleet of 1MW generators to supply power to the operation.

The tailings management plan has been developed to accommodate an additional 75 Mt of tailings. The tailings from the ‘‘Hard Sulphides’’ zone milling process will be deposited over a period of approximately 10 years. A peak production rate of 7.5 Mtpa has been catered for although the current schedule indicated the throughput to be 7.2Mtpa. Tailings will be deposited into a mined out satellite pit on the mine lease. The proposed deposition strategy has been formally approved by the appropriate government agency.

The mine is located in an arid area characterised by low rainfall and high evaporation which results in a net negative annual water balance. The existing key processing water management infrastructure will be used during Project A. The water dams will continue to provide raw water for gold processing and non-gold processing activities.

The ore for Project A will be sourced from a sulphide depth extension of the existing oxide pit. A two-phase mining approach for the pit is planned. The first phase is split into three stages, with stages 1 and 2 focussing on early ore from mining on the Eastern, Southern and Northern sections of the pit. Stage 3 is an intermediate pushback on the Western wall. The second phase is an expansion on the West-side of the pit. With the existing actual mined out open pit many adjustments were required to minimise waste stripping but still allow access to all the ore and allow for minimum mining widths for efficient and safe operations. A total of 77Mt of ore at a grade of 1.77g/t gold and a contained metal content of 4.4Moz gold will be targeted over the Life Of Mine (LOM).

Project A will have a construction period of 26 months and will have a LOM of 10 years from the date of first gold production. The total capital requirement for the execution of Project A is estimated at US$550M.

Project A is a Brownfield project. The capital investment is significant although shared by two JV partners. The project adds hard rock processing capacity through the addition to and upgrade of the existing plant.

3.3 Project B

3.3.1 Background

Project B is located in West Africa. The current mine operations and infrastructure are dispersed over an extensive area, coalesced with local villages and community infrastructure.

The mine is approaching its end of life. An opportunity was identified to process fresh and transitional material and extend the life of the mine. The mine was until recently predominately an oxide operation but has only sufficient oxide material (full grade and marginal ore) to maintain production until 2019. As a result, should the project not be considered then the mine will go into closure at the end of 2019

The key objective of the project is to maintain the gold profile of the mine and extend the mine’s life by enabling the current plant to treat fresh rock with minimal capital input. With known deposits of transitional and fresh rock material the potential to exploit this was investigated. The material inventory for both transitional and fresh rock is 1.9Moz of gold.

3.3.2 Scope of work

This feasibility study was completed and evaluated as the business case for converting the mine process plant into a hard rock treatment plant, enabling the treatment of fresh and transitional material. The capital requirement for this project is US$111M. The project will extend the life of mine by approximately 6 years until the current tailings storage facility (TSF) is filled in 2023. In addition to this there is an upside potential of approximately 7 years should the gold price recover beyond $1300/oz, although this would require a new tailings facility.

The current processing plant does not have the capability to treat transitional and fresh rock material. The key changes required as illustrated in Figure 3-2. These were identified during the study and are as follows:

- Additional three stage crushing circuit at ROM 2;
- Additional 12 MW ball mill circuit;
- Hybrid carbon in leach (CIL) circuit (conversion of 4 leach tanks); and
- Upgrade of the elution and electro-winning circuits.

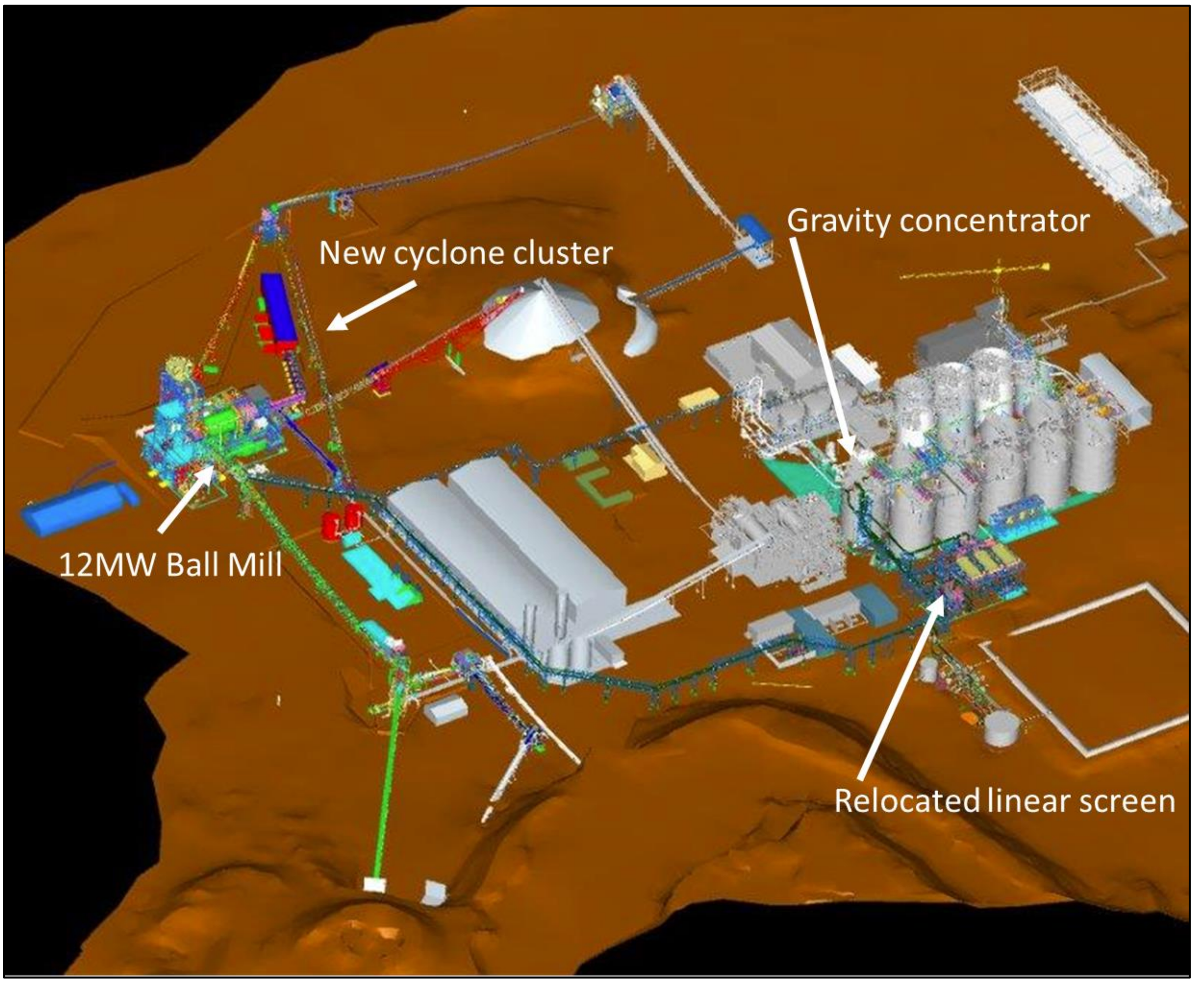


Figure 3-2 Project B design with existing infrastructure in grey

3.4 Project C

3.4.1 Background

Project C is proposed for an operation in East Africa. The operation has one shareholder. The operation exploits three open pits and has a single underground operation. The mine faces a decline in production as open pits deepen, Mineral Reserves are depleted and new economical open pit replacement Mineral Reserves have not been generated. Successive push backs of the open pits represent a significant increase in cost per ounce, to approximately US$1,100/Oz all in sustaining cost (AISC). This is due to the increase in waste movements and therefore stripping ratio. As the depth of the pits render the ounces lower margin, the lack of ore will drive the processing of marginal ore, resulting in lower profitability and reduced free cash flow delivery to shareholders.

To extend the life of mine, Project C targets high margin underground ounce production. Successful exploration work has identified a second underground opportunity under the primary open pit at the operation.

Project C's underground operation has the potential to produce some 800Koz as recovered gold ounces over approximately 8 years of mine life. If all the potential is realised, the operation will be a significant ounce contributor over the medium term. Due to reduced confidence in historical data, some 88% of the underground Mineral Resource has been recently reclassified as Inferred resources (previously Indicated – at risk). The project therefore carries above average geological risk. In mitigation of this risk, all underground workings will commence with hanging wall development to create drilling platforms from which infill drilling will take place.

Project C will commence with two portals within the main pit. The first portal will target production from the Block 5 area which due to its relative shallow location, has been drilled the most and has the highest geological confidence. The second portal will target the exploration of Block 4 from the hanging wall before mining of the defined material with subsequent exploration and mining of Blocks 3, 2 and 1 as shown in Figure 3-3

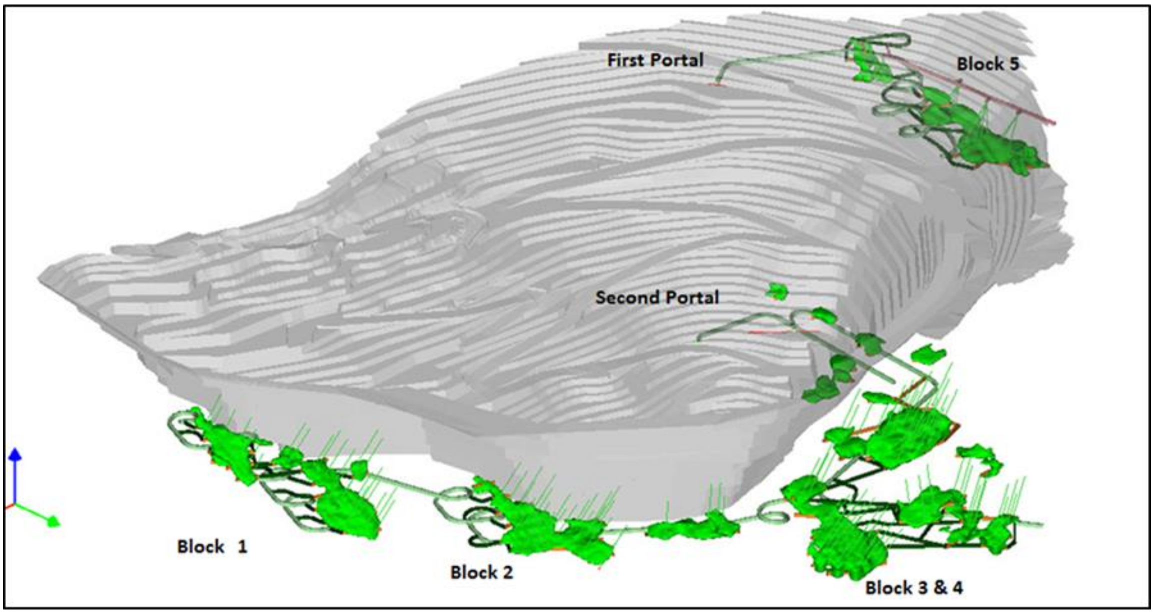


Figure 3-3 Project C design

Upgrading the geological confidence through a surface drilling campaign would render the total cost of extraction and exploration greater than the potential recovered gold value. Upgrading the geological confidence through the use of an exploration decline that will double as production and ventilation infrastructure has two key advantages:

1. The total cost of exploration and extraction remains below that of the value of the ounce potential; and
2. Production stopes can be accessed rapidly after delineation.

3.4.2 Scope of work

Project C proposes a drilling decline that will ultimately have both ventilation and production capability. The scope of work is focused on accessing underground drilling platforms, undertaking the drilling and then commencement of associated mining activities.

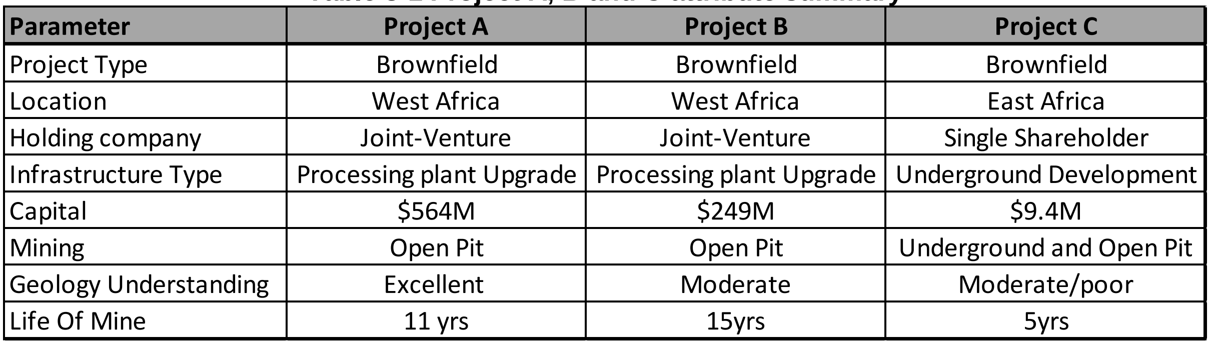
A variety of support equipment and infrastructure will be required for the commencement of mining activities including ventilation fans, backup power generation and the construction of portal infrastructure. Contract mining has been selected as part of the execution plan. Trackless equipment and sundry infrastructure will be part of the mining contract.

Project C has an opportunity to unlock future potential. The relatively small capital investment is focused on improving geological understanding and creating infrastructure for underground mining. The project has both significant upside and downside geological potential.

3.5 Comparison of characteristics of Project A, B and C

The three projects under consideration for possible investment have very different attributes, as summarised in Table 3-1. It is this unique combination of attributes that each Brownfield mining project has that makes a more inclusive ranking system such as the AHP useful.

Table 3-1 Project A, B and C attribute summary



Parameter	Project A	Project B	Project C
Project Type	Brownfield	Brownfield	Brownfield
Location	West Africa	West Africa	East Africa
Holding company	Joint-Venture	Joint-Venture	Single Shareholder
Infrastructure Type	Processing plant Upgrade	Processing plant Upgrade	Underground Development
Capital	$564M	$249M	$9.4M
Mining	Open Pit	Open Pit	Underground and Open Pit
Geology Understanding	Excellent	Moderate	Moderate/poor
Life Of Mine	11 yrs	15yrs	5yrs

3.6 Project financial modelling

Projects A, B and C represent three projects of a major gold producer. All the projects are based in Africa and have been subjected to various levels of study. At no point were the three projects competing against one another for funding. The projects however represent a cross section of typical brownfield projects a mining company undertakes and as such, a scenario where such projects were competing for funding at some point is likely. The Brownfield AHP attempts to define a non-traditional investment ranking under a potential scenario where several projects compete against one another for funding.

3.6.1 Data

All data used represents a snap shot in time for each of the projects. It is specifically noted that external factors such as government regulatory changes, additional optimisation or scope change could materially impact the evaluation of the projects from a discounted cash flow perspective. Any similarity or disconnect between the data presented in Project A, B and C when compared to any current operation as may be published in the media should be viewed as coincidental.

3.6.2 Model approach

The approach used in the generation of the Traditional Metrics (TM) project financial models was to:

- Use parameters common to each of the projects despite obvious differences (for example mining cost was modelled as a single input and did not differentiate between open pit and underground mining costs);
- Utilise outputs from the existing company project cost models such that the costs were imported into the TM project financial model as dollar values; and
- Utilise outputs from the existing company project models for physical parameters such as tonnes mined and ounces recovered.

By design the TM project financial model is high level and simplified. No attempt has been made to model complex financial instruments such as amortisation of the assets or interest on loans. It is acknowledged that such financial instruments can have a significant impact on the project valuations. Detailed financial modelling of projects is a discipline in its own right, and while the approach in this analysis is simplified and high level, the approach is consistent across all three projects. As such this renders the financial outputs comparable for the purposes of the AHP analysis.

The standard approach taken for all three TM models was:

1. Determine the country specific fiscal parameters including:
    a. Royalties;
    b. Taxation; and
    c. Company Country based Weighted Average Cost of Capital (WACC).
2. Utilization of a single gold price in all projects of $1250/oz;
3. Insert the project physical parameters;
4. Insert the project costs including:
    a. Operating costs; and
    b. Capital costs.
5. Determine revenue and Free Cash Flow;
6. Discount the cash flow and determine the values for the traditional project economic metrics:
    a. NPV;
    b. IRR; and
    c. Capital.

The financial models (Table 3-2, Table 3-3 and Table 3-4) are shown over a 15-year template for all three projects. When the life of the project is less than 15 years, empty columns are displayed.

3.6.3 Project models

Table 3-2 illustrates the summary of the TM model for Project A. Along with the traditional metrics of NPV, IRR and Capital, the model also calculates the All In Sustaining Cost (AISC) and Life Of Mine (LOM). The calculation of the additional elements has been done for use in the AHP model.

Table 3-2 Project A TM financial model

PROJECT A

Country Specific Fiscal Parameters	Unit	Value														
Royalty	%	6.00%														
Tax Rate	%	30.00%	30.00%	0.00%	0.00%	0.00%	0.00%	0.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%
NPV @ Country WACC	%	8.65%														
Gold Price	US$/oz	1250														

Physicals (Project ONLY)	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Tonnes Mined	T '000	14,925	28,751	28,799	32,153	31,512	31,989	31,593	33,370	26,660	18,754	16,771	3,296	-		
Ore Tonnes per Year (Treated)	T '000	-	-	4,520	7,101	7,200	7,200	7,200	7,221	7,200	7,200	7,200	7,221	708	-	-
Ounces per Year (Produced)	Oz '000			214	359	365	284	393	366	261	287	373	269	16		

Costs (Project ONLY)	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Processing Operating cost	$ '000			76,202	106,236	107,207	106,847	107,063	107,088	106,415	105,623	106,703	102,972	9,714		
Mining Operating cost	$ '000			80,883	91,896	89,083	91,956	94,996	93,028	73,869	60,191	112,379	25,632	524		
General and Andministrative costs	$ '000			32,150	32,150	32,150	32,150	32,150	32,150	32,150	32,150	32,150	12,860	3,215		
Sustaining Capital	$ '000			3,620	4,541	4,674	4,752	4,857	4,955	5,022	5,085	5,239	-	-	-	
Exploration Capital	$ '000															
Project Capital	$ '000	183,859	371,289	9,591												
Total Capital	$ '000	183,859	371,289	13,211	4,541	4,674	4,752	4,857	4,955	5,022	5,085	5,239	-	-	-	-
Royalties	$ '000	-	-	16,050	26,925	27,375	21,300	29,475	27,450	19,575	21,525	27,975	20,175	1,200	-	-

Investment Evaluation	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Revenue	$	-	-	267,500	448,750	456,250	355,000	491,250	457,500	326,250	358,750	466,250	336,250	20,000	-	-
Free Cash Flow before Tax	$	-183,859	-371,289	49,004	187,002	195,761	97,995	222,709	192,829	89,219	134,176	181,804	174,611	5,347	-	-
Tax	$	-	-	-	-	-	-	-	57,849	26,766	40,253	54,541	52,383	1,604	-	-
Free Cash Flow After Tax	$	-183,859	-371,289	49,004	187,002	195,761	97,995	222,709	134,980	62,453	93,923	127,262	122,228	3,743	-	-

NPV @ Country WACC	$ '000	239,733
IRR	%	18%

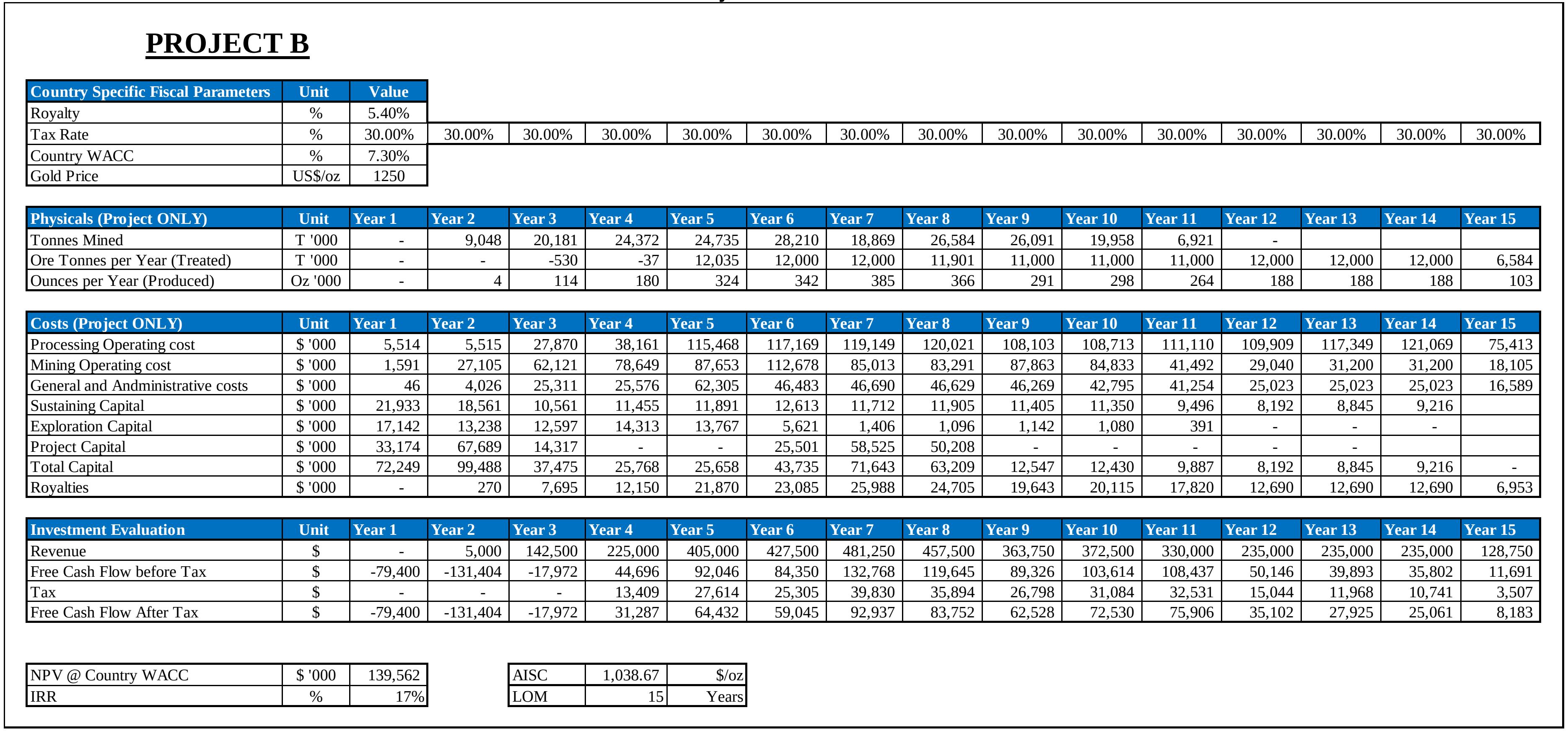
AISC	943.97	$/oz
LOM	11	Years

Project A has a number of project specific parameters which directly impact the valuation of the project. Such parameters include:

- A combined royalty of 6%, the highest of the three projects;
- Corporate tax break of 5 years commencing in the first year of production;
- Country WACC of 8.65%, the highest of the three projects; and
- No exploration capital – this is due to the fact that the deposit is extremely well drilled out and no exploration drilling is required for the execution of the project.

Table 3-3 illustrates the summary of the TM model for Project B. The TM model for each of the projects remains consistent despite the differences between the projects.

Table 3-3 Project B TM financial model



PROJECT B

Country Specific Fiscal Parameters	Unit	Value														
Royalty	%	5.40%														
Tax Rate	%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%
Country WACC	%	7.30%														
Gold Price	US$/oz	1250														

Physicals (Project ONLY)	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Tonnes Mined	T '000	-	9,048	20,181	24,372	24,735	28,210	18,869	26,584	26,091	19,958	6,921	-			
Ore Tonnes per Year (Treated)	T '000	-	-	-530	-37	12,035	12,000	12,000	11,901	11,000	11,000	11,000	12,000	12,000	12,000	6,584
Ounces per Year (Produced)	Oz '000	-	4	114	180	324	342	385	366	291	298	264	188	188	188	103

Costs (Project ONLY)	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Processing Operating cost	$ '000	5,514	5,515	27,870	38,161	115,468	117,169	119,149	120,021	108,103	108,713	111,110	109,909	117,349	121,069	75,413
Mining Operating cost	$ '000	1,591	27,105	62,121	78,649	87,653	112,678	85,013	83,291	87,863	84,833	41,492	29,040	31,200	31,200	18,105
General and Andministrative costs	$ '000	46	4,026	25,311	25,576	62,305	46,483	46,690	46,629	46,269	42,795	41,254	25,023	25,023	25,023	16,589
Sustaining Capital	$ '000	21,933	18,561	10,561	11,455	11,891	12,613	11,712	11,905	11,405	11,350	9,496	8,192	8,845	9,216	
Exploration Capital	$ '000	17,142	13,238	12,597	14,313	13,767	5,621	1,406	1,096	1,142	1,080	391	-	-	-	
Project Capital	$ '000	33,174	67,689	14,317	-	-	25,501	58,525	50,208	-	-	-	-	-		
Total Capital	$ '000	72,249	99,488	37,475	25,768	25,658	43,735	71,643	63,209	12,547	12,430	9,887	8,192	8,845	9,216	-
Royalties	$ '000	-	270	7,695	12,150	21,870	23,085	25,988	24,705	19,643	20,115	17,820	12,690	12,690	12,690	6,953

Investment Evaluation	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Revenue	$	-	5,000	142,500	225,000	405,000	427,500	481,250	457,500	363,750	372,500	330,000	235,000	235,000	235,000	128,750
Free Cash Flow before Tax	$	-79,400	-131,404	-17,972	44,696	92,046	84,350	132,768	119,645	89,326	103,614	108,437	50,146	39,893	35,802	11,691
Tax	$	-	-	-	13,409	27,614	25,305	39,830	35,894	26,798	31,084	32,531	15,044	11,968	10,741	3,507
Free Cash Flow After Tax	$	-79,400	-131,404	-17,972	31,287	64,432	59,045	92,937	83,752	62,528	72,530	75,906	35,102	27,925	25,061	8,183

NPV @ Country WACC	$ '000	139,562
IRR	%	17%

AISC	1,038.67	$/oz
LOM	15	Years

Project B has a number of project specific parameters which directly impact the valuation of the project. Such parameters include:

- A combined royalty of 5.4%;
- No corporate tax break;
- Country WACC of 7.3%, the lowest of the three projects; and
- Significant exploration capital reflecting significant geological uncertainty.

Table 3-4 illustrates the summary of the TM model for Project C. Despite the fact that this is an underground project, the TM has been constructed in such a manner that the inputs remain consistent.

Table 3-4 Project C TM financial model

PROJECT C

Country Specific Fiscal Parameters	**Unit**	**Value**														
Royalty	%	4.00%														
Tax Rate	%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%
Country WACC	%	7.50%														
Gold Price	US$/oz	1250														

Physicals (Project ONLY)	**Unit**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Tonnes Mined	T '000	156	284	155	133	230										
Ore Tonnes per Year (Treated)	T '000	156	284	155	133	230										
Ounces per Year (Produced)	Oz '000	23	50	32	30	54										

Costs (Project ONLY)	**Unit**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Processing Operating cost	$ '000	3,200	5,622	2,996	2,612	4,651										
Mining Operating cost	$ '000	35,622	41,096	24,798	24,899	18,313										
General and Andministrative costs	$ '000	2,678	4,903	2,707	2,190	3,790										
Sustaining Capital	$ '000	288	649	426	390	715										
Exploration Capital	$ '000	-	-	-	-	-										
Project Capital	$ '000	7,481	2,000	-	-	-										
Total Capital	$ '000	7,769	2,649	426	390	715										
Royalties	$ '000	1,129	2,503	1,619	1,476	2,702										

Investment Evaluation	**Unit**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Revenue	$	28,228.72	62,585	40,472	36,908	67,558	-	-	-	-	-	-	-	-	-	-
Free Cash Flow before Tax	$	-22,169	5,812	7,927	5,339	37,387	-	-	-	-	-	-	-	-	-	-
Tax	$	-	1,744	2,378	1,602	11,216	-	-	-	-	-	-	-	-	-	-
Free Cash Flow After Tax	$	-22,169	4,069	5,549	3,738	26,171	-	-	-	-	-	-	-	-	-	-

NPV @ Country WACC	$ '000	8,393
IRR	%	20%

AISC	1,068.15	$/oz
LOM	5	Years

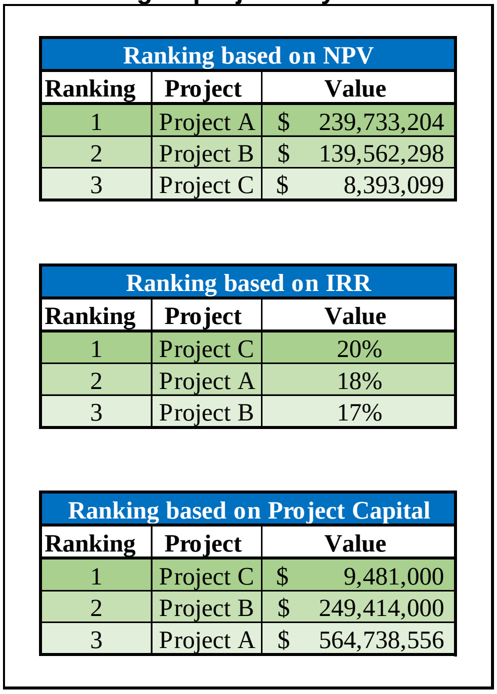
Project C has a number of project specific parameters which directly impact the valuation of the project. Such parameters include:

- A combined royalty of 4%, the lowest of the three projects;
- No corporate tax break;
- Country WACC of 7.5%; and
- Exploration costs captured within the mining costs.

3.6.4 TM model outcomes

The traditional financial metrics of NPV, IRR and capital were used to rank the three projects. As noted in Table 3-5, the differences in NPV of the three projects are significant, with Project A clearly delivering maximum value. The IRR is not significantly different between the three projects, however, Project C which is a shorter life project does deliver the best rate of return. The ranking of Capital is the inverse ranking of the NPV.

Table 3-5 Ranking of projects by traditional metrics



Ranking based on NPV

Ranking	Project	Value
1	Project A	$ 239,733,204
2	Project B	$ 139,562,298
3	Project C	$ 8,393,099

Ranking based on IRR

Ranking	Project	Value
1	Project C	20%
2	Project A	18%
3	Project B	17%

Ranking based on Project Capital

Ranking	Project	Value
1	Project C	$ 9,481,000
2	Project B	$ 249,414,000
3	Project A	$ 564,738,556

It is noted that all projects present positive returns and would garner significant support for approval in most mining companies. Given the great significance placed on long term value, coupled with high levels of geological confidence as shown in the exploration capital and under the assumption that the capital is available, Project A is likely to be ranked as the best investment opportunity. The project ranked second is likely to be Project B. Project B is ranked last in IRR, and second in both other categories. Significant geological uncertainty is reflected in the exploration budgets for both Project B and Project C. With a longer life of mine Project B is likely to be able to withstand geological uncertainty better than the shorter life Project C. Project C is ranked third. Based on this analysis, Table 3-6 represents a ranking of the projects based on traditional discounted cashflow metrics.

Table 3-6 Combined final ranking of projects

Ranking	Project
1	Project A
2	Project B
3	Project C

3.7 Chapter Summary

Three projects were selected for research analysis. To retain company confidentiality, the projects are referred to as Project A, Project B and Project C. The projects were selected as typical Brownfield mining projects competing for capital investment. The projects are all in Africa, however they are all in different countries, and as such different social, economic, environmental and legislative regimes are applicable. The projects have significantly varying timelines and investment requirements.

Project A creates sulphide ore (hard ore) processing capacity at an existing soft ore mine in West Africa. The processing of hard rock ore requires additional tailings storage capacity and an alternative power supply sought through the national power grid. The investment requirement is $550M.

Project B is a $111M investment in West Africa. The execution of the project will create hard rock processing capability at the existing soft rock processing facility. The project extends the life of the mine by approximately 6 years.

Project C in East Africa is currently an open pit mining operation. Underground mining has recently commenced and targets high margin underground ounce production. Successful exploration work has identified a second underground mining opportunity under the primary open pit at the operation. A modest $9.4M investment is required for the infrastructure and waste development associated with the creation of new portals to access this underground ore. Key attributes of each project are shown in Table 3-7.

Table 3-7 Project A, B and C attribute summary

Parameter	Project A	Project B	Project C
Project Type	Brownfield	Brownfield	Brownfield
Location	West Africa	West Africa	East Africa
Holding company	Joint-Venture	Joint-Venture	Single Shareholder
Infrastructure Type	Processing plant Upgrade	Processing plant Upgrade	Underground Development
Capital	$564M	$249M	$9.4M
Mining	Open Pit	Open Pit	Underground and Open Pit
Geology Understanding	Excellent	Moderate	Moderate/poor
Life Of Mine	11 yrs	15yrs	5yrs

A traditional DCF based financial model was developed for the analysis of the three projects under consideration. Utilising this standardised approach, the data for each project was incorporated into the model. Country specific tax regimes and royalties were included into the models and a suite of outputs including NPV and IRR were calculated, these outputs are ranked in Table 3-8.

Table 3-8 Ranking of projects by traditional metrics

	NPV Ranking	IRR Ranking	Capital Ranking
Project A	1	2	3
Project B	2	3	2
Project C	3	1	1

Project C is attractive from a capital perspective as it has the lowest capital requirement. Project A and Project B consistently ranked as first and second in the NPV and IRR comparison. Based on the importance placed on NPV and IRR, the overall ranking of the projects utilising traditional metrics and a DCF approach was determined to be:

1. Project A
2. Project B
3. Project C

4 ANALYTIC HIERARCHY PROCESS APPLICATION TO CASE STUDY PROJECTS

Having selected the analytic hierarchy process (AHP) and analysed the three available projects, this chapter applied the AHP process to the three projects. The population of criteria and sub-criteria was developed from corporate mining strategies and operational metrics. The available data was incorporated into the AHP and pairwise comparisons (weighting) of the criteria was completed. The results of the AHP are presented and analysed. In order to gain a deeper insight into the data and methodology, two hypothetical scenarios are considered.

4.1 AHP Level 1 selection

In order to select criteria for the AHP comparison, three relatively large but comparable companies were sought. The criteria of total ounces produced in 2016 (as published in the respective annual reports) was used to determine the top three gold producers. On this basis, the top three companies are Barrick Gold Corporation, Newmont Mining Corporation and AngloGold Ashanti Pty Ltd as illustrated in Table 4-1.

Table 4-1 Largest gold producing companies in 2016

Ranking	Company	2016 Production (Moz)
1	Barrick Gold Corporation	5.5
2	Newmont Mining Corporation	4.9
3	AngloGold Ashanti Pty Ltd.	3.6

Each of the three selected companies publish annual reports on which the analysis of common company values for the use in AHP was based. Barrick Gold Corporation states its “Vision”, Newmont Mining Corporation states its “Purpose” while AngloGold Ashanti Pty Ltd states its “Mission”. For the determination and selection of criteria for the Level 1 AHP, the words “vision”, “purpose”, and “mission” are deemed to essentially state the respective company strategies.

It is noted that the interpretation of a strategy specifically in an attempt to categorise metrics is subjective in nature. The absence or presence of a specific interpreted metric in the company statements should not be interpreted as a lack of such a metric in the strategy of the organisation but rather the subjective interpretation of a high-level strategy statement only.

4.1.1 Barrick Gold Corporation

Ranked the top gold producer in 2016, Barrick Gold Corporation in their 2016 annual report stated that "*Our Vision is the generation of wealth through responsible mining – wealth for our owners, our people, and the countries and communities with which we partner. We aim to be the leading mining company focused on gold, growing our cash flow per share by developing and operating high-quality assets through disciplined allocation of human and financial capital and operational excellence*." (Barrick Gold Corporation, 2017).

The strategy as outlined above speaks to traditional project metrics such as NPV, IRR and capital through the use of phrases such as:

- "generation of wealth"; and
- "growing cash flow".

The Barrick Gold Corporation strategy could also be interpreted to place a degree of importance on other metrics such as:

- Safety – phrases such as "responsible mining" support this;
- Resource - phrases such as "developing … high quality assets" support this;
- Community / Sustainability - phrases such as "wealth for … communities with which we partner" support this; and
- Operations - phrases such as "operational excellence" support this.

4.1.2 Newmont Mining Corporation

Ranked the second gold producer in 2016, Newmont Mining Corporation in their 2016 annual report stated that their Purpose and Values *"is to create value and improve lives through sustainable and responsible mining.*

Safety − We take care of our safety, health and wellness by recognizing, assessing and managing risk, and choosing safer behaviours at work and home to reach our goal of zero harm.

Integrity − We behave ethically and respect each other and the customs, cultures and laws wherever we operate.

Sustainability −We serve as a catalyst for local economic development through transparent and respectful stakeholder engagement, and as responsible stewards of the environment.

Inclusion − We create an inclusive environment where employees have the opportunity to contribute, develop and work together to deliver our strategy.

Responsibility- We deliver on our commitments, demonstrate leadership, and have the courage to speak up and challenge the status quo."(Newmont Mining Corporation, 2016)

The strategy as outlined above speaks to traditional project metrics such as NPV, IRR and Capital through the use of phrases such as:

- "Create value"; and
- "growing cash flow".

The Newmont Mining Corporation strategy either directly states or infers a degree of importance on other metrics such as:

- Safety – Specifically stated;
- Integrity – Specifically stated;

- Resource - phrases such as “sustainable mining” supports a strategy of continued exploration and responsible use of the resources;
- Community / Sustainability - phrases such as “respectful stakeholder engagement, and as responsible stewards of the environment” support this;
- Operations - phrases such as “deliver on our commitments, demonstrate leadership, and have the courage to speak up and challenge the status quo” although noted as “responsibility, would certainly support an operational excellence intent; and
- Inclusion – Specifically stated.

4.1.3 AngloGold Ashanti

Ranked the third gold producer in 2016, AngloGold Ashanti Pty Ltd. in their 2016 annual integrated report stated that their mission is *“To create value for our shareholders, our employees and our business and social partners through safely and responsibly exploring, mining and marketing our products. Our primary focus is gold, but we will pursue value creating opportunities in other minerals where we can leverage our existing assets, skills and experience to enhance the delivery of value.”* (AngloGold Ashanti, 2017b).

The strategy as outlined above speaks to traditional project metrics such as NPV, IRR and capital through the use of phrases such as:

- “Create Value”.

The AngloGold Ashanti strategy infers a degree of importance on other metrics such as:

- Safety – phrases such as “safely and responsibly exploring, mining and marketing our products” support this;
- Resource - phrases such as “we will pursue value creating opportunities” supports a strategy of continued exploration;
- Community / Sustainability - phrases such as “To create value for …our … social partners” support this; and

- Operations - phrases such as “responsibly exploring, mining” support an operational excellence intent.

4.1.4 Selection of Level 1 AHP

The values expressed in the company strategies are interpreted to define the value system for all major decisions within the company, as such the selection of these values as the level 1 criteria is appropriate. In order to select the most appropriate Level 1 criteria (or metric) for the AHP comparison, the interpreted metrics were placed in a matrix and cross referenced for commonality. The matrix of results is illustrated in Table 4-2.

.

Table 4-2 Matrix of common metrics within company strategies

Value	**Barrick Gold Corp.**	**Newmont Mining Corp**	**AngloGold Ashanti Pty Ltd**
Community / Sustainability	✓	✓	✓
Inclusion	X	✓	X
Integrity	X	✓	X
Operations	✓	✓	X
Resource	✓	X	✓
Traditional Metrics	✓	✓	✓
Safety	✓	✓	✓

Where ✓ = Metric Present and **X** = Metric not noted.

Of key importance in the determination of categories for use in the AHP was the availability of appropriate data to be used in the scoring of sub-criteria. The criterion of community/sustainability was interpreted to be a common metric within the strategies of the three companies. This category has been put into the AHP as a Level 1 metric. Given the locally based workforce at most operations, safety is arguably a sub-criteria of the community / sustainability metric, and has been modelled as such. The analysis of the company strategies identified four common metrics or values as shown in Table 4-3. These metrics have been selected as the Level 1 of the AHP process. The Level 1 Brownfield project ranking AHP is thus illustrated in Figure 4-1.

Table 4-3 Common metrics (values) in the company strategies

Traditional Metrics
Sustainability
Resource
Operations

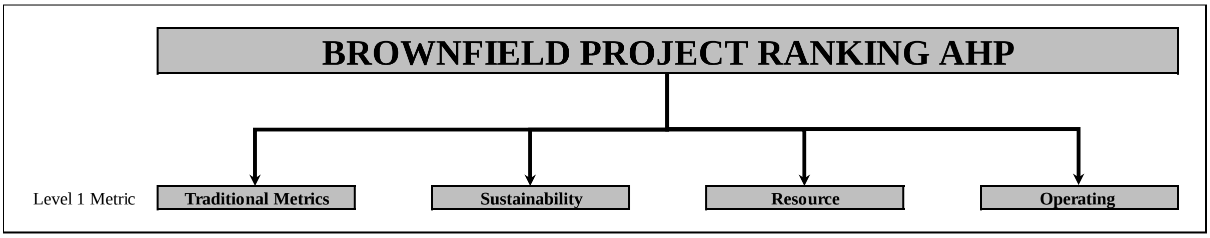


Figure 4-1 Brownfield AHP Level 1

4.2 Selection of AHP sub-criteria

Through careful but subjective analysis of the company strategies, four Level 1 criteria were selected. The selection of sub-criteria under each level 1 criterion, with (preferably) objective values adds a depth of understanding of the level 1 criterion attributes which can then be scored and weighted in the AHP process. As a preference the sub-criteria selected reflect industry wide norms and data commonly published in annual reports or similar publicly available company data.

4.2.1 Traditional metrics

Brownfield mining projects typically report a large number of metrics when applying for funding. There are three parameters which encompass most economic (traditional) aspects of projects and were thus selected for use as the three sub-criteria in the Traditional Metrics category:

1. **Net Present Value** (NPV) which is a reflection of the total project value in today’s terms based on a discounted cash flow;
2. **Internal Rate of Return** which is a measure of the rate of return; it measures the profitability of a venture; and
3. **Capital** as measured by the profitability index (PI) which measures the relationship between capital and future benefit. The index is calculated by dividing the NPV by the

capital cost, the greater the value the better the PI. The PI is therefore related to the NPV but provides an indication of value generated per unit of investment at a specific hurdle rate (the discount rate applied in the NPV calculation). This is of particular value when the absolute NPV values vary significantly.

While there are a number of additional metrics (such as capital payback) that are often presented when applying for the approval of a Brownfield mining project, none are more common nor more encompassing than the three selected criteria. The Brownfield project AHP with sub-criteria for traditional metrics assigned is illustrated in Figure 4-2.

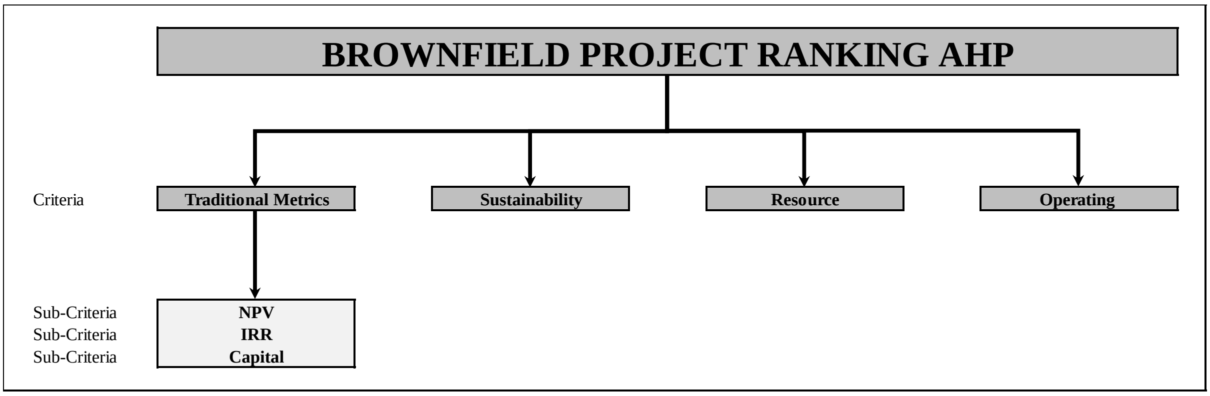


Figure 4-2 Brownfield project AHP with sub-criteria for traditional metrics assigned

4.2.2 Sustainability metrics

There exists two industry wide accepted metrics to measure safety:

- All injury frequency rate (AIFR); and
- Number of fatalities.

All injury frequency rate is defined as the total number of injuries and fatalities that occur per million hours worked. This metric is widely reported in company publications. The lower this value the better the operation is performing from a safety perspective. Number of fatalities defines the number of fatalities that occur at a mining operation within the year of reporting. As with the AIFR this metric is widely reported in company publications, again, the lower the value, the better the safety performance.

Based on their wide use and reporting, AIFR and fatalities were selected as the first two sub-criteria for the Safety metric. A Brownfield project would not commonly report such metrics prior to execution. With ranking of projects occurring prior to execution (thus prior to the reporting of project based AIFR and fatalities) the projects assume the values of the current operations. This is based on the understanding that the existing management team would ultimately operate the project and thus can be expected to achieve similar AIFR and fatalities values.

“Social license to operate” is selected as the third sub-criteria for the sustainability metric. As with the other sub-criteria in the sustainability metric, social license will be a reflection of the current operation. In order to assign a value to this sub-criterion, data published in annual sustainability reports was analysed. A value derived from an equal combination of the greenhouse emissions on a tonne treated basis (effectively representing commitment to the environment) and community investment on a tonne treated basis. The Brownfield project AHP with sub-criteria for safety metrics assigned is shown in Figure 4-3.

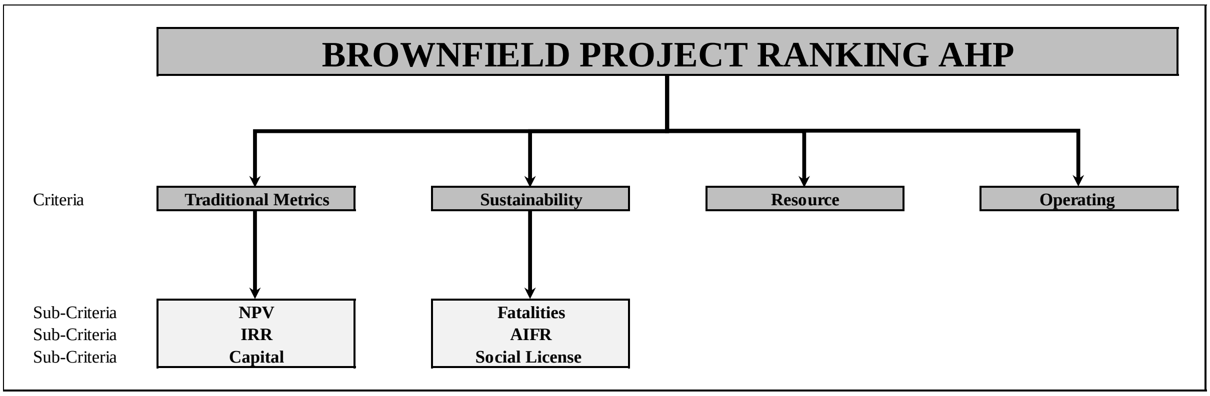


Figure 4-3 Brownfield project AHP with sub-criteria for sustainability metrics assigned

4.2.3 Resource metrics

The resource metric explores the value that a company potentially places on the exploitation and development of the Mineral Resources and Mineral Reserves in the context of the project. The following parameters were selected as representative of the resource metric:

- Life of mine;
- Resource category; and

- Gold grade.

The life of mine as defined in the project is an important sub-criterion as this defines the longevity of the project under current economic assumptions. Since it is desirable to present long term stability in a company, a longer life of mine is desirable.

The Mineral Resource category is a reflection of the geological confidence in a particular deposit. From a project perspective, the greater the volume of material in the measured or indicated categories, the greater the confidence in the project. Therefore, the higher this number, the more desirable.

Gold grade is an important metric for the resource category. A higher gold grade is desirable. The Brownfield project AHP with sub-criteria for resource metrics assigned is shown in Figure 4-4.

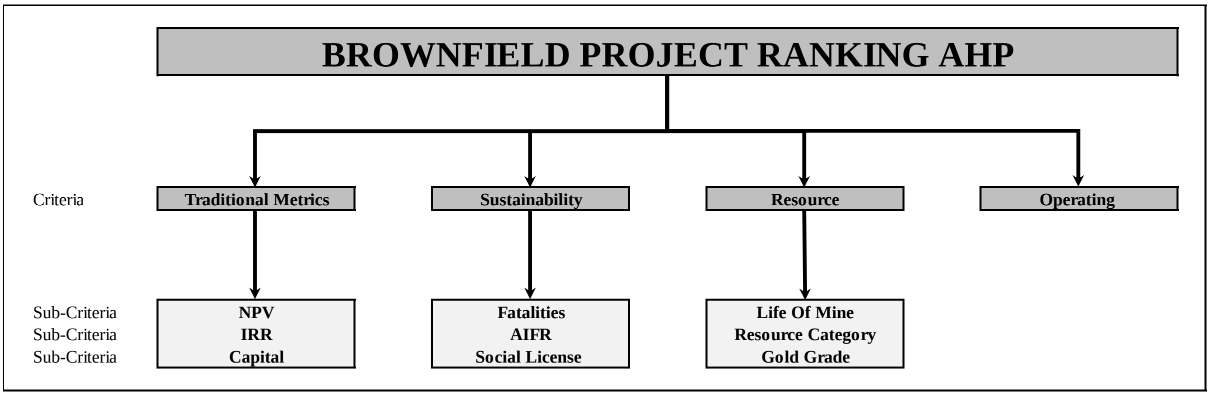


Figure 4-4 Brownfield project AHP with sub-criteria for resource metrics assigned

4.2.4 Operating metrics

Annual ounce production is a metric which is used to compare mining companies. The higher the annual production of a Brownfield project the more desirable the project. Ounce production is selected as one of the operating metric sub-criteria.

The World Gold Council (WGC), published a guidance note on the “all-in sustaining costs (AISC)’’ metric which gold mining companies can use to report their costs as part of their overall reporting disclosure. “All-in sustaining costs’’ incorporates all costs related to sustaining production and recognises the sustaining capital expenditures associated with developing and maintaining gold mining operations. In addition, this metric includes the cost associated with the corporate office structures that support these operations, the community and rehabilitation costs attendant on responsible mining and any exploration and evaluation costs associated with sustaining current operations (Heymann & Gold, 2014). The AISC ($/oz) is determined by adding all the aforementioned costs in USD terms divided by the ounces of gold sold. AISC is a key operational parameter used to rank mining operations and has been selected as a sub-criterion in the operating metric.

Productivity is defined as an expression of labour productivity based on the ratio of ounces of gold produced per month to the total number of employees in mining operations (AngloGold Ashanti 2017b). Productivity is a key operational parameter and has been selected as a sub-criterion in the operating metric. The Brownfield project AHP with all sub-criteria metrics assigned is shown in Figure 4-5.

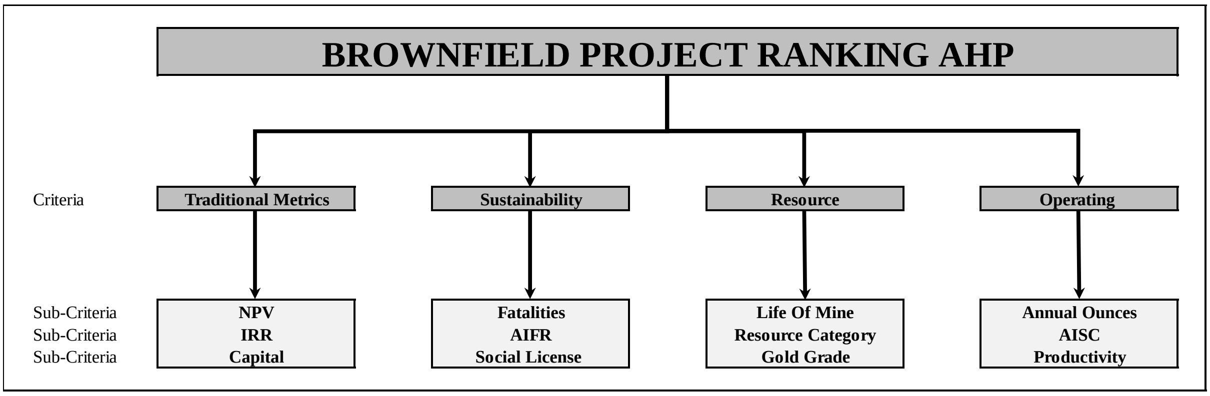


Figure 4-5 Brownfield project AHP with all sub-criteria metrics assigned

4.3 AHP model

In order to undertake the AHP analysis for the ranking of Brownfield mining projects, a Microsoft Excel AHP model was built on the principles outlined by Saaty (1987). The modelling process can be outlined in the following steps:

1. The problem is modelled as a hierarchy (Figure 4-6), containing the goal, criteria, sub-criteria and the alternatives as outlined in the data above;

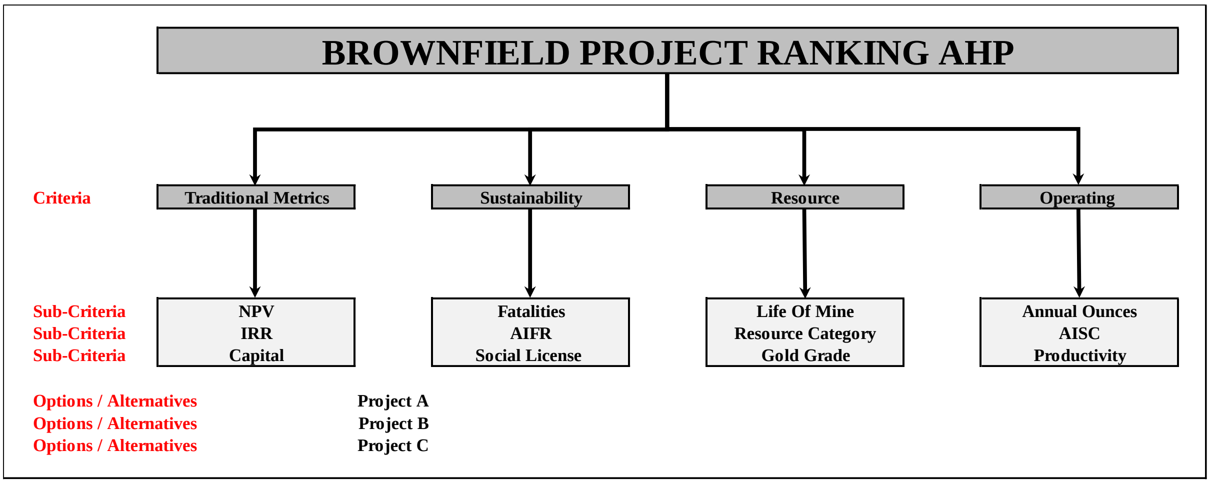


Figure 4-6 Brownfield project ranking hierarchy

2. A series of pairwise comparisons are undertaken for the criteria and within the sub-criteria;
3. Combine the results of the pairwise comparison to determine the overall priorities for the AHP
4. Ensure that there is consistency in the pairwise comparison;
5. Apply the relevant data to the sub-criteria and using the overall priorities, determine a score for each of the projects (alternatives) considered; and
6. Rank the Projects accordingly.

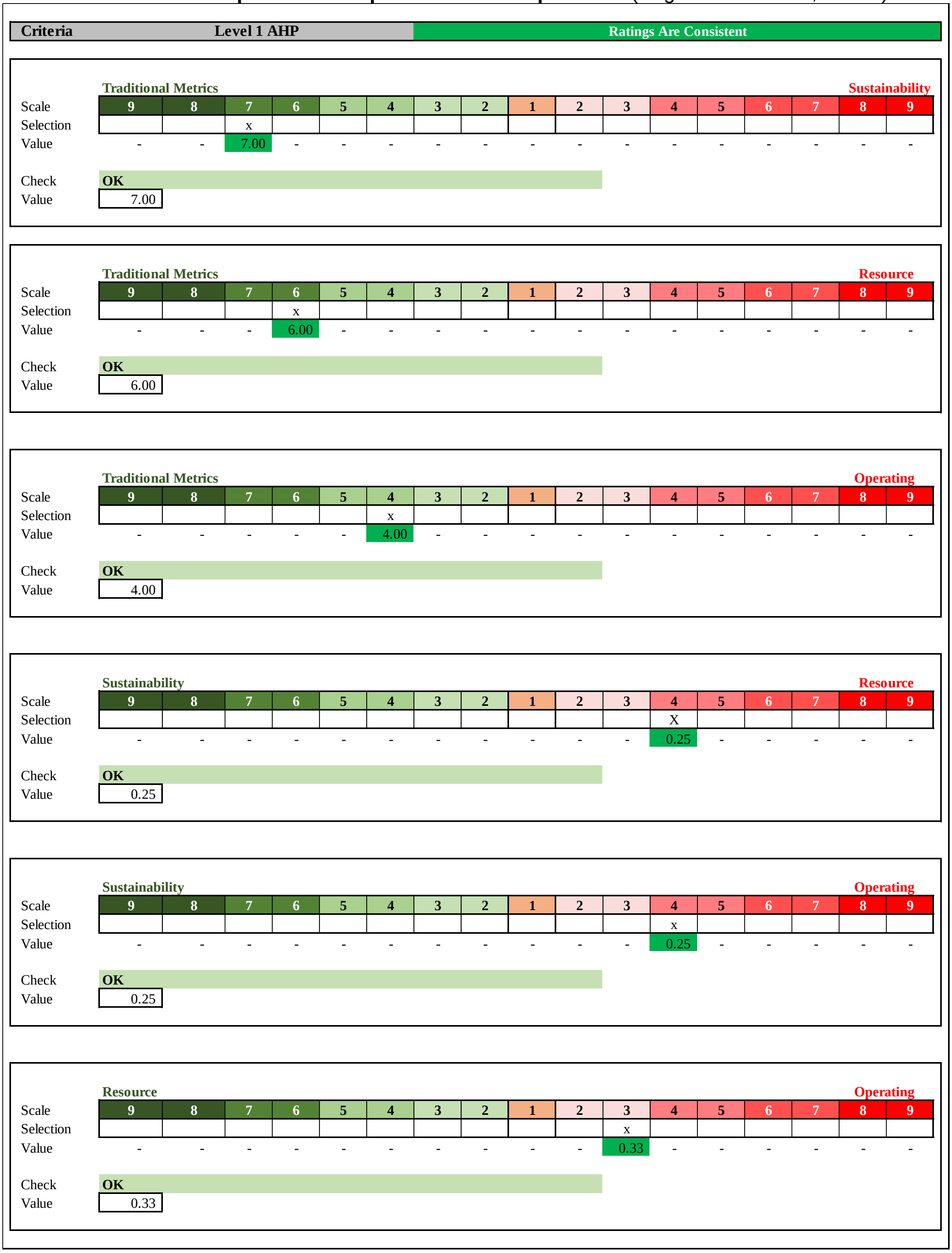
4.4 Pairwise comparison

In support of the research process and with specific reference to developing a working example of the AHP process within the mining environment, AngloGold Ashanti (AGA) held a workshop with relevant experts within the organisation. The experts are representative of all key stakeholders within the company in the context of making investment decisions, they are not representative of external interested parties such as communities or governments who would have potentially conflicting values at the first level of the AHP. As detailed in the *AGA AHP Workshop Meeting*, (2017), the pairwise comparisons were completed on the AHP model developed in this research project. The workshop facilitator ensured that the selections remained consistent throughout.

- Table 4-4 adapted from the *AGA AHP Workshop Meeting*, (2017) illustrate the results of the Level 1 pairwise comparison that will be used in the AHP model. The results and the calculation of the consistency index, consistency ratio and eigenvector are shown in Table 4-5 and Table 4-6.

- Table 4-7 adapted from the *AGA AHP Workshop Meeting*, (2017) illustrate the results of the Traditional Metrics pairwise comparison that will be used in the AHP model. The results and the calculation of the consistency index, consistency ratio and eigenvector are shown in Table 4-8 and Table 4-9.
- Table 4-10 adapted from the *AGA AHP Workshop Meeting*, (2017) illustrate the results of the Sustainability pairwise comparison that will be used in the AHP model. The results and the calculation of the consistency index, consistency ratio and eigenvector are shown in Table 4-11 and Table 4-12.
- Table 4-13 adapted from the *AGA AHP Workshop Meeting*, (2017) illustrate the results of the Resource pairwise comparison that will be used in the AHP model. The results and the calculation of the consistency index, consistency ratio and eigenvector are shown in Table 4-14 and Table 4-15.
- Table 4-16 adapted from the *AGA AHP Workshop Meeting*, (2017) illustrate the results of the Operating pairwise comparison that will be used in the AHP model. The results and the calculation of the consistency index, consistency ratio and eigenvector are shown in Table 4-17 and Table 4-18.

Table 4-4 Level 1 pairwise comparison workshop results (AngloGold Ashanti, 2017a)



Criteria	Level 1 AHP	Ratings Are Consistent

	Traditional Metrics																Sustainability
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection			x														
Value	-	-	7.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	7.00																

	Traditional Metrics																Resource
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	6.00																

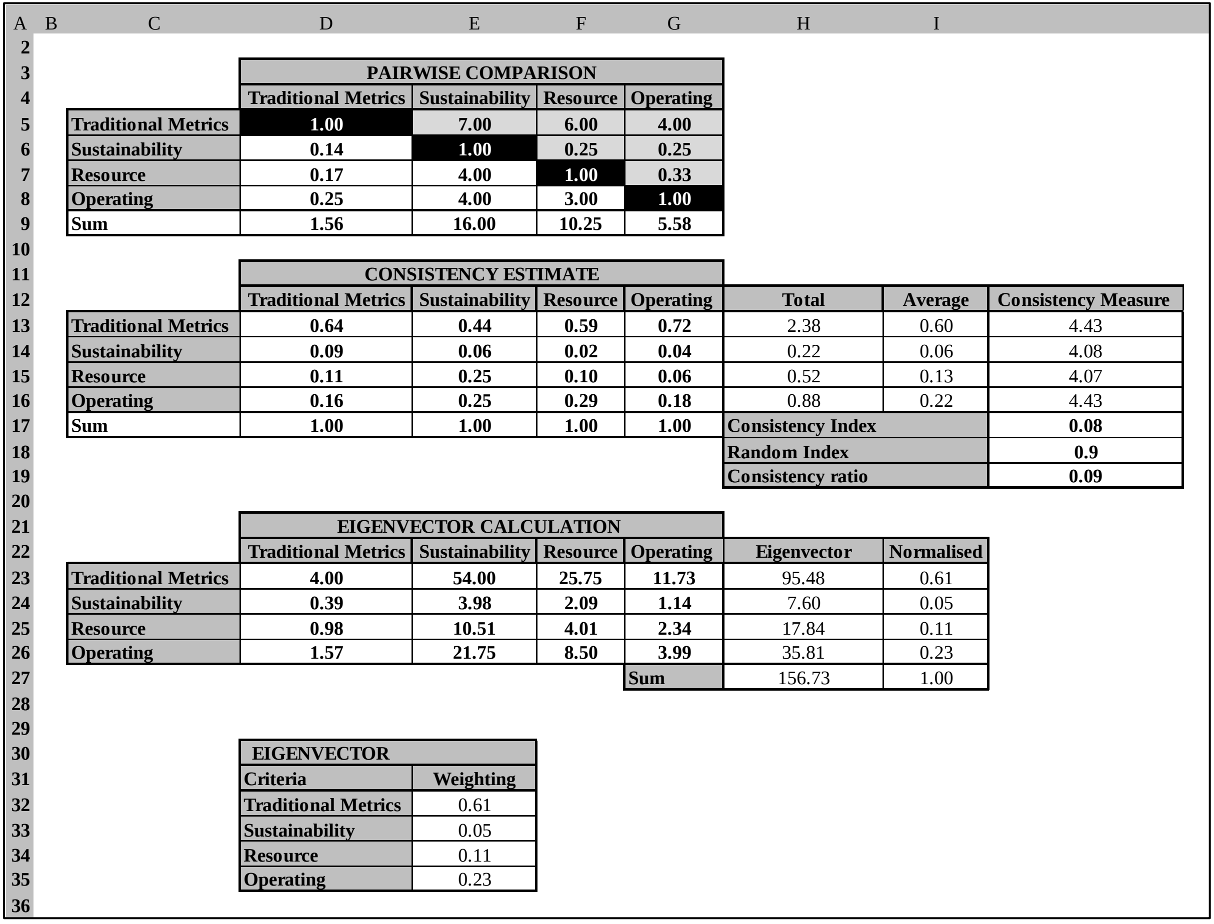
	Traditional Metrics																Operating
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection						x											
Value	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	4.00																

	Sustainability																Resource
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												X					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-
Check	OK																
Value	0.25																

	Sustainability																Operating
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-
Check	OK																
Value	0.25																

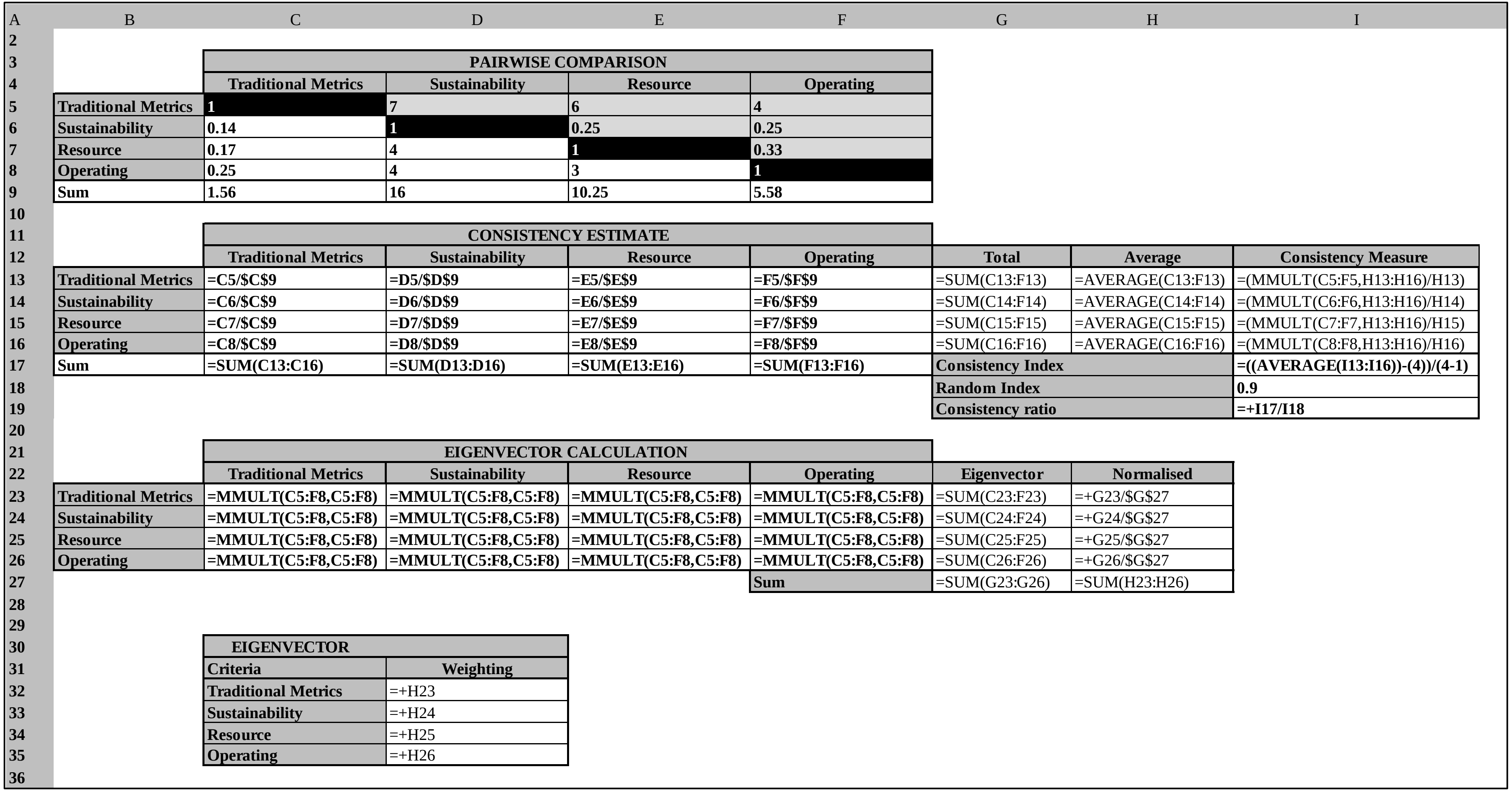
	Resource																Operating
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection											x						
Value	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	-	-
Check	OK																
Value	0.33																

Table 4-5 Level 1 calculation of consistency index and eigenvector



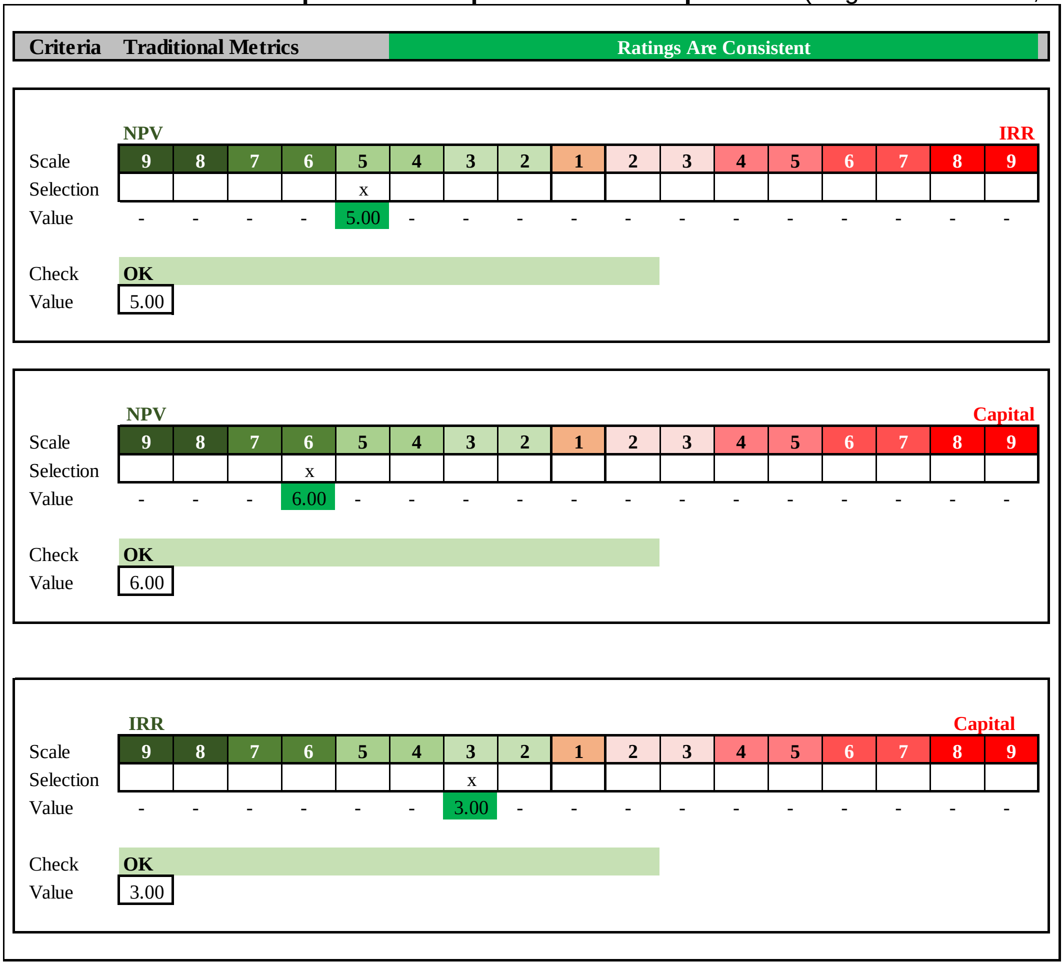
A	B	C	D	E	F	G	H	I	
2									
3			PAIRWISE COMPARISON						
4			Traditional Metrics	Sustainability	Resource	Operating			
5		Traditional Metrics	1.00	7.00	6.00	4.00			
6		Sustainability	0.14	1.00	0.25	0.25			
7		Resource	0.17	4.00	1.00	0.33			
8		Operating	0.25	4.00	3.00	1.00			
9		Sum	1.56	16.00	10.25	5.58			
10									
11			CONSISTENCY ESTIMATE						
12			Traditional Metrics	Sustainability	Resource	Operating	Total	Average	Consistency Measure
13		Traditional Metrics	0.64	0.44	0.59	0.72	2.38	0.60	4.43
14		Sustainability	0.09	0.06	0.02	0.04	0.22	0.06	4.08
15		Resource	0.11	0.25	0.10	0.06	0.52	0.13	4.07
16		Operating	0.16	0.25	0.29	0.18	0.88	0.22	4.43
17		Sum	1.00	1.00	1.00	1.00	Consistency Index		0.08
18							Random Index		0.9
19							Consistency ratio		0.09
20									
21			EIGENVECTOR CALCULATION						
22			Traditional Metrics	Sustainability	Resource	Operating	Eigenvector	Normalised	
23		Traditional Metrics	4.00	54.00	25.75	11.73	95.48	0.61	
24		Sustainability	0.39	3.98	2.09	1.14	7.60	0.05	
25		Resource	0.98	10.51	4.01	2.34	17.84	0.11	
26		Operating	1.57	21.75	8.50	3.99	35.81	0.23	
27						Sum	156.73	1.00	
28									
29									
30			EIGENVECTOR						
31			Criteria	Weighting					
32			Traditional Metrics	0.61					
33			Sustainability	0.05					
34			Resource	0.11					
35			Operating	0.23					
36									

Table 4-6 Level 1 consistency index and eigenvector formulas



A	B	C	D	E	F	G	H	I
2								
3		**PAIRWISE COMPARISON**						
4		**Traditional Metrics**	**Sustainability**	**Resource**	**Operating**			
5	**Traditional Metrics**	**1**	**7**	**6**	**4**			
6	**Sustainability**	**0.14**	**1**	**0.25**	**0.25**			
7	**Resource**	**0.17**	**4**	**1**	**0.33**			
8	**Operating**	**0.25**	**4**	**3**	**1**			
9	**Sum**	**1.56**	**16**	**10.25**	**5.58**			
10								
11		**CONSISTENCY ESTIMATE**						
12		**Traditional Metrics**	**Sustainability**	**Resource**	**Operating**	**Total**	**Average**	**Consistency Measure**
13	**Traditional Metrics**	**=C5/$C$9**	**=D5/$D$9**	**=E5/$E$9**	**=F5/$F$9**	=SUM(C13:F13)	=AVERAGE(C13:F13)	=(MMULT(C5:F5,H13:H16)/H13)
14	**Sustainability**	**=C6/$C$9**	**=D6/$D$9**	**=E6/$E$9**	**=F6/$F$9**	=SUM(C14:F14)	=AVERAGE(C14:F14)	=(MMULT(C6:F6,H13:H16)/H14)
15	**Resource**	**=C7/$C$9**	**=D7/$D$9**	**=E7/$E$9**	**=F7/$F$9**	=SUM(C15:F15)	=AVERAGE(C15:F15)	=(MMULT(C7:F7,H13:H16)/H15)
16	**Operating**	**=C8/$C$9**	**=D8/$D$9**	**=E8/$E$9**	**=F8/$F$9**	=SUM(C16:F16)	=AVERAGE(C16:F16)	=(MMULT(C8:F8,H13:H16)/H16)
17	**Sum**	**=SUM(C13:C16)**	**=SUM(D13:D16)**	**=SUM(E13:E16)**	**=SUM(F13:F16)**	**Consistency Index**		**=((AVERAGE(I13:I16))-(4))/(4-1)**
18						**Random Index**		**0.9**
19						**Consistency ratio**		**=+I17/I18**
20								
21		**EIGENVECTOR CALCULATION**						
22		**Traditional Metrics**	**Sustainability**	**Resource**	**Operating**	**Eigenvector**	**Normalised**	
23	**Traditional Metrics**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	=SUM(C23:F23)	=+G23/$G$27	
24	**Sustainability**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	=SUM(C24:F24)	=+G24/$G$27	
25	**Resource**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	=SUM(C25:F25)	=+G25/$G$27	
26	**Operating**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	**=MMULT(C5:F8,C5:F8)**	=SUM(C26:F26)	=+G26/$G$27	
27					**Sum**	=SUM(G23:G26)	=SUM(H23:H26)	
28								
29								
30		**EIGENVECTOR**						
31		**Criteria**	**Weighting**					
32		**Traditional Metrics**	=+H23					
33		**Sustainability**	=+H24					
34		**Resource**	=+H25					
35		**Operating**	=+H26					
36								

Table 4-7 Traditional metrics pairwise comparison workshop results (AngloGold Ashanti, 2017a)



Criteria **Traditional Metrics** **Ratings Are Consistent**

	NPV																IRR
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection					x												
Value	-	-	-	-	5.00	-	-	-	-	-	-	-	-	-	-	-	-

Check **OK**

Value 5.00

	NPV																Capital
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Check **OK**

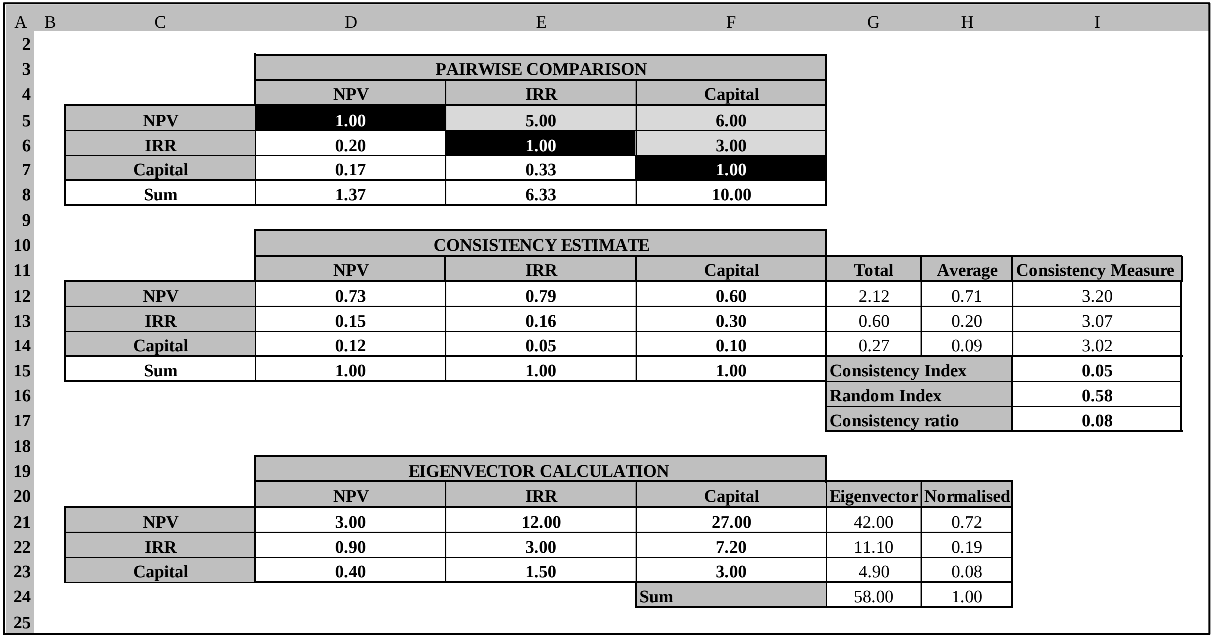
Value 6.00

	IRR																Capital
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection							x										
Value	-	-	-	-	-	-	3.00	-	-	-	-	-	-	-	-	-	-

Check **OK**

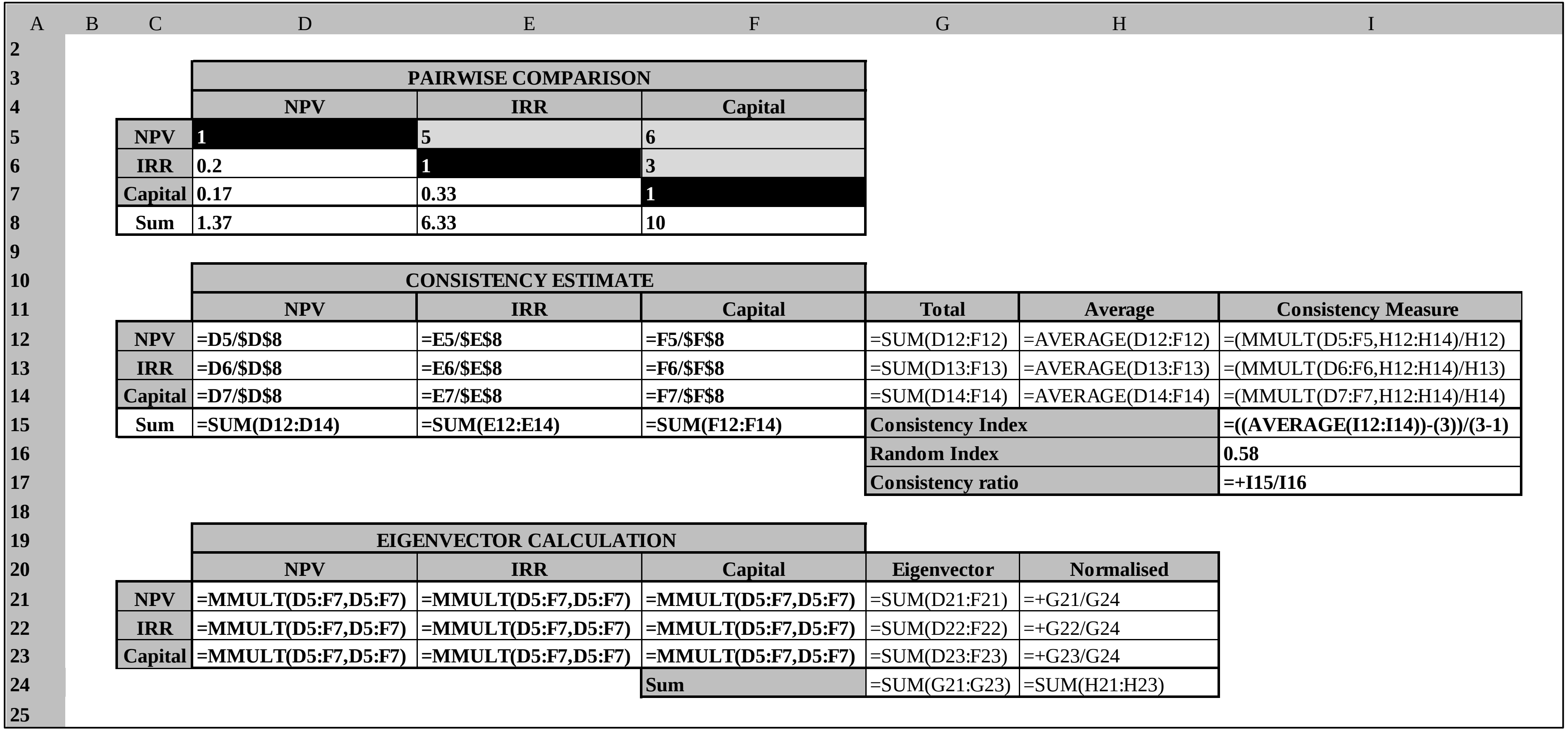
Value 3.00

Table 4-8 Traditional metrics calculation of consistency index and eigenvector



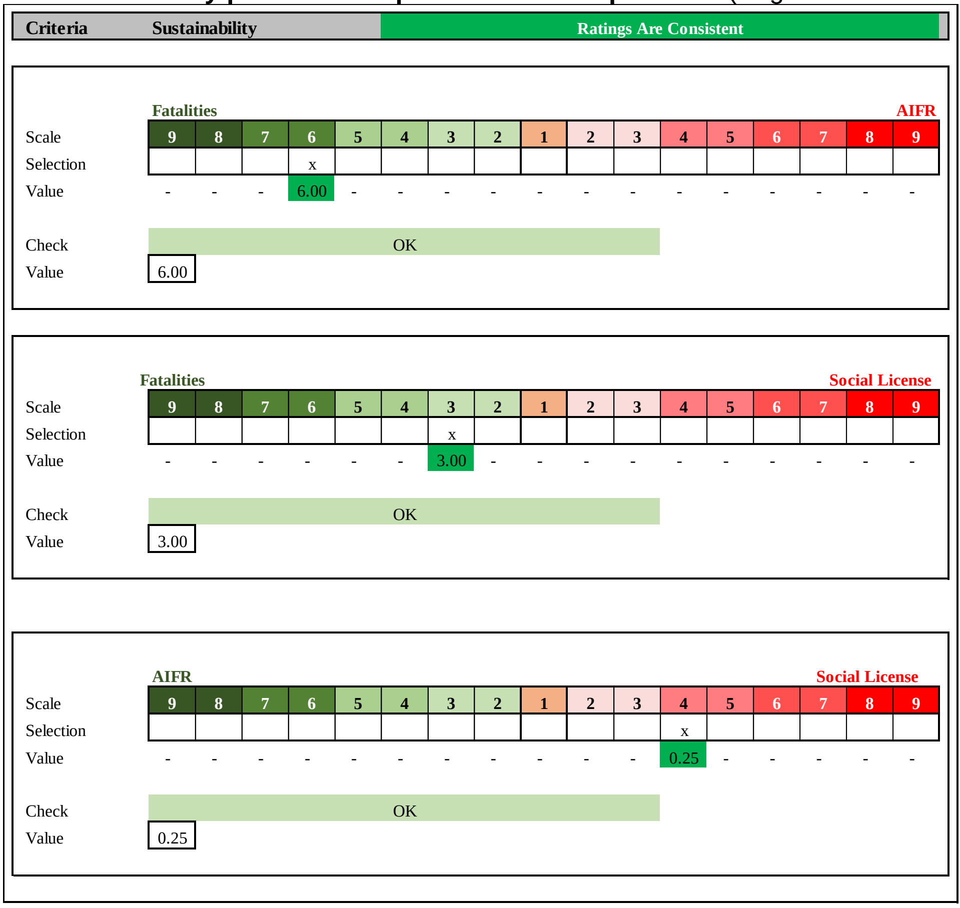
A	B	C	D	E	F	G	H	I
2								
3			**PAIRWISE COMPARISON**					
4			**NPV**	**IRR**	**Capital**			
5		**NPV**	**1.00**	**5.00**	**6.00**			
6		**IRR**	**0.20**	**1.00**	**3.00**			
7		**Capital**	**0.17**	**0.33**	**1.00**			
8		**Sum**	**1.37**	**6.33**	**10.00**			
9								
10			**CONSISTENCY ESTIMATE**					
11			**NPV**	**IRR**	**Capital**	**Total**	**Average**	**Consistency Measure**
12		**NPV**	**0.73**	**0.79**	**0.60**	2.12	0.71	3.20
13		**IRR**	**0.15**	**0.16**	**0.30**	0.60	0.20	3.07
14		**Capital**	**0.12**	**0.05**	**0.10**	0.27	0.09	3.02
15		**Sum**	**1.00**	**1.00**	**1.00**	**Consistency Index**		**0.05**
16						**Random Index**		**0.58**
17						**Consistency ratio**		**0.08**
18								
19			**EIGENVECTOR CALCULATION**					
20			**NPV**	**IRR**	**Capital**	**Eigenvector**	**Normalised**	
21		**NPV**	**3.00**	**12.00**	**27.00**	42.00	0.72	
22		**IRR**	**0.90**	**3.00**	**7.20**	11.10	0.19	
23		**Capital**	**0.40**	**1.50**	**3.00**	4.90	0.08	
24					**Sum**	58.00	1.00	
25								

Table 4-9 Traditional metrics consistency index and eigenvector formulas



A	B	C	D	E	F	G	H	I
2								
3			PAIRWISE COMPARISON					
4			NPV	IRR	Capital			
5		NPV	1	5	6			
6		IRR	0.2	1	3			
7		Capital	0.17	0.33	1			
8		Sum	1.37	6.33	10			
9								
10			CONSISTENCY ESTIMATE					
11			NPV	IRR	Capital	Total	Average	Consistency Measure
12		NPV	=D5/$D$8	=E5/$E$8	=F5/$F$8	=SUM(D12:F12)	=AVERAGE(D12:F12)	=(MMULT(D5:F5,H12:H14)/H12)
13		IRR	=D6/$D$8	=E6/$E$8	=F6/$F$8	=SUM(D13:F13)	=AVERAGE(D13:F13)	=(MMULT(D6:F6,H12:H14)/H13)
14		Capital	=D7/$D$8	=E7/$E$8	=F7/$F$8	=SUM(D14:F14)	=AVERAGE(D14:F14)	=(MMULT(D7:F7,H12:H14)/H14)
15		Sum	=SUM(D12:D14)	=SUM(E12:E14)	=SUM(F12:F14)	Consistency Index		=((AVERAGE(I12:I14))-(3))/(3-1)
16						Random Index		0.58
17						Consistency ratio		=+I15/I16
18								
19			EIGENVECTOR CALCULATION					
20			NPV	IRR	Capital	Eigenvector	Normalised	
21		NPV	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=SUM(D21:F21)	=+G21/G24	
22		IRR	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=SUM(D22:F22)	=+G22/G24	
23		Capital	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=SUM(D23:F23)	=+G23/G24	
24					Sum	=SUM(G21:G23)	=SUM(H21:H23)	
25								

Table 4-10 Sustainability pairwise comparison workshop results (AngloGold Ashanti, 2017a)



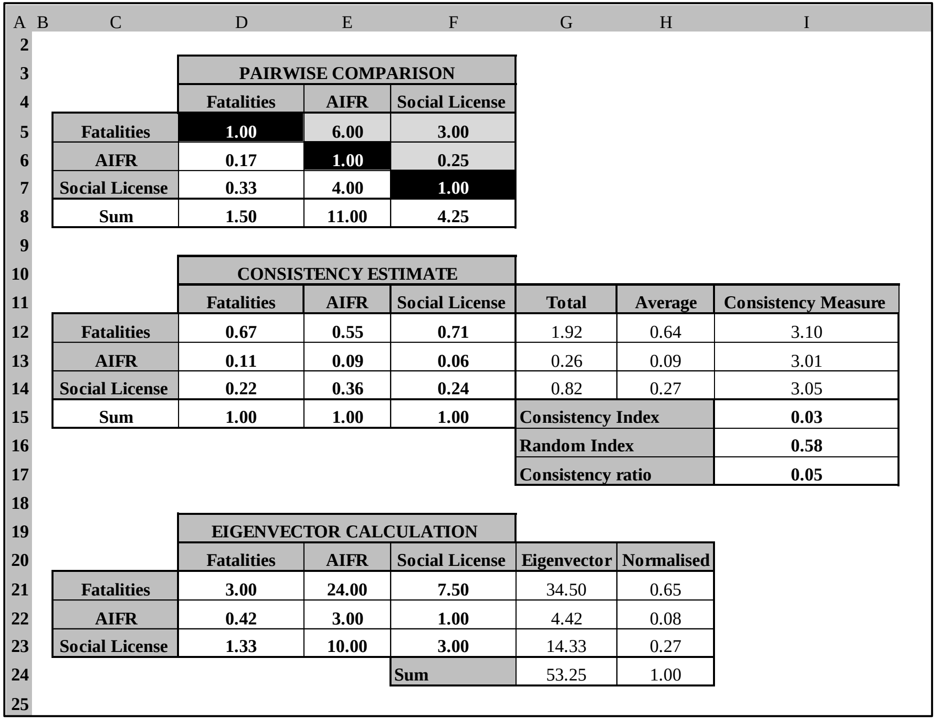
Criteria	Sustainability	Ratings Are Consistent

	Fatalities																AIFR
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	6.00																

	Fatalities																Social License
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection							x										
Value	-	-	-	-	-	-	3.00	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	3.00																

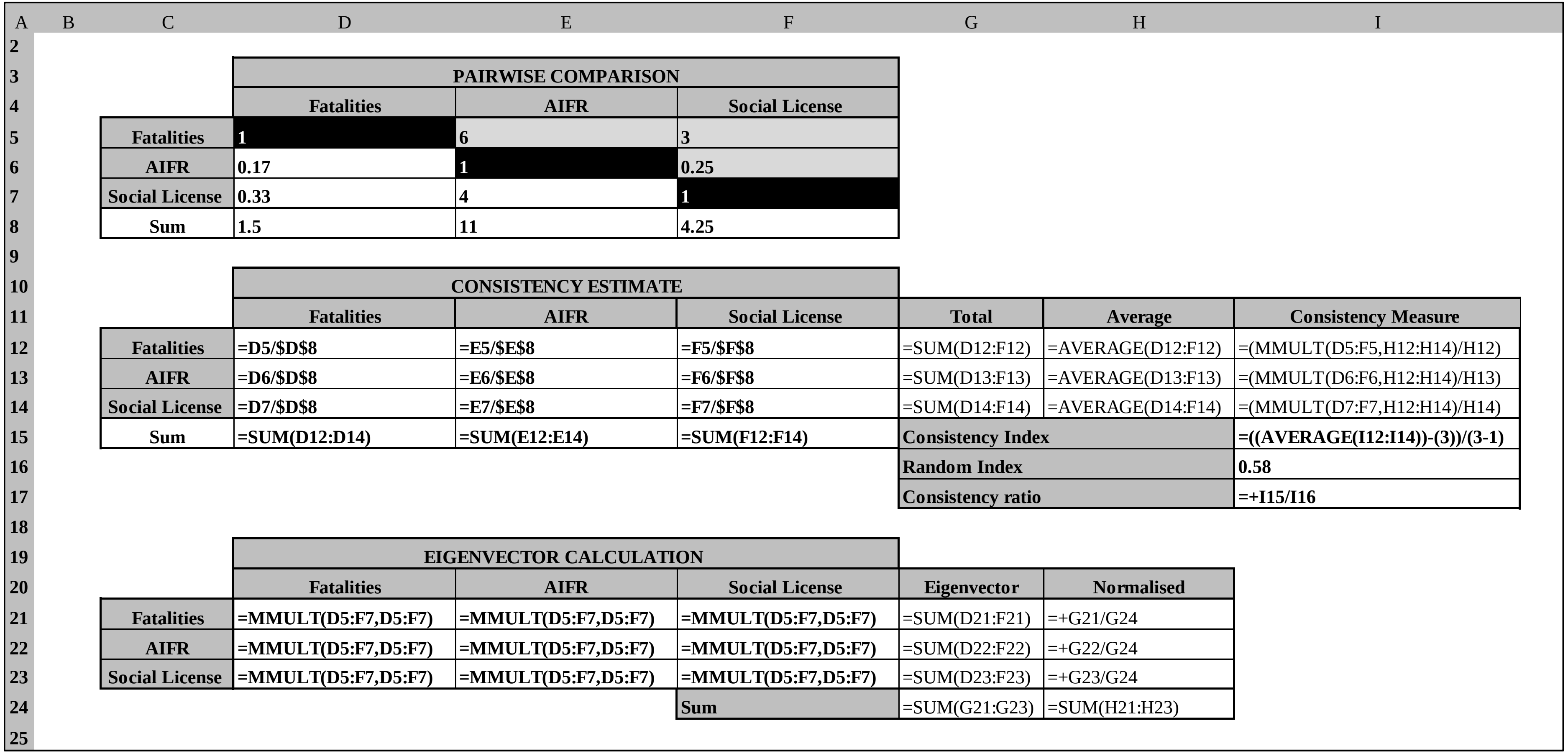
	AIFR																Social License
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-
Check	OK																
Value	0.25																

Table 4-11 Sustainability calculation of consistency index and eigenvector



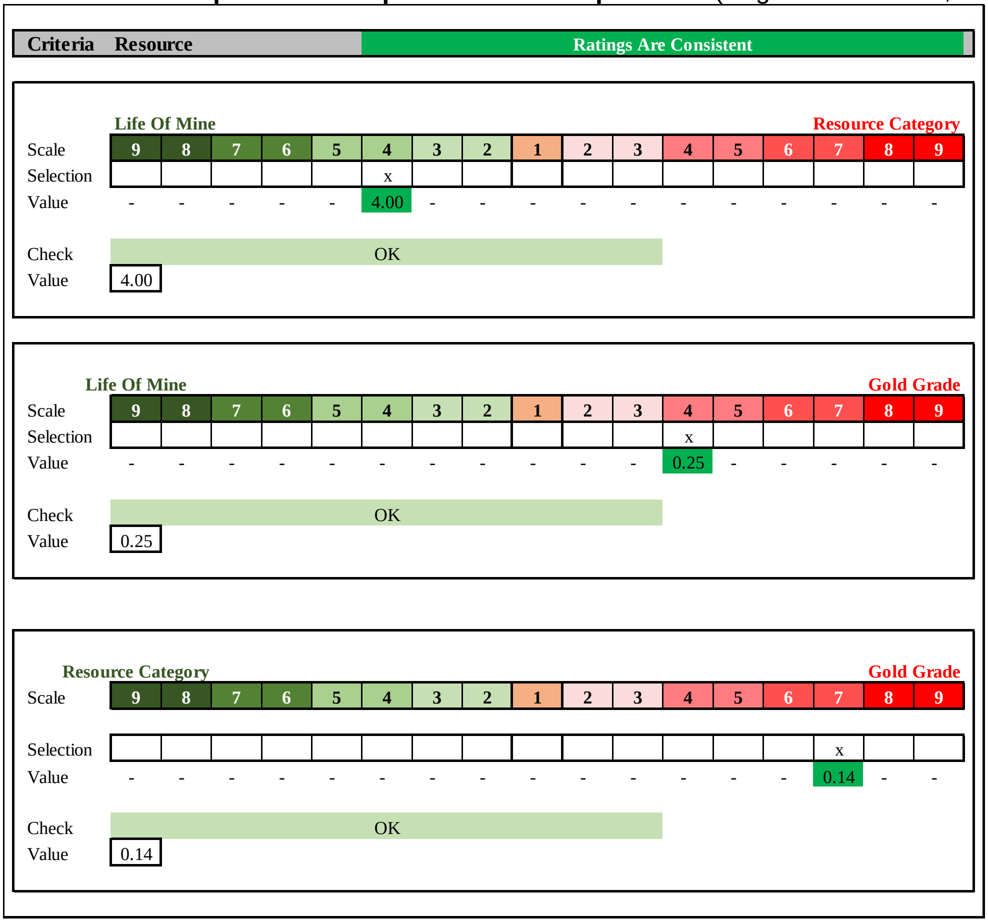
A B	C	D	E	F	G	H	I
2							
3		PAIRWISE COMPARISON					
4		Fatalities	AIFR	Social License			
5	Fatalities	1.00	6.00	3.00			
6	AIFR	0.17	1.00	0.25			
7	Social License	0.33	4.00	1.00			
8	Sum	1.50	11.00	4.25			
9							
10		CONSISTENCY ESTIMATE					
11		Fatalities	AIFR	Social License	Total	Average	Consistency Measure
12	Fatalities	0.67	0.55	0.71	1.92	0.64	3.10
13	AIFR	0.11	0.09	0.06	0.26	0.09	3.01
14	Social License	0.22	0.36	0.24	0.82	0.27	3.05
15	Sum	1.00	1.00	1.00	Consistency Index		0.03
16					Random Index		0.58
17					Consistency ratio		0.05
18							
19		EIGENVECTOR CALCULATION					
20		Fatalities	AIFR	Social License	Eigenvector	Normalised	
21	Fatalities	3.00	24.00	7.50	34.50	0.65	
22	AIFR	0.42	3.00	1.00	4.42	0.08	
23	Social License	1.33	10.00	3.00	14.33	0.27	
24				Sum	53.25	1.00	
25							

Table 4-12 Sustainability consistency index and eigenvector formulas



A	B	C	D	E	F	G	H	I
2								
3			**PAIRWISE COMPARISON**					
4			**Fatalities**	**AIFR**	**Social License**			
5		**Fatalities**	**1**	**6**	**3**			
6		**AIFR**	**0.17**	**1**	**0.25**			
7		**Social License**	**0.33**	**4**	**1**			
8		**Sum**	**1.5**	**11**	**4.25**			
9								
10			**CONSISTENCY ESTIMATE**					
11			**Fatalities**	**AIFR**	**Social License**	**Total**	**Average**	**Consistency Measure**
12		**Fatalities**	**=D5/$D$8**	**=E5/$E$8**	**=F5/$F$8**	=SUM(D12:F12)	=AVERAGE(D12:F12)	=(MMULT(D5:F5,H12:H14)/H12)
13		**AIFR**	**=D6/$D$8**	**=E6/$E$8**	**=F6/$F$8**	=SUM(D13:F13)	=AVERAGE(D13:F13)	=(MMULT(D6:F6,H12:H14)/H13)
14		**Social License**	**=D7/$D$8**	**=E7/$E$8**	**=F7/$F$8**	=SUM(D14:F14)	=AVERAGE(D14:F14)	=(MMULT(D7:F7,H12:H14)/H14)
15		**Sum**	**=SUM(D12:D14)**	**=SUM(E12:E14)**	**=SUM(F12:F14)**	**Consistency Index**		**=((AVERAGE(I12:I14))-(3))/(3-1)**
16						**Random Index**		**0.58**
17						**Consistency ratio**		**=+I15/I16**
18								
19			**EIGENVECTOR CALCULATION**					
20			**Fatalities**	**AIFR**	**Social License**	**Eigenvector**	**Normalised**	
21		**Fatalities**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	=SUM(D21:F21)	=+G21/G24	
22		**AIFR**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	=SUM(D22:F22)	=+G22/G24	
23		**Social License**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	=SUM(D23:F23)	=+G23/G24	
24					**Sum**	=SUM(G21:G23)	=SUM(H21:H23)	
25								

Table 4-13 Resource pairwise comparison workshop results (AngloGold Ashanti, 2017a)



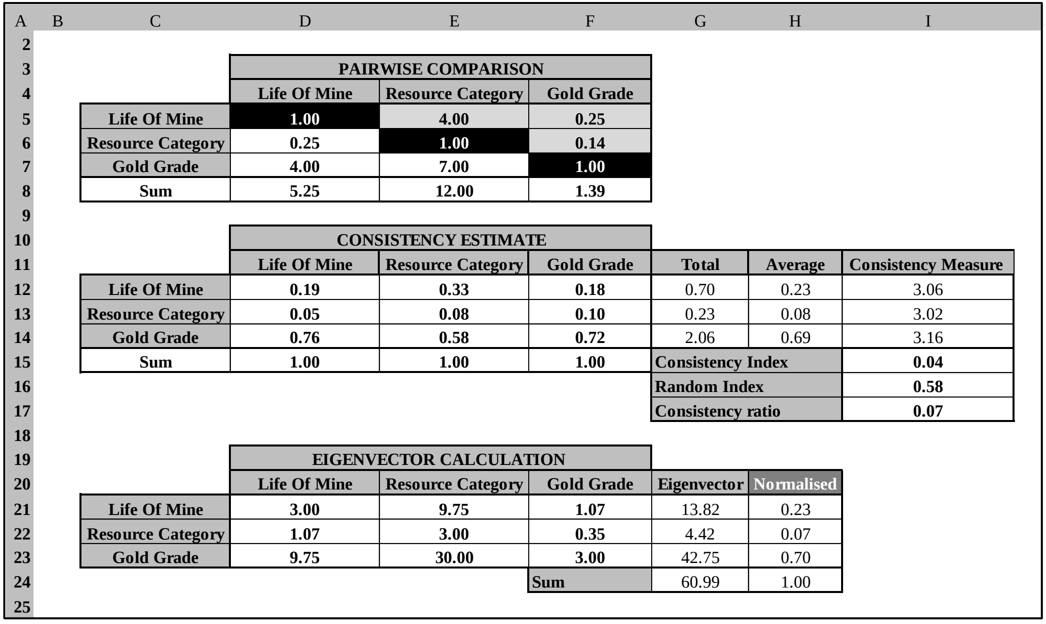
Criteria	Resource	Ratings Are Consistent

	Life Of Mine																Resource Category
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection						x											
Value	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	4.00																

	Life Of Mine																Gold Grade
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-
Check	OK																
Value	0.25																

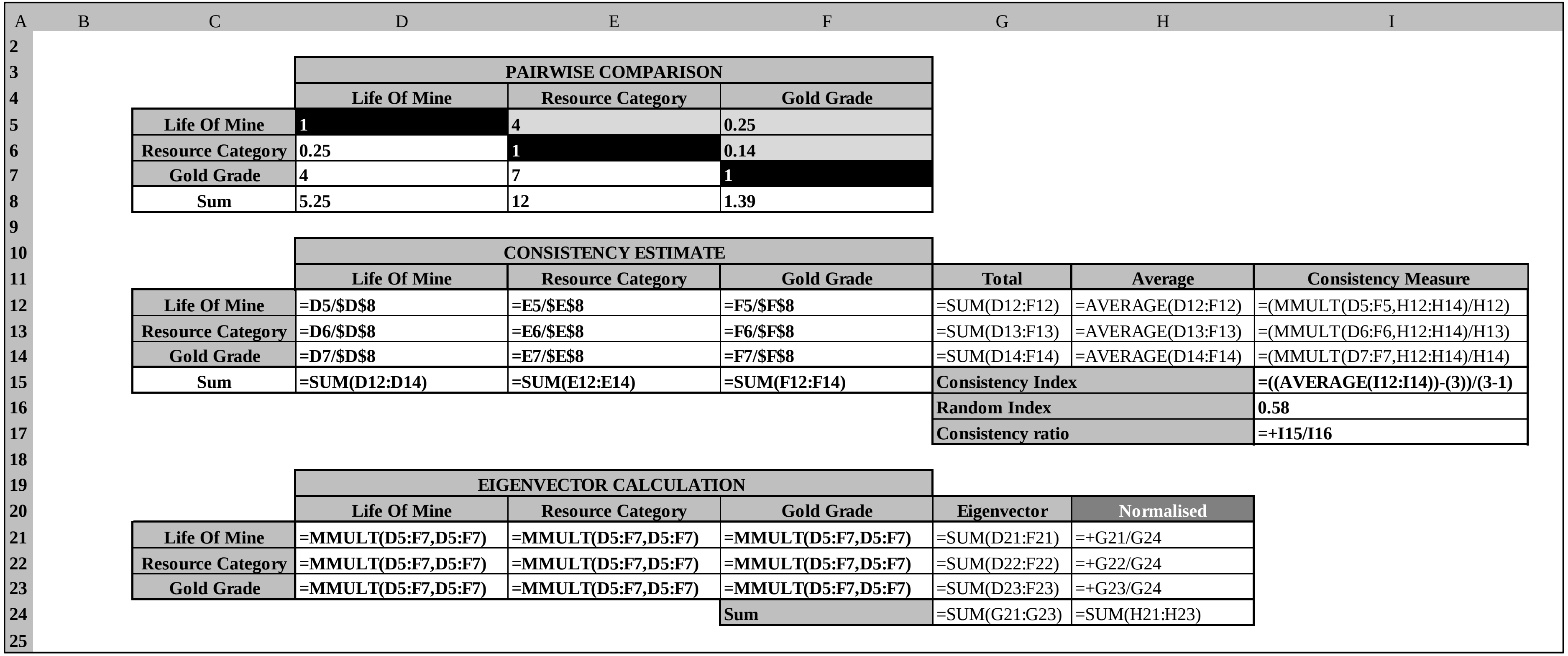
	Resource Category																Gold Grade
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection															x		
Value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	-
Check	OK																
Value	0.14																

Table 4-14 Resource calculation of consistency index and eigenvector



A	B	C	D	E	F	G	H	I
2								
3			PAIRWISE COMPARISON					
4			Life Of Mine	Resource Category	Gold Grade			
5		Life Of Mine	1.00	4.00	0.25			
6		Resource Category	0.25	1.00	0.14			
7		Gold Grade	4.00	7.00	1.00			
8		Sum	5.25	12.00	1.39			
9								
10			CONSISTENCY ESTIMATE					
11			Life Of Mine	Resource Category	Gold Grade	Total	Average	Consistency Measure
12		Life Of Mine	0.19	0.33	0.18	0.70	0.23	3.06
13		Resource Category	0.05	0.08	0.10	0.23	0.08	3.02
14		Gold Grade	0.76	0.58	0.72	2.06	0.69	3.16
15		Sum	1.00	1.00	1.00	Consistency Index		0.04
16						Random Index		0.58
17						Consistency ratio		0.07
18								
19			EIGENVECTOR CALCULATION					
20			Life Of Mine	Resource Category	Gold Grade	Eigenvector	Normalised	
21		Life Of Mine	3.00	9.75	1.07	13.82	0.23	
22		Resource Category	1.07	3.00	0.35	4.42	0.07	
23		Gold Grade	9.75	30.00	3.00	42.75	0.70	
24					Sum	60.99	1.00	
25								

Table 4-15 Resource consistency index and eigenvector formulas



A	B	C	D	E	F	G	H	I
2								
3			PAIRWISE COMPARISON					
4			Life Of Mine	Resource Category	Gold Grade			
5		Life Of Mine	1	4	0.25			
6		Resource Category	0.25	1	0.14			
7		Gold Grade	4	7	1			
8		Sum	5.25	12	1.39			
9								
10			CONSISTENCY ESTIMATE					
11			Life Of Mine	Resource Category	Gold Grade	Total	Average	Consistency Measure
12		Life Of Mine	=D5/$D$8	=E5/$E$8	=F5/$F$8	=SUM(D12:F12)	=AVERAGE(D12:F12)	=(MMULT(D5:F5,H12:H14)/H12)
13		Resource Category	=D6/$D$8	=E6/$E$8	=F6/$F$8	=SUM(D13:F13)	=AVERAGE(D13:F13)	=(MMULT(D6:F6,H12:H14)/H13)
14		Gold Grade	=D7/$D$8	=E7/$E$8	=F7/$F$8	=SUM(D14:F14)	=AVERAGE(D14:F14)	=(MMULT(D7:F7,H12:H14)/H14)
15		Sum	=SUM(D12:D14)	=SUM(E12:E14)	=SUM(F12:F14)	Consistency Index		=((AVERAGE(I12:I14))-(3))/(3-1)
16						Random Index		0.58
17						Consistency ratio		=+I15/I16
18								
19			EIGENVECTOR CALCULATION					
20			Life Of Mine	Resource Category	Gold Grade	Eigenvector	Normalised	
21		Life Of Mine	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=SUM(D21:F21)	=+G21/G24	
22		Resource Category	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=SUM(D22:F22)	=+G22/G24	
23		Gold Grade	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=MMULT(D5:F7,D5:F7)	=SUM(D23:F23)	=+G23/G24	
24					Sum	=SUM(G21:G23)	=SUM(H21:H23)	
25								

Table 4-16 Operating pairwise comparison workshop results (AngloGold Ashanti, 2017a).

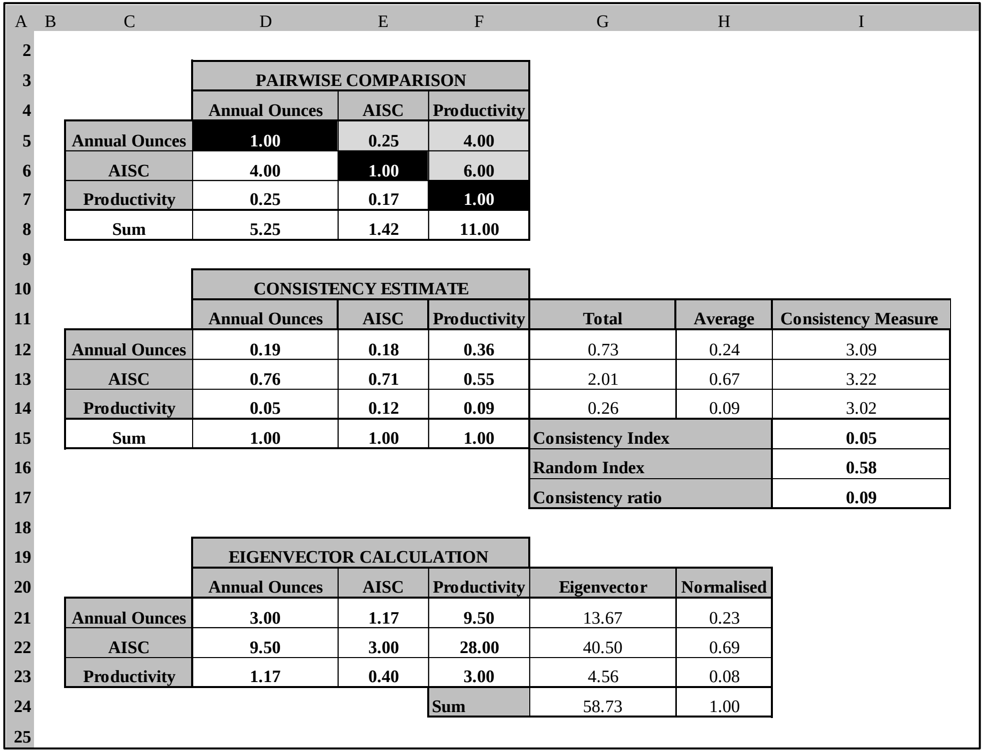
Criteria	Operating	Ratings Are Consistent

	Annual Ounces																AISC
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-
Check	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-
Check	OK																
Value	0.25																

	Annual Ounces																Productivity
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection						x											
Value	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-
Check	-	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	4.00																

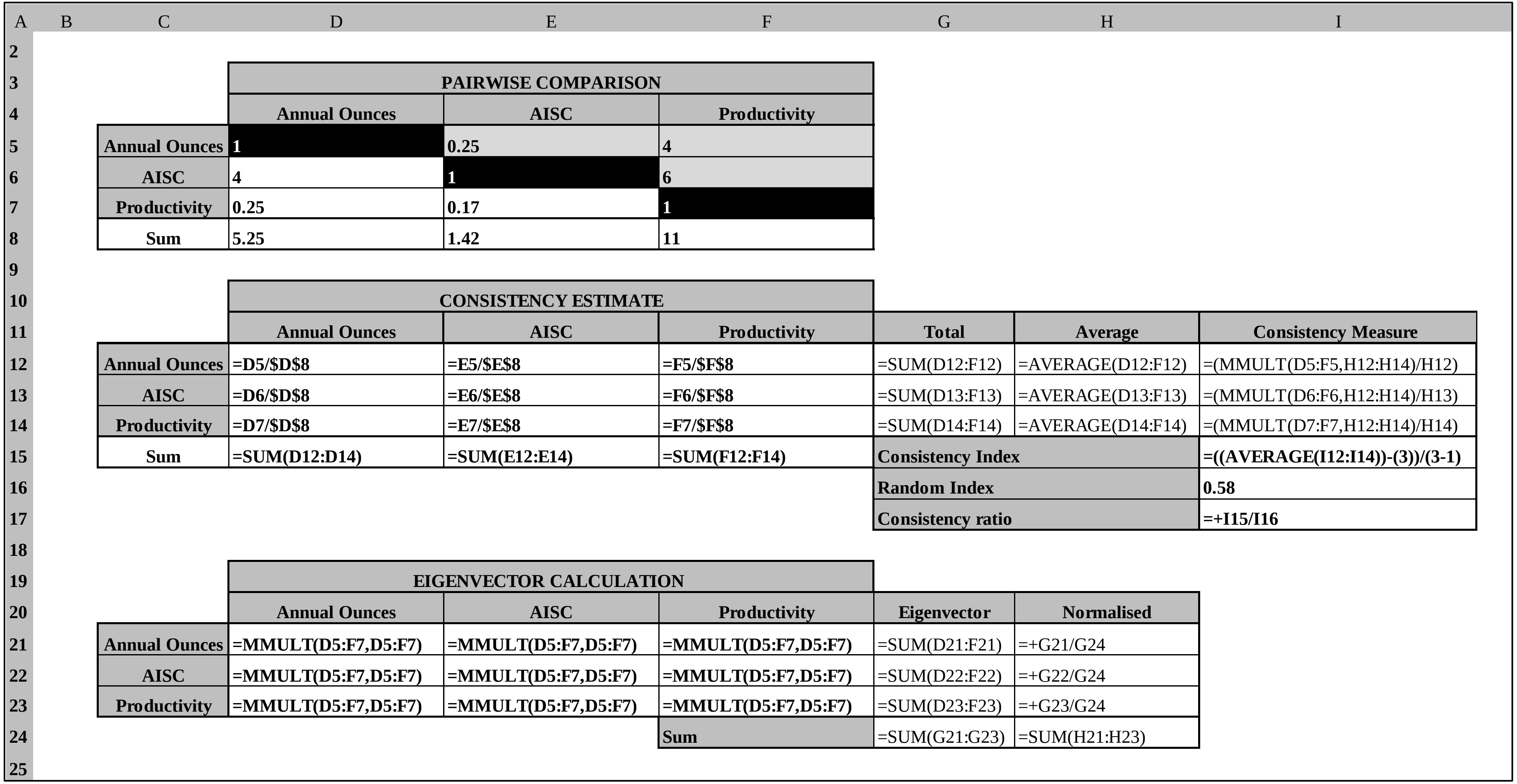
	AISC																Productivity
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	6.00																

Table 4-17 Operating calculation of consistency index and eigenvector



A	B	C	D	E	F	G	H	I
2								
3			PAIRWISE COMPARISON					
4			Annual Ounces	AISC	Productivity			
5		Annual Ounces	1.00	0.25	4.00			
6		AISC	4.00	1.00	6.00			
7		Productivity	0.25	0.17	1.00			
8		Sum	5.25	1.42	11.00			
9								
10			CONSISTENCY ESTIMATE					
11			Annual Ounces	AISC	Productivity	Total	Average	Consistency Measure
12		Annual Ounces	0.19	0.18	0.36	0.73	0.24	3.09
13		AISC	0.76	0.71	0.55	2.01	0.67	3.22
14		Productivity	0.05	0.12	0.09	0.26	0.09	3.02
15		Sum	1.00	1.00	1.00	Consistency Index		0.05
16						Random Index		0.58
17						Consistency ratio		0.09
18								
19			EIGENVECTOR CALCULATION					
20			Annual Ounces	AISC	Productivity	Eigenvector	Normalised	
21		Annual Ounces	3.00	1.17	9.50	13.67	0.23	
22		AISC	9.50	3.00	28.00	40.50	0.69	
23		Productivity	1.17	0.40	3.00	4.56	0.08	
24					Sum	58.73	1.00	
25								

Table 4-18 Operating consistency index and eigenvector formulas



A	B	C	D	E	F	G	H	I
2								
3			**PAIRWISE COMPARISON**					
4			**Annual Ounces**	**AISC**	**Productivity**			
5		**Annual Ounces**	**1**	**0.25**	**4**			
6		**AISC**	**4**	**1**	**6**			
7		**Productivity**	**0.25**	**0.17**	**1**			
8		**Sum**	**5.25**	**1.42**	**11**			
9								
10			**CONSISTENCY ESTIMATE**					
11			**Annual Ounces**	**AISC**	**Productivity**	**Total**	**Average**	**Consistency Measure**
12		**Annual Ounces**	**=D5/$D$8**	**=E5/$E$8**	**=F5/$F$8**	=SUM(D12:F12)	=AVERAGE(D12:F12)	=(MMULT(D5:F5,H12:H14)/H12)
13		**AISC**	**=D6/$D$8**	**=E6/$E$8**	**=F6/$F$8**	=SUM(D13:F13)	=AVERAGE(D13:F13)	=(MMULT(D6:F6,H12:H14)/H13)
14		**Productivity**	**=D7/$D$8**	**=E7/$E$8**	**=F7/$F$8**	=SUM(D14:F14)	=AVERAGE(D14:F14)	=(MMULT(D7:F7,H12:H14)/H14)
15		**Sum**	**=SUM(D12:D14)**	**=SUM(E12:E14)**	**=SUM(F12:F14)**	**Consistency Index**		**=((AVERAGE(I12:I14))-(3))/(3-1)**
16						**Random Index**		**0.58**
17						**Consistency ratio**		**=+I15/I16**
18								
19			**EIGENVECTOR CALCULATION**					
20			**Annual Ounces**	**AISC**	**Productivity**	**Eigenvector**	**Normalised**	
21		**Annual Ounces**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	=SUM(D21:F21)	=+G21/G24	
22		**AISC**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	=SUM(D22:F22)	=+G22/G24	
23		**Productivity**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	**=MMULT(D5:F7,D5:F7)**	=SUM(D23:F23)	=+G23/G24	
24					**Sum**	=SUM(G21:G23)	=SUM(H21:H23)	
25								

4.5 AHP model ranking

On completion of the pairwise comparisons, the AHP model structure was populated. As noted in Figure 4-7 the final ranking of strategic corporate values in the context of Brownfield projects, places the greatest importance on the traditional metrics.

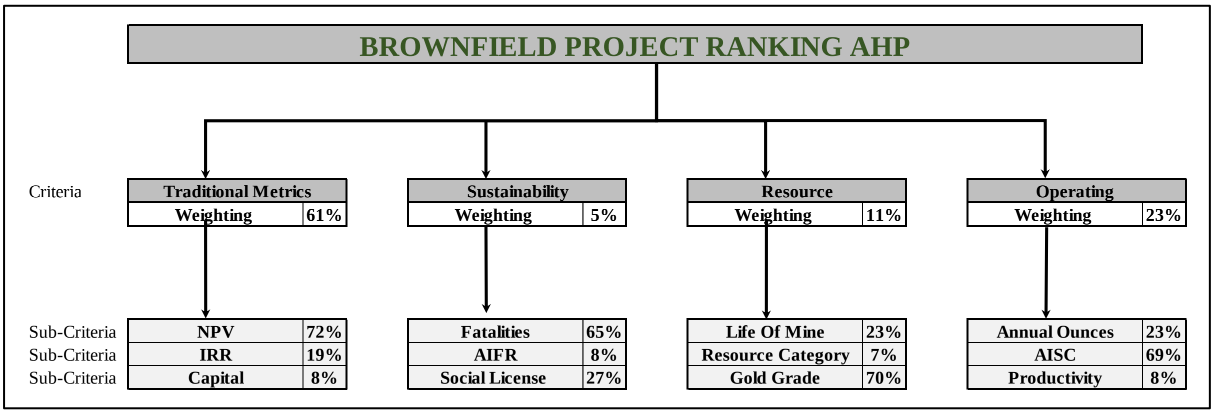


Figure 4-7 Combined pairwise comparison AHP model

4.6 AHP data

On completion of the pairwise comparison, the applicable data for each sub-criterion was sought for each of the three projects under consideration. The data was sourced from two sources:

- The project TM models as detailed in this report, and
- The publicly available annual reports and sustainability reports for AngloGold Ashanti.

The data tables populated with the relevant data are shown in Table 4-19, Table 4-20, Table 4-21 and Table 4-22.

Table 4-19 Traditional metric data table

	Traditional Metrics		
	NPV	IRR	Capital
	USD	%	PI
	Desirable to be High	Desirable to be High	Desirable to be High
Project Name	Value	Value	Value
Project A	**239,733,204**	**0.18**	**0.42**
Project B	**139,562,298**	**0.17**	**0.56**
Project C	**5,491,534**	**0.16**	**0.58**
Total	**384,787,035**	**0.51**	**1.56**

Table 4-20 Sustainability metric data table

	Sustainability		
	Fatalities	AIFR	Social License
	#	rate	calc
	Desirable to be	Desirable to be	Desirable to be
	Low	Low	High
	Input (Select)	Input (Select)	Input (Select)
Project Name	Value	Value	Value
Project A	0.00	0.85	0.24
Project B	0.00	0.22	0.25
Project C	0.00	0.45	0.50
Total	**0.00**	**1.52**	**1.00**

It is noted that the values for fatalities is zero for all projects, an excellent operational achievement. It is however unlikely that the values for fatalities will be consistently zero over the life of all assets and therefore this metric represents a significant potential point of differentiation.

Table 4-21 Resource metric data table

	Resource		
	Life Of Mine	Resource Category	Gold Grade
	yrs	calc	grade
	Desirable to be	Desirable to be	Desirable to be
	High	High	High
Project Name	Value	Value	Value
Project A	**11**	**0.87**	**1.84**
Project B	**15**	**0.75**	**0.84**
Project C	**5**	**0.13**	**6.35**
Total	**31**	**1.74**	**9.03**

Table 4-22 Operating metric data table

	Operating		
	Annual Ounces	AISC	Productivity
	Koz	$/oz	oz/tec
	Desirable to be	Desirable to be	Desirable to be
	High	Low	High
Project Name	Value	Value	Value
Project A	**317**	**943.97**	**13.89**
Project B	**249**	**1038.67**	**15.21**
Project C	**38**	**1068.15**	**22.74**
Total	**604**	**3050.80**	**51.84**

4.7 AHP results

The AHP successfully ranked the Brownfield projects under consideration. In line with the ranking from the TM financial model, the AHP ranking method generated the same project rankings for the traditional metrics as noted in Table 4-23.

Table 4-23 Brownfield project AHP traditional metrics results

	Traditional Metrics			Weight	0.61	Level 1
	NPV	IRR	Capital	Total Score	Weighted Score	Ranking
Project A	0.45	0.07	0.02	0.54	**0.33**	1
Project B	0.26	0.06	0.03	0.36	**0.22**	2
Project C	0.01	0.06	0.03	0.10	**0.06**	3

The sustainability record of Project C is significantly better than that of the other projects, in particular the criteria measuring social license scored particularly high. As a result, the ranking on the level 1 sustainability metric is the inverse of the traditional metrics scoring system, as shown in Table 4-24. With an overall weighting of 0.05, the impact of the sustainability metric is however minimal on the overall ranking of the projects.

Table 4-24 Brownfield project AHP safety metric results

	Sustainability			Weight	0.05	Level 1
	Fatalities	AIFR	Social License	Total Score	Weighted Score	Ranking
Project A	0.22	0.01	0.07	0.29	**0.01**	3
Project B	0.22	0.05	0.07	0.33	**0.02**	2
Project C	0.22	0.02	0.14	0.37	**0.02**	1

The resource metric, as with the sustainability metric, ranks the project inversely to the traditional metric ranking as shown in Table 4-25. The high score of Project C is driven by its significantly higher grade which is generally a pre-requisite for underground mining. As with the sustainability metric, with a weighting of 0.11, the resource metric is unlikely to have a significant impact on the overall project rankings.

Table 4-25 Brownfield project AHP resource metric results

	Resource			Weight	0.11	Level 1
	Life Of Mine	Resource Category	Gold Grade	Total Score	Weighted Score	Ranking
Project A	0.08	0.04	0.14	0.26	**0.03**	2
Project B	0.11	0.03	0.07	0.21	**0.02**	3
Project C	0.04	0.01	0.49	0.53	**0.06**	1

The operating metric which essentially scores how well the project is or will be run, understandably was weighted relatively highly during the pairwise comparison with a weighting of 0.23. As noted in Table 4-26 there is not a significant spread of scores (ranging from 0.27 to 0.39). However, the lower grade operations are more efficient.

Table 4-26 Brownfield project AHP operating metric results

	Operating			Weight	0.23	Level 1
	Annual Ounces	AISC	Productivity	Total Score	Weighted Score	Ranking
Project A	0.12	0.25	0.02	0.39	**0.09**	1
Project B	0.10	0.22	0.02	0.34	**0.08**	2
Project C	0.01	0.22	0.03	0.27	**0.06**	3

The weighting of the Level 1 criteria is critical to the overall AHP result. The workshop placed the majority of the importance and hence the highest value on the traditional metrics. Since the weighting of the traditional metrics is so high it is expected and reasonable for the AHP rankings to be the same as the TM financial model rankings. The Brownfield AHP ranking results are shown in Table 4-27.

Table 4-27 Brownfield projects AHP ranking

	Final Score	**Final Ranking**
Project A	0.46	1
Project B	0.34	2
Project C	0.20	3

The traditional metric weighting drives an AHP result that is reflective of a DCF analysis. This may question the need for an AHP approach. The use of AHP results in two key achievements for the ranking, firstly the sub-criteria of traditional metrics are formally defined and weighted. Generally, such criteria are presented as individual outcomes of the DCF analysis and not weighted and ranked. Secondly the AHP formally defines the weighting of other key metrics on the first and subsequent levels of the AHP, thus ensuring that the investment decision is truly representative of the company value system. Decision makers are now able to formally incorporate these values and weightings into their decision-making process. This allows for a robust and iterative decision-making process, continually re-assessing the metrics and relative weightings of the metrics.

4.8 Hypothetical scenarios

While the results of the AHP ranking presented in Section 4.7 present a valuable ranking of the projects, there was potential to gain further insight into the rankings through the generation of hypothetical scenarios. Two hypothetical scenarios were developed:

- **Hypothetical scenario 1.** In the strategies outlined by the three companies assessed in the study, no single value is defined as more important than any other. There is therefore an entirely valid argument that each of the Level 1 values as determined from the company strategies should carry equal importance i.e. equal weighting in the AHP (Figure 4-8). Hypothetical scenario 1 assumes equal weighting of the Level 1 AHP metrics in the ranking of Brownfield projects. All the remaining parameters and scoring remains unchanged; and
- **Hypothetical scenario 2.** One of the short comings of the selected projects for this study is that they present significantly different traditional metrics. Since the traditional metrics are weighted so high, the true value of applying AHP may not be realised. If the traditional metrics were closer in absolute values, the non-traditional metrics may prove the differentiator. In order to test this scenario, the traditional metrics of Projects B and C were adjusted to be within -5% and +5% of Project A values (Table 4-28). All other metrics and weightings remained unchanged.

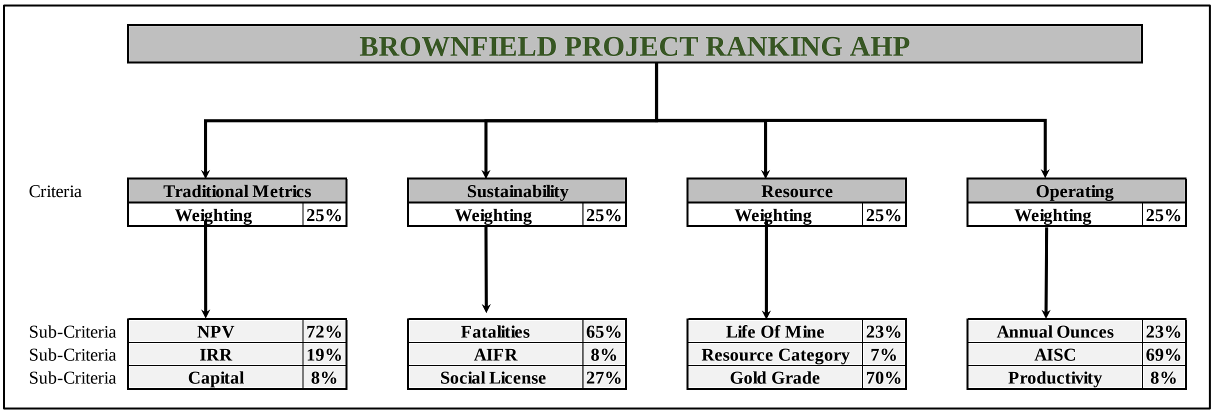


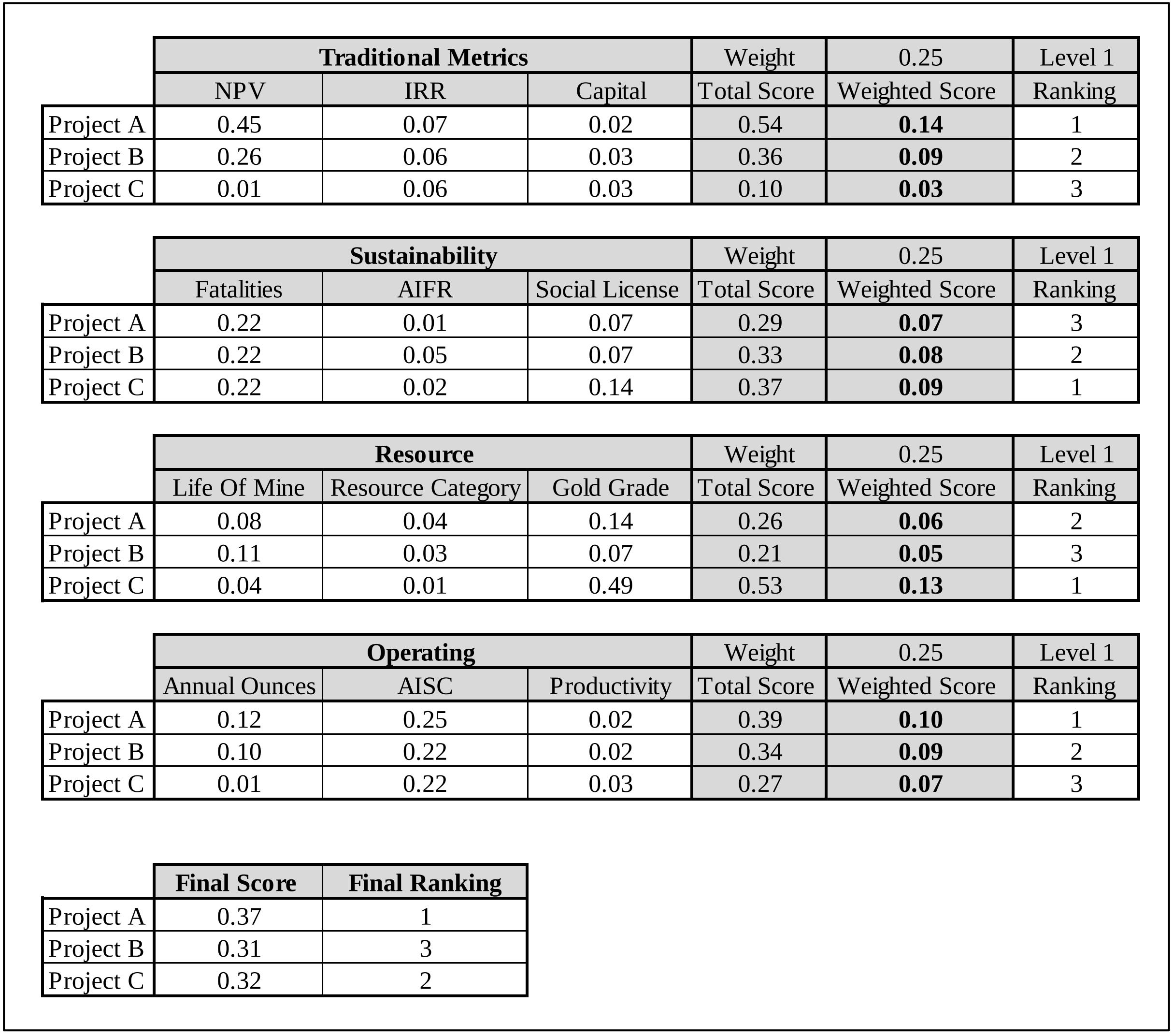
Figure 4-8 AHP hypothetical scenario 1 where level 1 criteria are weighted equally

Table 4-28 Traditional metrics criteria under hypothetical scenario 2

	Traditional Metrics		
	NPV	IRR	Capital
	USD	%	PI
	Desirable to be	Desirable to be	Desirable to be
	High	High	High
Project Name	Value	Value	Value
Project A	**239,733,204**	**0.18**	**0.42**
Project B	**227,746,544**	**0.17**	**0.40**
Project C	**251,719,864**	**0.19**	**0.45**
Total	**719,199,611**	**0.54**	**1.27**

While Project A remains the top ranked project under hypothetical scenario 1, as indicated in Table 4-29, Project C is now ranked second. This suggests that if all metrics are considered equal, the ranking of projects may differ from traditional metrics financial model ranking.

Table 4-29 Hypothetical scenario 1 AHP results



	Traditional Metrics			Weight	0.25	Level 1
	NPV	IRR	Capital	Total Score	Weighted Score	Ranking
Project A	0.45	0.07	0.02	0.54	**0.14**	1
Project B	0.26	0.06	0.03	0.36	**0.09**	2
Project C	0.01	0.06	0.03	0.10	**0.03**	3

	Sustainability			Weight	0.25	Level 1
	Fatalities	AIFR	Social License	Total Score	Weighted Score	Ranking
Project A	0.22	0.01	0.07	0.29	**0.07**	3
Project B	0.22	0.05	0.07	0.33	**0.08**	2
Project C	0.22	0.02	0.14	0.37	**0.09**	1

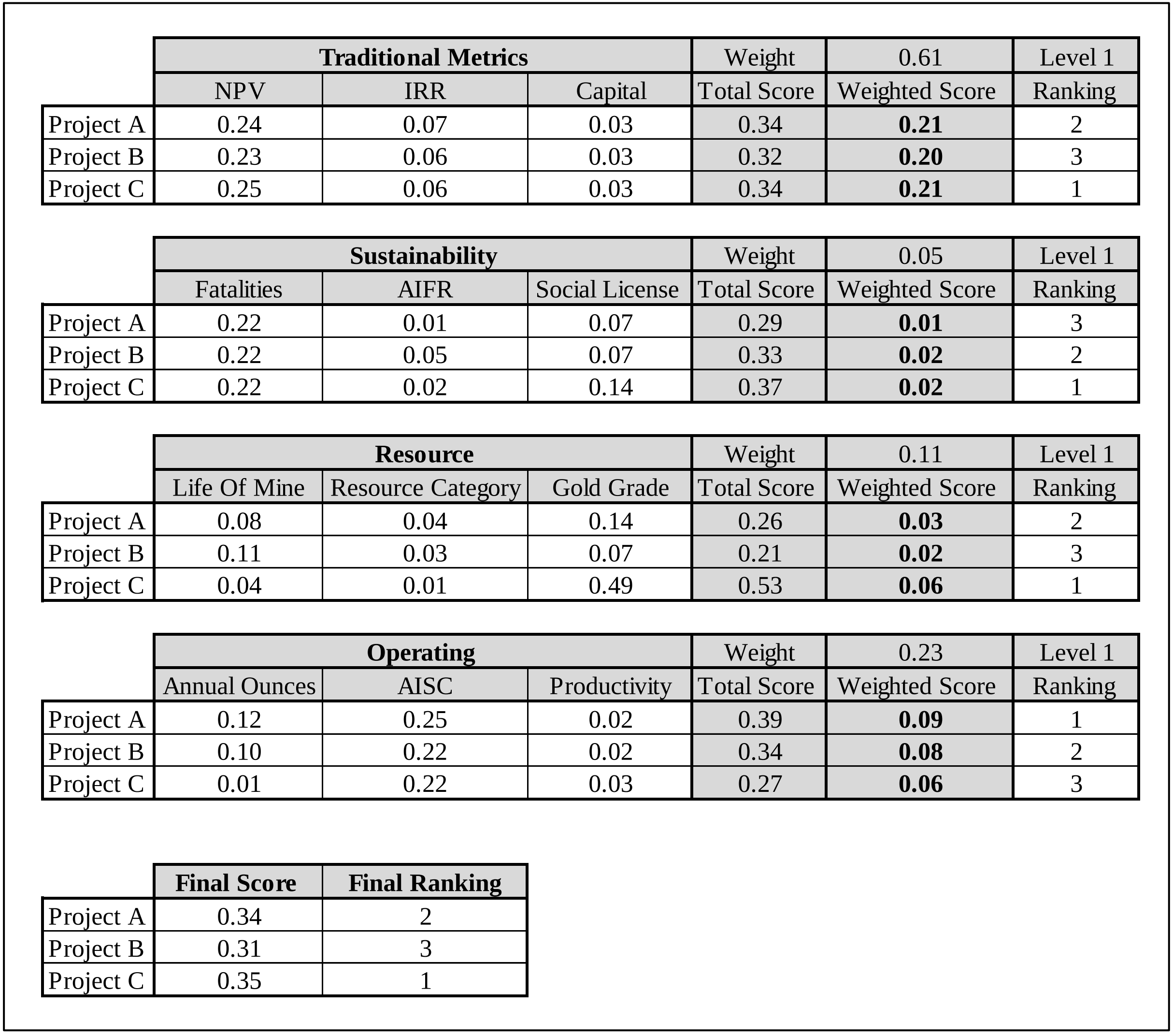
	Resource			Weight	0.25	Level 1
	Life Of Mine	Resource Category	Gold Grade	Total Score	Weighted Score	Ranking
Project A	0.08	0.04	0.14	0.26	**0.06**	2
Project B	0.11	0.03	0.07	0.21	**0.05**	3
Project C	0.04	0.01	0.49	0.53	**0.13**	1

	Operating			Weight	0.25	Level 1
	Annual Ounces	AISC	Productivity	Total Score	Weighted Score	Ranking
Project A	0.12	0.25	0.02	0.39	**0.10**	1
Project B	0.10	0.22	0.02	0.34	**0.09**	2
Project C	0.01	0.22	0.03	0.27	**0.07**	3

	Final Score	**Final Ranking**
Project A	0.37	1
Project B	0.31	3
Project C	0.32	2

Hypothetical scenario 2 as shown in Table 4-30 generated results which highlight the impact of the high weighting that traditional metrics received on Level 1 in this study. The data shows that given the assigned weightings, the rank of the project under traditional metrics determines the overall AHP ranking. In this case, Project C with the best score under the traditional metrics ranks highest on the overall AHP ranking. The learnings of Hypothetical scenario 1 and 2 suggest that as the weighting of non-traditional metrics increases, the non-traditional metrics of projects will likely become the points of differentiation and deciding factors for the ranking of projects.

Table 4-30 Hypothetical scenario 2 AHP results



	Traditional Metrics			Weight	0.61	Level 1
	NPV	IRR	Capital	Total Score	Weighted Score	Ranking
Project A	0.24	0.07	0.03	0.34	**0.21**	2
Project B	0.23	0.06	0.03	0.32	**0.20**	3
Project C	0.25	0.06	0.03	0.34	**0.21**	1

	Sustainability			Weight	0.05	Level 1
	Fatalities	AIFR	Social License	Total Score	Weighted Score	Ranking
Project A	0.22	0.01	0.07	0.29	**0.01**	3
Project B	0.22	0.05	0.07	0.33	**0.02**	2
Project C	0.22	0.02	0.14	0.37	**0.02**	1

	Resource			Weight	0.11	Level 1
	Life Of Mine	Resource Category	Gold Grade	Total Score	Weighted Score	Ranking
Project A	0.08	0.04	0.14	0.26	**0.03**	2
Project B	0.11	0.03	0.07	0.21	**0.02**	3
Project C	0.04	0.01	0.49	0.53	**0.06**	1

	Operating			Weight	0.23	Level 1
	Annual Ounces	AISC	Productivity	Total Score	Weighted Score	Ranking
Project A	0.12	0.25	0.02	0.39	**0.09**	1
Project B	0.10	0.22	0.02	0.34	**0.08**	2
Project C	0.01	0.22	0.03	0.27	**0.06**	3

	Final Score	Final Ranking
Project A	0.34	2
Project B	0.31	3
Project C	0.35	1

Figure 4-9 Hypothetical scenario 2 AHP results

4.9 Chapter Summary

To generate the level 1 criteria for the AHP, the three companies that produced the most gold globally in 2016 were selected (Barrick Gold Corporation, Newmont Mining Corporation and AngloGold Ashanti Pty Ltd). The respective strategies for each company was analysed for commonality, with four criteria (traditional metrics, sustainability, resource and operating) selected as the Level 1 AHP.

The sub-criteria metrics for each Level 1 criterion were selected from data commonly published in annual reports or similar publicly available company data. The parameters were selected as far as possible from industry norms deemed representative of the specific Level 1 criteria for example, NPV, IRR and Capital were selected as representative of the level 1 AHP category of traditional metrics.

During an AngloGold Ashanti workshop, pairwise comparisons were undertaken on the various levels of the AHP. The model calculated the consistency index, consistency ratio and eigen vector values to ensure consistent ranking of the criteria. Traditional metrics, sustainability, resource and operating were weighted 61%, 5%, 11% and 23% respectively during the workshop.

On completion of the pairwise comparison, data for each sub-criterion was sought for the three projects. The data was obtained from two sources:

- The project TM models as detailed in this report, and
- The publicly available annual reports and sustainability reports for AngloGold Ashanti.

The results of the AHP ranking are the same as the results of the DCF analysis with project A, B and C ranked 1, 2 and 3 respectively. This is as a result of the very high weighting of traditional metrics (61%) on the Level 1 pairwise comparison assigned during the AngloGold Ashanti workshop.

To further test the usefulness of the AHP in Brownfield project ranking, two hypothetical scenarios were analysed. The first scenario assumed that all Level 1 metrics were of equal importance. The resulting ranking of projects resulted in Project C moving to second place and Project B dropping to third place while Project A maintained its first place in the ranking. The scenario demonstrated that changing Level 1 priorities has a material impact on the ranking of the projects under consideration.

In the second Scenario tested, the traditional metrics of Projects B and C were adjusted to be within -5% and +5% of Project A values respectively. All other metrics and weightings remained unchanged Given the high weighting of traditional metrics, this scenario tested the AHP usefulness when traditional metrics were very similar between projects. As a result of the high weighting of traditional metrics, the scenario outputs confirmed that the ranking of the traditional metrics determined the overall ranking of the projects.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

The valuation and ranking of mining projects can be done in multiple ways utilising sales, market or income methods. Brownfield projects are unique in that they have, as attributes, a significant amount of data available for their valuation and ranking. Traditionally valuation and ranking of Brownfield mining projects is undertaken through the application of a discounted cash flow (DCF) financial model. The outputs of a DCF model include Net Present Value (NPV), Internal Rate of Return (IRR) and Capital. NPV, IRR and Capital are habitually used as the primary metrics for comparing and ranking Brownfield projects within the mining industry. In this research project, these elements are termed traditional metrics.

Historically, delivering a profit to shareholders, while abiding by the relevant laws was all that was required of a company to be successful. The advent of mass communication through the internet, social media and television has resulted in additional demands from shareholders on companies. Shareholders now demand that companies are socially and environmentally responsible, that business is done in a fair and open manner, which in the context of mining companies, the communities where mining takes place benefit from the mining activity. Doing business in a socially responsible manner is paramount in an era where, as detailed by Solomon (2012), negative media coverage can be linked to a possible share price decline.

Changing corporate values in line with increased social responsibility are manifested in changing corporate visions and mission statements. An analysis of three major gold mining companies with respect to their vision statements identified a set of common metrics for corporate values including traditional metrics, sustainability, resource (geology) and operating performance. The DCF method of valuation and ranking of competing projects only addresses the traditional metrics of a mining company. The identification of an alternative ranking tool which is inclusive of the new corporate values has the potential to add value to the decision-making process.

There are a number of Multiple Criteria Decision Making (MCDM) methods that could be applied to the ranking of Brownfield mining projects. A review of literature identified the Analytic Hierarchy Process (AHP) as the most commonly applied MCDM method. The strength of the AHP process lies in several key areas including its ease of use, flexibility and the ability to check the consistency of the relative weighting of decision criteria. This research project applied AHP to the ranking of Brownfield mining investments.

Three Brownfield mining projects were selected for analysis and the application of AHP to their ranking. The projects are detailed as follows:

- **Project A** – The project in West Africa, a joint venture between three parties adds hard rock processing capacity through the addition to and upgrade of the existing plant;
- **Project B** – The project in West Africa, has a single shareholder, converts the current mine processing plant into a hard rock treatment plant to enable the treatment of fresh and transitional material; and
- **Project C** – The project in East Africa, proposes an underground drilling decline focused on accessing underground drilling platforms, undertaking the drilling and then commencement of associated mining activities.

A discounted cash flow model was developed and the projects were ranked on the traditional metrics of NPV, IRR and Capital. The projects were ranked as follows:

1. Project A;
2. Project B; and
3. Project C.

The vision or mission statements as noted in annual reports for the three largest gold mining companies (Barrick Gold Corporation, Newmont Mining Corporation and AngloGold Ashanti) were analysed for common corporate values. The selection of gold companies was made as the project commodity being considered in this research project is gold. Four common corporate values were selected as appropriate representation of corporate values. The selected corporate values were used to populate Level 1 of the AHP. Three measurements (absolute or calculated) of each of these corporate values were selected as sub-criteria in the AHP. As an example, NPV, IRR and Capital were selected as sub-criteria for the Level 1 traditional metric. The resulting AHP model prior to weighting of the values is shown in Figure 5-1.

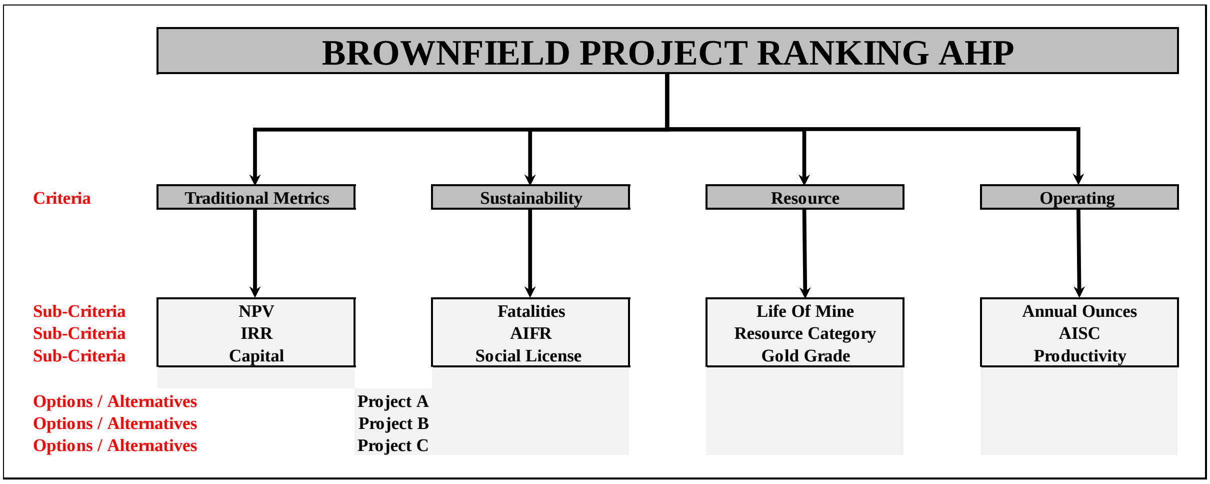


Figure 5-1 Brownfield project ranking AHP

One of the strengths of AHP is its ability to check the consistency of the weightings of criteria. This is done through a pairwise comparison process. As detailed in (AngloGold Ashanti, 2017a), a series of pairwise comparisons were undertaken on the AHP shown in Figure 5-1. The results of the pairwise comparison, expressed as percentages is shown in Figure 5-2. It is noted that all pairwise comparisons demonstrated consistency in weighting.

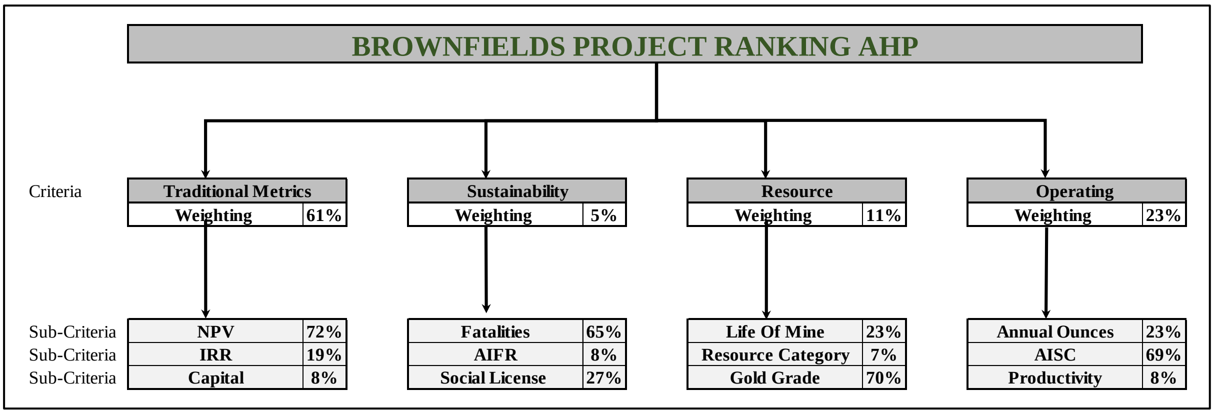
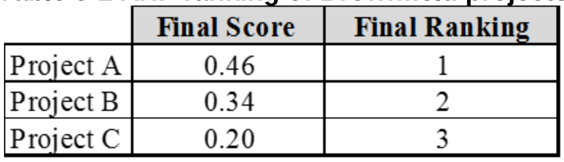


Figure 5-2 Brownfield project ranking AHP with pairwise comparison results

Data used within the AHP to score the various sub-criteria was sourced from either the discounted cash flow models developed within this research project or from annual public reports produced by AngloGold Ashanti. The values for each sub-criterion was entered into the AHP and the appropriate weighting applied. The AHP then ranked the projects as shown in Table 5-1.

Table 5-1 AHP ranking of Brownfield projects



	Final Score	Final Ranking
Project A	0.46	1
Project B	0.34	2
Project C	0.20	3

The results of the AHP ranking and the traditional metrics ranking are the same. The reason that the rankings are the same is that the traditional metrics have been assigned a weighting of 68%, which is more than double the weighting of the remaining metrics combined. Due to the weighting, the ranking of the traditional metrics dictates the overall ranking of the projects.

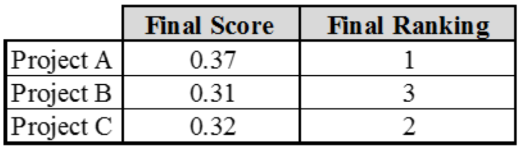
The confidence and value placed on the traditional metrics is understandable given that such measurements have been so entrenched in corporate values. While the outcome of the initial investigation has resulted in a ranking that is identical to the traditional metrics DCF approach, there still remains potential benefit of applying AHP to the ranking of Brownfield projects. Two scenarios were developed to further test the usefulness of the AHP for the ranking of Brownfield projects and these are:

- **Hypothetical scenario 1** assumes equal weighting of the Level 1 AHP metrics in the ranking of Brownfield projects. All remaining parameters and scoring remains unchanged; and
- **Hypothetical scenario 2** tests whether there would be a change in project ranking if the traditional metrics were closer in absolute value. In order to test this scenario, the traditional metrics of Projects B and C were adjusted to be within -5% and +5% of Project A respectively. All other metrics and weightings remained unchanged.

As noted in Table 5-2, the ranking of the projects where all Level 1 metrics are weighted equally changes from the DCF model and AHP model presented in the study. This indicates that:

- As times change and corporate values evolve, the AHP provides an unbiased tool to present a ranking based on an organisation's value system at the time; and
- Project rankings based on traditional metrics such as NPV may not be valid as corporate values evolve.

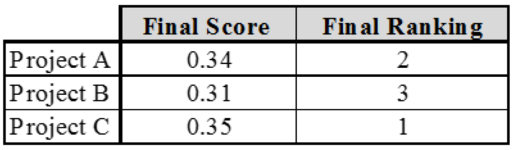
Table 5-2 Hypothetical scenario 1 Brownfield project ranking



	Final Score	Final Ranking
Project A	0.37	1
Project B	0.31	3
Project C	0.32	2

The results of hypothetical scenario 2 are shown in Table 5-3, where the traditional metric values of Project B and C were adjusted to be within -5% and +5% of Project A values. This scenario substantiates the findings of the current study where it has been demonstrated that because of the high weighting of the traditional metrics, the scores of the traditional metrics determines the overall ranking of the project. Despite the relatively minor differences in traditional metrics, the overall project rankings are still determined by this Level 1 criterion alone.

Table 5-3 Hypothetical scenario 2 Brownfield project ranking



	Final Score	Final Ranking
Project A	0.34	2
Project B	0.31	3
Project C	0.35	1

5.2 Conclusions

The evolving nature of a mining company's corporate values, as influenced by shifting shareholder expectations potentially renders inadequate the sole use of traditional project metrics (NPV, IRR and Capital) for project ranking. The traditional DCF model does not adequately produce a project ranking that is truly inclusive of non-traditional metrics such as sustainability factors. An alternative ranking system has the potential to add value through inclusion of all corporate values in the decision-making process. The aim of this research project was to rank Brownfield mining projects using the Analytic Hierarchy Process.

During the research, three projects were evaluated. A traditional DCF approach was utilised in the evaluation and subsequent ranking of the projects. In this research, the available data for each of the three projects was analysed and an AHP model developed. Critically, the AHP model included the non-traditional corporate values of sustainability, resource and operating which were derived from the mission statements of three of the world's largest gold only mining companies. The AHP process is therefore inclusive of all corporate values while the DCF approach excludes many of the key corporate values.

The research has demonstrated that the application of the Analytic Hierarchy Process (AHP) provides a tool that satisfies changing corporate value systems through its ability to include all corporate values. Additionally, AHP provides an easy to use, flexible and transparent tool. The research has demonstrated successful application of AHP to Brownfield mining project ranking.

The key result of the research project is that the ranking of the three projects under consideration remains the same for both the traditional DCF approach and the more inclusive AHP result. The weightings applied to the various AHP Level 1 metrics are reflective of the entrenched value that mining professionals place on the DCF approach. As a result of the traditional metrics having a weighting of 0.68, the ranking of the projects by this metric dictates the overall AHP ranking of the projects.

To further test the usefulness of the AHP approach in the ranking of Brownfield mining projects, additional hypothetical scenarios were considered. Under a scenario where all Level 1 priorities were deemed equally important (i.e. 0.25 weighting), but all project data was unchanged, a new project ranking was generated. Such analysis indicates that as corporate values and the relative importance of each value changes over time, there is a distinct possibility that the ranking of Brownfield mining projects will change. Under a second scenario where the values of the traditional metrics were modified to be within -5% and +5% of each other, the rankings of the traditional metrics again dictated the overall ranking of the projects. This indicates that the AHP rankings remained too heavily in favour of the traditional metrics for the other metrics to influence the rankings in a meaningful manner.

The research has demonstrated that when two or more projects are ranked against each other, changing corporate value systems, if integrated into an analytical hierarchy process, can impact the ranking of a series of projects, and potentially therefore a decision on investment. AHP has been applied in a variety of mining related applications, with Musingwini & Minnitt (2008) proposing its use in the ranking of platinum projects competing for funding. While this research focuses on Brownfield gold mining projects, the application is in line with the suggested use by Musingwini & Minnitt (2008). The aim of the research of this project was to investigate if the AHP can be used for ranking of Brownfield mining investments in order to account for non-traditional investment criteria. The application of AHP to Brownfield mining project rankings has been achieved, the results of which suggest that AHP is a valuable tool in the ranking of projects and subsequent mining investment decisions in the future.

5.3 Recommendations for additional research

Although successful and within the limits of the research proposal, the methodology applied in this body of research is not exhaustive. There remains a number of opportunities for further research, such as:

- Identification of further values on both the Level 1 Criteria;
- Identification of additional sub-criteria within the Level 1 criteria for added value in the overall ranking;
- In-depth analysis of the relationships between the various sub-criteria in order to be certain that existing relationships between such criteria are not unduly impacting the overall ranking; and

- Further analysis of the weighting of Level 1 criteria, through survey or preferable through interviews with a large pool of executives who routinely make such investment decisions.

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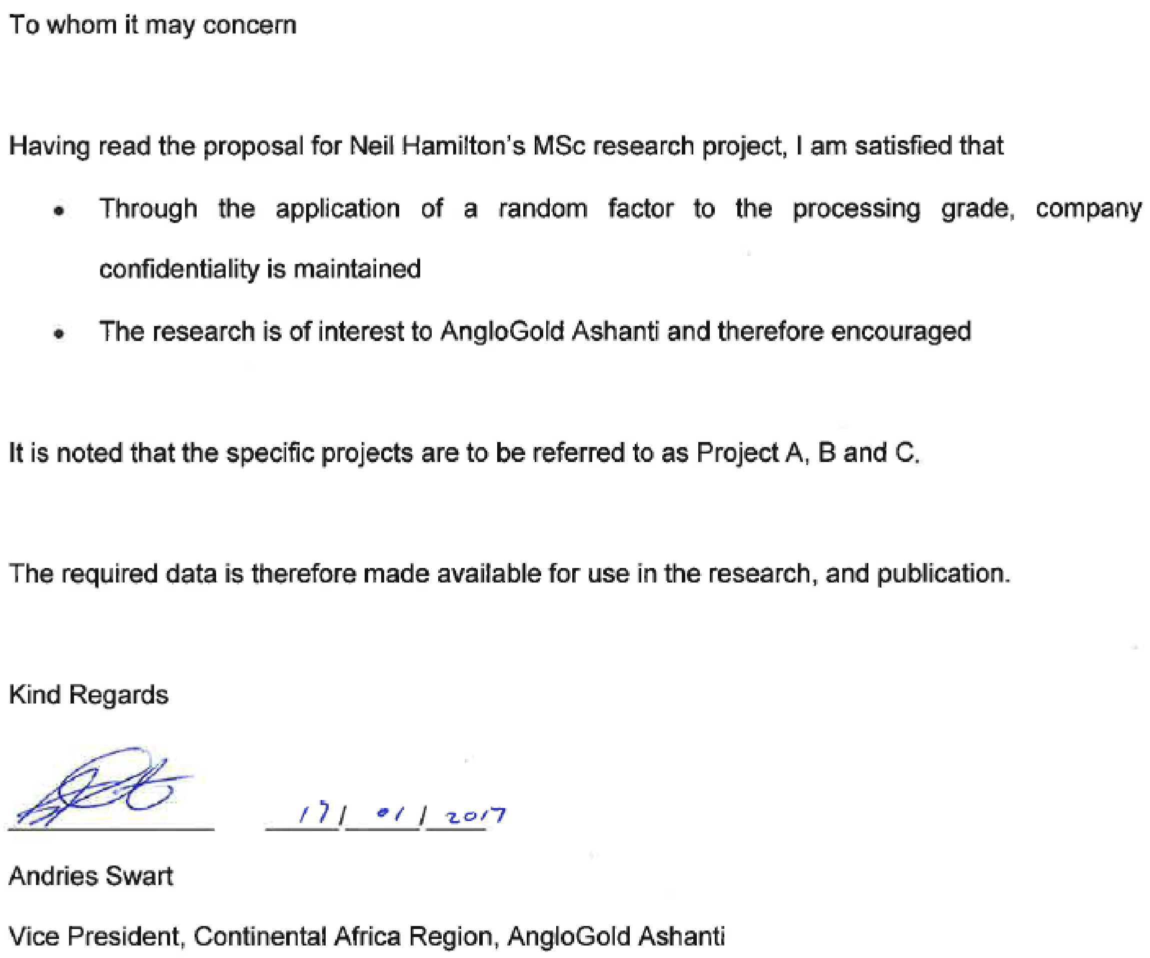
7 APPENDIX 1 - PERMISSION TO USE DATA



To whom it may concern

Having read the proposal for Neil Hamilton's MSc research project, I am satisfied that

- Through the application of a random factor to the processing grade, company confidentiality is maintained
- The research is of interest to AngloGold Ashanti and therefore encouraged

It is noted that the specific projects are to be referred to as Project A, B and C.

The required data is therefore made available for use in the research, and publication.

Kind Regards

17 / 01 / 2017

Andries Swart

Vice President, Continental Africa Region, AngloGold Ashanti

8 APPENDIX 2 - ANGLOGOLD ASHANTI MULTIPLE DECISION CRITERIA MODELLING WORKSHOP.

AngloGold Ashanti

Multiple Decision Criteria Modelling Workshop

Discussion on the theoretical application of MCDM, in particular the AHP process, to decisions facing the company

June 2017

Document Number

020163-PS-02-2.3-001

CONTENTS

1. PURPOSE

This paper details the proceedings of a workshop held at the AGA offices in Newtown, Johannesburg. The outcomes of this workshop are to be used for the guidance of the application of AHP in brownfield project ranking. The work is regarded as proof of concept for potential application within the organisation for projects such as P500 and OE.

2. CONTEXT

Analytic Hierarchy Process (AHP) is one of many multiple criteria decision making (MCDM) tools available. The strength that AHP brings to the decision-making process is the ability to mathematically check the consistency of the relative weightings of the metrics.

AHP therefore provides a tool that could potentially be used to provide a consistent ranking of a multitude of initiatives (such as P500 and OE). The workshop was held for two key reasons:

- Introduce key management to the AHP concept;
- Rank the criteria developed during prior academic research such that an accurate proof of concept AHP can be developed.

3. RESEARCH

In order to develop the proof of concept within the mining environment, research was presented to the group on three well understood CAR mining projects. In order to develop an AHP model, the values found in the top three mining companies mission statements were analysed and presented. A series of relevant sub-criteria were then presented and ratified during the workshop. Following the selection of the sub-criteria, a series of pairwise comparisons were undertake on the AHP criteria and sub-criteria.

As noted during the workshop, the comparisons will be used in both an internal proof of concept document and for the use by N Hamilton in his MSc and subsequent academic publication. On this basis the views and scoring in the pairwise comparison as well as the selection of sub-criteria were specifically selected as being representative of the gold industry and not specific to AngloGold Ashanti. The AHP model was populated during the workshop, the selected Level 1 criteria and the associated sub-criteria are shown in Figure 1.

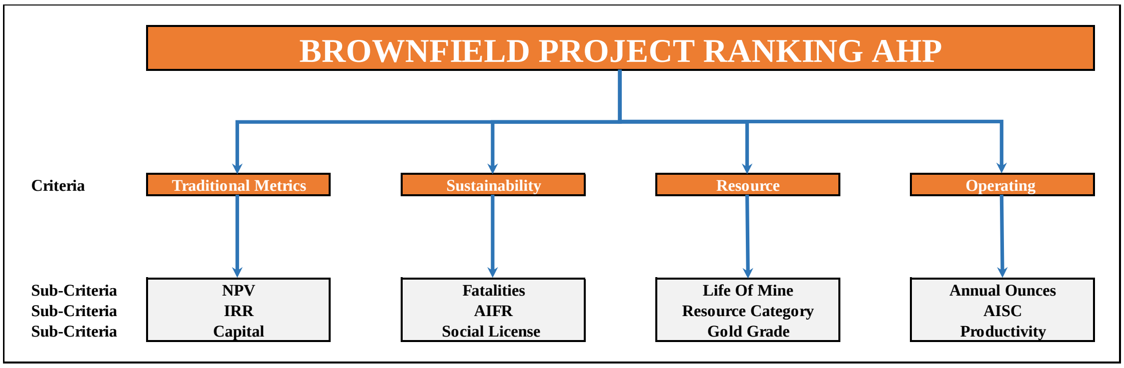
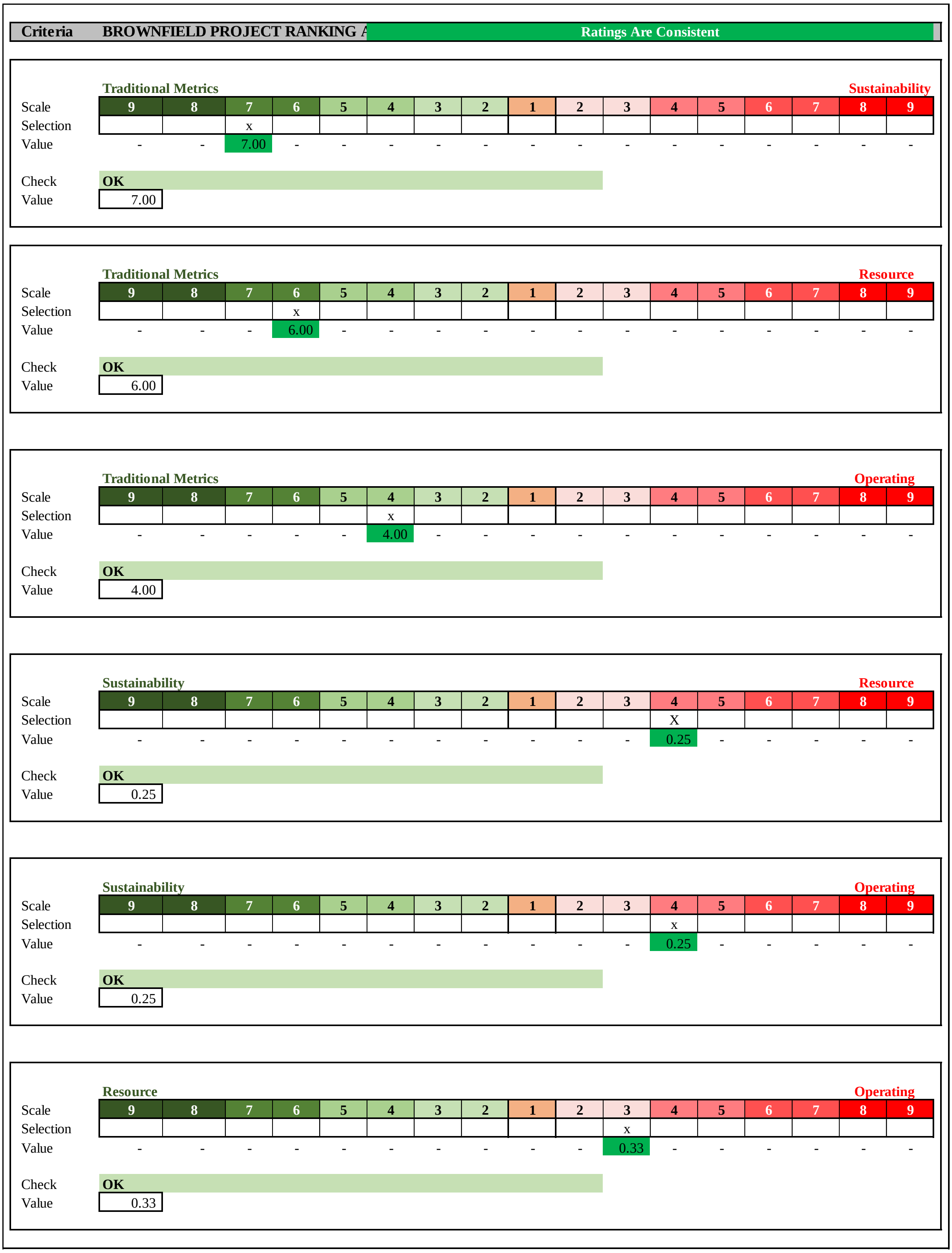


Figure 1 AHP model with Level 1 Criteria and associated sub-criteria

4. PAIRWISE COMPARISON

A pairwise comparison was undertaken on the criteria and sub-criteria using standard AHP approach as defined in the literature, Figures 2 - 6 show the results of the comparisons. Per the AHP approach, the consistency of the inputs was tested and only once the consistency factor for each series of comparisons was satisfactory were the ratings deemed complete.



Criteria **BROWNFIELD PROJECT RANKING A** **Ratings Are Consistent**

Traditional Metrics **Sustainability**

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection			x														
Value	-	-	7.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Check **OK**
Value 7.00

Traditional Metrics **Resource**

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Check **OK**
Value 6.00

Traditional Metrics **Operating**

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection						x											
Value	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-

Check **OK**
Value 4.00

Sustainability **Resource**

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												X					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-

Check **OK**
Value 0.25

Sustainability **Operating**

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-

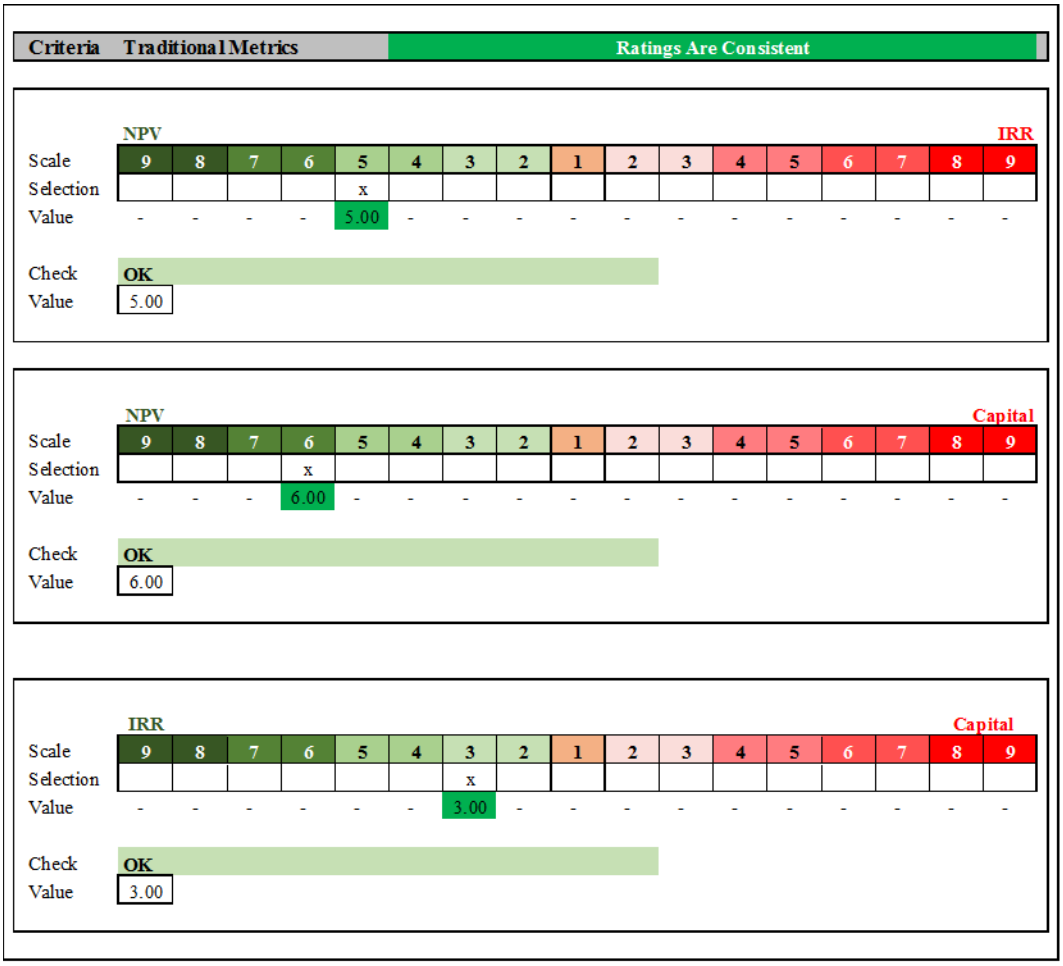
Check **OK**
Value 0.25

Resource **Operating**

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection											x						
Value	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	-	-

Check **OK**
Value 0.33

Figure 2 Traditional Metrics Pairwise comparison Workshop Results



Criteria	Traditional Metrics	Ratings Are Consistent

	NPV																IRR
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection					x												
Value	-	-	-	-	5.00	-	-	-	-	-	-	-	-	-	-	-	-

Check OK

Value 5.00

	NPV																Capital
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Check OK

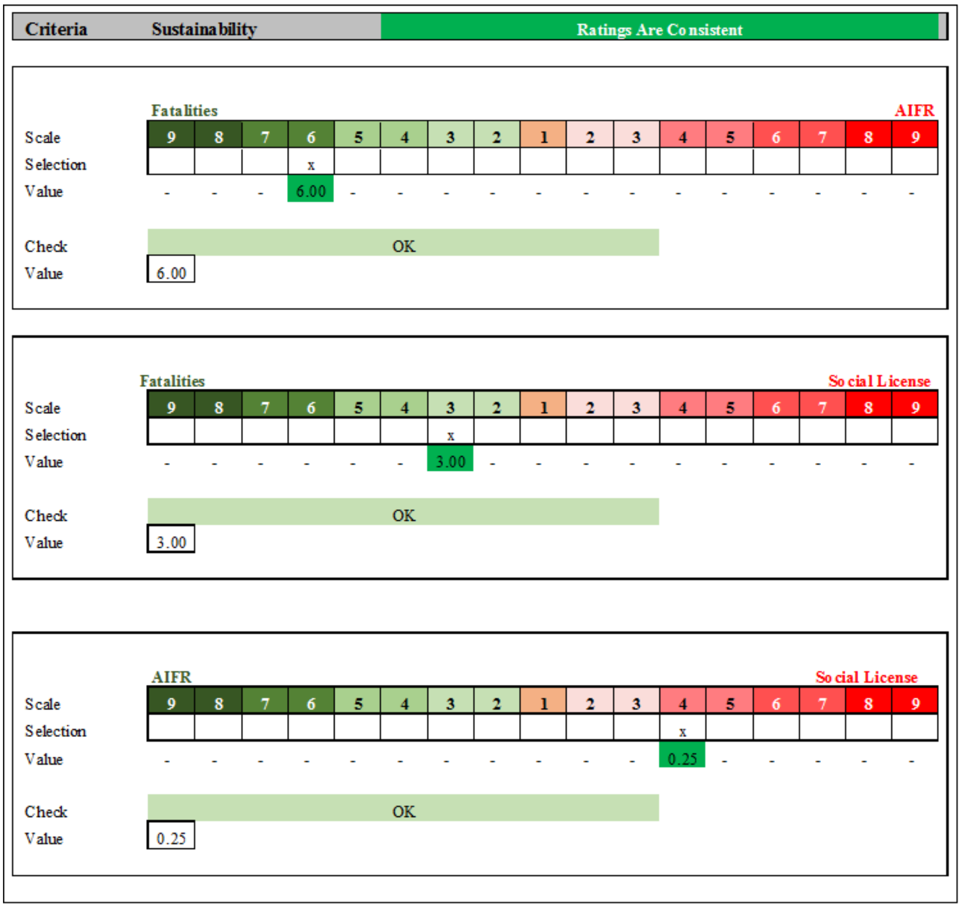
Value 6.00

	IRR																Capital
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection							x										
Value	-	-	-	-	-	-	3.00	-	-	-	-	-	-	-	-	-	-

Check OK

Value 3.00

Figure 3 Traditional Metrics Pairwise comparison Workshop Results



Criteria **Sustainability** Ratings Are Consistent

	Fatalities																AIFR
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Check OK

Value 6.00

	Fatalities																Social License
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection							x										
Value	-	-	-	-	-	-	3.00	-	-	-	-	-	-	-	-	-	-

Check OK

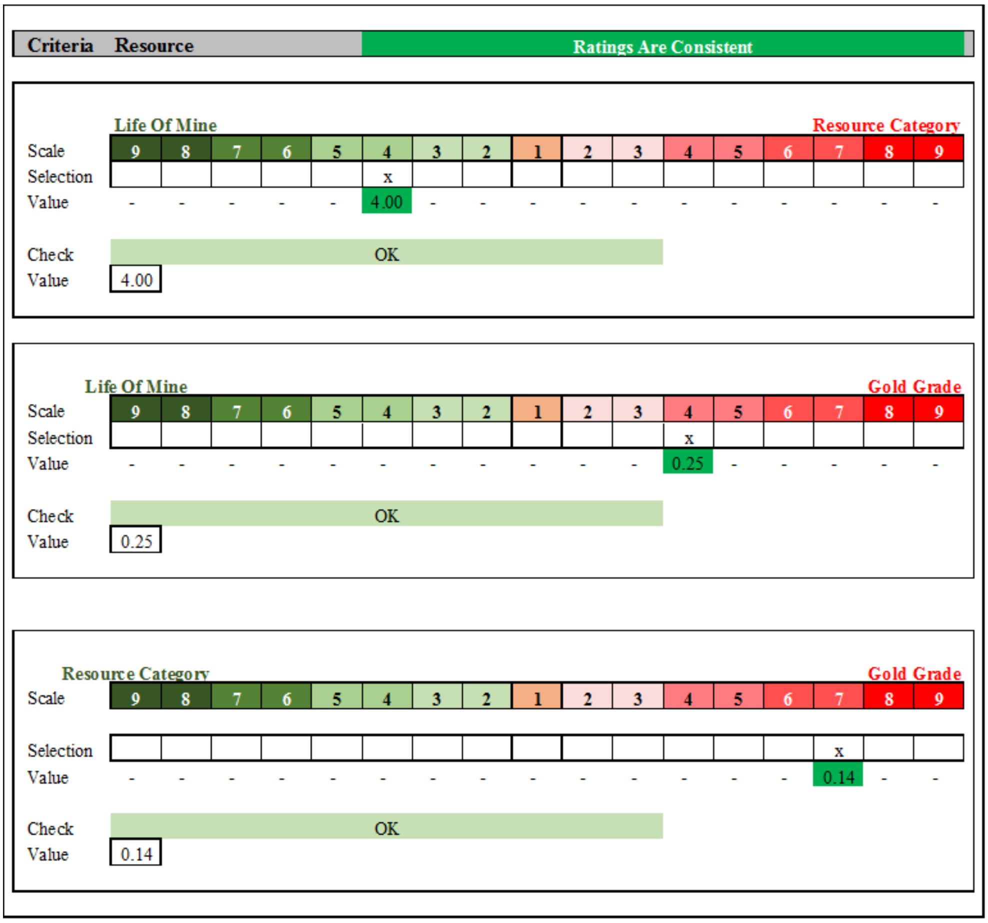
Value 3.00

	AIFR																Social License
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-

Check OK

Value 0.25

Figure 4 Sustainability Pairwise comparison Workshop Results



Criteria **Resource** | Ratings Are Consistent

Life Of Mine — Resource Category

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection						x											
Value	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-

Check OK

Value 4.00

Life Of Mine — Gold Grade

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-

Check OK

Value 0.25

Resource Category — Gold Grade

Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection															x		
Value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	-

Check OK

Value 0.14

Figure 5 Resource Pairwise comparison Workshop Results

Criteria	Operating	Ratings Are Consistent

	Annual Ounces																AISC
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection												x					
Value	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-
Check	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-
Check	OK																
Value	0.25																

	Annual Ounces															Productivity	
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection						x											
Value	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-
Check	-	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	4.00																

	AISC															Productivity	
Scale	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selection				x													
Value	-	-	-	6.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Check	OK																
Value	6.00																

Figure 6 Operating Pairwise comparison Workshop Results

On conclusion of the pairwise comparison exercise, the AHP model was completed with the weightings of the criteria shown in Figure 7 as a percentage. The workshop concluded the rankings were consistent with their views and agreed that the work on a proof of concept could proceed and that the results are made available for academic use.

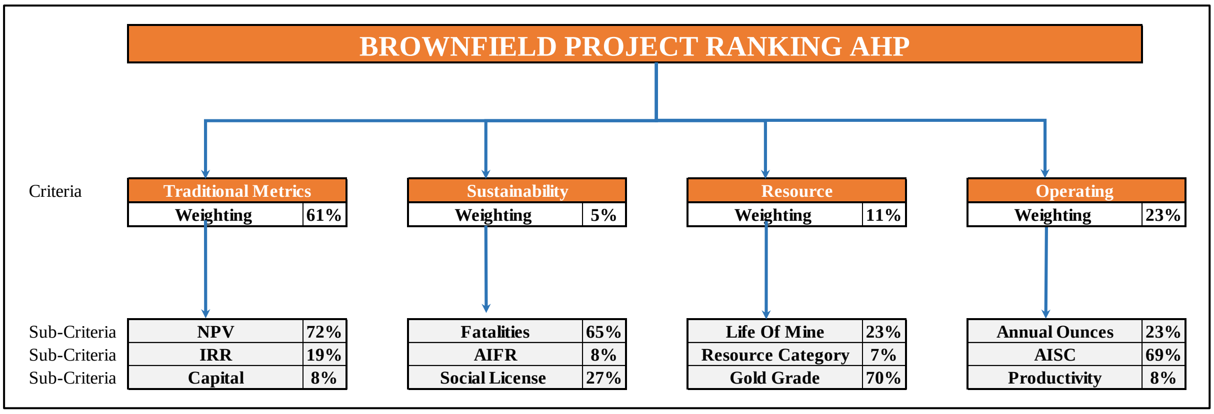


Figure 7 AHP Model with ranking of criteria and sub-criteria complete

5. APPROVAL

This document is authorised for academic use by N Hamilton in support of his research relating to his MSc.

A Swart

VP Projects