Monte Carlo simulation in Platinum mine project evaluation

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ABSTRACT

The purpose of this research is to explore and understand whether adopting a Monte Carlo simulation approach in evaluation of Platinum mine projects provides for better investment decision making in selection and approval of the projects. Mining projects are complex business opportunities and tend to be capital intensive. They are relatively risky and the business case attractiveness is influenced by many underlying natural, economic and physical uncertainties. While Discounted Cashflow (DCF) method with Net Present Value (NPV) and Internal Rate of Return (IRR) measures is one of the most commonly used evaluation methods in mining, adopting a Monte Carlo simulation to model uncertainties in calculating NPV and IRR can provide for a more realistic financial evaluation of the project.

For the research, a sample of three Platinum mining project business case were analysed and the key parameters influencing the projects' attractiveness were identified. A business case model for one of the project was developed in Excel. Monte Carlo simulation was done using @ Risk software with the respective distribution associated with those input parameters. The results were then analysed and presented to a mix of industry professionals from different disciplines. Qualitative input was collected to determine whether the simulated NPV and IRR results provide for better decision making than the NPV and IRR provided from the static DCF results.

The survey results concluded that despite certain concerns regarding complexity in Monte Carlo model and lack of sufficient transparency in selecting the input parameter distributions, it still caters for better decision making in evaluation and selection of a business case. It provides decision makers with insight into the relevant uncertainties and their impacts on the business case. It helps managers appreciate the range of the impact of the input factors and allows them to identify mitigating levers to boost the value of the project's return. It confirmed that, probabilistic simulation, if done correctly, can significantly improve the project evaluation process add to competitive advantage of the organisation.

Note: The real name the projects has not been included in this research report. The Excel model developed for simulation used price sensitive information and hence

has not been shared with the research report. But the variability and probability distributions used has been depicted for analysis and conclusion.

DECLARATION

I, ______________________ , declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

____

(Sailesh Kumar Sahu)

Signed at …………………………………………………

On the …………………………….. day of ………………………… 20…..

DEDICATION

This humble research report is dedicated to my family and friends.

ACKNOWLEDGEMENT

Firstly, I want to thank my supervisor Professor Anthony Stacey, for believing in me and allowing me to embark on this privileged adventure, I will be forever grateful.

I want to thank my colleagues David Munjeri (Financial Analyst) for helping me with the HSF runs and Mike Marshall (Senior Project Manager, Studies) & Sudhir Surujhlal (Senior Strategy Manager) for helping me understand the nitty-gritty of Platinum mining project valuation. Thank you for your support and guidance.

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TABLE OF CONTENTS

ABSTRACT ii

DECLARATION iv

DEDICATION v

ACKNOWLEDGEMENT vi

LIST OF TABLES x

LIST OF FIGURES xi

CHAPTER 1. INTRODUCTION 1

1.1 Purpose of the study 1
1.2 Context of the study 1
1.3 Problem statement 2
1.3.1 Main problem 2
1.3.2 Sub-problems 2
1.4 Significance of the study 3
1.5 Delimitations of the study 3
1.6 Definition of terms 3
1.7 Assumptions 4

CHAPTER 2. LITERATURE REVIEW 5

2.1 Introduction 5
2.2 Mining project evaluation 5
2.2.1 Mining project context 5
2.2.2 Mining project evaluation techniques 6
2.2.3 DCF with NPV and IRR as a basis for valuation 7
2.2.4 Key parameters influencing mining project value 11
2.3 Monte Carlo simulation 12
2.3.1 Monte Carlo simulation 12
2.3.2 Investment appraisal using MCS technique 13
2.3.3 Use of MCS in mining and other industries 13
2.3.4 Project evaluation in AAP 14
2.4 Conclusion of literature review 15
2.4.1 Research Question 1 16
2.4.2 Research Question 2 16

CHAPTER 3. RESEARCH METHODOLOGY 17

3.1 RESEARCH METHODOLOGY 17
3.2 RESEARCH DESIGN 18
3.2.1 INPUT DISTRIBUTIONS OF THE KEY PARAMETERS................................ 18
3.2.2 MONTE CARLO SIMULATION IN AIDING DECISION MAKING 20
3.3 POPULATION AND SAMPLE 21
3.3.1 POPULATION 21
3.3.2 SAMPLE AND SAMPLING METHOD................................ 21
3.4 THE RESEARCH INSTRUMENT................................ 22
3.5 PROCEDURE FOR DATA COLLECTION 22
3.6 DATA ANALYSIS AND INTERPRETATION................................ 23
3.7 LIMITATIONS OF THE STUDY 23
3.8 VALIDITY AND RELIABILITY 23
3.8.1 EXTERNAL VALIDITY 23
3.8.2 INTERNAL VALIDITY 24
3.8.3 RELIABILITY................................ 24

CHAPTER 4. PRESENTATION OF RESULTS 25

4.1 KEY INPUT PARAMETERS DRIVING PLATINUM PROJECTS VALUE 25
4.1.1 SELECTION OF THE PROJECT SAMPLES 25
4.1.2 SENSITIVITY ANALYSIS OF THE SELECTED PROJECTS................................ 28
4.1.3 DETERMINATION OF THE KEY INPUT PARAMETERS................................ 33
4.1.4 CONCLUSION................................ 35
4.2 MONTE CARLO SIMULATION................................ 35
4.2.1 DEVELOPMENT OF THE EXCEL MODEL 35
4.2.2 SELECTION OF INPUT PARAMETERS AND THEIR ASSOCIATED DISTRIBUTION 37
4.2.3 SIMULATION RESULTS 50
4.2.4 CONCLUSION................................ 52
4.3 SURVEY RESULTS 52
4.3.1 PRESENTATION OF SIMULATION RESULTS AND INTERVIEWS................................ 52
4.3.2 SURVEY RESULTS SUMMARY................................ 54
4.3.3 CONCLUSION................................ 56
4.4 SUMMARY OF THE RESULTS................................ 56

CHAPTER 5. DISCUSSION OF THE RESULTS 58

5.1 INTRODUCTION 58
5.2 DISCUSSION PERTAINING INPUT DISTRIBUTIONS OF THE KEY PARAMETERS................................ 58
5.2.1 KEY INPUT PARAMETERS DRIVING PLATINUM PROJECT VALUE 58
5.2.2 MODEL DEVELOPMENT AND SIMULATION 60
5.3 DISCUSSION PERTAINING TO MONTE CARLO SIMULATION AIDING DECISION MAKING 64
5.3.1 MONTE CARLO SIMULATION IN AIDING DECISION MAKING 64
5.4 CONCLUSION................................ 70

CHAPTER 6. CONCLUSIONS & RECOMMENDATIONS...............71

6.1 INTRODUCTION 71
6.2 CONCLUSIONS OF THE STUDY 71
6.3 RECOMMENDATIONS 72
6.4 SUGGESTIONS FOR FURTHER RESEARCH...73

REFERENCES 75

APPENDIX A 79

OUTPUT OF SENSITIVITY ANALYSIS...79

APPENDIX B 88

SIMULATION INPUT PARAMETERS 88
SIMULATION NPV RESULTS 90
SIMULATION IRR RESULTS...92

APPENDIX C 94

RESPONDENTS PROFILE...94
INTERVIEW TEMPLATE 95

APPENDIX D 97

CONSISTENCY MATRIX 97

LIST OF TABLES

Table 1: Capex Accuracy in Mining Projects (AAP Project Estimating Procedure) 10

Table 2: Input parameters 19

Table 3: Profile of respondents 22

Table 4: Selected project sample 28

Table 5: Project A HSF output summary 29

Table 6: Project B HSF output summary 30

Table 7: Project C HSF output summary 31

Table 8: Key input parameters ranking for NPV 34

Table 9: Key input parameters ranking for IRR 34

Table 10: Key input parameters ranking for Cash Margin 34

Table 11: Selected key input parameters for Monte Carlo simulation 35

Table 12: Project D HSF output summary 36

Table 13: Mineral content of the orebody in selected business case 40

Table 14: Baseline assumed recoveries in the business case 43

Table 15: On-Mine cost elements 47

LIST OF FIGURES

Figure 1: Mining Project Maturity (Anglo Project Way, 2010)................................ 9

Figure 2: Source of Uncertainties in Mining Projects (Martinez & Watson, 2012) 10

Figure 3: Mixed-method for research question 1 19

Figure 4: Location of AAP Operations in South Africa (AAP Annual Report, 2014) 26

Figure 5: AAP Project Development Lifecycle (Anglo Project Way, 2010) 27

Figure 6: Project A Sensitivity Chart 32

Figure 7: Project B Sensitivity Chart 32

Figure 8: Project C Sensitivity Chart 33

Figure 9: Validity of the Excel Model 37

Figure 10: Input Parameter: Exchange Rate 38

Figure 11: Simulated Input Parameter: Exchange Rate 40

Figure 12: 4E Prill Split for the Business Case 41

Figure 13: Revenue Contribution of the Minerals 41

Figure 14: Simulated Input Parameter: Pt Price 42

Figure 15: Simulated Input Parameter: Ni Price 43

Figure 16: Simulated Input Parameter: Concentrator Recoveries for Pt 44

Figure 17: Simulated Input Parameter: Smelting and Refining Recoveries 45

Figure 18: Simulated Input Parameter: Grade 47

Figure 19: Simulated Input Parameter: On-Mine Cash Costs (Total) 48

Figure 20: Simulated Input Parameter: Tonnes mined, milled 49

Figure 21: Simulated Input Parameter: Capex (Total) 50

Figure 22: Simulated Output: NPV 51

Figure 23: Simulated Output: IRR 51

Figure 24: Survey Respondents’ Profile 52

Figure 25: Survey Results 54

Figure 26: Stages in Cashflow (Adopted from Morley et al., 1999) 59

Figure 27: Historical Pt Price: Goodness-of-fit Test 62

Figure 28: Historical Cu Price: Goodness-of-fit Test 63

CHAPTER 1. INTRODUCTION

1.1 Purpose of the study

The purpose of this research is to understand whether adopting a Monte Carlo Simulation approach in evaluation of Platinum mine projects provides for better investment decision making in selection and approval of the projects.

The research aim to incorporate Monte Carlo Simulation to model uncertainties associated with various key parameters that impact the evaluation criteria for mine projects in Anglo American Platinum and assess if it provides better information for the decision makers in reviewing and approving these projects.

1.2 Context of the study

Mining projects are inherently risky (Martinez & Watson, 2012). Platinum mine projects like other mining projects are typically long-term investments. The value of a mine project over time is influenced by a number of factors e.g. ore grade, Platinum group metal prices, capital cost (Capex), operating cost (Opex), exchange rates etc.

Worldwide the Discounted Cash Flow (DCF) method is most widely used for mine project evaluation (Mirakovski et al., 2009). Under the DCF method, the Net Present Value (NPV) and Internal Rate of Return (IRR) are generally the key criteria in evaluating investment in mining projects. The NPV and IRR calculations, however, are based on point estimate of the parameters e.g. Capex, Opex, metal prices, exchange rates etc. As mining projects are typically long-term, the point estimates do not reflect the uncertainties relating to these factors (Stirzaker, 1997). Hence the NPV and IRR do not provide the full picture for the decision makers to make the investment decisions.

1.3 Problem statement

1.3.1 *Main problem*

Anglo American Platinum (AAP) is world's leading producer of Platinum group metals (AAP annual report, 2014). In evaluating new investments in Platinum projects, AAP uses the NPV and IRR as the key criteria. The NPV and IRR calculations are based on point estimates of the parameters in the future that are discounted at specific discount rates. Decision makers use these criteria in evaluating and approving the mine projects for investments. The deterministic assumption of the parameters e.g. Capex, Opex, ore grade, metal price etc. provides a point estimate of the NPV and IRR. The calculations do not take into account the inherent uncertainties associated with these input parameters and hence do not provide a holistic evaluation of the business case of the project to the decision makers.

The research will incorporate uncertainties in evaluating the projects by using distributions of the key input parameters and not the point estimates. This will yield a distribution of values for the NPV and IRR and will provide more useful information for the decision makers in approving projects.

1.3.2 *Sub-problems*

The first sub-problem is to determine what the key input parameters are in the NPV and IRR calculations of the Platinum mine projects. In addition, it will be required to determine the associated distributions of each of the key parameters that can be used for modelling the uncertainties for the Monte Carlo simulation.

The second sub-problem is to determine whether the simulated NPV and IRR results provide for better decision making than the NPV and IRR provided from the static DCF results.

1.4 Significance of the study

The research may provide a better way of evaluating mine projects by providing a distribution of NPV and IRR values to the decision makers that incorporates future uncertainties of certain key input parameters. This new approach may prove to be a better way of evaluating the organisations' pipeline of projects; enabling them to optimise on capital and resource allocation and maximise future returns. It could potentially be incorporated in to the business process of AAP.

The outcome of the research could also provide value for the broader mining community in South Africa by demonstrating the value of probabilistic simulation in project evaluation process that can optimise resource allocation and create additional value.

1.5 Delimitations of the study

Although the outcome of the research may be applied broadly in the mining industry, the research will be focussed on Platinum projects within AAP. It will be limited to the mining projects in South Africa and Zimbabwe that the company operates in. The research will use project data for AAP mining projects and will exclude the process plant projects and stay-in-business (SIB) projects.

1.6 Definition of terms

Monte Carlo: Monte Carlo Simulation is a computerized mathematical technique that allows accounting for risk in quantitative analysis and decision making (Palisade website, 2015).

Platinum Group Metal: The metal group consisting six silver-white metals: Platinum, palladium, rhodium, ruthenium, iridium, and osmium. They occur together in nature and are produced from the same ore. They are mined mainly in South Africa, Russia, and North America (International Platinum Group Metals Association website, 2015).

1.7 Assumptions

Besides any strategic reasons, it is assumed that NPV and IRR are the key criteria used for mine project evaluation in AAP. It is a reasonable assumption due to the fact that AAP has been profitable over the years and do not have constraints in terms of access to capital for project section.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

The purpose of the research is to investigate and understand whether use of Monte Carlo Simulation in evaluating Platinum mining projects in AAP will assist with better investment decision making. The literature review provides a context for the mining projects with its high degree of inherent risks. It then investigates various investment evaluation techniques in practice and continues with discussions on the merits and demerits of using DCF along with NPV and IRR as investment evaluation metric.

The subsequent section discusses various sources of uncertainty in mining projects along with the key input parameters that drive the value of a mining project. It then touches on the use of Monte Carlo Simulations in various industries, the various steps involved in its use and its potential merits. It discusses why a combination of DCF and MCS method provides for a more realistic financial evaluation of the project. This is followed by a brief on the AAP's project evaluation process and a summary of the literature review.

2.2 Mining project evaluation

2.2.1 *Mining project context*

Mining projects are complex business opportunities. Mining projects tend to be capital intensive and usually requires many years of successful operation to break even on cost incurred (Iloiu & Iloiu, 2009). As an industry, mining is regarded as relatively risky compared to other industries (Martinez & Watson, 2012). This is primarily due to the fact that value of a mining project or business case is influenced by many underlying natural, economic and physical uncertainties. Mining projects are often long-term and the business case attractiveness depends upon the performance of the project over the life of mine (LOM) (Bhappu & Guzman, 1995). When an opportunity exists to either acquire an existing mining operation or to invest capital in developing a new mine, the stockholders or the owner of the mining company wants to know the value of the mine. In a capital constraint environment and increasing uncertainties around commodity prices, the investment decisions become far trickier and vital as companies try to balance between long-term sustainability and short-term financial goals (Martinez & Watson, 2012).

2.2.2 *Mining project evaluation techniques*

The use of an adequate project evaluation technique becomes important while evaluating mining investments due to the inherent risks and uncertainties involved. There are many evaluation techniques that are available and are used at different levels in various mining companies. An ideal mining project evaluation method should be able to provide decision makers with answers relating to timing of the project capital investment and the capacity of the project i.e. its optimum production profile for the LOM (Mirakovski et al., 2009).

Iloiu and Iloiu (2009) evaluated four evaluation techniques that are popular in mining industry e.g. Net Present Value (NPV) and Internal Rate of Return (IRR) under the Discounted Cashflow Method (DCF); Decision Tree Method (DTM); Monte Carlo Simulation (MCS) method; and Real Option Valuation (ROV). The DCF method do not allow for flexibility in management decision making as all the input parameters are decided for the rest of the LOM while modelling the business case. This in turn excludes managerial decision making in the future relating to changing environments that may change the input parameters (Iloiu & Iloiu, 2009). The DTM scores over DCF in terms of allowing flexibility to include different managerial strategies and calculate all the expected NPV. This provides the whole picture of the project; however, this method becomes cumbersome when the number of variables increases. MCS method is not a standalone method and it is used along with DCF or DTM. It tries to model the uncertainties by assigning statistical distribution to the variables or the project parameters. This provides the decision makers with a number of possible outcomes of the project (Iloiu & Iloiu, 2009). The ROV method's strength is mainly in its flexibility to accommodate managerial decisions at any given point in time. This allows decision makers to respond to future events in a way that increases return. However, the need for and the value of flexibility depends on the uncertainty of a company about future reinvestment needs (Damodaran, 2005). Firms with predictable reinvestment needs value flexibility less than firms whose investment needs are volatile.

There are many other valuation methods e.g. differential discounting, tail margin, Black-Scholes option pricing, Farm-in analysis etc. (Lilford & Minnitt, 2005).Because the focus of the literature review was on evaluation methods specifically for new mining projects, discussions on the above mentioned methods have been excluded as they are primarily used for stock valuation or running asset valuation. Lilford and Minnitt (2005) conclude that selection of the valuation method depends on the project teams' ability to correctly interpret all the available information on the input variables e.g. commodity price, exchange rate, technical information, economic information and other risks.

2.2.3 *DCF with NPV and IRR as a basis for valuation*

DCF method with NPV and IRR measures is one of the most commonly used evaluation methods in mining. Bhappu and Guzman (1995) did a survey and found that some 95% of the surveyed mining companies use some sort of DCF technique in their decision making with NPV and IRR as the key criteria. Parameter such as payback period was also used as secondary criteria in decision making.

DCF technique has specific strengths over other methods used in the industry e.g. its ability to consider royalties, leases, taxation and financial gearing on the resulting cashflow (Lilford & Minnitt, 2004). DCF, in addition, has the ability to model unredeemed capital balances, losses, deprecation etc. on the free cashflow. DCF is suitable to be used to evaluate a mining project in a stable macroeconomic environment (Lilford & Minnitt, 2004).

NPV is a standard method that calculates the net income flow of a mining asset over its entire economic life (Domingo & Lopez-Dee, 2007). It involves forecasting the net cashflow the mining project would generate if exploited optimally. It then discounts it to the current date with appropriate cost of capital or discount rate. NPV methodology is aligned to the concept of maximising the value of a firm by choosing the right project with maximum NPV. Domingo & Lopez-Dee (2007) describe the four key elements of NPV as:

Time value of money: NPV recognises the concept that a rand earned today is worth more than a rand earned a year from now;

Income flows: NPV calculates the projects expected income flows and eliminates accounting inconsistencies as the income inflows consists all the cash flows and not just profits;

Risks: NPV can incorporate the risks associated with the project in terms of the expected income flow and discount rate.

Flexibility: NPV method provides flexibility as it can adjust for inflation, and be used with other analytical tools such as scenario analysis.

Financial literature defines IRR as “The discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero.” This basically means the higher a project's IRR, the more attractive the project is. Along with NPV, IRR is also widely used to rank several prospective projects that firm is considering investing (Bhappu & Guzman, 1995). Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best.

Despites many benefits of the NPV, it has its own limitations. The two main inputs that NPV analysis has are net income flow and discount rate. Determining the net income flow is not easy as it involves a number of assumptions and expectations underpinning the income flow (Domingo & Lopez-Dee, 2007). Guj and Garzon (2007) argue that for resources projects with low cashflow and healthy net present value, the NPV method will continue to be an appropriate method for project investment decisions. However, the NPV/DCF method can be biased in evaluating or comparing marginal business cases due to the fact that it often applies a single risk-adjusted discount rate to compare the value of the project with different risk characteristics. Choosing an appropriate discount rate is crucial for assessing the value of the mining project in NPV method at the same time an NPV obtained using suitable variable discount rates within the lifetime of the asset is more realistic then the NPV calculated using one constant risk-based discount rate (Domingo & Lopez-Dee, 2007). DCF/NPV techniques do not account for the ability of the managers to take advantage of changing situations in future of the project (Bhappu & Guzman, 1995).

Despite the above mention drawbacks in the NPV method, it is still a powerful tool and is still widely used in evaluation and comparing mining projects. There are many other tools e.g. Modern Asset Pricing (MAP) which in certain cases provide a better evaluation but they still use DCF analysis as the basis and only compliment it further (Guj & Garzon, 2007).

Eliis (1995) offers that despite the exact answer to the real value of a project or mineral property is not fully determinable from the DCF/NPV method, it is still recommended to use NPV as the primary method of valuing operating mine, or mineral assets that has indicated resources and a degree of engineering, production, Capex and Opex data.

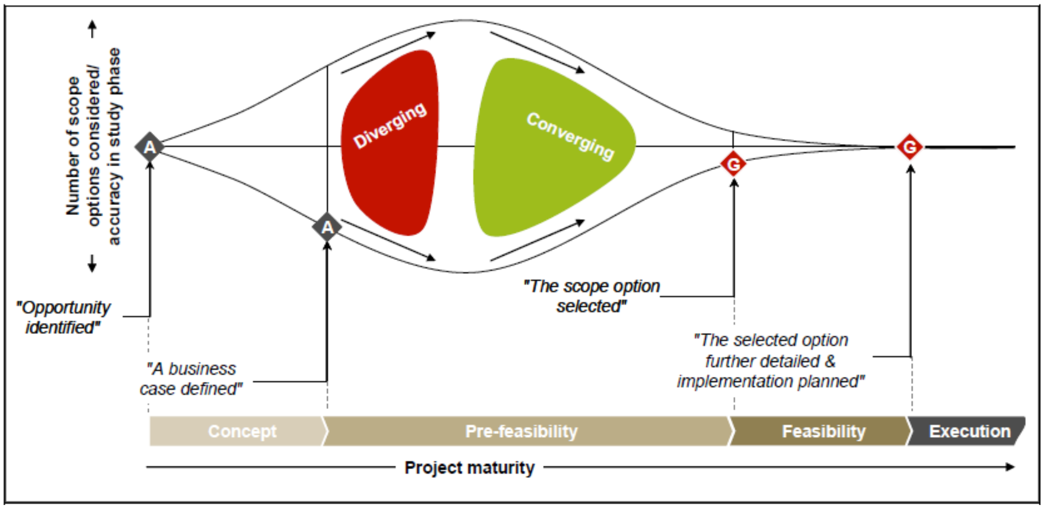

Figure 1: Mining Project Maturity (Anglo Project Way, 2010)

From the Concept stage until the end of Feasibility when the final decision is made for capital approval for implementation, there is a varying degree of information relating to engineering, Capex, Opex and production (Figure 1). AAP uses NPV as the key criteria along with IRR as the secondary criteria in comparing and deciding on project capital investment. The Capex estimate accuracy level depends on the degree of engineering progress at various stages (Table 1). It can be said that in the case of AAP, the premises on which Ellis (1996) recommends the use of DCF/NPV, holds true.

Table 1: Capex Accuracy in Mining Projects (AAP Project Estimating Procedure)

Phase of the Project	Class	Classification of Accuracy
Concept Phase	0	Accuracy range of +40% to -25% before contingency is considered.
		Capital cost estimate need to support the business case and a decision to proceed to pre-feasibility stage.
Pre-Feasibility Phase	1	Accuracy range of +25% to -15% before contingency is considered.
		Capital cost estimate of accuracy needed to support the selection of a single option and a decision to proceed to feasibility stage.
Feasibility Phase	2	Accuracy range of +15% to -5% before contingency is considered.
		Capital cost estimate sufficiently detailed and accurate to support project funding and control.

Mining projects are inherently risky (Martinez & Watson, 2012) as they are influenced by a number of underlying natural, economic and operational/technical uncertainties over the LOM (Figure 2). These are not known with much certainty during the project evaluation stage.

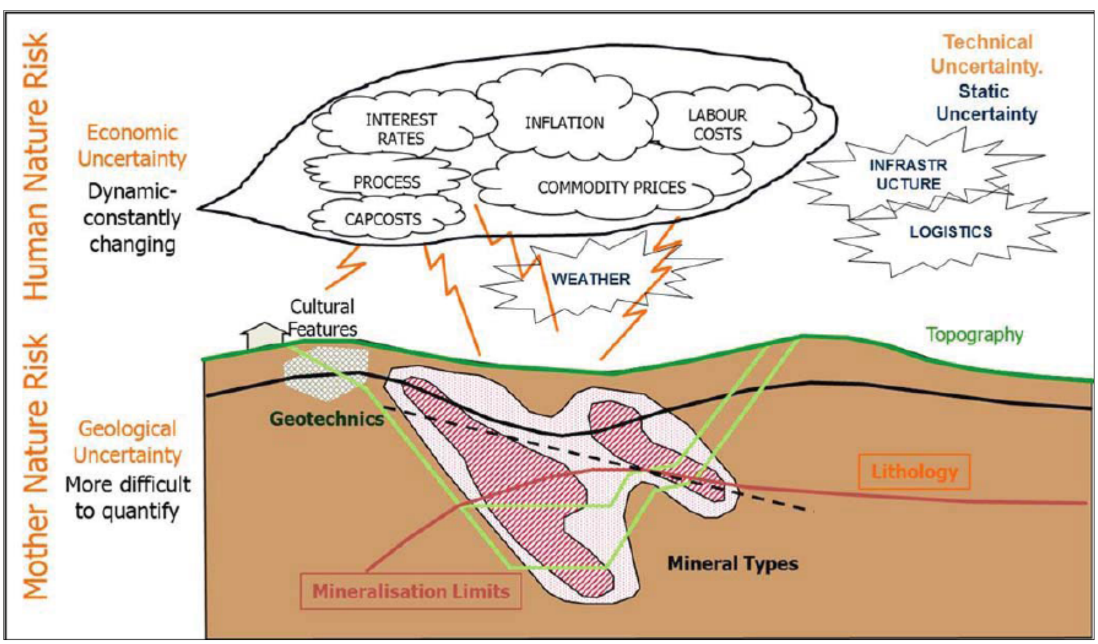

Figure 2: Source of Uncertainties in Mining Projects (Martinez & Watson, 2012)

The natural risks comes from geology i.e. distribution of ore underground as well as the ore grade. This is due to the fact that during the investment decision making, the sampling obtained is not fully representative of the full orebody. The economic uncertainties come from a variety of factors e.g. Capex, Opex and commodity prices. According to Martinez and Watson (2012), the uncertainty of Capex and Opex estimation is primarily due the lack of engineering and economic information at the beginning of the mining project. Analysts do not know with absolute certainty how much it is going to cost to produce a unit of the commodity. In addition, future metal price and exchange rate are always uncertain. Metal price and exchange rate depends on a number of factors including demand and supply forces and speculative pricing (Martinez & Watson, 2012).

2.2.4 *Key parameters influencing mining project value*

There have been many articles written on general risk factor or input parameters that impact the value of a mining project e.g. Capex, Opex, commodity price, ore grade, metal recovery etc. An internal study done at De Beers (2008) found long term diamond price, Capex, Opex, project schedule and ramp-up time as the top five value driver in Diamond mining projects. Surveys and research reports by Independent Project Analysis (IPA, 2015) indicates similar generic value drivers for mining business case. Erdem et al., (2012) provide a comprehensive list of input parameters that influenced the value of a copper mine project which also included parameters viz. ore grade, copper price, process recovery, Capex, Opex, interest rates etc.

For AAP’s Platinum project, the key input parameters influencing the valuation of the project in terms of NPV and IRR are most likely to be generic as discussed above. However, the various factors need to be determined from the existing projects data; and the associated distributions needs to be established for meaningful simulation.

2.3 Monte Carlo simulation

2.3.1 *Monte Carlo simulation*

Pergler and Freeman (2008) define probabilistic modelling as “any form of modelling that utilizes presumed probability distributions of certain input assumptions to calculate the implied probability distribution for chosen output metrics.” This is different to the standard static model e.g. a typical Excel spreadsheet, where changing the values of input assumptions at random and one can see the impact of those changes on the outputs. Monte Carlo Simulation (MCS), also known a probabilistic simulation, is the most commonly used technique for probabilistic modelling. It is used to understand and evaluate the impact of risk and uncertainty in financial, project management, cost, and other forecasting models (Riskamp, 2015).

It is a computerized mathematical technique that allows analysts and decision makers to account for risk in quantitative analysis. This technique has found widespread use amongst professionals in a variety of fields e.g., finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation, and the environment (Palisade, 2015).

Simulations and statistical sampling were already in use before the development of MCS method (Metropolis, 1987). The early variant of MCS goes back to 1930 when Enrico Fermi experimented with the method while studying neutron diffusion. By 1940, the modern version of Markov Chain MCS was invented by Stanislaw Ulam. The history of MCS method is closely linked with the development of computers and its aid in computing complex algorithms (Brown, 2011). The first knows MCS program was written in 1947. The method was also central to the simulations required for the famous ‘Manhattan Project’. Brown (2011) notes that with advancement in computers and computing technologies, MCS method has seen evolution in code development as well as wider use in a variety of industries.

MCS performs quantitative risk analysis by building models of possible results by substituting a range of values i.e. probability distribution for the factors that has uncertainty associated with (Palisade, 2015). It then simulates the results by reiterations of various set of random values within the probability distribution function and produces distributions of possible outcome values. The probability distributions of the input parameters are a realistic way of describing uncertainty in the parameters (Raychaudhuri, 2008). The common probability distributions that are normally applied are normal distribution, lognormal distribution, uniform distribution, triangular distribution, PERT distribution and discreet distribution defined by the analysts themselves (Palisade, 2015).

2.3.2 *Investment appraisal using MCS technique*

Investment appraisal using MCS technique consists of the following four steps (Hacura et al., 2001):

- Development of the conceptual model of the business case: this involves creation of the DCF model with defined mathematical relationship between the numerical variables
- Building the simulation model: this involves selection of the key project input parameters and determining their associated probability distribution
- Verification and validation of the model: this involves checking the integrity of the model i.e. ensuring that the model is free from logical error. Data validation includes ensuring that all input data and the associate distributions are true representation of the system being modelled.
- Performing the simulation: this involves generation of random scenarios and the distribution of the output.
- Analysis: this involves interpretation of the results and decision making.

2.3.3 *Use of MCS in mining and other industries*

There are many case studies done in a variety of industries modelling the value driving parameters individually or in a combination using MCS method e.g. valuation of governmental support in BOT projects (Cheah & Liu, 2005); real estate evaluation using MCS (Hoesli et al., 2005) and a host of other use of MCS in biotechnology, project management and financial sectors. One of the more elaborate use MCS in mining has been in Derekoy copper deposit case study (Erdem et al., 2012) that looked at MCS modelling of all of the input parameters. Erdem et al. (2012) argue that despite the improvements in simulation technologies e.g. MCS, it is not used frequently in mining industry despite the fact that it is an industry ideally suited to take advantage of this method. There was no significant work found in determining the key parameters or value drivers for Platinum mining projects and the MCS modelling of risk thereof.

Monte Carlo analysis is capable to cope with simultaneous changes to many of the input parameters (Strizaker, 1997). It allows the analyst to model the real case more closely. It is important that proper skill is applied to determine the range over which the key input parameters are likely to vary. Bhappu and Guzman (1995) argue that a typical DCF evaluation technique utilises constant or static mining and processing rate as well as ore grades and metal recovery. Other authors on similar subjects (Erdem et al., 2012) argue that with a static DCF that is without a MCS input, a dynamic and flexible model construction is not feasible as uncertainty cannot be modelled into it. The uncertainties are the true characterisation of a project and a proper evaluation is only possible when the uncertainties are modelled into a dynamic DCF (Erdem et al., 2012). A combination of DCF and MCS method provides valuable information about the robustness of the project. The output is unbiased and therefore provides for a more realistic financial evaluation of the project (Erdem et al., 2012).

2.3.4 *Project evaluation in AAP*

The Anglo American Plc Investment Evaluation Guideline (AAP IEG, 2013) provides the framework for project evaluation within AAP. It recognises that most capital projects within AAP are long-term and require significant capital investment. This necessitates that the business case is underpinned by solid technical and commercial evaluation and verified though the validation of all the underlying assumptions.

The primary investment evaluation tool prescribed by the guideline is the DCF analysis, which determines the NPV of all expected cash inflows and cash outflows arising specifically from, or associated with, the particular project or asset. The NPV calculations are done on a standalone basis for a new project (Greenfields). For an existing project or asset (Brownfields) on an incremental basis for) the NPV calculations are done both on a “do nothing” basis, then an investment case, resulting in an incremental case.

The hurdle rate or discount rate is defined from the corporate finance department from time to time. Typically this depends on the weighted average capital cost of the company (WACC) along with project premium (to cater for risk inherent in new projects with execution risk, unfamiliar technology or metallurgy etc.), acquisition premium (to cater for integration risk and the inherent lack of information typical of acquisition scenarios) and a country risk premium (to cater for country specific risks).

The DCF analysis is typical. It uses real money terms (i.e. excluding inflation), and takes the net cashflow that is post-tax in to the DCF analysis. It uses both US$ and ZAR denomination. The output of the DCF analysis typically covers information of LOM, production profile, NPV and IRR, discount rate, unit cost, Capex, Opex, royalty, taxes and operating margins.

The project value (NPV) is tracked through a dashboard called Project Value Tracking (PVT) which involves the comparison of project value at various time frames. The updated forecast NPV includes the latest economic parameters; actual results achieved to date and forecast Capex, Opex and schedule. Variances between the approved business case NPV is restated at real money terms and is highlighted and explained using a waterfall chart.

The AAP guideline alludes to a static DCF model for investment analysis. It appears that there is a high likelihood that the current project evaluation framework in AAP can be further improved by incorporating MCS into the DCF and it is expected to provide better assistance to the decision makers in approving projects.

2.4 Conclusion of literature review

There are various investment evaluation techniques available. Despite certain limitations, DCF along with NPV and IRR as metric are widely used in mining and other industries as an investment tool. However, DCF alone is static and does not provide with a robust evaluation of project such as mining projects with so many uncertainties associated with it. It can be complemented by MCS technique that could significantly enhance the evaluation of the projects. However, determining the key input parameters and the associated distribution is the key to the success of MCS technique. MCS has been successfully used in many industries with positive results and similar benefits can be reasonably expected from its usage mining sector in general and Platinum mining in particular.

The current project evaluation procedure in AAP is based on static DCF models and it is expected that introducing MCS into the process will significantly increase the granularity on the project evaluation and will assist with better decision making in selection and approval of projects in AAP.

2.4.1 *Research Question 1*

What are the key input parameters that drive the value of Platinum mine business case and what are the respective distribution associated with those parameters.

2.4.2 *Research Question 2*

It is proposed that the simulated NPV and IRR results will provide for better decision making than the NPV and IRR provided from the static DCF results.

CHAPTER 3. RESEARCH METHODOLOGY

This section describes the research methodology that was applied to find answers to the two research questions for the purpose of concluding the research. This includes discussions around the mixed-method methodology for research. It discusses the benefits of mixed-method and why it was appropriate for this particular research.

It describes the methodology followed to answer the research question 1 and 2 and discusses the external validity, internal validity and reliability relating to the proposed methodology.

3.1 Research methodology

To answer the research question 1 i.e. determination of the key value driving parameters in Platinum business case and their associated distributions for Monte Carlo Simulation; and research question 2 i.e. if the simulated NPV and IRR results provide information for better decision making ; a mixed-method research methodology of qualitative and quantitative methodology was followed.

Jick (1979) defines mixed-method research design as utilisation of different methodologies i.e. qualitative and quantitative methodology to research the same occurrence. “The emergence of mixed methods as a third methodological movement in the social and behavioural sciences began during the Mixed Methods as a “Movement” during 1980’s” (Tashakkori & Teddlie, 2003; p.48). Historically the mixed-method has been used for decades (Driscoll et al., 2007). Mixed-methods are generally used to expand the depth of research to mitigate weakness of either of the qualitative and quantitative method alone. De Lisle (2011) further argues that the interest in mixed-method research and the diverse ways in which quantitative and qualitative methodologies can be systematically combined has been growing. Driscoll (2007) states that mixed-method methodology provides practical advantages in exploring complex research question. Mixed-method research design is logical and intuitive providing a bridge between qualitative and quantitative paradigms (Onwuegbuzie & Leech, 2006). Qualitative and quantitative data complimenting each other provides robustness of the research process, one clarifying the other throughout the study. This provides researchers with more than one view point and creates a purer understanding of the occurrence (Jick, 1979). The method followed had the flexibility to meet the need of the study. It provided opportunities for triangulation of data and ensuring its validity.

There are many challenges and disadvantages in the mixed-methods approach. The primarily challenge comes from manipulation or combining the qualitative and quantitative data into one (Driscoll et al., 2007). Lieber (2009) further mentions that management, processing and analysis of both qualitative and quantitative data together requires more time and money to make the process more effective and efficient.

Despites this relative disadvantage over a single qualitative or quantitative research method, it can be concluded that combination of methods provides a better understanding than either the quantitative or qualitative method alone (Driscoll et al., 2007). Using the mixed-method processes can also lead to discovery of emergent themes or information that would not have been otherwise possible with either qualitative or quantitative method alone (Driscoll et al., 2007).

To answer the research question 1, it was required to identify the key value driving parameters through quantitative analysis of a number of projects in the AAP database. However to determine the associated probability distribution, a combination of both quantitative and qualitative measures including expert opinion were adopted.

To answer the research question 2, it was required to simulate the quantitative model followed by analysis of the results and then presentation the results to a variety of stakeholders. A qualitative response was then collected from the stakeholders to determine the usefulness of the simulated NPV and IRR results for better decision making.

3.2 Research Design

3.2.1 *Input distributions of the key parameters*

For the research question 1 i.e. to determine the key value driving parameters in Platinum mining projects and their associated probability distributions, a mix of quantitative and qualitative methods was used (Figure 3).

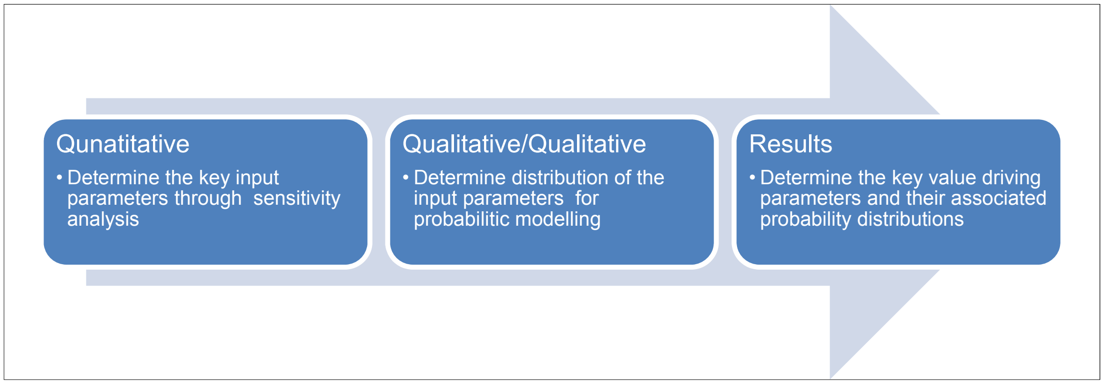

Figure 3: Mixed-method for research question 1

There are typically 3 types of mines in AAP e.g. opencast mine, underground mine with vertical shaft and underground mine with inclined shaft. The business cases in AAP are developed using Oracle Hyperion Strategic Finance (HSF) tool. HSF is a feature-rich financial forecasting and modelling tool. 3 sample projects from the three type of mines were selected for the sensitivity analysis to determine the top key input parameters. HSF financial data was collected for the 3 sample projects. The input parameters (Table 2) were then flexed (between -10% and +10%) individually while keeping the other parameters constant and HSF runs were run with the flexed parameters and their impact on NPV, IRR and Cash Margin were mapped to rank the parameters.

Table 2: Input parameters

Input Value Parameters Flexing			
1	Exchange rate	12	On Mine costs: Total
2	Metal prices: All	13	On Mine costs: Shaft Head
3	Metal prices: Pt	14	On Mine costs: Concentrator
4	Metal prices: PGMs	15	On Mine costs: Indirect
5	Metal prices: BMs	16	Power: On Mine, Smelt, Refining costs
6	Metal prices: Cr conc (all grades)	17	Capex: Total
7	Grade	18	Capex: Projects: Expansion
8	Tonnes mined, milled	19	Capex: Projects: Replacement
9	Concentrator Recoveries	20	Capex: Stay in Business: On Mine
10	Smelting Recoveries	21	Capex: Stay in Business: Off Mine
11	Off Mine costs: Total		

The input parameters were ranked in order of their influence on the NPV, IRR and Cash Margin. Originally the intent was to determine the probability distributions of the top five key input parameters for the Monte Carlo simulation. However, later it was decided to define the probability distributions for the top 11 input parameters for the simulation. This was done to get better simulation results for the purpose of the survey.

3.2.2 *Monte Carlo simulation in aiding decision making*

For the research question 2 i.e. to determine if the risk-based simulated NPV and IRR provided with information for better decision making, a mix of quantitative and qualitative methods were adopted. It included the following steps:

Static model generation: As HSF do not have functionality to run probabilistic simulation, an Excel based deterministic model was developed that replicated the logic and calculations of HSF. Another project's input information were used in the Excel model to accurately calculate the NPV and IRR of the project's business case. The output of the Excel model were compared with that of the HSF as a validation of the Excel model.

Identification of distributions for the input parameters: This step involved identifying the underlying distributions of the input parameters with respect to the project selected for simulation. Both qualitative and quantitative methods were adopted to identify the distributions. Qualitative analysis included observations on historical data for the input variables as well as opinions from subject matter experts on those parameters. Quantitative methods used included goodness-of-fit tests on historical data to determine input parameters distributions.

Monte Carlo Simulation: Once the probability distribution associated with the input parameters were determined, Monte Carlo simulations was run on the Excel model. NPV and IRR output along with its distribution were generated.

Result analysis and presentation: The simulated results were then analysed and presented to a mix of professionals from different disciplines (Table 3) and qualitative input was collected through unstructured interview and the response were then analysed and presented.

3.3 Population and sample

3.3.1 *Population*

The population in this research was all the Platinum capital mining projects in in AAP. It excluded process plant projects and other stay-in-business projects.

3.3.2 *Sample and sampling method*

For the purpose of determining the answers to research question 1 i.e. to determine the key value driving parameters in Platinum mining projects, three projects were selected from AAP's project database, one for each of the three types of mines that AAP operates i.e. opencast mine, underground mine with vertical shaft and underground mine with inclined shaft.

AAP mines four types of orebody viz. Merensky, UG2, Platreef and Main Sulphide Zone (MSZ) (AAP annual report, 2014). The vertical and inclined shafts are mainly used to mine Merensky, UG2 and MSZ orebody, opencast is used to mine the Platreef orebody (AAP annual report, 2014). Hence selection of the three mine projects, one for each of the three types of mine were a good representative sample of AAP project database for mining projects.

For the determination of the input distributions, expert opinion was sought from a range of experts in different disciplines, both within AAP as well as experts from outside who provide services to AAP. A range of professional (Table 3) were also presented with the results of Monte Carlo simulation and their feedback was analysed and used to answer the research question 2.

Table 3: Profile of respondents

Description of respondent type	Number sampled
Project Managers	8
Project Reviewers	4
Techno-economist	1
Strategy Managers	2
Financial Modeller	1
Mining Engineer	1
General Managers	3

3.4 The research instrument

The primary research instrument that was used is @RISK (pronounced “at risk”) to perform the Monte Carlo simulation on the business case in the Microsoft Excel model. For the purpose of this exercise @RISK student version from Palisade was used.

To collect feedback from the various professionals (Table 3) on the usefulness of the simulated NPV and IRR results for better decision making, unstructured interview / discussions were used. The unstructured interview were deemed appropriate for collection of feedback as this provided the freedom to the respondent to answer why he or she thought whether the simulated results are more informative and if it helped in better decision making.

3.5 Procedure for data collection

AAP project database was relied upon to source project data on the three types of mining project that were sampled to determine the key value driving parameters. This included the HSF financial model as well as detail feasibility report of these projects.

The survey feedback on simulated results were collected via one-on-one interview with the various professional (Table 3) through unstructured interviews and discussions.

3.6 Data analysis and interpretation

Data collected from the AAP project database i.e. the HSF financial model was used as a reference to develop the Excel model. Monte Carlo simulation was used to model uncertainties and its influence on NPV and IRR will be presented. The feedback from the professionals was used to discuss and conclude the usefulness of simulated business case in providing better information for decision making.

3.7 Limitations of the study

It was assumed that the respondents were familiar with basic statistical concepts e.g. probability distributions, confidence interval, simulation etc. While most of the proposed respondents had some understanding of the concepts, the quality of their feedback depended on their level of understanding of the statistical concepts.

Expert opinion was used to determine the probability distribution of the input parameters when no proxy or empirical means existed. This had potential weakness but has been separately explained in chapter 5.

3.8 Validity and reliability

3.8.1 *External validity*

The outcome of the research was intended to answer the research questions for the population i.e. AAP's mining projects. The adopted method to sample one projects from each of the three projects type in AAP mining project enhanced the external validity of the research outcome.

While the research focussed on AAP, the results could be generalised for the Platinum mining projects within South Africa due to the fact that all of the other mining companies in South Africa mine any of the three orebodies i.e. Merensky, UG2 and Platreef. In addition the input parameters are similar as the mining methods are either conventional or mechanised for all of the Platinum miners in South Africa and factors viz. metal price, exchange rates etc. are same for all mining projects and operations.

3.8.2 *Internal validity*

Internal validity is primarily relevant in research that that try to establish a causal relationship (Trochim & Donnelly, 2001). Although this research did not try to establish a causal relationship, the concept of internal validity was still applicable in a sense that “was this research done right?” There have been many similar studies done using MCS technique, albeit in other industries e.g. real estate, oil, finance etc. This research methodology was aligned to the commonly used methods in Monte Carlo simulation.

3.8.3 *Reliability*

According to Merriam (1995) reliability concerns the ability of the researcher to discover the same results regarding the occurrence in a replicated study. As the method is primarily quantitative, and as the results of the research suggests, the methodology adopted was reliable.

The risk of bias that could have come from the expert opinion while deciding the probability distributions was mitigated by speaking to more than one subject matter expert while deciding on those parameter.

CHAPTER 4. PRESENTATION OF RESULTS

In this chapter, the results and the inferences drawn from the research relating to the two research questions has been delineated. The outcome of the research has been presented in separate sections in order to provide better clarity and understanding. The chapter then concludes with the summary of the research results.

4.1 Key input parameters driving Platinum projects value

To identify the key input parameters, a sample of three projects were selected from AAP's project database. The approach in selection of these three project samples was underpinned by the aim to get a true representation of all the orebodies that AAP mines as well as the geographical locations that these projects battery limits were located in.

To identify the key input parameters that impacted the business case attractiveness i.e. NPV and IRR, the HSF financials were run separately, a number of times, flexing the input parameters within a range. The outputs were then mapped to identify the sensitivities and the key influencing parameters were then identified.

4.1.1 *Selection of the project samples*

AAP's mineral resources, mining rights and its operations are primarily in South Africa and Zimbabwe (AAP annual report, 2014). AAP primarily operates in South Africa with majority of its operating mine located in the country (Figure 4). AAP has only one cross-border operations in Zimbabwe called Unki mines. Unki mines business is US$ denominated while all the South African operations' business is South African Rand (ZAR) denominated.

a. Geographical location and orebodies

AAP's South African mines and projects exploits the Bushveld complex i.e. Merensky and UG2 ore bodies namely in 'Western Limb' in North West province and 'Western Limb' in Mpumalanga and Limpopo province. In addition AAP exploits the Platreef ore body in 'Northern Limb' in Limpopo province (Figure 4). The Unki mine in Zimbabwe exploits the MSZ ore body.

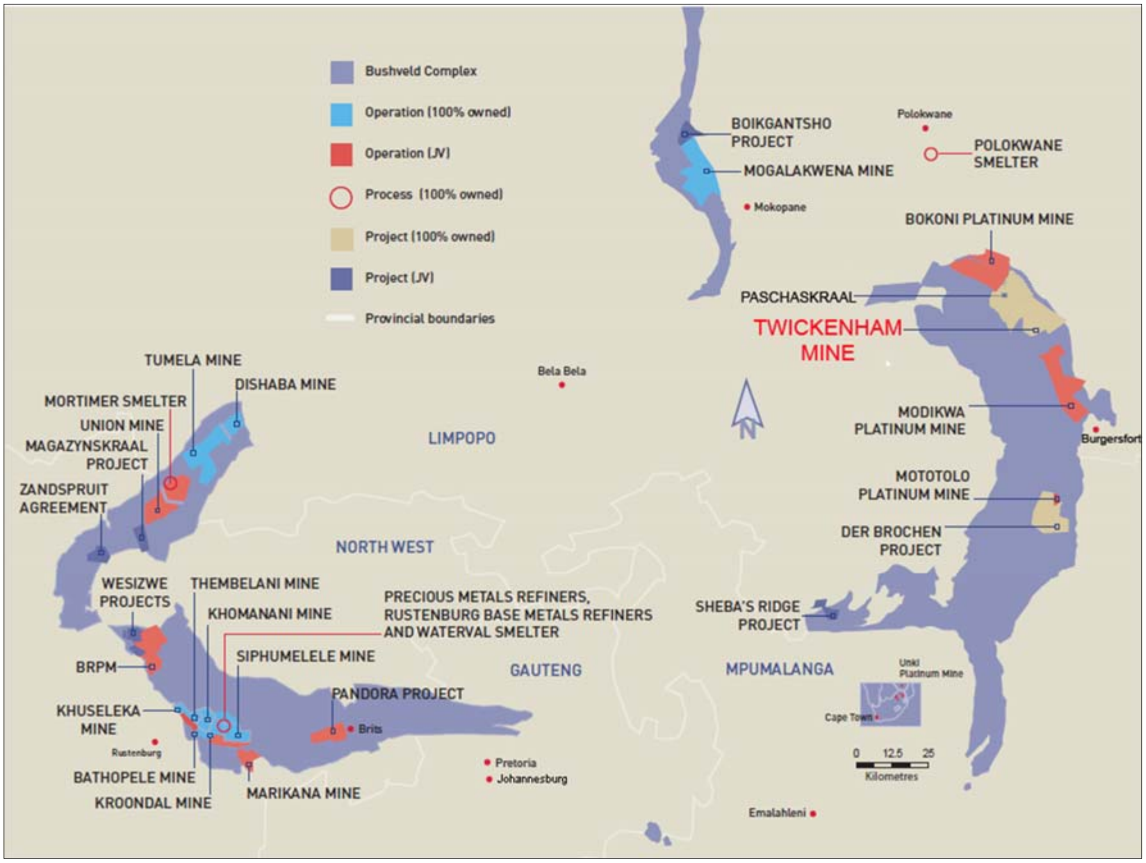

Figure 4: Location of AAP Operations in South Africa (AAP Annual Report, 2014)

b. Mining method

As described in Chapter 3, there are typically three types of mining operations in AAP e.g. opencast mine, underground mine with vertical shaft and underground mine with inclined shaft. AAP has opencast mines in Northern Limb at Mogalakwena mine (Figure 4) where the Platreef ore body is close to the surface. Rest of the operations in Eastern and Western Limbs are underground mines where the Merensky and UG2 orebodies are deep in the ground and are exploited though a choice of vertical and inclined shafts. It is to be note that deep orebodies like Merensky and UG2 are typically mined or exploited through a vertical or inclined shaft. The selection of the vertical or inclined shaft depends on the location and orientation of the orebody so as to maximise ease of access and economical extraction of the ore from the underground.

c. Project stages

AAP maintains a pipeline of project to maintain its production profile and growth trajectory. The business opportunities are identified and they are pushed through a project pipeline as business case. The project business case then passes through various phases e.g. Concept, Prefeasibility, Feasibility and Execution/Implementation before becoming a full-fledged operation. The Concept, Prefeasibility and Feasibility stages are also known as Front-End-Loading (FEL) stages. At the end of each phase, the project goes through a review process where it gets approved to pass on to the next stage if it meets the criteria of the stage gate (Figure 5).

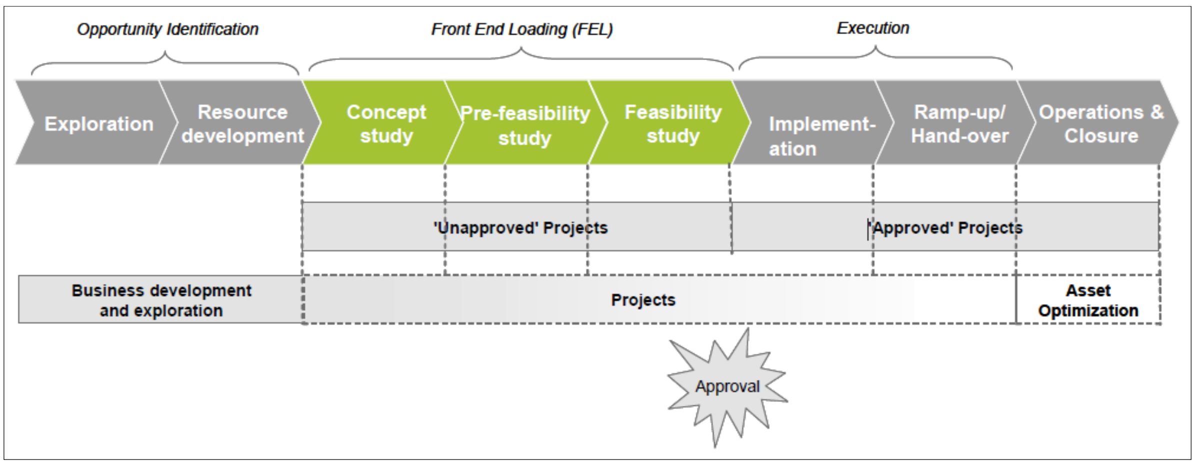

Figure 5: AAP Project Development Lifecycle (Anglo Project Way, 2010)

The Concept stage validates the business opportunity, defines a business case and identify the scope alternatives that will be traded off in the next stage (Anglo Project Way 2010). This this is not an option selection stage due to the inherent inaccuracy in project definition and design data. The aim of the Concept stage is to justify moving into pre-feasibility, discarding through the identification of a fatal flaw(s), or shelving of the project.

The Prefeasibility stage identifies the universe of opportunities for the project or the business case. This includes including a broadening stage – ensuring the full option set is considered – and a narrowing stage, eliminating options in order that the project is focused on one scope (Figure 1). This stage demonstrates that all the discarded project options have been studied to the degree that they are identified as inferior (Anglo Project Way 2010).

The Feasibility stage further develops the detail of the selected option, providing greater clarity to the required level of accuracy for approval of the project. The detailed work done in this stage completes the business case with a high level of confidence and demonstrate the risks are mitigated and are controllable (Anglo Project Way 2010).

Based on the various criteria discussed in this section e.g. geographical location, type of orebody, mining method, and projects stage, a sample of three projects were selected from AAP's project database. The selected three project and their attributable criteria has been depicted in Table 4. It can be seen that the three selected projects amongst them cover all the criteria and represent a good sample for AAP's Platinum mine projects.

Table 4: Selected project sample

Project Sample	Orebody	Mining Method	Location	Project Stage
Project A	Platreef	Opencast	Northern Limb	Concept
Project B	UG2	Underground Inclined Shaft	Eastern Limb	Feasibility
Project C	Merensky and UG2	Underground Vertical Shaft	Western Limb	Prefeasibility

In selecting the projects it was also considered that the project data is relatively recent and all the design and financial data have recently been concluded. The three selected project has all been in various FEL stages and all the information relating to these three business cases are valid 2015 data with the business case runs on HSF being in either year 2014 or 2015.

4.1.2 *Sensitivity analysis of the selected projects*

a. Selected project overview

Project A was an expansion to a major opencast operation in the Northern Limb. The project entailed expanding the current mine so as to exploit the Platreef orebody to depths greater than 600m. The project scope included expanding the current mine as well as the concentrating facilities. The downstream smelting and refining capacities of AAP was sufficient and no additional capacity was required to treat the additional output of the expanded operation. The selected valuation in HSF for the project was done at the operational level for the LOM plan and not as a standalone incremental basis. The project was studied at a Concept level in 2014 and was approved to go to Prefeasibility in 2015. The current operation throughput is at around 1 million tonnes per month and the project would add an additional 70,000 tonnes per month to the current operation taking the total Platinum production to around 400,000 Oz per annum. Table 5 summarise the salient points of the project from HSF output data.

Table 5: Project A HSF output summary

Key Results		**Rand million (Real 2015)**
Project A		
NPV	@ 11.50%	28,894
IRR		N/A
Payback (years)		-
Cash Margin %		22.08%
Capex sum of real		8,072
Life of Asset		60 years

Project B was a new mechanised mine development to mine UG2 orebody. The project was located in the Eastern Limb of the Bushveld Igneous complex (Figure 4). The project went through Concept and Prefeasibility study during the period 2008 to 2014. The longer durations of FEL stages was due to the fact that the project went through a number of capital constraints deferments as a result of downturn in the macroeconomic environment during 2009-10 and again in 203-14. At the time the project was selected to be in the sample, it was in Feasibility stage. The mine development under the project consisted of two inclined shafts producing 125,000 tonnes per month equivalent of producing 157,000 Oz of Platinum per annum. The shaft decline was on the reef so as to bring in early revenue and better NPV. Table 6 summarises the salient points for the project from the HSF output data.

Table 6: Project B HSF output summary

Key Results		Rand million (Real 2015)
Project B		
NPV	@ 11.50%	1,621
IRR		14.93%
Payback (years)		10
Cash Margin %		27.97%
Capex sum of real		5,462
Life of Asset		45 years

Project C was an expansion of the existing mining operation in Western Limb (Figure 4) which uses conventional mining methods. The current operation exploits both Merensky and UG2 orebodies. However, the operation was not in a position to maintain its production profile above the cash positive threshold of 4 million tonnes per annum out of its existing mining layout and infrastructure. In order to extend the life of mine. The new expansion under this project entailed sinking a new vertical shaft that would provide additional hoisting capacity to allow the operation to access additional Merensky and UG2 orebody for exploitation. In addition, it included expanding the current infrastructure and bulk services to service the additional shaft. For the valuation of the business case, co-extraction of both the UG2 and Merensky had been considered with the UG2 being the leading reef to be mined.

The project could be looked at both an asset optimisation and expansion opportunities where the new shaft compartments under the project would provide double sided access to the man and material conveyance to cater for the unique mine level layout improving material car handling cycle times by utilizing the up trip for empties (asset optimisation). At the same time the project will provide access to exploit additional orebody (expansion). The valuation of the project was hence done at an operational level and not as standalone incremental valuation. Table 7 summarises the salient points for the project from the HSF output data.

Table 7: Project C HSF output summary

Key Results		Rand million (Real 2015)
Project C		
NPV	11.50%	2,398
IRR		27.32%
Payback (years)		9
Cash Margin %		34.62%
Capex sum of real		3,806
Life of Asset		19 years

b. Sensitivity analysis

For each of the selected project, 21 different input parameters were flexed at ±10% to gauge the impact of the variation in input value parameters on the NPV, IRR and Cash Margin of the individual business cases. The input parameters that were flexed have been depicted in Table 2 (Chapter 3).

HSF reruns were done with flexed input parameters (±10%) on Project A's financials. The output results were then mapped to rank the input parameters in terms of their influence on NPV. Similar mapping was also done to rank the input parameters in terms of their influence on Cash Margins. For project A, as the net cash flow were all positive for the LOM, there was no IRR. The ranked parameters for NPV sensitivity analysis for Project A has been depicted in Figure 6. The tornado diagram (Figure 6) shows the impact of the input parameters, when they vary between -10% to +10%, on the base case NPV. Subsequently it also ranks the input parameters in the order of their respective impact on the base case NPV.

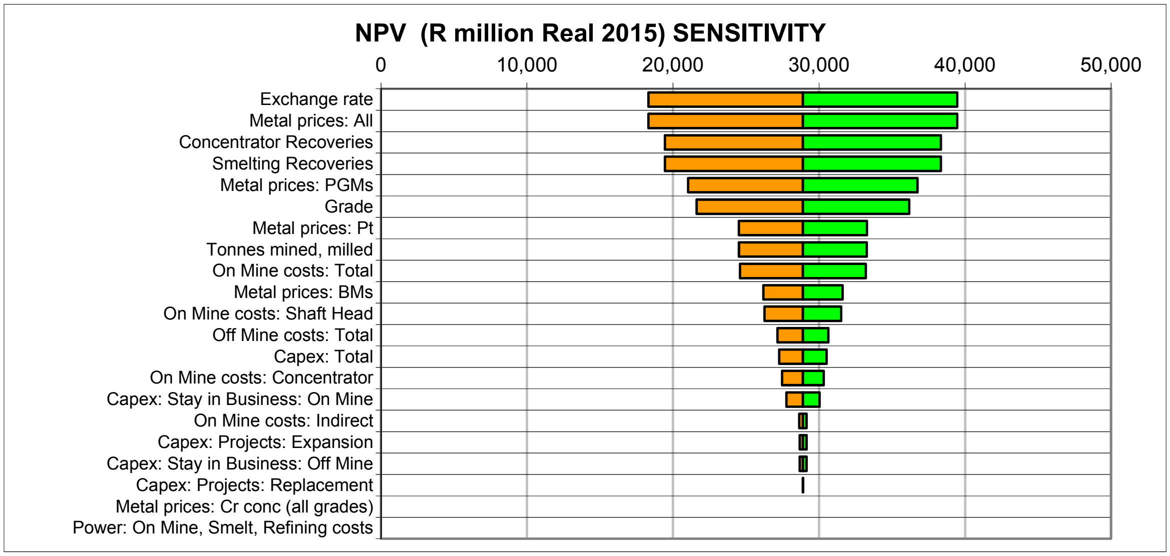

Figure 6: Project A Sensitivity Chart

Similarly for Project B and Project C, HSF reruns were done with flexed input parameters (±10%) and their impact on NPV, IRR and Cash Margin were mapped. The ranked parameters for NPV sensitivity analysis for both the projects have been depicted in Figure 7 and Figure 8 respectively.

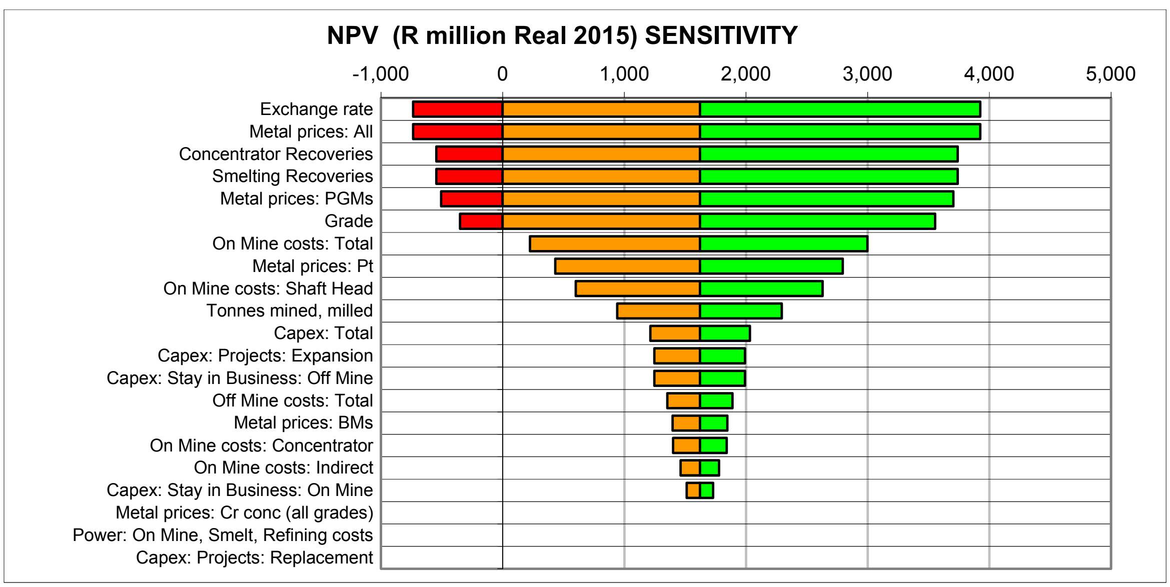

Figure 7: Project B Sensitivity Chart

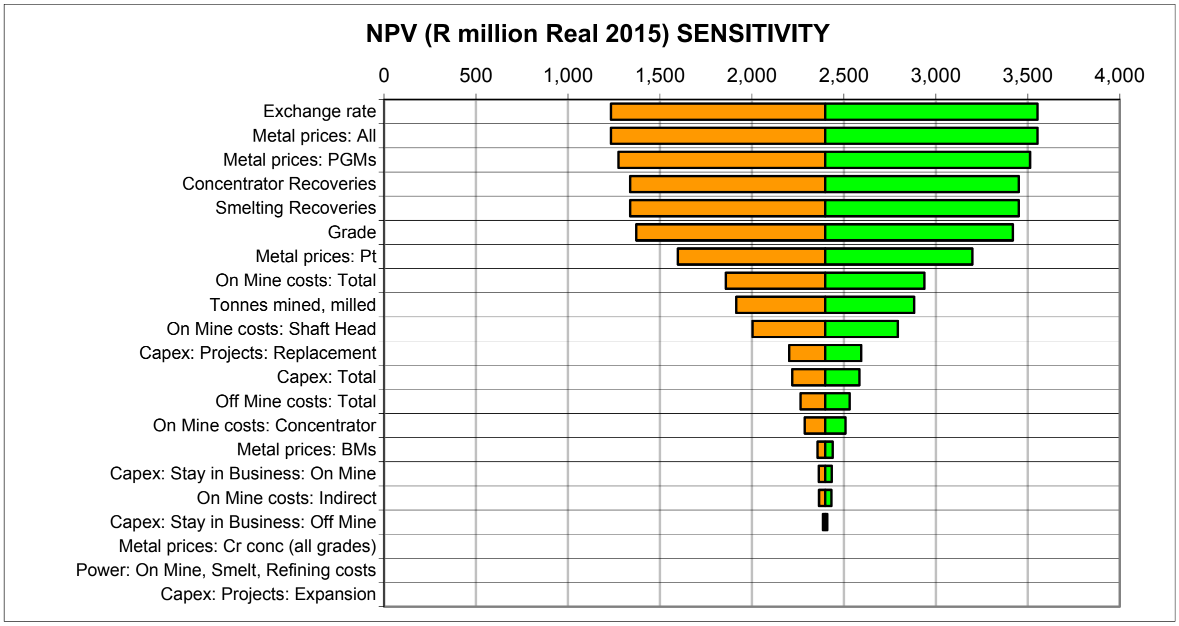

Figure 8: Project C Sensitivity Chart

The detail inputs and output of the sensitivity analysis of the three selected projects has been appended in Appendix A. It can be seen from the sensitivity analysis chart that for different business cases for the sensitivity analysis (with respect to the NPV, IRR and Cash Margin) the ranking of the 21 input parameter varies. For example 'Smelting Recoveries' ranks fourth for Project A and B but ranks fifth for Project C in terms if influencing the NPV of the projects.

4.1.3 *Determination of the key input parameters*

From the sensitivity analysis of the input parameters on the NPV, IRR and Cash Margin of the business cases, the input parameters were ranked individually for each of the project. An arithmetic ranking approach was followed to rank the 21 input parameters in order of their impact on the 3 output parameters e.g. NPV, IRR and Cash Margin. The output of the ranking exercise has been depicted in Table 8, 9 and 10. Table 8 depicts the rank of the 21 parameters in order of their influence on the NPV of the 3 business cases selected. Similarly Table 9 and Table 10 depicts the rank of the 21 parameters in order of their influence on the IRR and Cash Margin of the 3 business cases.

Table 8: Key input parameters ranking for NPV

Ranking of NPV influencing factors			
1	Exchange rate	12	Off Mine costs: Total
2	Metal prices: All	13	Metal prices: BMs
3	Concentrator Recoveries	14	On Mine costs: Concentrator
4	Smelting Recoveries	15	Capex: Stay in Business: On Mine
5	Metal prices: PGMs	16	Capex: Stay in Business: Off Mine
6	Grade	17	On Mine costs: Indirect
7	Metal prices: Pt	18	Capex: Projects: Expansion
8	On Mine costs: Total	19	Capex: Projects: Replacement
9	Tonnes mined, milled	20	Metal prices: Cr conc (all grades)
10	On Mine costs: Shaft Head	21	Power: On Mine, Smelt, Refining costs
11	Capex: Total		

Table 9: Key input parameters ranking for IRR

Ranking of IRR influencing factors			
1	Exchange rate	12	Off Mine costs: Total
2	Metal prices: All	13	Metal prices: BMs
3	Concentrator Recoveries	14	On Mine costs: Concentrator
4	Metal prices: PGMs	15	Capex: Stay in Business: Off Mine
5	Smelting Recoveries	16	Capex: Projects: Replacement
6	Grade	17	On Mine costs: Indirect
7	Metal prices: Pt	18	Capex: Projects: Expansion
8	On Mine costs: Total	19	Capex: Stay in Business: On Mine
9	Tonnes mined, milled	20	Metal prices: Cr conc (all grades)
10	On Mine costs: Shaft Head	21	Power: On Mine, Smelt, Refining costs
11	Capex: Total		

Table 10: Key input parameters ranking for Cash Margin

Ranking of Cash Margin influencing factors			
1	Exchange rate	12	Metal prices: BMs
2	Metal prices: All	13	On Mine costs: Concentrator
3	Concentrator Recoveries	14	Capex: Stay in Business: On Mine
4	Metal prices: PGMs	15	Tonnes mined, milled
5	Smelting Recoveries	16	On Mine costs: Indirect
6	Grade	17	Capex: Stay in Business: Off Mine
7	On Mine costs: Total	18	Capex: Projects: Replacement
8	Capex: Total	19	Capex: Projects: Expansion
9	Metal prices: Pt	20	Metal prices: Cr conc (all grades)
10	On Mine costs: Shaft Head	21	Power: On Mine, Smelt, Refining costs
11	Off Mine costs: Total		

4.1.4 *Conclusion*

It can be seen from Table 8, Table 9 and Table 10 that the ranking of the input parameters are almost the same for NPV and IRR, barring one rank change between “Metal prices: PGM” and “Smelting Recoveries”; while there is a moderate change in ranking when it comes to influence on Cash Margin. However, the top 11 ranked input parameters remain the same in terms of their influence on NPV, IRR.

For the purpose of the Monte Carlo Simulation, the top 11 input parameters impacting the NPV and IRR were selected to be modelled and simulated using @Risk. They are listed in Table 11.

Table 11: Selected key input parameters for Monte Carlo simulation

Selected input parameters for MC simulation			
1	Exchange rate	7	Metal prices: Pt
2	Metal prices: All	8	On Mine costs: Total
3	Concentrator Recoveries	9	Tonnes mined, milled
4	Smelting Recoveries	10	On Mine costs: Shaft Head
5	Metal prices: PGMs	11	Capex: Total
6	Grade		

4.2 Monte Carlo simulation

4.2.1 *Development of the Excel model*

A ‘Project D’ was selected as the business case for the Monte Carlo simulation. The project was in Feasibility stage in early 2015 and the business case evaluation was in real 2014 terms. The static DCF output from HSF runs for the project has been summaries in Table 12.

As it can be seen, the project had a negative NPV of R91m and was considered to be marginal. Decision makers hoped that if the market fundamental changes, the project could generate positive NPV and could fly. As the project was marginal, it was ideally suited for Monte Carlo simulation to test its robustness by incorporating the uncertainties involved with the top 11 key input parameters.

Table 12: Project D HSF output summary

Key Results		Rand million (Real 2014)
Project D		
NPV	@ 11.50%	(91)
IRR		11.6%
Payback (years)		13
Cash Margin %		29.48%
Capex sum of real		7,517
Life of Asset		34 years

An Excel model was developed to replicate, as much as possible, the logic and calculations of HSF valuation. AAP uses a set of Global Assumptions (GAs) intended to be used in the financial models for the project evaluations. The GAs generally contain AAP's views and projections of the externalities e.g. exchange rate, metal prices etc. The GAs are AAP's sensitive information and hence has not been divulged anywhere in the research report. As the same GAs were used in the Excel model for simulation, the Excel model developed for simulation has not been shared with the research report. Only the output has been shared for analysis and conclusion which is deemed sufficient for the purpose of this research.

The logic in the Excel model was carefully checked and mapped with the help of a modelling expert. The validity of the Excel model was tested at a summary level by comparing the key output parameters over the LOM in both the Excel model and the HSF. They have been depicted in Figure 9. The difference were minor. The NPV and IRR calculated in the Excel model were negative R 83m and 11.19% respectively compared to negative R91m and 11.6% in the HSF. This provided sufficient confidence in the Excel model developed. It was deemed sufficient to include and model the uncertainties relating to the key 11 input parameters and run the for Monte Carlo simulation using @Risk to get the simulated NPV and IRR for presentation and conducting usefulness survey.

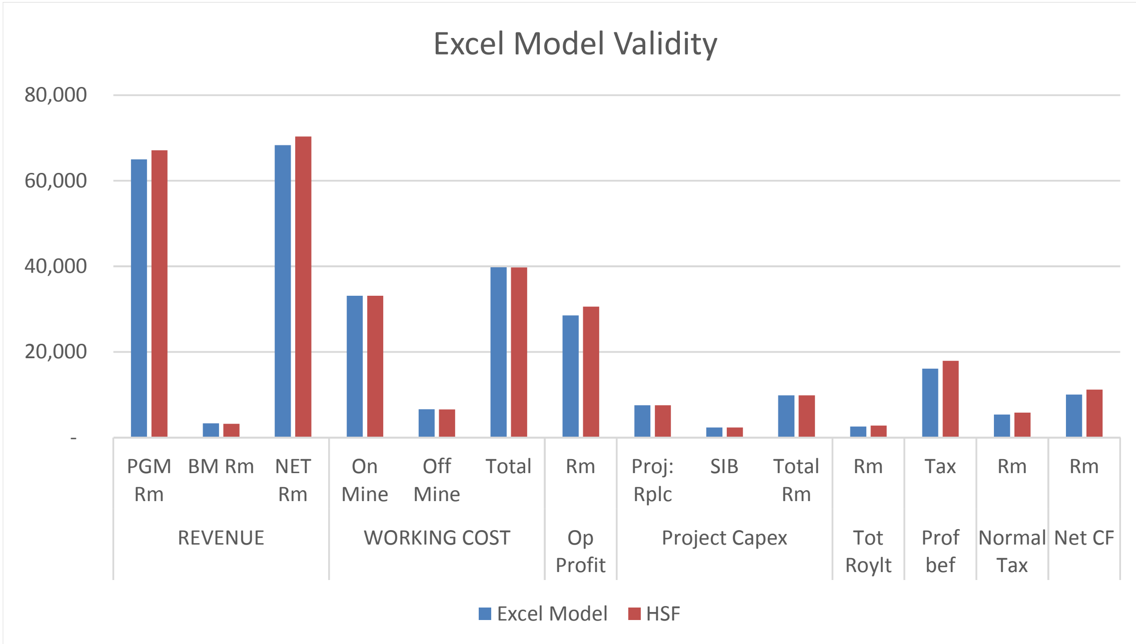

Figure 9: Validity of the Excel Model

4.2.2 *Selection of input parameters and their associated distribution*

The quality of a Monte Carlo simulation relies heavily on the appropriate use of the probability distribution of the input parameters (Vose, 2008). The selected distributions should accurately represent the uncertainties and variability involved with each of the parameters.

The following sub-sections provides the approach and rational behind selection of the appropriate distributions for each of the 11 top key input parameters identified for the Monte Carlo simulation. The input parameters were individually analysed with respect to the business case selected (Project D). They were modelled suitably, keeping in context the business case selected, to incorporate the potential uncertainties involved with each parameters. The simulated input parameters were termed “Modified” to keep the integrity of the Excel model intact after the Monte Carlo simulation so that comparative analysis could be easier.

a. Exchange rate

The input parameter 'Exchange rate" is the rate of exchange of United States Dollar (US$) to South African Rand (ZAR). All but one of the mining operations of AAP are based in South Africa. Due to this, most of the input costs are primarily in ZAR. However, the metal produced, both PGMs and Base Metals, is sold in US$. Hence exchange rate has a big impact in the net cashflow projections for a mine for the LOM.

The projection of exchange rate for the valuation of business case was done as per the GAs used for the model. Figure 10 depicts the nominal exchange rate on purchasing power parity (PPP) basis as well as the real 2014 exchange rate for the LOM i.e. until 2048 of the business case. When ZAR depreciates against US$, it benefits the business case as the input cost as for the same dollar price of the commodity the revenue in ZAR terms increase while the input costs in ZAR remains the same. The opposite happens when ZAR appreciates against US$.

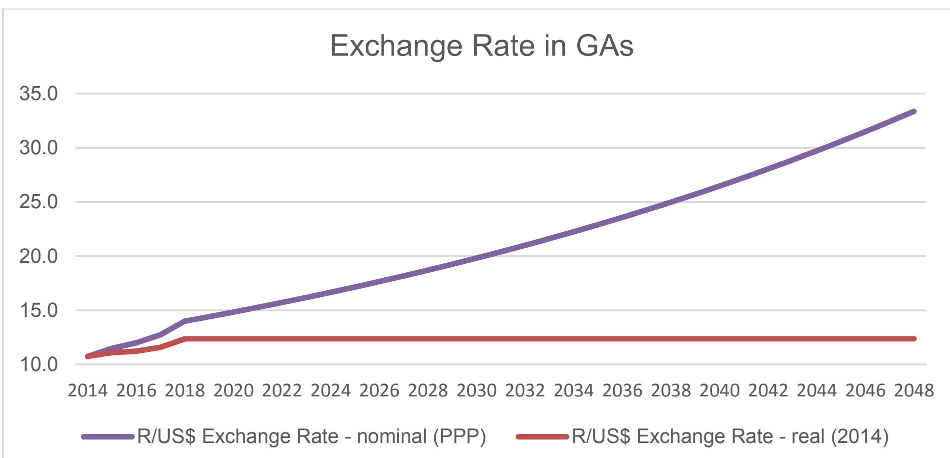

Figure 10: Input Parameter: Exchange Rate

South Africa is primarily regarded as a commodity exporter. When commodity process increases, it generally causes ZAR to appreciate as foreign investors become more interested in commodity market equities and bonds (de Jager, 2012). With the commodity price increase in US$ terms, it generally increase the wages rate in South Africa which leads to higher inflation. At the same time this induces a positive wealth effect. The real appreciation of ZAR happens when domestic inflation increases relative to the inflation in US$ terms. According to MacDonald and Ricci, (2003), there is a strong correlation between commodity price increase and real exchange rate appreciation of the currency of the commodity exporters' country. Hence when commodity process increases, e.g. prices of Platinum, it can be assumed that ZAR appreciates with respect to US$.

Engel and Hakkio (1996) attempted to establish the distribution of exchange rate of United States Dollar (US$) with respect to the currencies of European Monetary System (EMS). The evidence found by them suggests that the exchange rate of US$ against the EMS can be described by a mixture of two distributions. Although both normal distribution, the characteristics are different, with one holding good for stable times and one for times of volatility. Similar studies done later (Tucker & Pond, 1998) on six major currencies found that the distributions of exchange rate are too long-tailed and leptokurtic and do not really follow a normal distribution. The study hinted at using a mixed-jump distribution to cater for the observed discontinuities in the exchange rates.

Coppes (1995) established that if one studies the daily changes in exchange rate of US$, they are not normally distributed with more observations around the mean and in the tails. This was not customary with the characteristics of a normal distribution curve. Daily exchange rate is more of a leptokurtic distribution than normal distribution. However, if one considers the changes over more than one day, the exchange rate distributions more closely followed the characteristics of a normal distribution curve. Coppes (1995) further noted that if the averages of monthly exchange rate is considered, it tends to follow the normal distribution more closely. Many other studied have examined the distributions of foreign exchange rate. It is generally accepted that foreign exchange rate are normally distributed (So, 1986) and almost all exchange market and currency portfolio management models assume a normal distribution for exchange rate.

Based on the above discussions and advice from one of the respondents (financial modeller), a normal distribution was used to model the real US$ to ZAR exchange rate. A simulated input parameter distribution with its statistical characteristics has been depicted in Figure 11.

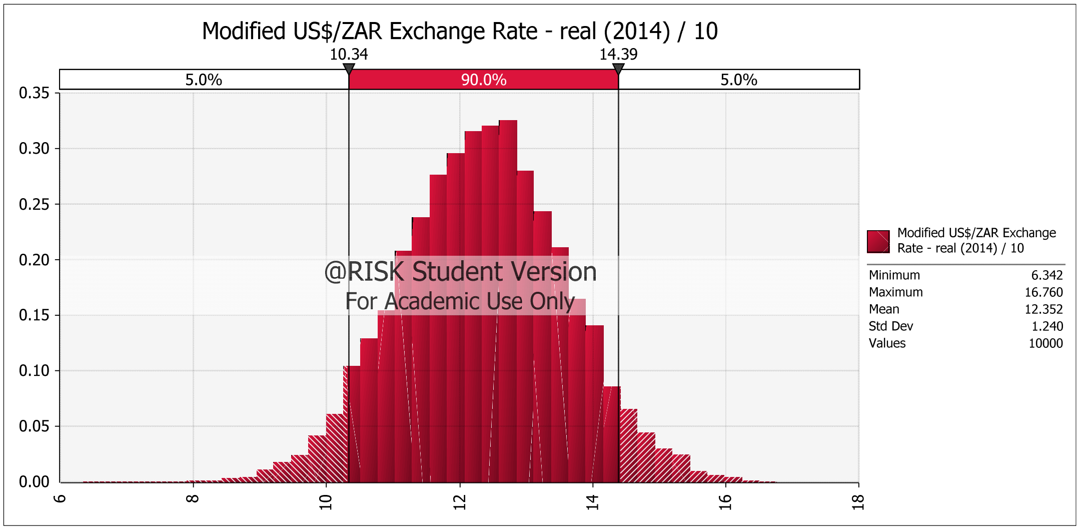

Figure 11: Simulated Input Parameter: Exchange Rate

b. Metal prices (All), Metal prices (PGM), Metal Prices (Pt)

3 of the top 11 key input parameters were directly related to the prices of metal and hence revenue of the business case. PGM metal prices, as well base metal drove the value of the business case. The mineral content of the ore in the business case has been depicted in Table 13.

Table 13: Mineral content of the orebody in selected business case

Metal split	
Pt Metal Split %	59.14%
Pd Metal Split %	28.78%
Rh Metal Split %	11.21%
Au Metal Split %	0.86%
Ir Metal Split %	4.17%
Os Metal Split %	-
Ru Metal Split %	19.09%
Ni %/t	0.12%
Cu %/t	0.02%
Co %/t	0.02%
Total Check (4E=100%)	100.00%

It is important to note that the 3 PGMs i.e. Platinum (Pt), Palladium (Pd), Rhodium (Rh) and Gold (Au) are called 4E and are generally the key revenue contributor under the PGM recovery. However, other PGMs e.g. Iridium (Ir), Osmium (Os), and Ruthenium (Ru) are recovered but are not the key revenue drivers. The 4E mineral content known as prill split has been depicted in Figure 12.

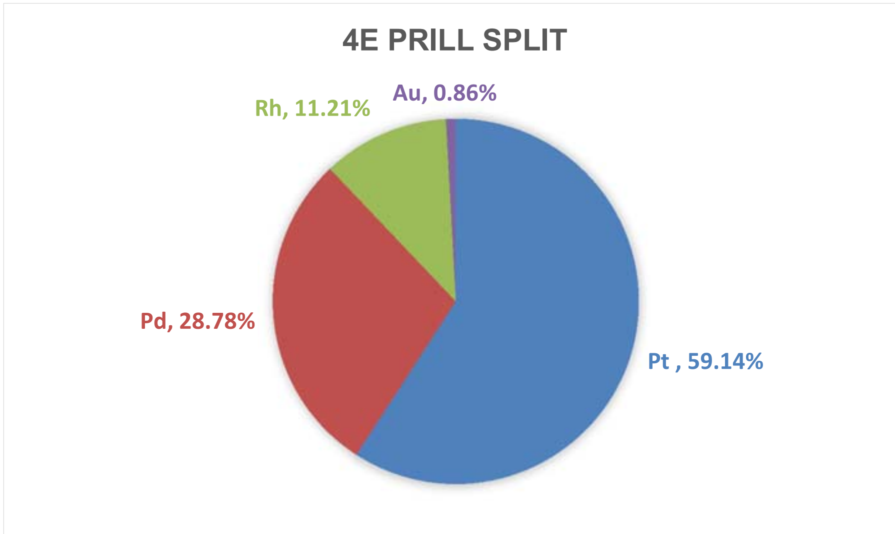

Figure 12: 4E Prill Split for the Business Case

For the business case simulated, the revenue contribution of the mineral per tonne of ore mined and processed has been depicted in Figure 13. It can be seen that Pt (41.4%) and Ni (40.1) are the key revenue contributors followed by Pd. (10.7).

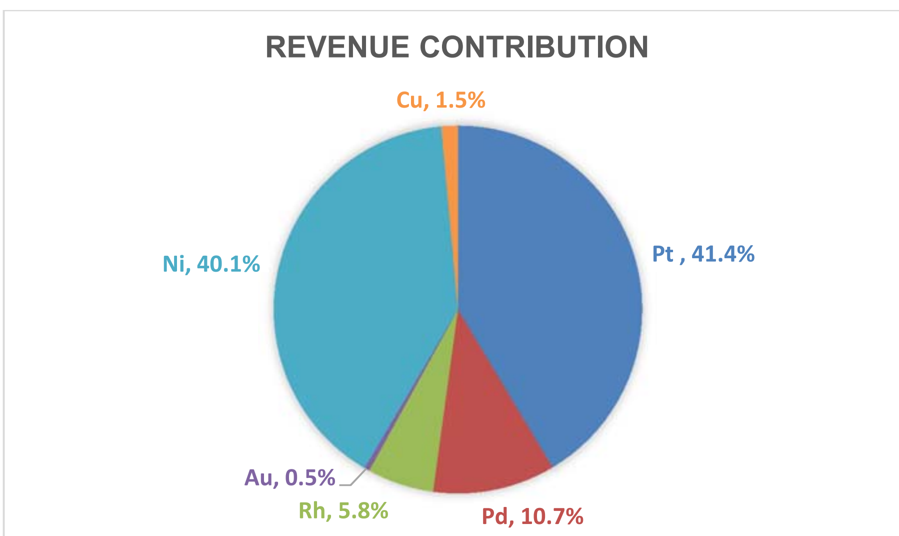

Figure 13: Revenue Contribution of the Minerals

In the mining industry, metal prices are normally modelled as the average of the last 3 years prices (Dehghani & Ataee-pour, 2012). This is particularly true for the precious and base metal miners. However, a lot of evidence (Lane et al., 2013) has demonstrated that in a highly competitive and organised market, price change will be close to random. Empirical modelling done for prices forecast of gold (Lane et al., 2013), suggest that all changes future prices are independent of any past history of prices.

The projected metal prices in the GAs were used in the Excel model for future revenue forecasts. These metal price forecasts had already taken into consideration the various factors that impact it. It was hence, found prudent to use a normal distribution to simulate the future price forecasts for all the metals. The simulated input parameter distributions of the 2 key revenue i.e. Pt and Ni has been depicted in Figure 14 and Figure 15 respectively.

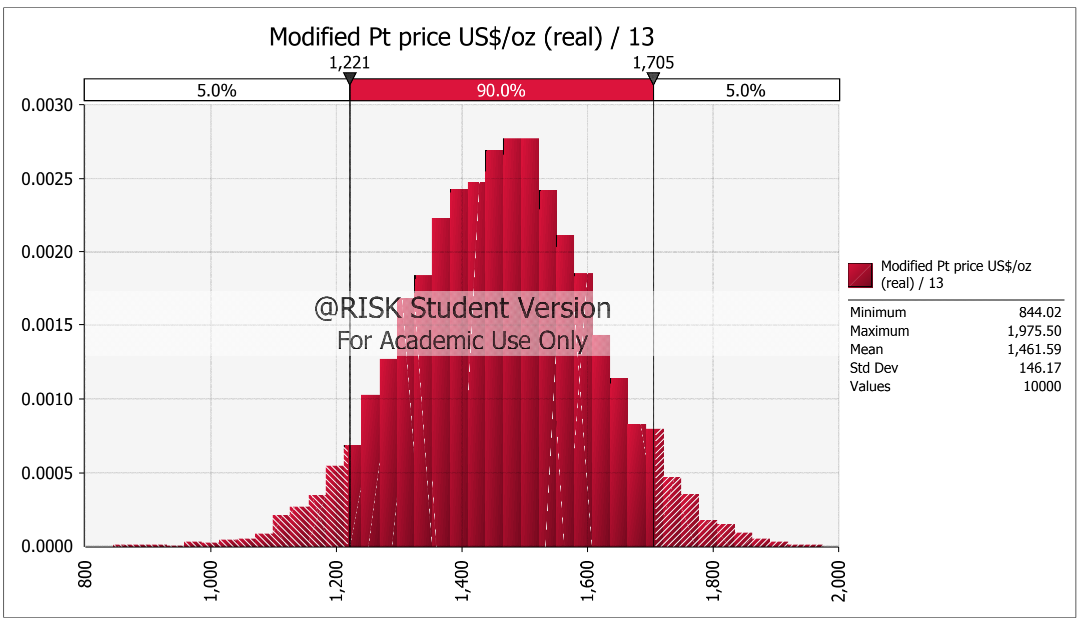

Figure 14: Simulated Input Parameter: Pt Price

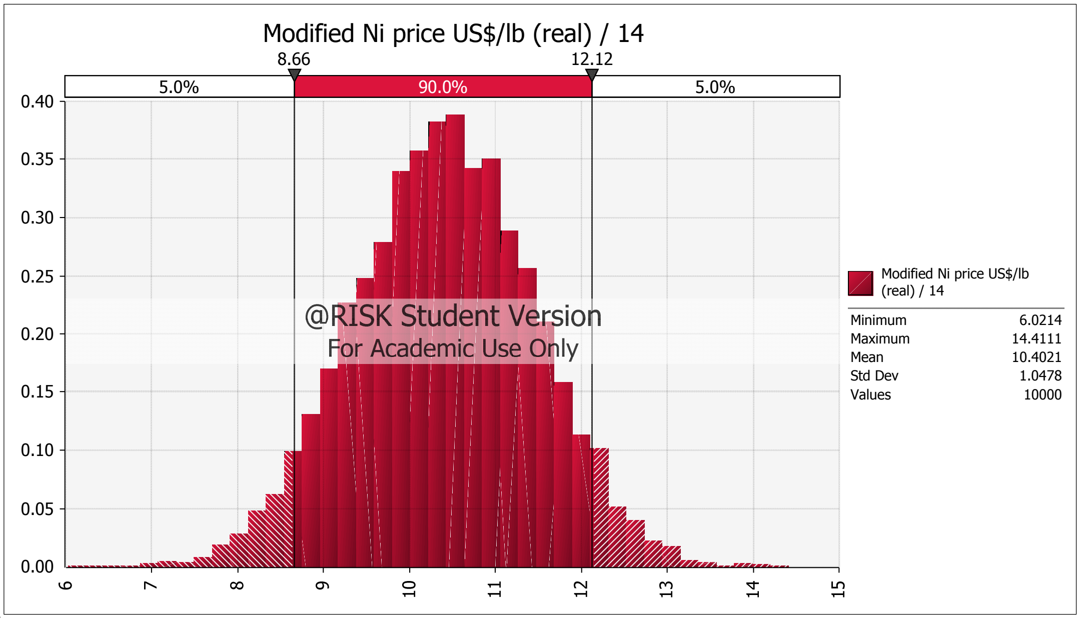

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Figure 15: Simulated Input Parameter: Ni Price

c. Concentrator recoveries and Smelting recoveries

The 2 input parameters Concentrator and Smelter recoveries represent the percentage of recovered metal and mineral through the processing of the mine ore. The ore body mined gets processed through Concentrator, Smelters and Refineries to get the refined metals. Although the process is highly optimised, not all the metal in the ore gets recovered. Table 14 represents the baseline recoveries assumed in the business case. It is self-evident that the more the recovery is in the process the more value it will add to the business case.

Table 14: Baseline assumed recoveries in the business case

Baseline recoveries	
Pt Conc. Rec. %	84.08%
Pd Conc. Rec. %	81.22%
Rh Conc. Rec. %	78.43%
Au Conc. Rec. %	69.73%
Ir Conc. Rec. %	79.11%
Os Conc. Rec. %	-
Ru Conc. Rec. %	69.21%
Ni Conc. Rec. %	17.88%
Cu Conc. Rec. %	71.84%
Co Conc. Rec. %	3.36%
Net smelt and ref recov factor %	98.50%

Simply put, Concentrating is the process where the ore is crushed and milled to liberate the minerals. The process output is known as Concentrate. It is followed by smelting process where the Concentrate is smelted to produce Matte. The Matte is then refined to produce various metals e.g. PGMs and Base Metals.

Concentrator recoveries are usually ascertained by running pilot campaigned on the ore to be mined and the ranges of Concentrator recoveries assumed for the business cases are fairly accurate. However, due to factors such as, grade dilution in mined ore due to geological reasons, efficiency in Concentrator plants etc. could impact the recovery. Expert opinion suggested that it rarely goes up by 5% of the established recovery and chances of it going down is a bit high but is within a range of 1% to 10%. A truncated normal distribution was hence used to simulate Concentrator recoveries for all the metals in the input parameter. A simulated input distribution for Concentrator recoveries for Pt has been depicted in Figure 16.

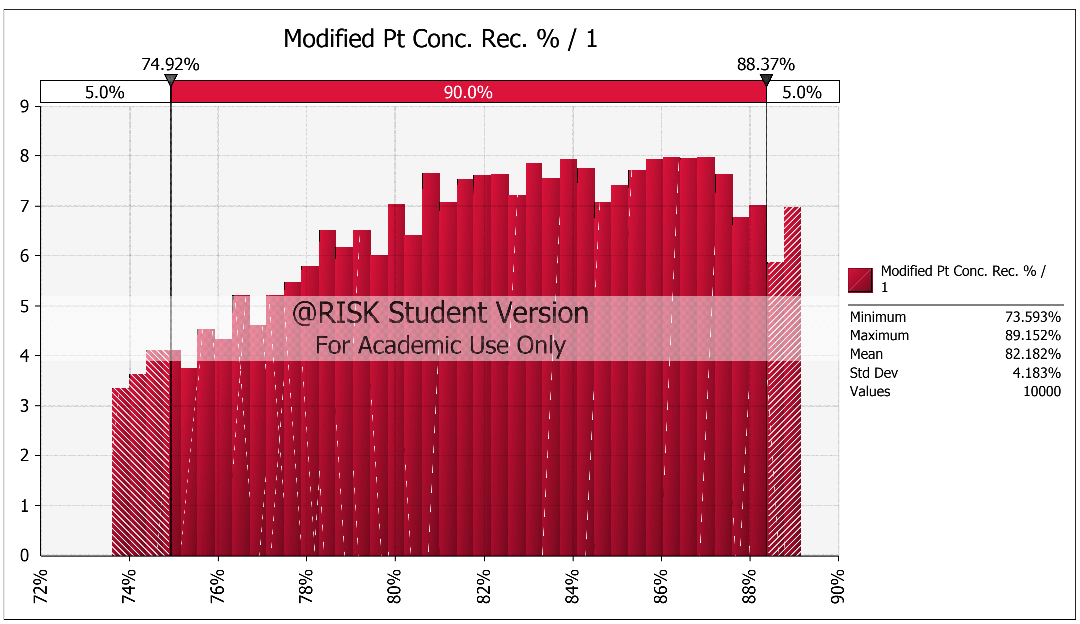

Figure 16: Simulated Input Parameter: Concentrator Recoveries for Pt

Similarly Smelting and Refining recoveries are also ascertained through a number of pilot campaigns and are fairly accurate. According to expert opinion, it rarely goes below the baseline. Hence a triangular distribution was applied for this particular input parameter. A simulated input distribution for the Smelting and Refining recoveries is depicted in Figure 17.

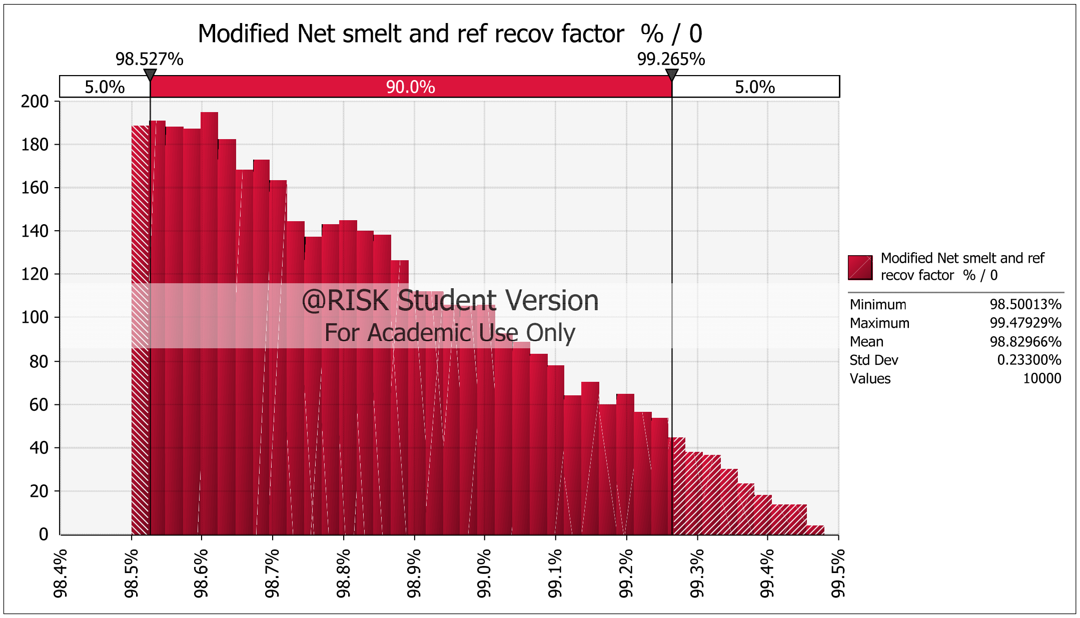

Figure 17: Simulated Input Parameter: Smelting and Refining Recoveries

d. Grade

The input parameter Grade defines the concentration of the valuable mineral within the ore body being mined. Evidently the higher the Grade, the better the revenues will be for the same amount of input costs or tonnes mined. The level of confidence on the orebody i.e. the amount of mineral concentration in the ore and its characterisation is dependent on the level of definition of the mineral resource. According to the level of definition an ore body could be classified as Measured, Indicated or Inferred. According to the standard classification (USGS, 2001) the three types resource classification are defined as follows:

"Measured.—Quantity is computed from dimensions revealed in outcrops, trenches, workings, or drill holes; grade and/or quality are computed from the results of detailed sampling. The sites for inspection, sampling, and measurements are spaced so closely and the geologic character is so well defined that size, shape, depth, and mineral content of the resource are well established."

"Indicated.—Quantity and grade and/or quality are computed from information similar to that used for measured resources, but the sites for inspection, sampling, measurement

are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than that for measured resources, is high enough to assume continuity between points of observation."

"Inferred.—Estimates are based on an assumed continuity beyond measured and/or indicated resources, for which there is geologic evidence. Inferred resources may or may not be supported by samples or measurements."

The business case simulated had its resource classified as 'Measured' and the accuracy of the Grade was on the higher side. However, estimation of ore Grade can still be inaccurate as the single point information do not provide any reference to the potential uncertainties involved in the assessment. 'Any resource and reserve estimation is guaranteed to be wrong. Some, however, are less wrong than others' (Morley et al. 1999).

As a consequence, Grade variability can significantly impact the business case. To model these uncertainties expert opinion was sought from a senior Geologist at AAP. The suggestion was that the Grade could be modelled as a normally distributed for all the reserve classification types and the range could be as follows:

- Measured: for the 90% confidence interval the Grade (x) varies between 0.9x to 1.1x
- Indicated: for the 90% confidence interval the Grade (x) varies between 0.8x to 1.2x
- Inferred: for the 90% confidence interval the Grade (x) varies between 0.7x to 1.3x

The input distribution for the Measured ore Grade was hence selected to be normally distributed with the Grade (x) varying between 0.9x to 1.1x within the 90% confidence interval. A simulated input distribution for Grade has been depicted in Figure 18.

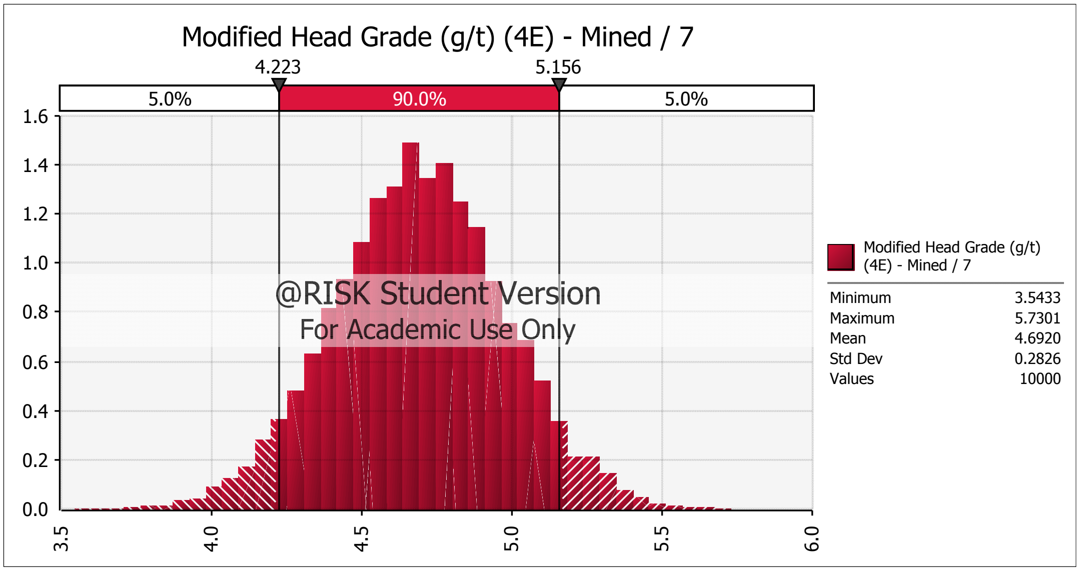

Figure 18: Simulated Input Parameter: Grade

e. On-Mine costs (Total); On-Mine costs (Shaft Head)

On-Mine costs (Shaft Head) consist of all the costs relating to the operation of the shaft or the mine. In included (Table 15) direct labour costs, stores costs (e.g. explosives, fuel, consumables), contractors cost (e.g. waste stripping, shaft development), utilities costs (e.g. electricity, water) and sundries. On-Mine costs (Total) includes head office cost allocation and any other costs allocated to the operation. Table 15 depicts the On-Mine costs for one particular year in the business case.

Table 15: On-Mine cost elements

	All figures are in ZAR (Millions)
On-Mine Cash Costs (Total)	512.5
On-Mine Cash Costs (Shaft Head)	500.7
Labour (Rm constant)	303.4
Stores (Rm constant)	105.4
Contractors (Rm constant)	14.1
Utilities (Rm constant)	46.0
Sundries (Rm constant)	31.8
On-mine direct central services costs	3.1
On-mine alloc. central services costs - additional	8.7

On-mine costs has direct bearing on the business case attractiveness and operations always strive to keep it down. Expert opinion suggests that, depending on the mine management, crew and operational efficiency, the On-Mine costs vary between 90% and 115% of the estimated costs.

A triangular distribution was suggested and was used to model this parameter. According to modelling expert Vose (2008), a triangular distribution is useful to model expert opinion or one's belief of likelihood of outcomes based on experience. A simulated input distribution for On-mine cash costs (Total) has been depicted in Figure 19.

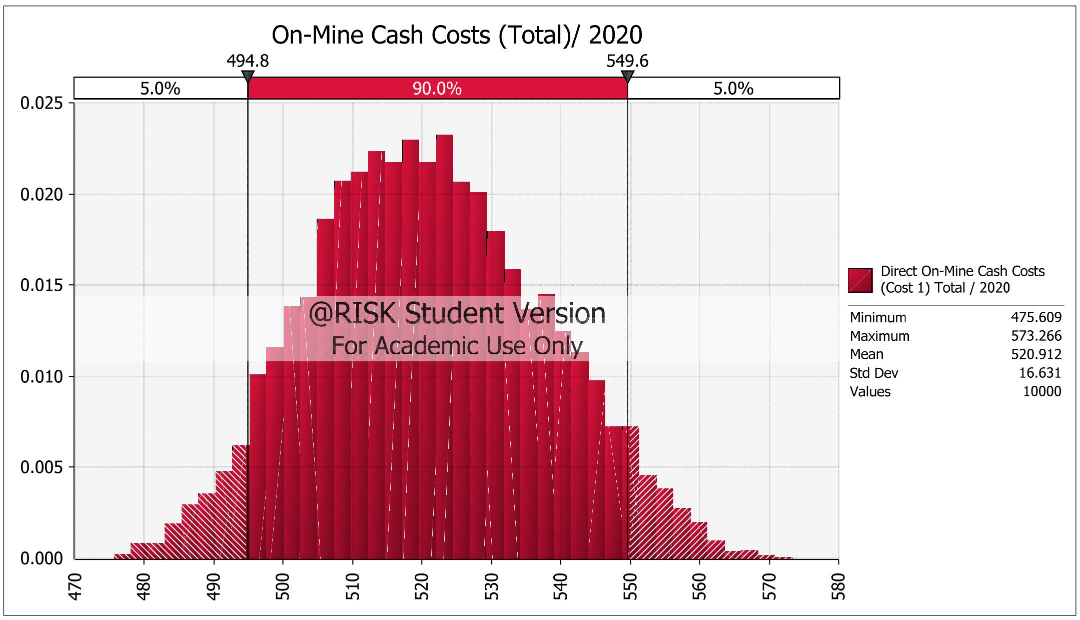

Figure 19: Simulated Input Parameter: On-Mine Cash Costs (Total)

f. Tonnes mined, milled

A mining operation in AAP usually consists of a mine and a Concentrator facility to produce concentrates from the mined ore. The input parameter 'Tonnes mined, milled', represents the production profile of the mine. It quantifies the throughput or the amount of ore mined and milled through the Concentrator to produce concentrate. Although there will be point estimates for this parameter in the business case for the LOM, the point estimate could be inaccurate and vary every year due to various uncertainties. Usually these point estimates already takes into consideration various factors that could impact the mining throughput e.g. reasonable allowance for operational disruptions during annual wage negotiations or allowance for unforeseen stoppages due to unplanned maintenance. Despite all these consideration, the production profile is still likely to change from the estimates, either upward or downward. This parameter is positively correlated to the return on the business case.

Expert advice suggested that there are many underlying factors that impact production e.g. crew efficiency, advance per blast etc. In turn these factors are also influenced by a host of other factors e.g. different mine development types, equipping of mine levels, ledging, stoping etc. As suggested, a normal distribution was hence used to model the parameter “Tonnes mined, milled’. A simulated input distribution for ‘Tonnes mined, milled has been depicted in Figure 20.

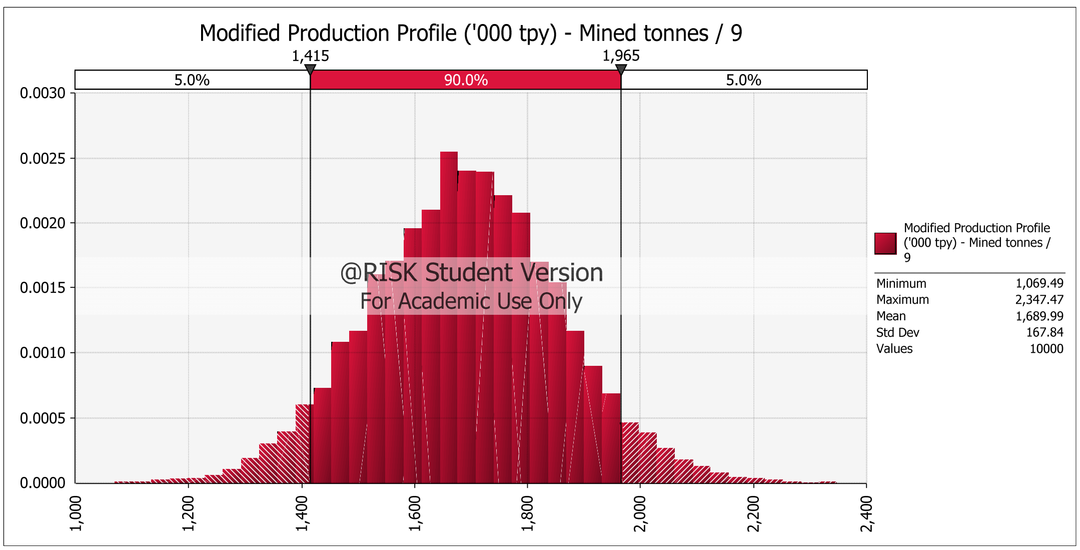

Figure 20: Simulated Input Parameter: Tonnes mined, milled

g. Capex: Total

The parameter Capex entails the cost estimate or capital that is to be spent to build the mining asset for production. Capex is another source of uncertainty in a business case. Even if care is taken to accurately estimate the Capex, it is the author’s view that projects are usually experience budget overrun. The variations comes from a variety of factors including poor engineering definition, poor management of the project etc.

Capital cost for this business case was spread over a period 12 years with a total capital of R6.9 billion in constant 2014 terms. As the business case was at Feasibility level (Table

1, Chapter 2), the Capex estimate was sufficiently detailed and accurate to support project funding and control. The accuracy range for this Class 2 estimate, as defined by APW (2010) was at +15% to -5% level.

Palisade (2015) recommends a triangular distribution when the minimum, maximum, and most likely values are known. It is a good model for skewed (+15%, -5%) distribution. Hence a triangular distribution was used for this input parameter. The simulated input parameter for Capex is depicted in Figure 21.

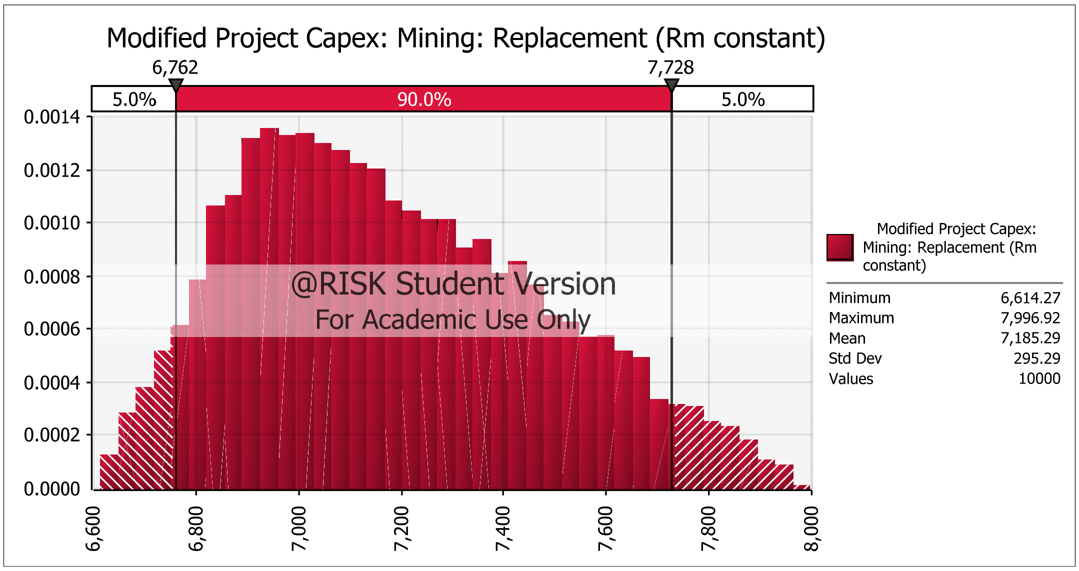

Figure 21: Simulated Input Parameter: Capex (Total)

4.2.3 *Simulation results*

The Monte Carlo simulation on the business case was done by using @Risk. 10,000 iterations were done and the simulated NPV (Figure 22) and IRR (Figure 23) were presented to respondents during for the survey. Detail summary reports for input parameters and the simulated output results have been captured in Appendix B. Some intuitive observations are as follows:

- There is only 36.2% probability that the project will have a positive NPV
- 4 of the top fine input parameters to which the attractiveness of the business case is dependent on are external factors on which AAP will have no control.

Interestingly, the simulated IRR results (Figure 23) shows a small distribution of negative IRR besides the main distribution of the IRR results which are positive. Multiple IRR for the same net cashflow stream or negative IRR are often resulted when net cashflow stream deviates substantially from the norm i.e. initial negative net cashflow in a business becoming cashflow positive after a few years. These multiple or negative IRRs are too difficult to interpret and are often meaningless.

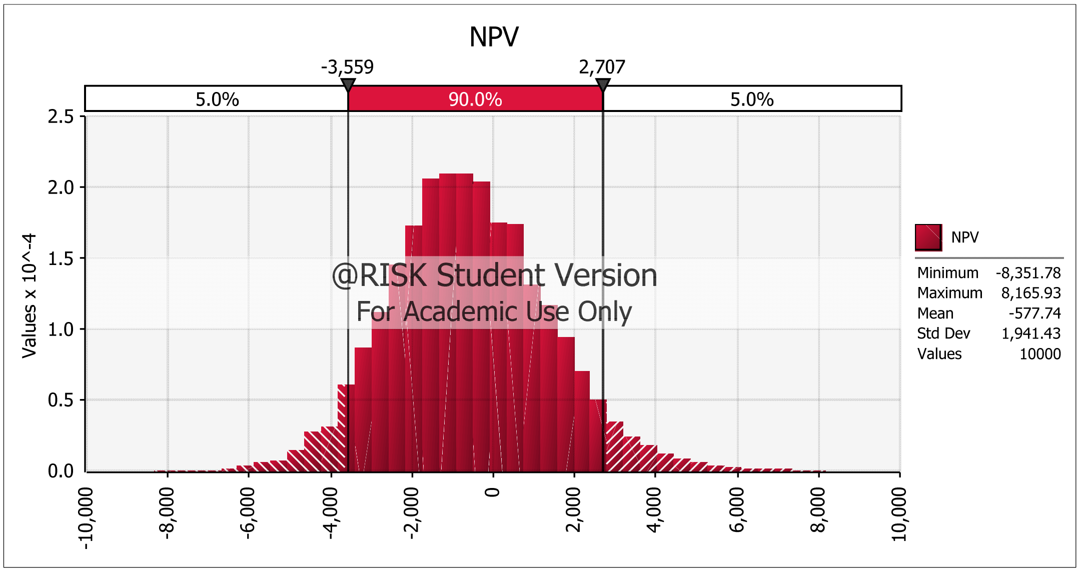

Figure 22: Simulated Output: NPV

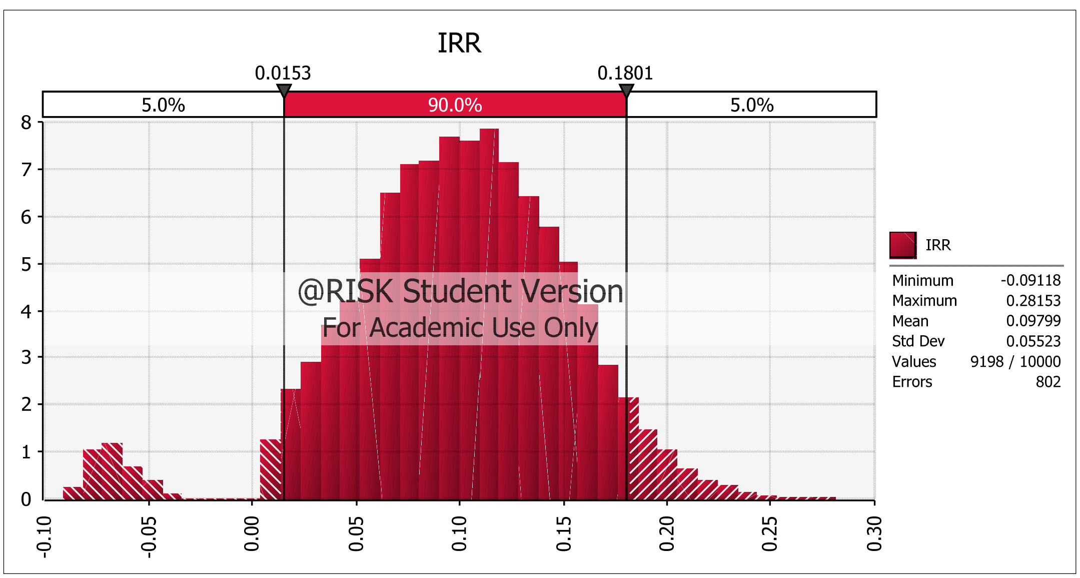

Figure 23: Simulated Output: IRR

4.2.4 *Conclusion*

From the original static DCF generated NPV and IRR suggested that the selected business case was marginal. However after the simulation, the resultant NPV and IRR suggested that the project is not really marginal and in fact has more downside than upside potential.

4.3 Survey results

This section presents the results and conclusions pertaining to the second research question i.e. does the simulated NPV and IRR provide for better decision making than the static NPV and IRR.

4.3.1 *Presentation of simulation results and interviews*

a. Demographic profile of the respondents

All the twenty respondents were AAP employees directly involved with mining projects and mining project evaluation. The detail profile of the respondents have been presented in Appendix C.

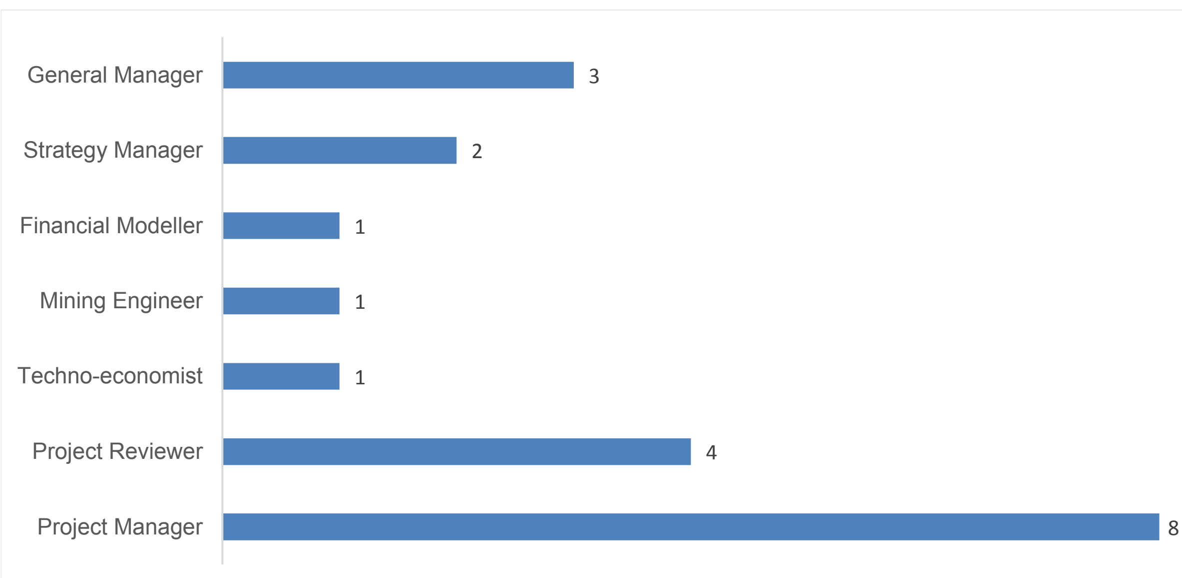

Figure 24: Survey Respondents' Profile

The project management discipline respondents included project managers, senior project managers and project reviewers. Other technical disciplines respondents included strategy managers, financial modellers, mining engineers and techno-economists. Three general managers were also interviewed to include the views of upper management at AAP. A summary of the respondents demographic has been depicted in Figure 24.

b. Interviews

For the survey, each of the twenty respondents were interviewed face-to-face. The outcome of the Monte Carlo simulation from the Excel model were presented to the respondents along with the results from the static DCF model. Both the static model and simulation model in Excel was demonstrated and explained to the respondents. An interview template (Appendix C) was used to capture the unstructured interview and additional comments from the respondents were noted.

The interviews captured three main themes e.g. the familiarity of the respondent with probabilistic modelling, their concerns regarding the use of probabilistic modelling in mining project evaluation and advantage of using a probabilistic modelling such as Monte Carlo simulation in evaluation mining business case. The three main themes were ideal in judging if the respondents felt that Monte Carlo simulation assists in better decision making while evaluating Platinum mining business case.

Familiarity of the respondent with the concept of probabilistic modelling and particularly with Monte Carlo simulation was asked to gauge the respondents' level of understanding of the concept. The unstructured interview helped in capturing if the respondent has previously used Monte Carlo simulation at AAP or his/her previous organisation and for what purpose. It also captured their personal experience relating to their previous use of Monte Carlo simulation.

The unstructured interview also captured the key concerns of the respondents in terms of the complexity and lack of transparency in the model. Respondents were asked if they felt that the Monte Carlo simulation techniques were too complex to understand and there is lack of transparency in modelling the input parameters distributions.

The third theme of the unstructured interview was the advantages of using Monte Carlo simulation in mining project evaluation. Based on the presented outcome of the simulation the respondents were asked:

- If it helped them identifying the key risk parameters that influence the business case of the project
- If it helped them appreciating the range of the impact of the input parameters on the output NPV and IRR
- If it helped them identifying mitigating levers to boost the value of the projects by influencing the input parameters
- And finally if it helped them in better decision making by providing all the above information in comparison the static DCF results

4.3.2 *Survey results summary*

The outcome of the interviews of the twenty respondents has been summarised in Figure 25.

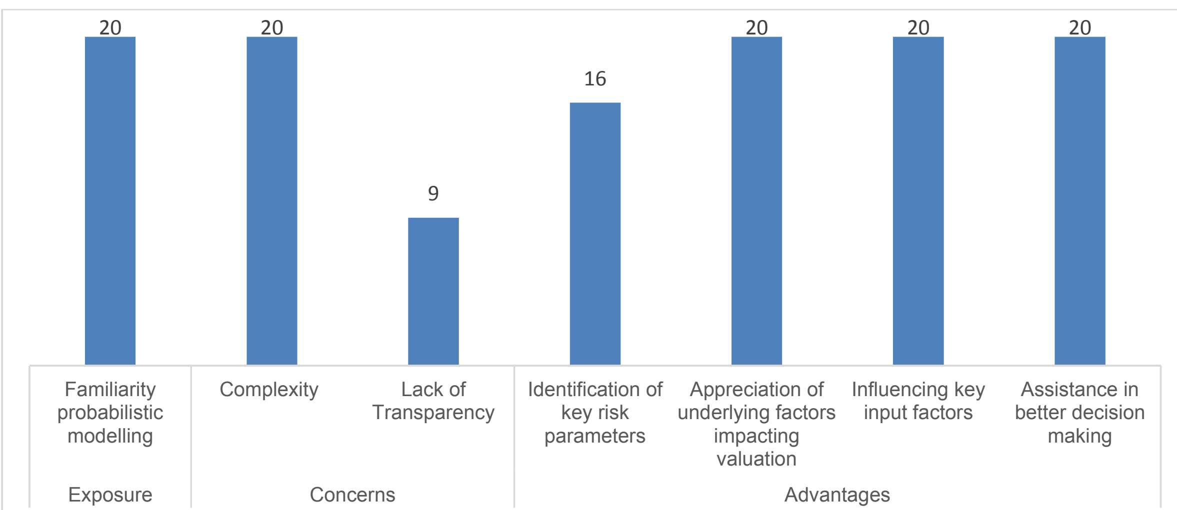

Figure 25: Survey Results

a. Familiarity

All the respondents said they were familiar with the concept of probabilistic modelling and Monte Carlo (Figure 25). All the respondents had been professionally exposed to the concept. Few had used it in their professional work but their use has been limited to Quantitative Risk Analysis (QRA) for capital estimating and project scheduling. The level of familiarity ranged from basic knowledge of probabilistic simulation to advanced level where the respondents were aware of different types of distributions for the input parameters. For example, all the project reviewers were aware of the Monte Carlo tool and were able to discuss around the distributions, especially on Capex. In addition, some discipline experts were also able to discuss and debate on the input parameters distributions e.g. the mining engineer on ore grade.

b. Concerns

All the twenty respondents had similar opinion about the complexity involved in the modelling for Monte Carlo simulation (Figure 25). Many opined that model on which the simulation is done on must be accurate and a true reflection of the business case. In addition, they opined that, the discipline experts had to work closely with the modelling expert to establish the links so that impact of the input parameters are accurately modelled and linked so that the their influence on output parameters are auditable. There were also some concerns from the respondents regarding human error in modelling that could lead to completely irrelevant outputs. Some general managers and senior project reviewers agreed that modelling is very complex and there is limited expertise available in the field, While the respondents had no concerns about the ability of the tool i.e. @Risk but were conservative about the underlying model in Excel.

Nine of the twenty respondents raised cornered about the modelling transparency in terms of the distribution used for the input parameters (Figure 25). While they did not disagree with distribution applied to the model but opined selection of the distribution is always debatable. For example, input distribution for Capex could be a triangular distribution or a truncated normal distribution with same mean and standard deviation. Most respondents mentioned that the integrity of the data used to derive input distribution as well as expert opinion is crucial and they would like to see and understand that thought process. For most, validation of data and transparency in modelling was of paramount importance while making decisions with outcome of such simulations.

c. Advantage

All the twenty respondents were unanimous that the simulated results provided them with better information and that would certainly assisted them for better and informed decision making (Figure 25). They agreed that the simulated results with the tornado graphs helped them identifying the key influencing factors. This would provide them with insights so that they can tweak or manage the influencing factors for better value. This would enable them to control and mitigate parameters for better returns. One of the respondent opined that if non-financial parameters e.g. ramp-up delays could be modelled into the model then the model could even be more useful.

4.3.3 *Conclusion*

From the interview outcome, it is evident that despite certain concerns relating to the modelling complexity and its lack transparency in selection of distributions for the input parameters, there is sufficient advantage in using Monte Carlo. All the respondents agreed that as a tool, Monte Carlo simulation helps in better decision by providing additional information. The tool assists the decision makers to identify the risks and to understand the influence of the input parameters on the output. This further assist in mitigating or exploiting the value levers for better results, generally leading to better decision making.

4.4 Summary of the results

3 sample projects were selected for the sensitivity analysis to determine the key input parameters that drive the value of a mining project. From the sensitivity analysis, out of the total 21 parameters, 11 key input parameters were selected and ranked.

An excel model was developed to mimic the HSF model so as to enable Monte Carlo simulation. The model was checked and validated for integrity and consistency. Another project was selected and its information was used in the developed Excel model for the simulation. Appropriate distributions were selected for the 11 key input parameters and Monte Carlo simulation was run. The simulated NPV and IRR were then used for the purpose of the survey for collection of qualitative input on whether the simulation results and the associated additional information helped for better decision making.

The results survey of the 20 respondents indicated that despite the perceived complexity in Monte Carlo model and a lack of sufficient transparency in selecting the input parameter distributions, it still provides for better decision making while evaluating mining projects.

CHAPTER 5. DISCUSSION OF THE RESULTS

5.1 Introduction

This chapter provides an analysis of the results of the research work. The second section of the chapter discusses the outcome of relating to the research question 1 i.e. identification of the key input parameters that drive the value of a Platinum mine project in AAP. It analyses the business case model development in Excel and the selection of the associated distributions of the input parameters. The third section provides an analysis of the outcome relating to the research question 2 i.e. whether the simulated NPV and IRR results provide for better decision making than the NPV and IRR provided by the static DCF results.

The last section provides a conclusion summary for both the first and second research questions.

5.2 Discussion pertaining input distributions of the key parameters

5.2.1 *Key input parameters driving Platinum project value*

The sensitivity analysis on the three sample projects identified the top 11 key input parameters that impacted the project's valuation i.e. NPV and IRR of the project business case. They have been depicted in Table 11.

A schematic depiction of a typical cashflow model is presented in Figure 26. Each layer in the pyramid is essential for the calculation of the next. For example, for the NPV and IRR calculation for a business case, we require revenue projection that is dependent on commodity prices. Similarly we require to forecast capital and operating costs to determine the net cashflow from the business case for the NPV calculation.

8 of the top 11 key input parameters (Table 11) that were established from the sensitivity analysis of the three sample projects selected were directly related to layer 2 of the cashflow pyramid (Figure 26) i.e. revenue and commodity prices. They are exchange rate,

metal prices (all, PGMs, Pt), concentrator and smelting recoveries and grade. It is found reasonable as these factors have a direct impact on the revenue generation.

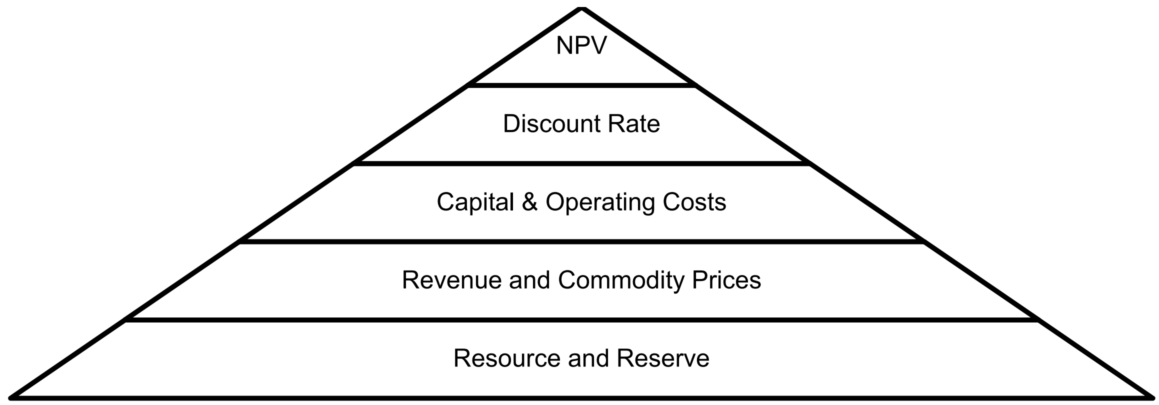

Figure 26: Stages in Cashflow (Adopted from Morley et al., 1999)

The other 3 of the top 11 input parameters were directly related to layer 3 of the cashflow pyramid (Figure 11) i.e. capital and operating cost. They are on-mine cost (total and shaft head) and Capex (Total). This can also be said to be reasonable as these parameters impact the net cashflow from the business case.

While doing quantitative risk assessment for uncertainties in a typical mining project studies, Kuhn and Visser (2014), identified Shaft head costs, Capex, Head grade and production schedule as the major risk drivers for the attractiveness of a business case. Kuhn and Visser (2014) further mention that project business case are highly sensitive to revenue and operating cost including initial capital. This compares favourably with the outcome obtained from the sensitivity analysis of the three selected projects.

Dimitrakopoulos & Ramazan (2004) identified uncertainties in estimated ore grade and long-term production schedules / projections as the key uncertainties in open pit mining. This compared favourably with 2 of the top 11 identified input parameters i.e. Grade and Tonnes mined, milled.

A case study done by Erdem et al. (2012) on Derekoy copper deposit (Kırklareli, Turkey) found, amongst other, ore density (grade), annual interest rate, mining cost, mining recovery, metallurgical cost, processing cost, processing recovery, stripping costs and selling price as the key uncertainties impacting the valuation of the Derekoy copper ore body. This also compared favourably with the 11 key parameters identified from the sensitivity analysis of the 3 sample project.

From the discussion and comparison above it can be inferred that the top 11 input parameters identified from the sensitivity analysis are reasonable and they in deed are the primary factors that influence the valuation of a Platinum mining project.

5.2.2 *Model development and simulation*

a. Model development

For probabilistic modelling, the base case model in Excel should accurately represent the reality of the business case. The Excel model should be free from logical errors. Data validity check should ensure that input data are truly representative of the project being modelled (Hacura et al., 2001). While HSF systems does it easily, it has no functionality to run Monte Carlo. On the other hand, replicating HSF in Excel in which probabilistic modelling could be run, is relatively difficult, if not impossible. For the purpose of this research, the attempt made in developing the Excel model which replicated HSF logic and calculation was deemed adequate for probabilistic modelling.

Actual data was used in the Excel model to determine the static DCF based NPV and IRR so that it can be objectively compared with output of the Monte Carlo simulation. The output of the Excel model was then validated against the output of the actual HSF run of the business case and they were found comparable.

b. Selection of input parameter distribution in Monte Carlo

As previously observed, the accuracy of a probabilistic modelling heavily relies on the appropriate modelling of the input parameters. According to an industry expert in probabilistic modelling, "inappropriate use of probability distributions has proved to be a very common failure of risk analysis models" (Vose, 2008). Within AAP, it is the author's view that, many personnel in technical discipline do not have adequate understanding of the theory behind probability distribution functions. This has also come out during the qualitative discussions for the survey leg of the research. The knock-on effect of selecting an inappropriate distribution further exacerbates the business case simulation by resulting in irrelevant simulated outputs.

The challenge faced, while determining the distribution of the input parameter, was that either limited historical data was available or historical data were found to be irrelevant in deciding the characteristics of the input parameters. Due to this many of the input distributions were selected based on advice from the experts and theoretical references were confirmed in validating the same. Experts view on the most likely, minimum and maximum values for the input parameters range and then the level of confidence they have in the most likely helped in selection of the various distributions and their respective characteristics. The defence to adopting this approach is that, input parameter distribution selection based on parametric distribution i.e. distribution selected on theoretical basis requires a great deal of knowledge in the underlying assumptions. According to Vose (2008), parametric distributions are selected when

- The theory behind the distribution is exactly applicable to the problem in hand
- There is a proven track record of that particular distribution has accurately represented the parameter in the past

In the selected business case and the available information for the input parameters, none of the above were applicable. Hence non-parametric distributions were used which were intuitively easy to understand and were flexible to modify depending on the experts' opinion. It was also easy to explain to the survey respondents. Various other attempts were made to ascertain the input parameter distributions based on historical data where enough data points were available. There was enough historical data available for the metal prices.

For example, historical Platinum prices (monthly averages of London Metal Exchange quotes) were obtained and they were adjusted to constant 2014 prices by using US inflation rate. 297 data points i.e. monthly average price of Platinum in US$/Oz, (April 1990 to Dec 2014) were thus calculated for constant 2014 prices. @Risk was used to run goodness-of-fit test to determine the statistical distribution function that best fits the data. The output of the same has been depicted in Figure 27. The top 2 fit based on chi-squared statistics were Exponential and Gamma distributions.

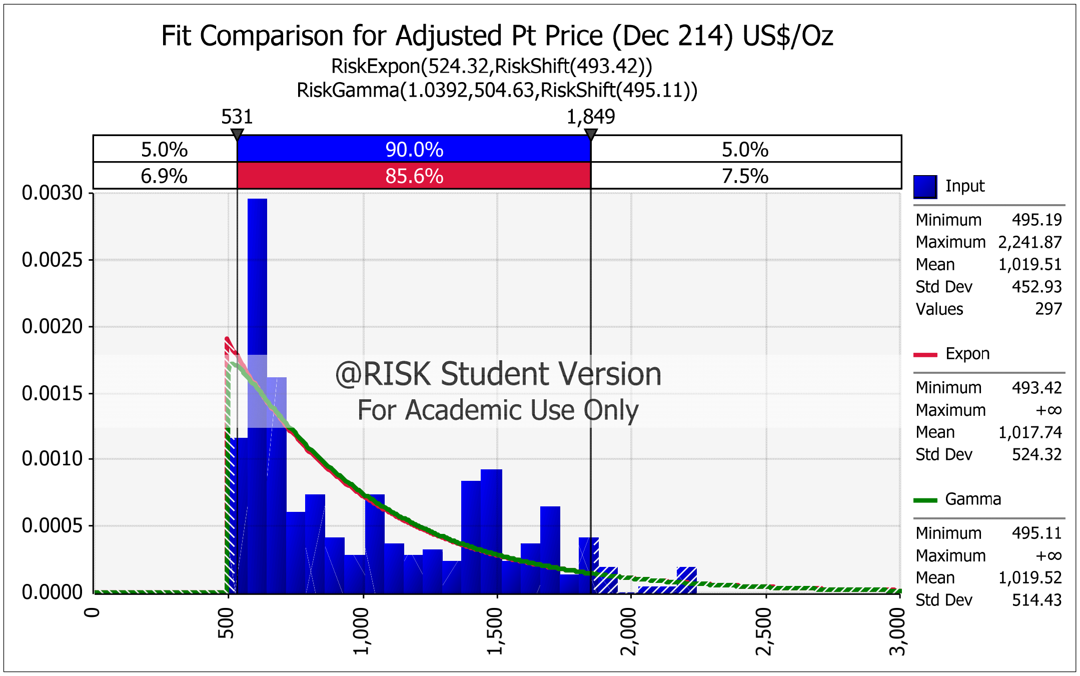

Figure 27: Historical Pt Price: Goodness-of-fit Test

Similarly for Copper, the goodness-of-fit tests was done taking into account 297 data points (monthly average of Copper price in US$/lb, April 1990 to December 2014). The goodness-of-fit tests output has been depicted in Figure 28. It can be seen that the top 2 fit based on chi-squared statistics were Triangular and Gamma distributions.

When this input distributions were presented for discussion to some discipline experts and techno-economists, they advised to use a normal distribution rather than the distributions identified through the goodness-of-fit tests. The rational was that the distribution means, maximum and minimum were not in line with the metal price forecasts in the GAs which was considered to be more scientifically forecasted considering a multitude of global economic factors.

The Monte Carlo simulation was hence done using normal distributions for metal prices. For a similar exercise, Derekoy copper deposit case study (Erdem et al., 2012) used a Weibull distribution for the selling price of Copper which is different to the distributions determined by the goodness-of-fit tests using historical prices. It can be said that there is a general discrepancy in selection of input parameter distributions and different experts have different opinions.

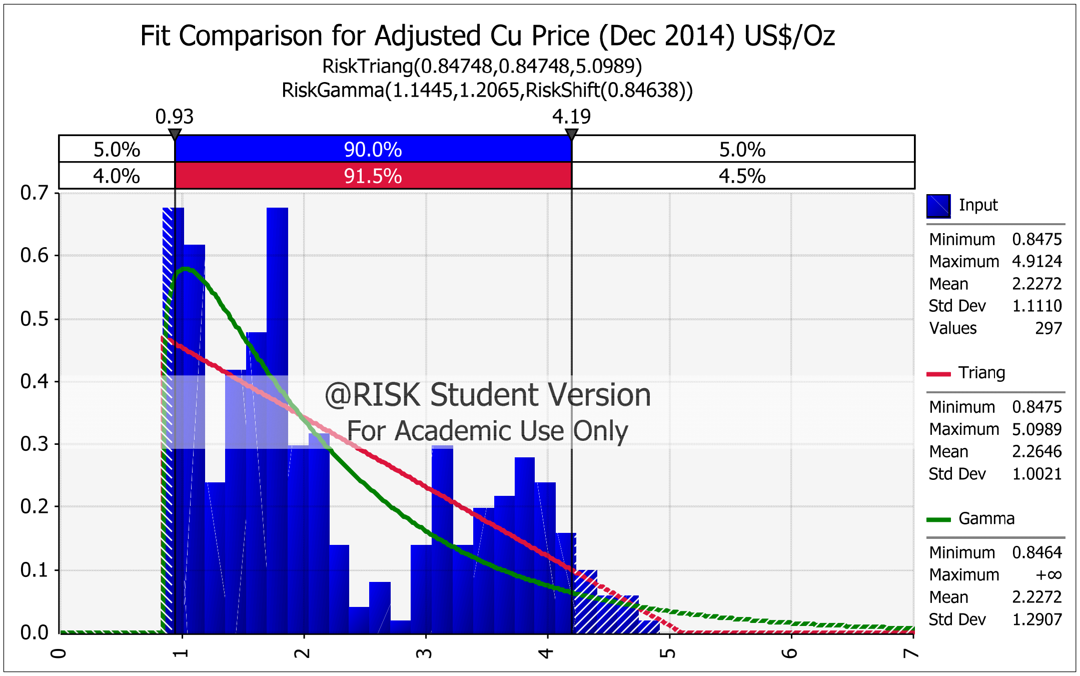

Figure 28: Historical Cu Price: Goodness-of-fit Test

Similar goodness-of-fit testes were done for Palladium and Nickel using historical prices. However, the distribution obtained were not used in the simulations and expert advice was followed.

A criticism of the model could be that, for the input parameters whose distributions were based on experts' opinion, there could be potential that some elements of expected value bias could have creeped in. The expert opinions were not tested against opinions from other similar experts. However, while presenting the simulated results to the respondents during the survey, the rationale behind selection of the input parameter distributions were explained to the respondents and no material disagreement or comment was noted from them. Kuhn and Visser (2014) suggests that to determine the input parameters distributions, a facilitated workshop approach should be adopted bringing in the collective knowledge of the discipline experts and the expert probabilistic modeller. This was beyond the scope of this research as the intention was not to refine a business case but to prepare the probabilistic model to a sufficient level so that it can be presented to an assortment of respondents and their opinion on the utility of probabilistic modelling could be gauged.

Another criticism of the Excel model could be that it did not model the impact of the variability of the random variables on themselves hence was unable to determine the correlation between the input parameters. For example, a higher grade of ore is generally associated with a higher concentrate recoveries and could be said to have positive correlation between themselves. Correctly modelling correlations amongst the input variables would have required extensive historical data and expert studies. For the purpose of this research a pragmatic approach was followed and correlations were not modelled. However, this was not a major risk to the integrity of the research as the intention was not to refine the business case but to present a model to a range of experts to gauge their opinion on whether the Monte Carlo simulation aids in better decision making.

5.3 Discussion pertaining to Monte Carlo simulation aiding decision making

5.3.1 *Monte Carlo simulation in aiding decision making*

a. Familiarity with Monte Carlo simulation

Uncertainties in business, management of uncertainties and making long-term investment decisions on projects whose attractiveness is contingent upon a number of uncertainties has been the characteristics of the Mining business for a long time. According to Davies et al., (2012) probabilistic modelling tools like Monte Carlo have been around for decades and many Nobel prizes have been awarded for innovations in the field of economics and finance pertaining to uncertainties and decision theory. However, use of probabilistic modelling still remain in its incipient stage in mining, industrial and other services sectors.

A report from McKinsey & Company (2008) by Buehler et al., suggests that only a quarter of the corporates use Monte Carlo in their strategic planning process and only a third use it for any quantitative risk assessments. Financial institutions have been the pioneers in development and usage of probabilistic modelling related tools and products. However, the usage of similar tools in Mining industry remains low. This is despite Mining being an industry with capital intensive and long-term business ventures with its fair share of uncertainties where probabilistic modelling could really assist in value creation.

The results of the survey done for this research indicated that although the respondents were familiar with the Monte Carlo, the level of awareness were found to be shallow. AAP does not have an established process to use Monte Carlo in business model simulation. It is not necessarily prescribed and there is no higher level of expertise available in-house to do such exercise. All respondent noted that increasing awareness of this tool at various level, both in technical disciplines and decision making level, will hugely benefit the company.

Providing training to introduce the concept of probabilistic modelling will be the first step. Refresher courses should be rolled out to train technical discipline experts the basics of probability and statistics; reading and interpreting of histograms, cumulative frequency plots, tornado diagrams etc. The training should not only include how to use simulation software like @Risk but also how to communicate with decision makers so that they understand the logic. The output format i=should be designed to provide the decision makers with useful information that will provide them with more insights into the underlying factors and assist in decision making.

Some respondents suggested that creating a core group of practitioners and providing for a forum will encourage discussions and enhancement of the body of knowledge in probabilistic modelling within AAP. This forum, through its internal sponsors, then can provide step by step plan to gradually introduce the practice of probabilistic modelling in the organisation. Plan should include conceptual introduction along with awareness of what value it will add to the current business practice. It should allow for 'quick wins' so that benefits of the doing Monte Carlo is visible. The plan should take into consideration the cultural mind-set of the disciplines e.g. maturity level of the personnel in the discipline departments with regards to Monte Carlo. Care should be taken not to introduce large changes in the business process at once and keeping the Monte Carlo simulation simple but effective. Infrastructure e.g. software, proper communication and reporting tools should be progressively introduced into the AAP project systems so that slowly the probabilistic modelling concept is embedded in the project review and approval systems.

b. Concerns

All the twenty respondents cited some concern or the other regarding the use of Monte Carlo as a business simulation tool. The four major reasons for their concerns could be summarised as follows:

- A perception that Monte Carlo modelling is too complex and is difficult to implement
- Difficulty in interpreting the analysis and lack of clarity in how to use the simulated output / data
- Perceived lack of transparency in modelling the input parameters' distributions
- A perception that probabilistic modelling tools use a lot of guess work in selecting the distribution of input parameters and the resulting outputs could be highly inaccurate.

For decades, financial institutions have been pioneers in development and usage of probabilistic modelling techniques (McKinsey & Company, 2008). However, the sub-prime mortgage crisis and melting down of bigger financial institutions like Lehman Brothers, highlighted the shortcomings in the processes previously regarded as well established. Markets in reality has not behaved exactly like in the models and these sophisticated models have not been good in predicting business outcomes. These events create doubts in the minds of the mangers and decision makers in other industry and they remain sceptical of the usefulness of the business case simulation. Many decision makers cited bad experiences with the Monte Carlo simulation as their reason of not trusting them. However, the same respondents, when probed further, agreed that those business case simulation attempts were not holistic and were not properly thought through.

The concerns raised by the respondents regarding the usefulness of probabilistic modelling is neither new nor unreasonable. It is always difficult to model the 'unknown unknowns' (Vose, 2008).In addition, it is not possible to model all the uncertainties of the real world into a business model. The business case in real world is a complex systems of interrelations of external and internal factors. While a probabilistic model can mostly model the internal factors it is limited in modelling external factors. At best, it can capture and model a few of the key external factors. However, probabilistic modelling can afford the decision makers the opportunity to test the robustness of the business case. Probabilistic modelling can provide a platform where managers can stretch the parameters beyond the expected ranges and see the impact on the business case and hence testing its robustness in the process.

Most respondents agreed that in theory, the probabilistic modelling has its benefits and could aid to better decision making. Computation is fairly easy with software plugins like @Risk or CrystalBall and modelling can be easily done in an Excel spreadsheet. However, they all noted that models are complex and most of the times a 'black box'. While the technical side of the approach is not complex, they all agreed that modelling experts are required to guide and validate the process alongside the discipline experts. For example, Geologist must work along with the modelling expert while determining the distribution of ore grade as the input parameter to the model. However, it is a big challenge to identify the key drivers, agree on the uncertainties around them and to model their input distributions taking into account all the relevant information and expert opinions.

Respondents also commented on the lack of guidance in using the results and the output. Some rued that most managers and some decision makers do not have the level of understanding to make use of the available information and most of the time they go with their 'gut-feel'. Experts (Vose, 2008) suggest that forcing decision makers with simulation and statistical information who do not want to use it will be of limited value. They must be educated so that they appreciate the value of it in decision making.

Many respondents also agreed that the input parameters need to be modelled appropriately. Input parameters' range and distribution should be based on facts and/or historical data or there is sufficient rationale behind selection of an input distribution based on an 'expert opinion'. In the absence of it, many reckoned, it is a case of "garbage in, garbage out". While fact-based input parameter modelling is relatively agreeable, it is the opinion based modelling that, the respondents reckoned, creates doubt in their minds.

Behavioural finance suggest that, one should be wary of many heuristics e.g. anchoring heuristics, available heuristics, confirmation heuristics, etc. while judging the distribution of the input parameters. Experts in probabilistic modelling (Buehler et al., 2008) suggest that care should be taken in validating uncertainty estimates on expert opinion given all the heuristics of biases the experts need to overcome.

There are many ways one can avoid or at least minimise these biases. Facilitated workshops where experts are brought in together could help some of the biases. Delphi technique is another method that can be used to get the opinion of individuals about a parameter, collating them into one and then sharing them with all the experts to formulate the rational. There are many other methods and processes that can be followed to limit the biases in 'expert opinion' in modelling the input uncertainties. However, they are beyond the scope of this research and hence not been dwelled in.

Confidence in Monte Carlo as a modelling tool received little doubt from respondents. All of them agreed that the tool is sound and it did not concern them. What was of concern to them was the ability of the individual and the collective users in AAP to model the uncertainties into the model. In addition the nascent level of expertise in the organisation relating to the use of probabilistic modelling as well as the complexities involved in incorporating the tools into the project evaluation and various other systems and process remained a key concern.

c. Advantages

Survey results (Figure 25) shows compulsive evidence that the Monte Carlo simulated results provided with better information than static DCF results. All respondents noted that this would assist them and the decision makers in making more informed decisions.

The @Risk results presented for the business case simulation provided information on the possible range of outcomes. Decision makers could see and appreciate the underlying characteristics of the input parameters i.e. the best possible estimate of the parameter and how likely that can happen. It definitely constituted better data and brought more clarity and insight into the business case presented. The additional information helped the managers to frame the range of outcomes more meaningfully. It can be argued that even in static DCF model the managers implicitly do the 'range framing' anyway, but the author feels that the Monte Carlo simulation process provides the decision makers with a comprehensive summary of information so that they can make their decision more correctly. For example, Project X has an R500m NPV but with a 10% chance that the NPV will be negative, while Project Y R600m NPV with 50% chance of having a negative NPV provides useful information while selecting and approving of projects.

Understanding and appreciation of the value levers in the input parameters that influence the project outcome (i.e. NPV and IRR) provides the decision makers with more information and allows them to consider the value of flexibility in decision making. At project stage, it allows managers to optimise on various options e.g. mine sizing, mining cuts, recovery adjustments etc., so as to maximise project value. Even at operational level, the information on underlying parameters and their influence provides levers for value optimisation e.g. tweaking production profile to control input costs and maximise on metal price fluctuations.

The Monte Carlo simulation and its results can constantly make available information that will allow managers to do value flexibility and real options during the project or operational phase of the mining venture. For example, if in future prices of PGM basket price is likely to go down and prices of base metal is likely to go up, managers can value optimise the mining cut to extract more base metal from the orebody to maximise returns. The additional information is beneficial in pre-empting negative influence or externalities allowing managers to proactively react to externalities and preserve value by suitably adjusting to the new reality.

By participating in the probabilistic modelling process, the participants as well as the managers gain insight into the value drivers of the business case and the uncertainties around the input parameters. This brings in managerial attention where it is needed the most. Managers become more aware of what might drive value appreciation or erosion and to what extent (Pergler and Freeman, 2008). It allows them to ask 'what if' questions in a fact-based and fully informed way and helps them to make better decisions.

Pergler and Freeman (2008) notes that probabilistic modelling using tools like @Risk present a huge opportunity for managers in all industry, particularly sectors facing significant uncertainty. However, it is imperative that the tools are used and interpreted correctly. Although probabilistic modelling will not make accurate future predictions for the business case, it could act as a powerful facilitator or medium allowing decision makers to gain insight into the nitty-gritty of the business case. It is the author's view that this would help the managers in making more informed decisions as the decision makers get a better feel of the realistic range of possibilities.

Probabilistic modelling done correctly i.e. modelling representing correctly business case in hand, right selection of input parameters distributions, and right analysis could potential provide AAP with a competitive advantage by improving on the selection of the right projects, optimising on the selected projects and possibly considering real options in operational environment. This will assist managers selecting between options with different output and risk profiles and mitigating the risks.

5.4 Conclusion

From the detail analysis and discussions if the preceding sections, it can be concluded that the top 11 input parameters identified from the sensitivity analysis were reasonable and they in deed are the primary factors that influence the valuation of a Platinum mining project.

The Excel model developed was valid and robust enough for the Monte Carlo simulation. While there were some debate and difference in opinion around the selection of input parameters distributions, a rational approach was followed in selection of the distributions and the Monte Carlo simulation was run. The output suggested that the business case for the selected project had more downside than upside potential. It was not really a marginal business case as previously envisaged from the results of the static DCF based NPV and IRR.

Survey results suggested that the respondents believe that, despite certain concerns, Monte Carlo is useful and could assist in better decision making. The low level of familiarity with the Monte Carlo simulation within AAP can be improved. A conceptual discussions regarding promoting the use of probabilistic simulation, establishing a body of knowledge and a step by step process to embed the usage of Monte Carlo in AAP projects system and processes was done. Monte Carlo, if done correctly, could assist by improving on the selection and approval of the right projects and could potential provide AAP with a competitive advantage.

CHAPTER 6. CONCLUSIONS & RECOMMENDATIONS

6.1 Introduction

This chapter summarises the conclusions of the research study and provides recommendations for AAP as internal stakeholder as well as industry as a whole. It also provides suggestions for future endeavours and research in this particular area.

6.2 Conclusions of the study

The purpose of this research was to establish whether adopting a Monte Carlo simulation approach in evaluation of Platinum mine projects provides for better investment decision making in selection and approval of the projects. The research aimed to incorporate Monte Carlo simulation to model uncertainties associated with the top key parameters that impact the evaluation criteria for mine projects in AAP and establish if it provided better information for the decision makers in reviewing and approving of these projects.

The research study determined the key input driving parameters that drive value of a Platinum mine project. It created an Excel model to model the uncertainties involved with the key input parameters with their associated probability distributions. The Monte Carlo simulation was then run and the output were used to do a qualitative survey to establish if the simulated information provided for better decision making.

The survey results concluded that despite certain concerns regarding the perceived complexity in Monte Carlo model and a lack of sufficient transparency in selecting the input parameter distributions, it still provides for better decision making in evaluation and selection of a business case. It provides decision makers with insight into the relevant uncertainties and their impacts on the business case. It helps managers appreciate the range of the impact of the input factors and allows them to identify mitigating levers to boost the value of the project's return. The survey outcome concluded that probabilistic simulation, if done correctly, can significantly improve the project evaluation process within AAP and add to competitive advantage of the organisation.

6.3 Recommendations

Mining as a business requires substantial upfront capital investment, the return on which are often long-term. As a business, Mining projects are fraught with uncertainties and managing these uncertainties is vital in optimising value and return on investment. From the research outcome, it is quite evident that Monte Carlo simulation could be a potent tool to model uncertainties. It can provide clarity and better insight into value driving levers that can be managed or mitigated so as to maximise return. Mining industry, with its myriad of uncertainties in their business, is ideally suited to make use of the dynamic DCF modelling using Monte Carlo.

The banking and financial sectors have been pioneer in usage of probabilistic modelling and there is no reason why other industrial sectors e.g. Mining can not emulate the benefits of probabilistic modelling achieved by their financial counterparts. Although awareness of the benefits of probabilistic modelling is quite evident in Mining industry, the technical understanding and usage of the Monte Carlo tool is still in its incipient stages. Limited expertise in stochastic modelling as well as lack of skills in interpreting the simulation results are often seen in Mining organisations. Usage of tools such as Monte Carlo is generally on a case to case basis rather than as a norm embedded in the business process of the Mining companies.

It is the author's belief that a well-framed Monte Carlo simulation will definitely assist in better decision making in evaluation and selection of projects for investments within AAP. The low level of familiarity with the Monte Carlo simulation within AAP can be improved. A structured approach, sponsored by a higher authority e.g. Executive Head of Projects, should be adopted to roll out the concept within the projects division. Targeted training program, establishing practice groups will help enhancing the body of knowledge in Monte Carlo simulation modelling in the projects department. A step by step plan should be mapped to embed the usage of the tool in AAP projects system and processes.

The benefits of Monte Carlo simulation can also be realised for evaluation of projects in other mining companies operating in different commodities. Sharing of ideas on modelling uncertainties in probabilistic simulation can be done in regional forums and the body of knowledge could further be enhanced benefitting the entire mining community in southern Africa.

Benefit of probabilistic modelling is immense. Applied appropriately, it can significantly improves business decision making in many other industries. It can help managing uncertainties and create additional value out of risks. Probabilistic modelling could provide operational and management flexibility in managing uncertainties and hence creating value out of it. The challenge, however, remains in embedding the concept in the business process and getting the right skills in the managerial and executive levels to make the best use of what Monte Carlo simulation has to offer.

6.4 Suggestions for further research

For the purpose of the research only 11 of the 21 key input parameters were selected for Monte Carlo simulation. As a direct extension to this research, future research could include determining the distributions for all the other input parameters. Endeavours can also be made in modelling correlations in input parameters and analysing the impact of the same on the overall business case. In future studies that is undertaken to include the other 10 input parameters, potential correlations amongst input parameters could be identified and modelled in the Monte Carlo simulation.

Other research could also be potentially be done in further refining of the input parameters' distributions e.g. for Grade, variability from the historical drilling data on different orebodies (Merensky, UG2) could be studied to establish probability models for different orebodies and determination of the input distribution for Grade in business case simulation.

Future case studies could be undertaken at project level in Platinum or other commodities to demonstrate value of Monte Carlo simulation by modelling the uncertainties of the parameters at project level.

Future research could also be done to explore possibility of including parametric distributions to model input parameters. This will include establishing theoretical basis for adopting different distributions for the individual input parameters.

Future research could also focus in modelling socio-political uncertainties into the stochastic business model. For example, production disruptions during annual wage negotiations and labour strikes could be modelled to further enhance business's ability to forecast and manage uncertainties at the same time preserving business value by appropriately planning for mitigating actions.

There is enormous potential to extend this research into other industries e.g. real estate, manufacturing etc. There is enough merit in conducting similar research in these industry to unravel the benefit of probabilistic modelling in aiding business decision making. Monte Carlo simulation case studies and research in these industries could potentially unlock values by enabling managers and decision makers to manage uncertainties more proactively.

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APPENDIX A

Output of sensitivity analysis

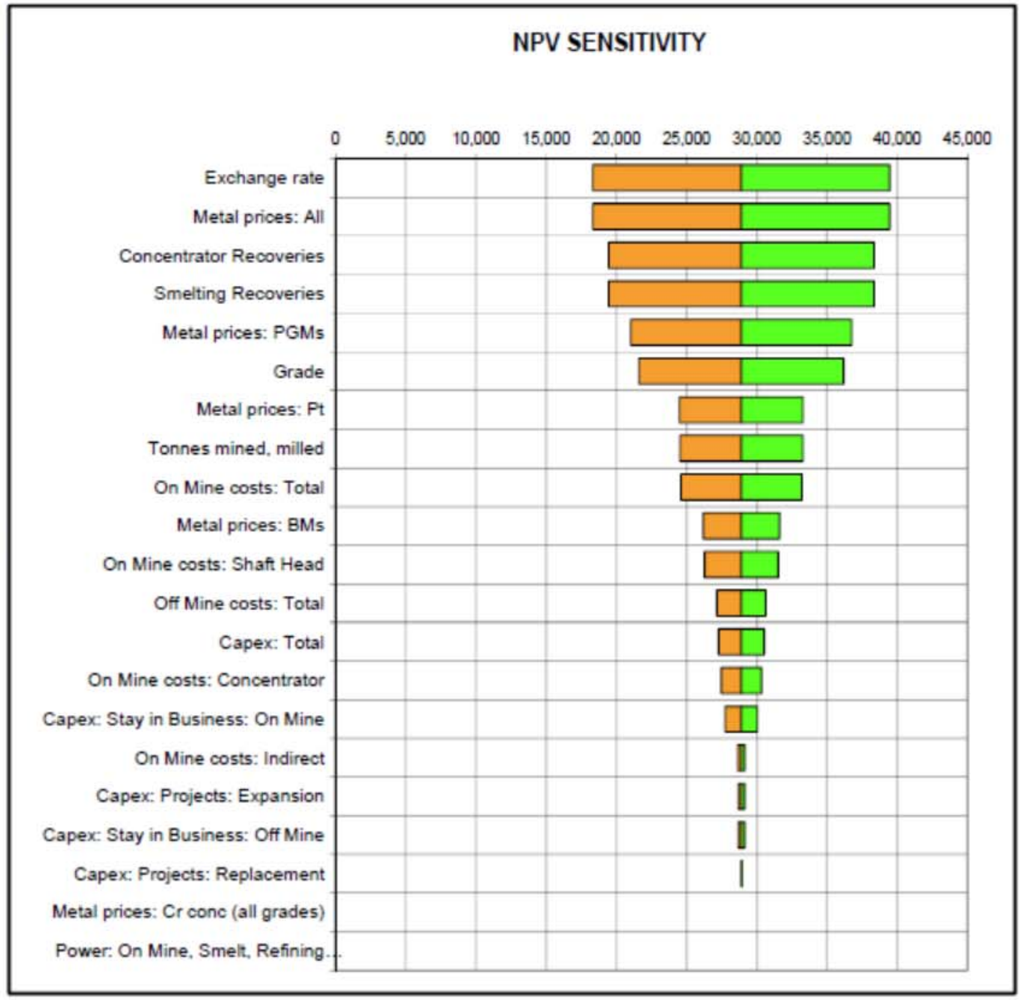
NPV SENSITIVITY DRIVERS

Rand Millions, real terms 2015

Project A_Opencast

NPV	10 % Worse			Base	10% Better		
KEY DRIVERS	Decr %	Decr	NPV	NPV	NPV	Incr	Incr %
Exchange rate	-37%	-10,577	18,317	28,894	39,460	10,566	37%
Metal prices: All	-37%	-10,577	18,317	28,894	39,460	10,566	37%
Metal prices: Pt	-15%	-4,392	24,502	28,894	33,285	4,391	15%
Metal prices: PGMs	-27%	-7,856	21,038	28,894	36,747	7,853	27%
Metal prices: BMs	-9%	-2,713	26,181	28,894	31,607	2,713	9%
Metal prices: Cr conc (all grades)	NA	0	0	0	0	0	#DIV/0!
Grade	-25%	-7,281	21,613	28,894	36,173	7,279	25%
Tonnes mined, milled	-15%	-4,376	24,518	28,894	33,270	4,376	15%
Concentrator Recoveries	-33%	-9,453	19,441	28,894	38,340	9,446	33%
Smelting Recoveries	-33%	-9,453	19,441	28,894	38,340	9,446	33%
Off Mine costs: Total	-6%	-1,741	27,153	28,894	30,636	1,742	6%
On Mine costs: Total	-15%	-4,309	24,585	28,894	33,203	4,309	15%
On Mine costs: Shaft Head	-9%	-2,623	26,271	28,894	31,517	2,623	9%
On Mine costs: Concentrator	-5%	-1,432	27,462	28,894	30,326	1,432	5%
On Mine costs: Indirect	-1%	-254	28,640	28,894	29,148	254	1%
Power: On Mine, Smelt, Refining costs	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Total	-6%	-1,627	27,267	28,894	30,521	1,627	6%
Capex: Projects: Expansion	-1%	-220	28,674	28,894	29,144	250	1%
Capex: Projects: Replacement	0%	-1	28,893	28,894	28,896	2	0%
Capex: Stay in Business: On Mine	-4%	-1,135	27,759	28,894	30,029	1,135	4%
Capex: Stay in Business: Off Mine	-1%	-220	28,674	28,894	29,144	250	1%

NPV	10 % Worse			Base	10% Better		
RANKED DRIVERS	Decr %	Decr	NPV	NPV	NPV	Incr	Incr %
Exchange rate	-37%	-10,577	18,317	28,894	39,460	10,566	37%
Metal prices: All	-37%	-10,577	18,317	28,894	39,460	10,566	37%
Concentrator Recoveries	-33%	-9,453	19,441	28,894	38,340	9,446	33%
Smelting Recoveries	-33%	-9,453	19,441	28,894	38,340	9,446	33%
Metal prices: PGMs	-27%	-7,856	21,038	28,894	36,747	7,853	27%
Grade	-25%	-7,281	21,613	28,894	36,173	7,279	25%
Metal prices: Pt	-15%	-4,392	24,502	28,894	33,285	4,391	15%
Tonnes mined, milled	-15%	-4,376	24,518	28,894	33,270	4,376	15%
On Mine costs: Total	-15%	-4,309	24,585	28,894	33,203	4,309	15%
Metal prices: BMs	-9%	-2,713	26,181	28,894	31,607	2,713	9%
On Mine costs: Shaft Head	-9%	-2,623	26,271	28,894	31,517	2,623	9%
Off Mine costs: Total	-6%	-1,741	27,153	28,894	30,636	1,742	6%
Capex: Total	-6%	-1,627	27,267	28,894	30,521	1,627	6%
On Mine costs: Concentrator	-5%	-1,432	27,462	28,894	30,326	1,432	5%
Capex: Stay in Business: On Mine	-4%	-1,135	27,759	28,894	30,029	1,135	4%
On Mine costs: Indirect	-1%	-254	28,640	28,894	29,148	254	1%
Capex: Projects: Expansion	-1%	-220	28,674	28,894	29,144	250	1%
Capex: Stay in Business: Off Mine	-1%	-220	28,674	28,894	29,144	250	1%
Capex: Projects: Replacement	0%	-1	28,893	28,894	28,896	2	0%
Metal prices: Cr conc (all grades)	#DIV/0!	0	0	0	0	0	#DIV/0!
Power: On Mine, Smelt, Refining costs	#DIV/0!	0	0	0	0	0	#DIV/0!



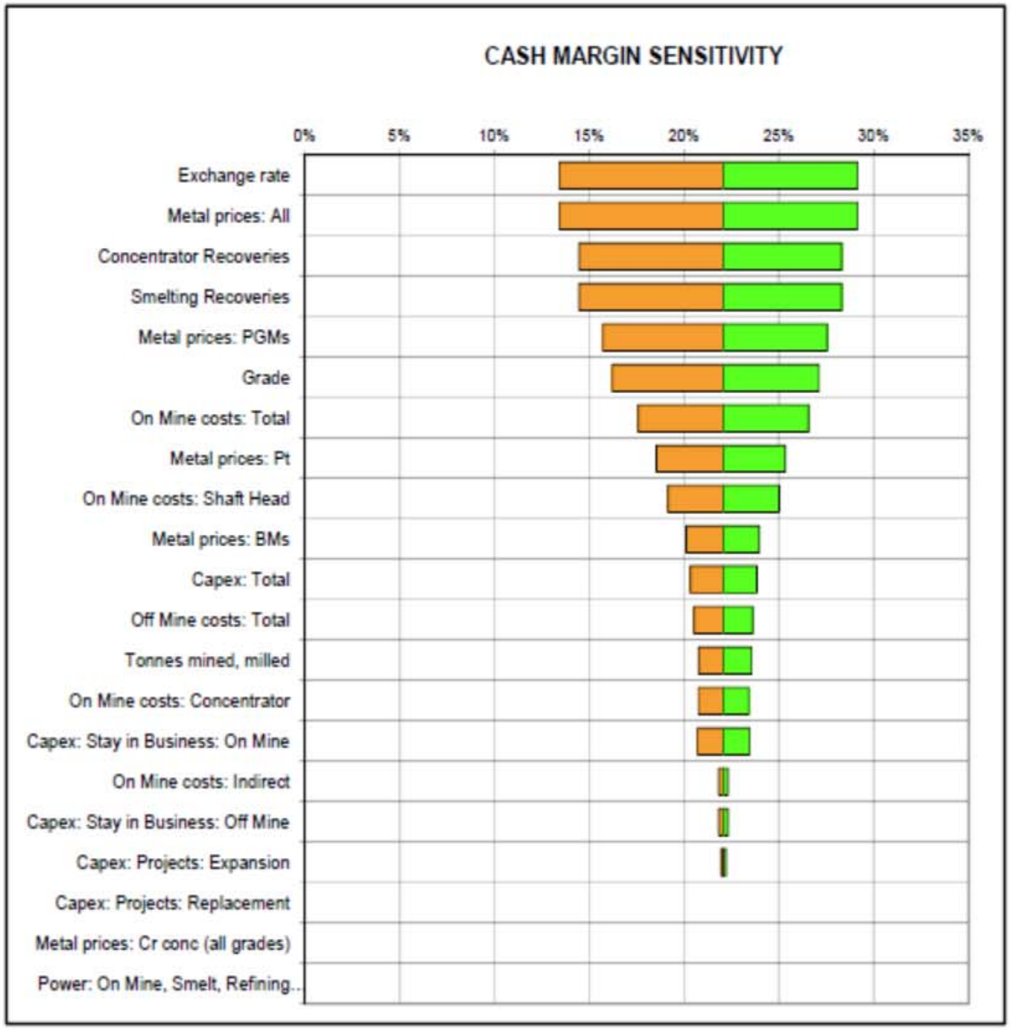
CASH MARGIN SENSITIVITY DRIVERS

Project A_Opencast

Cash Margin %

CASH MARGIN KEY DRIVERS	10 % Worse			Base	10% Better		
	Decr %	Decr	CM%	CM%	CM%	Incr	Incr %
Exchange rate	-39%	-9%	13%	22%	29%	7%	32%
Metal prices: All	-39%	-9%	13%	22%	29%	7%	32%
Metal prices: Pt	-16%	-4%	19%	22%	25%	3%	15%
Metal prices: PGMs	-29%	-6%	16%	22%	28%	5%	25%
Metal prices: BMs	-9%	-2%	20%	22%	24%	2%	8%
Metal prices: Cr conc (all grades)	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Grade	-27%	-6%	16%	22%	27%	5%	23%
Tonnes mined, milled	-6%	-1%	21%	22%	24%	1%	7%
Concentrator Recoveries	-35%	-8%	14%	22%	28%	6%	28%
Smelting Recoveries	-35%	-8%	14%	22%	28%	6%	28%
Off Mine costs: Total	-7%	-2%	21%	22%	24%	2%	7%
On Mine costs: Total	-20%	-5%	18%	22%	27%	4%	20%
On Mine costs: Shaft Head	-13%	-3%	19%	22%	25%	3%	13%
On Mine costs: Concentrator	-6%	-1%	21%	22%	23%	1%	6%
On Mine costs: Indirect	-1%	0%	22%	22%	22%	0%	1%
Power: On Mine, Smelt, Refining costs	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Total	-8%	-2%	20%	22%	24%	2%	8%
Capex: Projects: Expansion	-1%	0%	22%	22%	22%	0%	1%
Capex: Projects: Replacement	0%	0%	22%	22%	22%	0%	0%
Capex: Stay in Business: On Mine	-6%	-1%	21%	22%	23%	1%	6%
Capex: Stay in Business: Off Mine	-1%	0%	22%	22%	22%	0%	1%

CASH MARGIN RANKED DRIVERS	10 % Worse			Base	10% Better		
	Decr %	Decr	CM%	CM%	CM%	Incr	Incr %
Exchange rate	-39%	-9%	13%	22%	29%	7%	32%
Metal prices: All	-39%	-9%	13%	22%	29%	7%	32%
Concentrator Recoveries	-35%	-8%	14%	22%	28%	6%	28%
Smelting Recoveries	-35%	-8%	14%	22%	28%	6%	28%
Metal prices: PGMs	-29%	-6%	16%	22%	28%	5%	25%
Grade	-27%	-6%	16%	22%	27%	5%	23%
On Mine costs: Total	-20%	-5%	18%	22%	27%	4%	20%
Metal prices: Pt	-16%	-4%	19%	22%	25%	3%	15%
On Mine costs: Shaft Head	-13%	-3%	19%	22%	25%	3%	13%
Metal prices: BMs	-9%	-2%	20%	22%	24%	2%	8%
Capex: Total	-8%	-2%	20%	22%	24%	2%	8%
Off Mine costs: Total	-7%	-2%	21%	22%	24%	2%	7%
Tonnes mined, milled	-6%	-1%	21%	22%	24%	1%	7%
On Mine costs: Concentrator	-6%	-1%	21%	22%	23%	1%	6%
Capex: Stay in Business: On Mine	-6%	-1%	21%	22%	23%	1%	6%
On Mine costs: Indirect	-1%	0%	22%	22%	22%	0%	1%
Capex: Stay in Business: Off Mine	-1%	0%	22%	22%	22%	0%	1%
Capex: Projects: Expansion	-1%	0%	22%	22%	22%	0%	1%
Capex: Projects: Replacement	0%	0%	22%	22%	22%	0%	0%
Metal prices: Cr conc (all grades)	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Power: On Mine, Smelt, Refining costs	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!



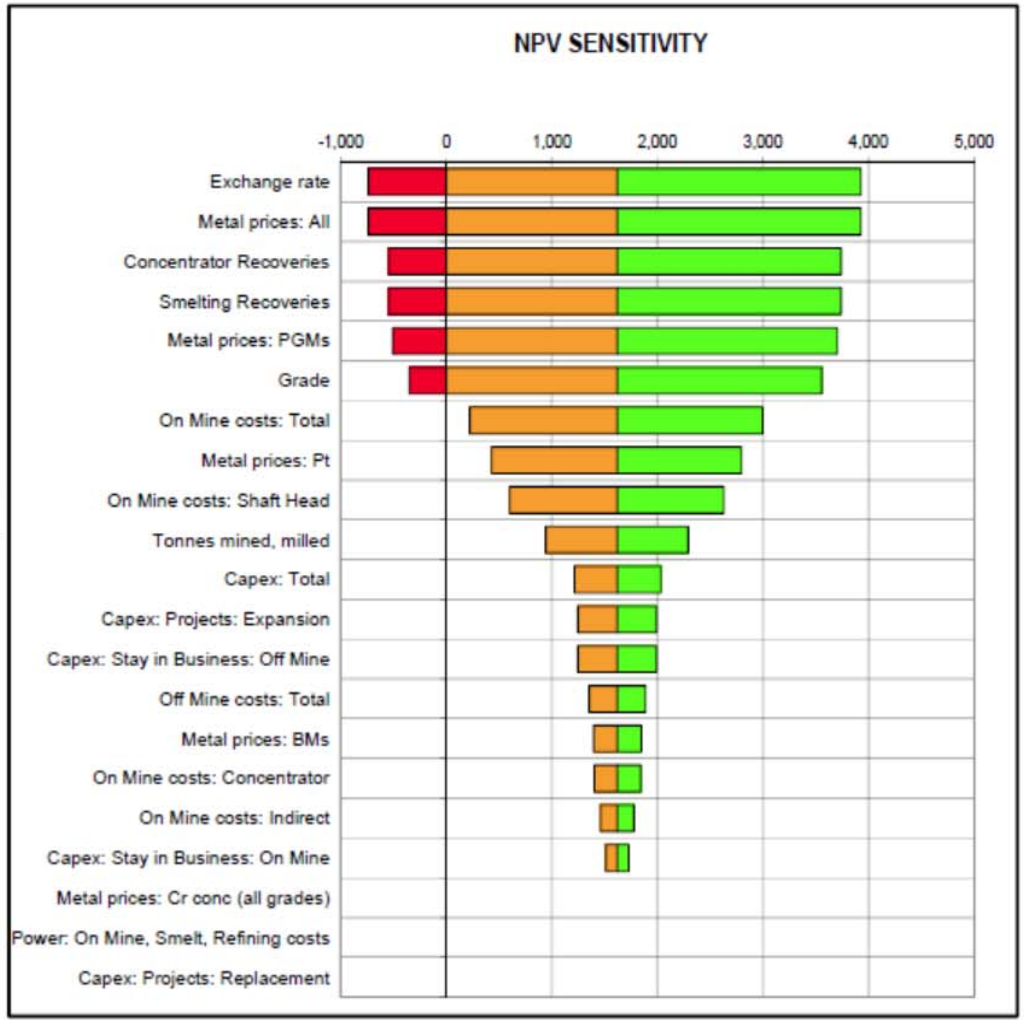
NPV SENSITIVITY DRIVERS

Rand Millions, real terms 2015

Project B_Underground Declined Shaft

NPV	10 % Worse			Base	10% Better		
KEY DRIVERS	Decr %	Decr	NPV	NPV	NPV	Incr	Incr %
Exchange rate	-145%	-2,357	-736	1,621	3,924	2,303	142%
Metal prices: All	-145%	-2,357	-736	1,621	3,924	2,303	142%
Metal prices: Pt	-73%	-1,189	432	1,621	2,795	1,174	72%
Metal prices: PGMs	-131%	-2,127	-506	1,621	3,704	2,083	129%
Metal prices: BMs	-14%	-225	1,396	1,621	1,846	225	14%
Metal prices: Cr conc (all grades)	#DIV/0!	0	0	0	0	0	#DIV/0!
Grade	-122%	-1,971	-351	1,621	3,555	1,934	119%
Tonnes mined, milled	-42%	-679	942	1,621	2,293	673	42%
Concentrator Recoveries	-134%	-2,165	-544	1,621	3,740	2,119	131%
Smelting Recoveries	-134%	-2,165	-544	1,621	3,740	2,119	131%
Off Mine costs: Total	-17%	-268	1,353	1,621	1,888	267	16%
On Mine costs: Total	-86%	-1,397	224	1,621	2,997	1,377	85%
On Mine costs: Shaft Head	-63%	-1,020	601	1,621	2,628	1,007	62%
On Mine costs: Concentrator	-14%	-220	1,401	1,621	1,841	220	14%
On Mine costs: Indirect	-10%	-158	1,463	1,621	1,778	157	10%
Power: On Mine, Smelt, Refining costs	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Total	-25%	-407	1,214	1,621	2,032	411	25%
Capex: Projects: Expansion	-23%	-375	1,246	1,621	1,991	370	23%
Capex: Projects: Replacement	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Stay in Business: On Mine	-7%	-108	1,513	1,621	1,729	108	7%
Capex: Stay in Business: Off Mine	-23%	-375	1,246	1,621	1,991	370	23%

NPV	10 % Worse			Base	10% Better		
RANKED DRIVERS	Decr %	Decr	NPV	NPV	NPV	Incr	Incr %
Exchange rate	-145%	-2,357	-736	1,621	3,924	2,303	142%
Metal prices: All	-145%	-2,357	-736	1,621	3,924	2,303	142%
Concentrator Recoveries	-134%	-2,165	-544	1,621	3,740	2,119	131%
Smelting Recoveries	-134%	-2,165	-544	1,621	3,740	2,119	131%
Metal prices: PGMs	-131%	-2,127	-506	1,621	3,704	2,083	129%
Grade	-122%	-1,971	-351	1,621	3,555	1,934	119%
On Mine costs: Total	-86%	-1,397	224	1,621	2,997	1,377	85%
Metal prices: Pt	-73%	-1,189	432	1,621	2,795	1,174	72%
On Mine costs: Shaft Head	-63%	-1,020	601	1,621	2,628	1,007	62%
Tonnes mined, milled	-42%	-679	942	1,621	2,293	673	42%
Capex: Total	-25%	-407	1,214	1,621	2,032	411	25%
Capex: Projects: Expansion	-23%	-375	1,246	1,621	1,991	370	23%
Capex: Stay in Business: Off Mine	-23%	-375	1,246	1,621	1,991	370	23%
Off Mine costs: Total	-17%	-268	1,353	1,621	1,888	267	16%
Metal prices: BMs	-14%	-225	1,396	1,621	1,846	225	14%
On Mine costs: Concentrator	-14%	-220	1,401	1,621	1,841	220	14%
On Mine costs: Indirect	-10%	-158	1,463	1,621	1,778	157	10%
Capex: Stay in Business: On Mine	-7%	-108	1,513	1,621	1,729	108	7%
Metal prices: Cr conc (all grades)	#DIV/0!	0	0	0	0	0	#DIV/0!
Power: On Mine, Smelt, Refining costs	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Projects: Replacement	#DIV/0!	0	0	0	0	0	#DIV/0!



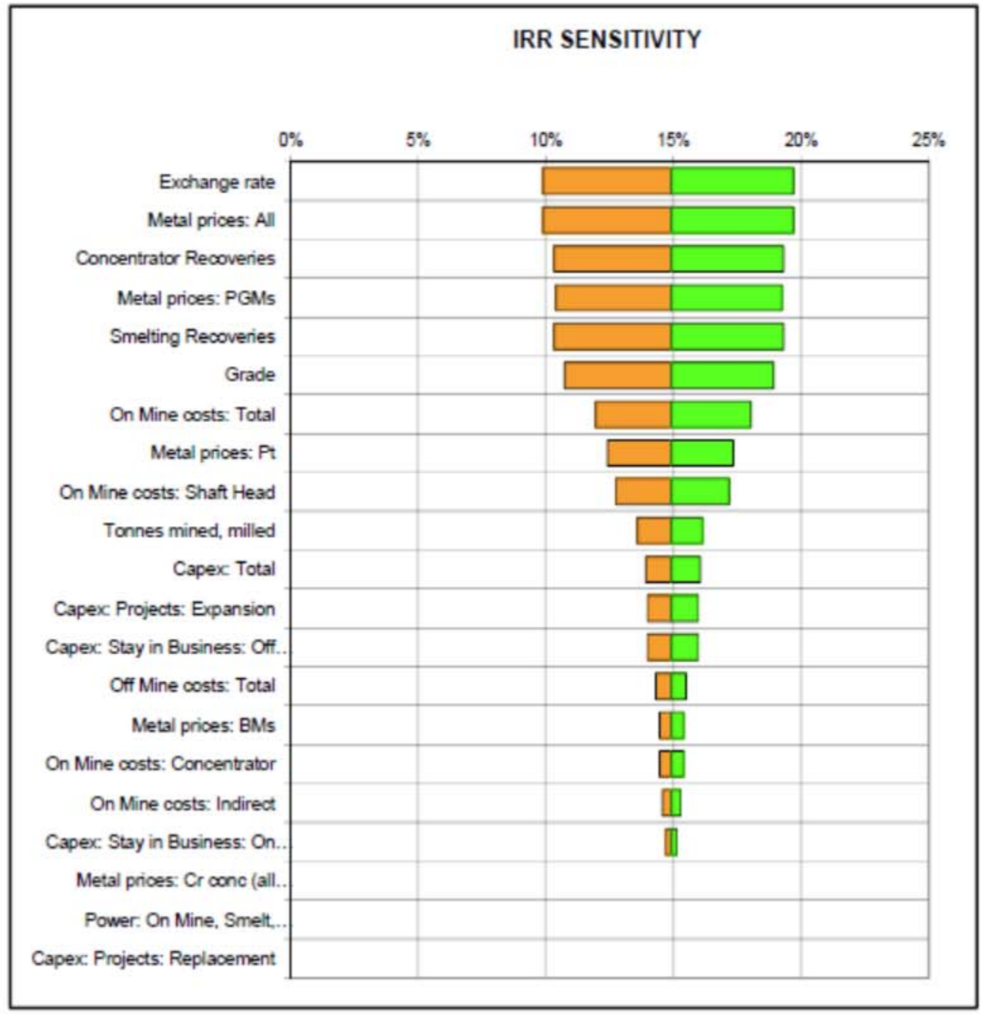
IRR SENSITIVITY DRIVERS

IRR %

Project B_Underground Declined Shaft

IRR KEY DRIVERS	10 % Worse Decr %	 Decr	 IRR	Base IRR	10% Better IRR	 Incr	 Incr %
Exchange rate	-34%	-5%	10%	15%	20%	5%	32%
Metal prices: All	-34%	-5%	10%	15%	20%	5%	32%
Metal prices: Pt	-17%	-2%	12%	15%	17%	2%	16%
Metal prices: PGMs	-30%	-5%	10%	15%	19%	4%	29%
Metal prices: BMs	-3%	0%	14%	15%	15%	0%	3%
Metal prices: Cr conc (all grades)	0%	0%	0%	0%	0%	0%	0%
Grade	-28%	-4%	11%	15%	19%	4%	27%
Tonnes mined, milled	-9%	-1%	14%	15%	16%	1%	8%
Concentrator Recoveries	-31%	-5%	10%	15%	19%	4%	29%
Smelting Recoveries	-31%	-5%	10%	15%	19%	4%	29%
Off Mine costs: Total	-4%	-1%	14%	15%	16%	1%	4%
On Mine costs: Total	-20%	-3%	12%	15%	18%	3%	21%
On Mine costs: Shaft Head	-15%	-2%	13%	15%	17%	2%	15%
On Mine costs: Concentrator	-3%	0%	14%	15%	15%	0%	3%
On Mine costs: Indirect	-2%	0%	15%	15%	15%	0%	2%
Power: On Mine, Smelt, Refining costs	0%	0%	0%	0%	0%	0%	0%
Capex: Total	-7%	-1%	14%	15%	16%	1%	8%
Capex: Projects: Expansion	-6%	-1%	14%	15%	16%	1%	7%
Capex: Projects: Replacement	0%	0%	0%	0%	0%	0%	0%
Capex: Stay in Business: On Mine	-1%	0%	15%	15%	15%	0%	1%
Capex: Stay in Business: Off Mine	-6%	-1%	14%	15%	16%	1%	7%

IRR RANKED DRIVERS	10 % Worse Decr %	 Decr	 IRR	Base IRR	10% Better IRR	 Incr	 Incr %
Exchange rate	-34%	-5%	10%	15%	20%	5%	32%
Metal prices: All	-34%	-5%	10%	15%	20%	5%	32%
Concentrator Recoveries	-31%	-5%	10%	15%	19%	4%	29%
Metal prices: PGMs	-30%	-5%	10%	15%	19%	4%	29%
Smelting Recoveries	-31%	-5%	10%	15%	19%	4%	29%
Grade	-28%	-4%	11%	15%	19%	4%	27%
On Mine costs: Total	-20%	-3%	12%	15%	18%	3%	21%
Metal prices: Pt	-17%	-2%	12%	15%	17%	2%	16%
On Mine costs: Shaft Head	-15%	-2%	13%	15%	17%	2%	15%
Tonnes mined, milled	-9%	-1%	14%	15%	16%	1%	8%
Capex: Total	-7%	-1%	14%	15%	16%	1%	8%
Capex: Projects: Expansion	-6%	-1%	14%	15%	16%	1%	7%
Capex: Stay in Business: Off Mine	-6%	-1%	14%	15%	16%	1%	7%
Off Mine costs: Total	-4%	-1%	14%	15%	16%	1%	4%
Metal prices: BMs	-3%	0%	14%	15%	15%	0%	3%
On Mine costs: Concentrator	-3%	0%	14%	15%	15%	0%	3%
On Mine costs: Indirect	-2%	0%	15%	15%	15%	0%	2%
Capex: Stay in Business: On Mine	-1%	0%	15%	15%	15%	0%	1%
Metal prices: Cr conc (all grades)	0%	0%	0%	0%	0%	0%	0%
Power: On Mine, Smelt, Refining costs	0%	0%	0%	0%	0%	0%	0%
Capex: Projects: Replacement	0%	0%	0%	0%	0%	0%	0%



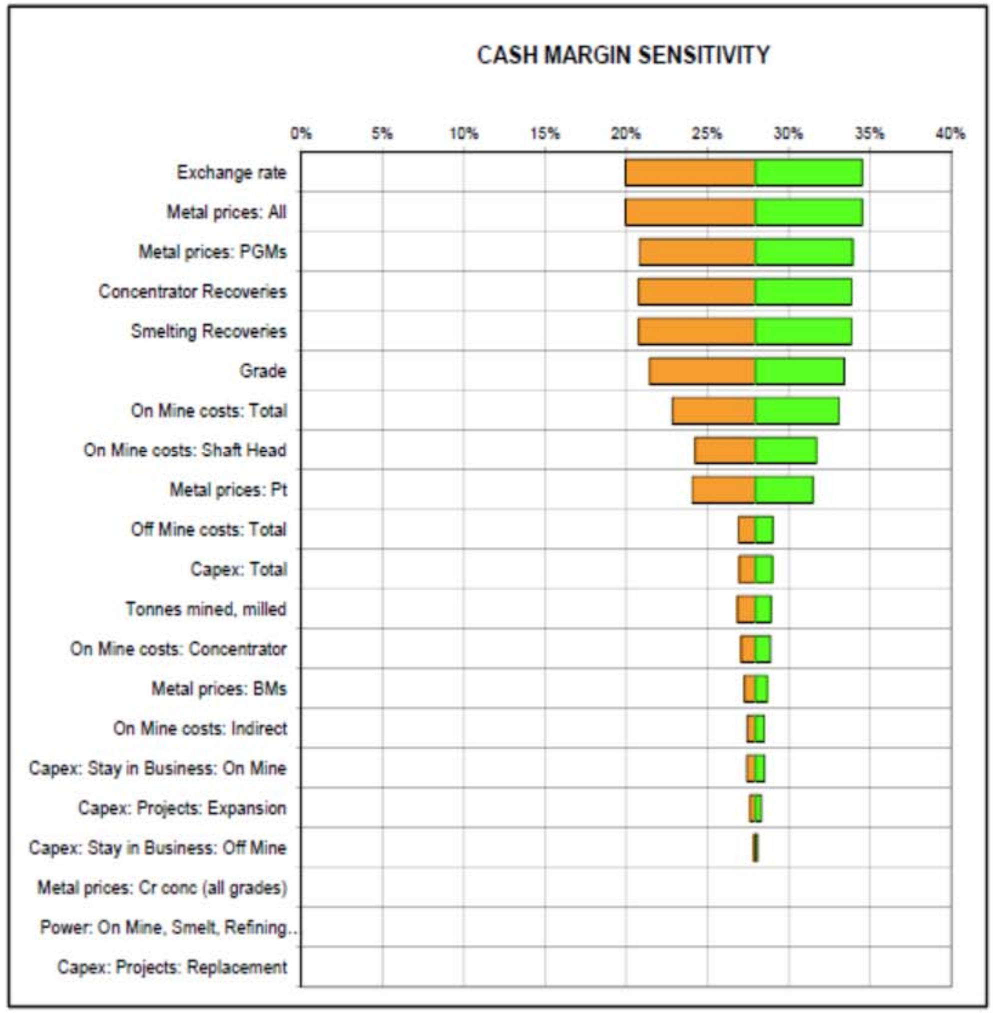
CASH MARGIN SENSITIVITY DRIVERS

Cash Margin %

Project B_Underground Declined Shaft

CASH MARGIN KEY DRIVERS	10 % Worse			Base	10% Better		
	Decr %	Decr	CM%	CM%	CM%	Incr	Incr %
Exchange rate	-29%	-8%	20%	28%	35%	7%	23%
Metal prices: All	-29%	-8%	20%	28%	35%	7%	23%
Metal prices: Pt	-14%	-4%	24%	28%	31%	4%	13%
Metal prices: PGMs	-26%	-7%	21%	28%	34%	6%	21%
Metal prices: BMs	-3%	-1%	27%	28%	29%	1%	2%
Metal prices: Cr conc (all grades)	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Grade	-23%	-7%	21%	28%	33%	5%	19%
Tonnes mined, milled	-4%	-1%	27%	28%	29%	1%	3%
Concentrator Recoveries	-26%	-7%	21%	28%	34%	6%	21%
Smelting Recoveries	-26%	-7%	21%	28%	34%	6%	21%
Off Mine costs: Total	-4%	-1%	27%	28%	29%	1%	4%
On Mine costs: Total	-18%	-5%	23%	28%	33%	5%	18%
On Mine costs: Shaft Head	-13%	-4%	24%	28%	32%	4%	13%
On Mine costs: Concentrator	-3%	-1%	27%	28%	29%	1%	3%
On Mine costs: Indirect	-2%	-1%	27%	28%	28%	1%	2%
Power: On Mine, Smelt, Refining costs	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Total	-4%	-1%	27%	28%	29%	1%	4%
Capex: Projects: Expansion	-1%	0%	28%	28%	28%	0%	1%
Capex: Projects: Replacement	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Stay in Business: On Mine	-2%	-1%	27%	28%	29%	1%	2%
Capex: Stay in Business: Off Mine	0%	0%	28%	28%	28%	0%	0%

CASH MARGIN RANKED DRIVERS	10 % Worse			Base	10% Better		
	Decr %	Decr	CM%	CM%	CM%	Incr	Incr %
Exchange rate	-29%	-8%	20%	28%	35%	7%	23%
Metal prices: All	-29%	-8%	20%	28%	35%	7%	23%
Metal prices: PGMs	-26%	-7%	21%	28%	34%	6%	21%
Concentrator Recoveries	-26%	-7%	21%	28%	34%	6%	21%
Smelting Recoveries	-26%	-7%	21%	28%	34%	6%	21%
Grade	-23%	-7%	21%	28%	33%	5%	19%
On Mine costs: Total	-18%	-5%	23%	28%	33%	5%	18%
On Mine costs: Shaft Head	-13%	-4%	24%	28%	32%	4%	13%
Metal prices: Pt	-14%	-4%	24%	28%	31%	4%	13%
Off Mine costs: Total	-4%	-1%	27%	28%	29%	1%	4%
Capex: Total	-4%	-1%	27%	28%	29%	1%	4%
Tonnes mined, milled	-4%	-1%	27%	28%	29%	1%	3%
On Mine costs: Concentrator	-3%	-1%	27%	28%	29%	1%	3%
Metal prices: BMs	-3%	-1%	27%	28%	29%	1%	2%
On Mine costs: Indirect	-2%	-1%	27%	28%	28%	1%	2%
Capex: Stay in Business: On Mine	-2%	-1%	27%	28%	29%	1%	2%
Capex: Projects: Expansion	-1%	0%	28%	28%	28%	0%	1%
Capex: Stay in Business: Off Mine	0%	0%	28%	28%	28%	0%	0%
Metal prices: Cr conc (all grades)	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Power: On Mine, Smelt, Refining costs	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Projects: Replacement	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!



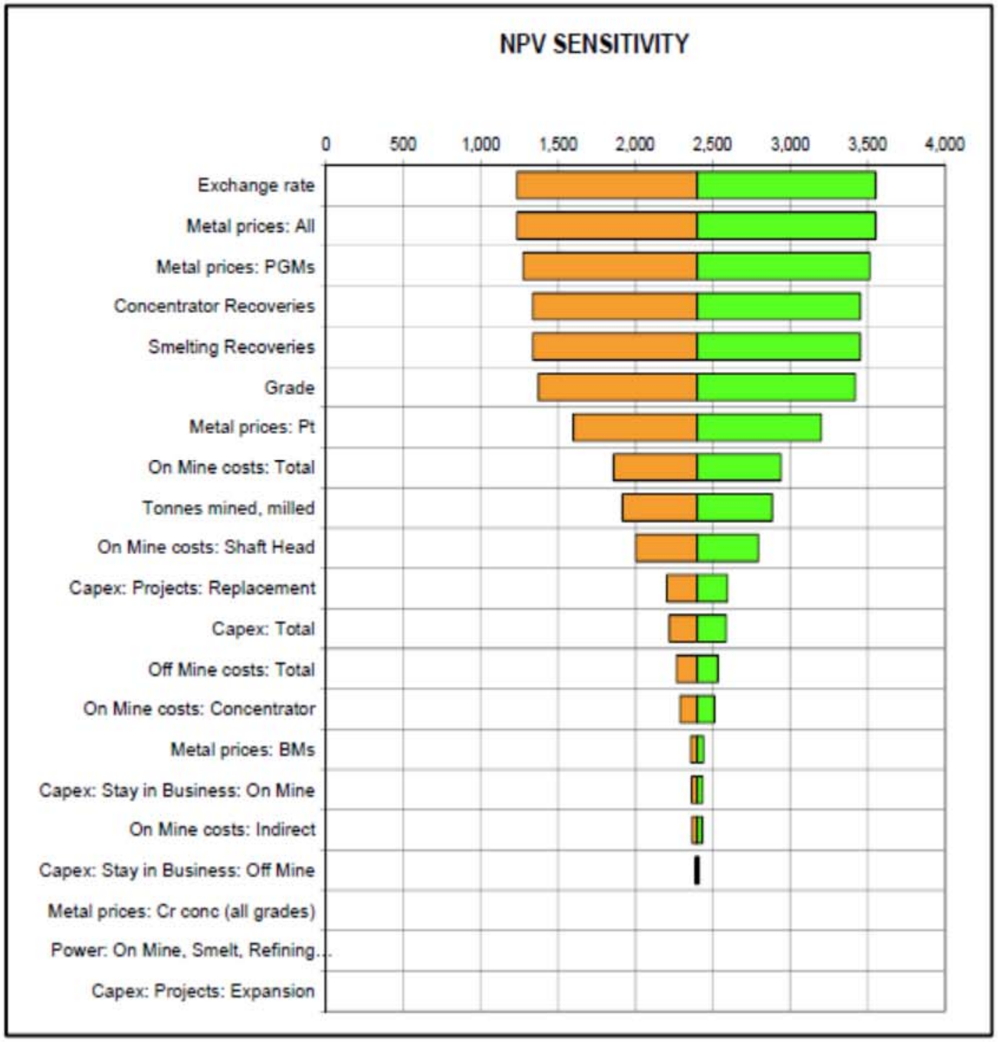
NPV SENSITIVITY DRIVERS

Rand Millions, real terms 2015

Project C_Underground Vertical Shaft

NPV	10 % Worse			Base	10% Better		
KEY DRIVERS	Decr %	Decr	NPV	NPV	NPV	Incr	Incr %
Exchange rate	-49%	-1,164	1,234	2,398	3,552	1,154	48%
Metal prices: All	-49%	-1,164	1,234	2,398	3,552	1,154	48%
Metal prices: Pt	-33%	-801	1,597	2,398	3,199	801	33%
Metal prices: PGMs	-47%	-1,123	1,275	2,398	3,512	1,114	46%
Metal prices: BMs	-2%	-41	2,357	2,398	2,439	41	2%
Metal prices: Cr conc (all grades)	#DIV/0!	0	0	0	0	0	#DIV/0!
Grade	-43%	-1,027	1,372	2,398	3,419	1,020	43%
Tonnes mined, milled	-20%	-483	1,915	2,398	2,882	484	20%
Concentrator Recoveries	-44%	-1,060	1,338	2,398	3,451	1,053	44%
Smelting Recoveries	-44%	-1,060	1,338	2,398	3,451	1,053	44%
Off Mine costs: Total	-6%	-134	2,264	2,398	2,532	134	6%
On Mine costs: Total	-23%	-540	1,858	2,398	2,938	540	23%
On Mine costs: Shaft Head	-16%	-395	2,003	2,398	2,794	396	16%
On Mine costs: Concentrator	-5%	-111	2,287	2,398	2,509	111	5%
On Mine costs: Indirect	-1%	-33	2,365	2,398	2,432	34	1%
Power: On Mine, Smelt, Refining costs	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Total	-7%	-179	2,219	2,398	2,584	186	8%
Capex: Projects: Expansion	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Projects: Replacement	-8%	-195	2,203	2,398	2,594	196	8%
Capex: Stay in Business: On Mine	-1%	-35	2,363	2,398	2,434	36	1%
Capex: Stay in Business: Off Mine	-1%	-12	2,386	2,398	2,410	12	0%

NPV	10 % Worse			Base	10% Better		
RANKED DRIVERS	Decr %	Decr	NPV	NPV	NPV	Incr	Incr %
Exchange rate	-49%	-1,164	1,234	2,398	3,552	1,154	48%
Metal prices: All	-49%	-1,164	1,234	2,398	3,552	1,154	48%
Metal prices: PGMs	-47%	-1,123	1,275	2,398	3,512	1,114	46%
Concentrator Recoveries	-44%	-1,060	1,338	2,398	3,451	1,053	44%
Smelting Recoveries	-44%	-1,060	1,338	2,398	3,451	1,053	44%
Grade	-43%	-1,027	1,372	2,398	3,419	1,020	43%
Metal prices: Pt	-33%	-801	1,597	2,398	3,199	801	33%
On Mine costs: Total	-23%	-540	1,858	2,398	2,938	540	23%
Tonnes mined, milled	-20%	-483	1,915	2,398	2,882	484	20%
On Mine costs: Shaft Head	-16%	-395	2,003	2,398	2,794	396	16%
Capex: Projects: Replacement	-8%	-195	2,203	2,398	2,594	196	8%
Capex: Total	-7%	-179	2,219	2,398	2,584	186	8%
Off Mine costs: Total	-6%	-134	2,264	2,398	2,532	134	6%
On Mine costs: Concentrator	-5%	-111	2,287	2,398	2,509	111	5%
Metal prices: BMs	-2%	-41	2,357	2,398	2,439	41	2%
Capex: Stay in Business: On Mine	-1%	-35	2,363	2,398	2,434	36	1%
On Mine costs: Indirect	-1%	-33	2,365	2,398	2,432	34	1%
Capex: Stay in Business: Off Mine	-1%	-12	2,386	2,398	2,410	12	0%
Metal prices: Cr conc (all grades)	#DIV/0!	0	0	0	0	0	#DIV/0!
Power: On Mine, Smelt, Refining costs	#DIV/0!	0	0	0	0	0	#DIV/0!
Capex: Projects: Expansion	#DIV/0!	0	0	0	0	0	#DIV/0!



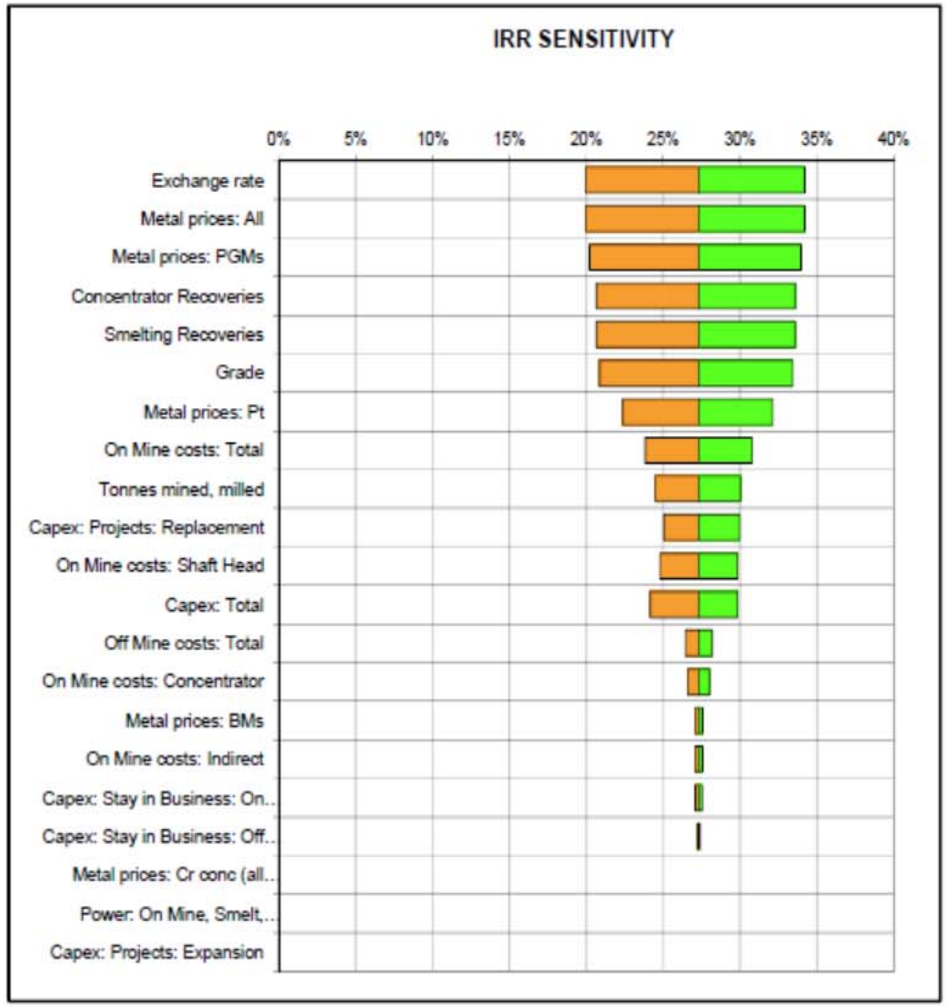
IRR SENSITIVITY DRIVERS

IRR %

Project C_Underground Vertical Shaft

IRR	10 % Worse			Base	10% Better			
KEY DRIVERS	Decr %	Decr	IRR	IRR	IRR	IRR	Incr	Incr %
Exchange rate	-27%	-7%	20%	27%	34%	34%	7%	25%
Metal prices: All	-27%	-7%	20%	27%	34%	34%	7%	25%
Metal prices: Pt	-18%	-5%	22%	27%	32%	32%	5%	18%
Metal prices: PGMs	-26%	-7%	20%	27%	34%	34%	7%	24%
Metal prices: BMs	-1%	0%	27%	27%	28%	28%	0%	1%
Metal prices: Cr conc (all grades)	0%	0%	0%	0%	0%	0%	0%	0%
Grade	-24%	-6%	21%	27%	33%	33%	6%	22%
Tonnes mined, milled	-10%	-3%	25%	27%	30%	30%	3%	10%
Concentrator Recoveries	-24%	-7%	21%	27%	34%	34%	6%	23%
Smelting Recoveries	-24%	-7%	21%	27%	34%	34%	6%	23%
Off Mine costs: Total	-3%	-1%	26%	27%	28%	28%	1%	3%
On Mine costs: Total	-13%	-3%	24%	27%	31%	31%	3%	13%
On Mine costs: Shaft Head	-9%	-3%	25%	27%	30%	30%	3%	9%
On Mine costs: Concentrator	-3%	-1%	27%	27%	28%	28%	1%	3%
On Mine costs: Indirect	-1%	0%	27%	27%	28%	28%	0%	1%
Power: On Mine, Smelt, Refining costs	0%	0%	0%	0%	0%	0%	0%	0%
Capex: Total	-12%	-3%	24%	27%	30%	30%	3%	9%
Capex: Projects: Expansion	0%	0%	0%	0%	0%	0%	0%	0%
Capex: Projects: Replacement	-8%	-2%	25%	27%	30%	30%	3%	10%
Capex: Stay in Business: On Mine	-1%	0%	27%	27%	28%	28%	0%	1%
Capex: Stay in Business: Off Mine	0%	0%	27%	27%	27%	27%	0%	0%

IRR	10 % Worse			Base	10% Better			
RANKED DRIVERS	Decr %	Decr	IRR	IRR	IRR	IRR	Incr	Incr %
Exchange rate	-27%	-7%	20%	27%	34%	34%	7%	25%
Metal prices: All	-27%	-7%	20%	27%	34%	34%	7%	25%
Metal prices: PGMs	-26%	-7%	20%	27%	34%	34%	7%	24%
Concentrator Recoveries	-24%	-7%	21%	27%	34%	34%	6%	23%
Smelting Recoveries	-24%	-7%	21%	27%	34%	34%	6%	23%
Grade	-24%	-6%	21%	27%	33%	33%	6%	22%
Metal prices: Pt	-18%	-5%	22%	27%	32%	32%	5%	18%
On Mine costs: Total	-13%	-3%	24%	27%	31%	31%	3%	13%
Tonnes mined, milled	-10%	-3%	25%	27%	30%	30%	3%	10%
Capex: Projects: Replacement	-8%	-2%	25%	27%	30%	30%	3%	10%
On Mine costs: Shaft Head	-9%	-3%	25%	27%	30%	30%	3%	9%
Capex: Total	-12%	-3%	24%	27%	30%	30%	3%	9%
Off Mine costs: Total	-3%	-1%	26%	27%	28%	28%	1%	3%
On Mine costs: Concentrator	-3%	-1%	27%	27%	28%	28%	1%	3%
Metal prices: BMs	-1%	0%	27%	27%	28%	28%	0%	1%
On Mine costs: Indirect	-1%	0%	27%	27%	28%	28%	0%	1%
Capex: Stay in Business: On Mine	-1%	0%	27%	27%	28%	28%	0%	1%
Capex: Stay in Business: Off Mine	0%	0%	27%	27%	27%	27%	0%	0%
Metal prices: Cr conc (all grades)	0%	0%	0%	0%	0%	0%	0%	0%
Power: On Mine, Smelt, Refining costs	0%	0%	0%	0%	0%	0%	0%	0%
Capex: Projects: Expansion	0%	0%	0%	0%	0%	0%	0%	0%



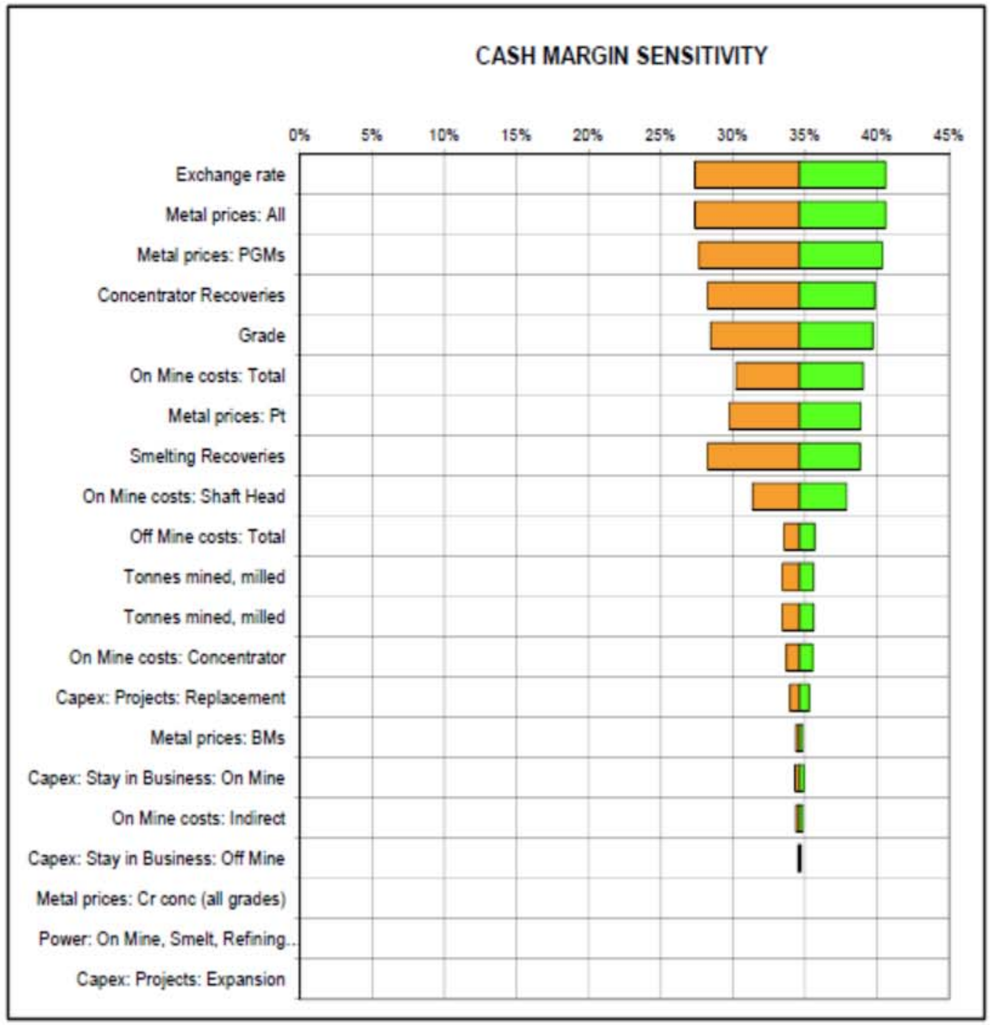
CASH MARGIN SENSITIVITY DRIVERS

Cash Margin %

Project C_Underground Vertical Shaft

CASH MARGIN	10 % Worse			Base	10% Better		
KEY DRIVERS	Decr %	Decr	CM%	CM%	CM%	Incr	Incr %
Exchange rate	-21%	-7%	27%	35%	41%	6%	17%
Metal prices: All	-21%	-7%	27%	35%	41%	6%	17%
Metal prices: Pt	-14%	-5%	30%	35%	39%	4%	12%
Metal prices: PGMs	-20%	-7%	28%	35%	40%	6%	17%
Metal prices: BMs	-1%	0%	34%	35%	35%	0%	1%
Metal prices: Cr conc (all grades)	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Grade	-18%	-6%	28%	35%	40%	5%	15%
Tonnes mined, milled	-3%	-1%	33%	35%	36%	1%	3%
Concentrator Recoveries	-18%	-6%	28%	35%	40%	5%	15%
Smelting Recoveries	-18%	-6%	28%	35%	39%	4%	12%
Off Mine costs: Total	-3%	-1%	34%	35%	36%	1%	3%
On Mine costs: Total	-13%	-4%	30%	35%	39%	4%	13%
On Mine costs: Shaft Head	-9%	-3%	31%	35%	38%	3%	9%
On Mine costs: Concentrator	-3%	-1%	34%	35%	36%	1%	3%
On Mine costs: Indirect	-1%	0%	34%	35%	35%	0%	1%
Power: On Mine, Smelt, Refining costs	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Total	-3%	-1%	34%	35%	36%	1%	3%
Capex: Projects: Expension	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Projects: Replacement	-2%	-1%	34%	35%	35%	1%	2%
Capex: Stay in Business: On Mine	-1%	0%	34%	35%	35%	0%	1%
Capex: Stay in Business: Off Mine	0%	0%	35%	35%	35%	0%	0%

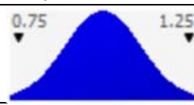
CASH MARGIN	10 % Worse			Base	10% Better		
RANKED DRIVERS	Decr %	Decr	CM%	CM%	CM%	Incr	Incr %
Exchange rate	-21%	-7%	27%	35%	41%	6%	17%
Metal prices: All	-21%	-7%	27%	35%	41%	6%	17%
Metal prices: PGMs	-20%	-7%	28%	35%	40%	6%	17%
Concentrator Recoveries	-18%	-6%	28%	35%	40%	5%	15%
Grade	-18%	-6%	28%	35%	40%	5%	15%
On Mine costs: Total	-13%	-4%	30%	35%	39%	4%	13%
Metal prices: Pt	-14%	-5%	30%	35%	39%	4%	12%
Smelting Recoveries	-18%	-6%	28%	35%	39%	4%	12%
On Mine costs: Shaft Head	-9%	-3%	31%	35%	38%	3%	9%
Off Mine costs: Total	-3%	-1%	34%	35%	36%	1%	3%
Tonnes mined, milled	-3%	-1%	33%	35%	36%	1%	3%
Tonnes mined, milled	-3%	-1%	33%	35%	36%	1%	3%
On Mine costs: Concentrator	-3%	-1%	34%	35%	36%	1%	3%
Capex: Projects: Replacement	-2%	-1%	34%	35%	35%	1%	2%
Metal prices: BMs	-1%	0%	34%	35%	35%	0%	1%
Capex: Stay in Business: On Mine	-1%	0%	34%	35%	35%	0%	1%
On Mine costs: Indirect	-1%	0%	34%	35%	35%	0%	1%
Capex: Stay in Business: Off Mine	0%	0%	35%	35%	35%	0%	0%
Metal prices: Cr conc (all grades)	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Power: On Mine, Smelt, Refining costs	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!
Capex: Projects: Expension	#DIV/0!	0%	0%	0%	0%	0%	#DIV/0!



APPENDIX B

Simulation Input Parameters

@RISK Model Inputs
Performed By: ssahu
Date: Saturday, January 2, 2016 2:22:50 PM

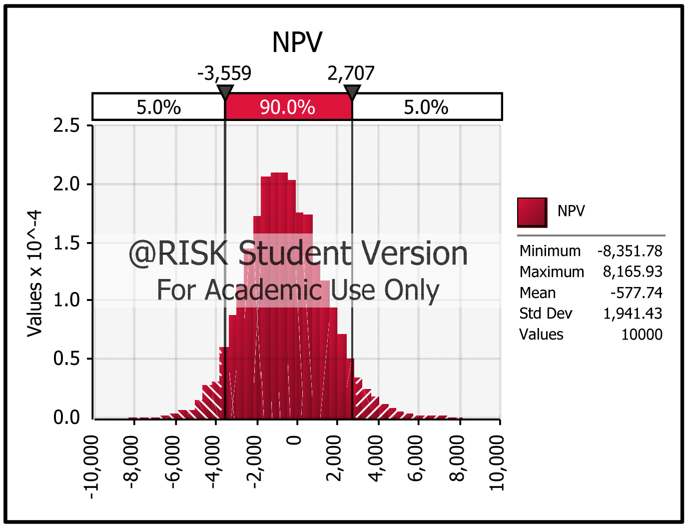
Name	Graph	Function	Min	Mean	Max
Modified Production Profile ('000 tpy) - Mined tonnes		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Head Grade (g/t) (4E) - Mined		RiskNormalAlt(5%,0.9,95%,1.1,RiskStatic(1))	-∞	1.000	+∞
Modified Pt Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Pd Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Rh Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Au Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Ir Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Os Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Ru Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Ni Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Cu Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060
Modified Co Conc. Rec. %		RiskNormal(1,0.1,RiskTruncate(0.875,1.06),RiskStatic(1))	0.875	0.976	1.060

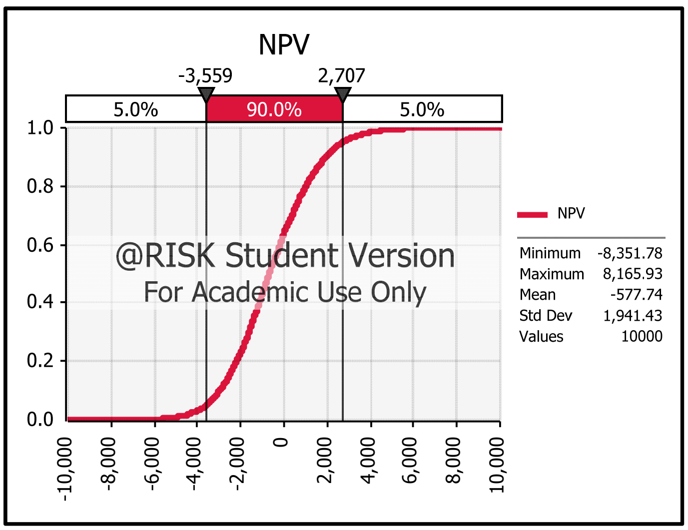
Modified Labour (Rm constant)		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
Modified Stores (Rm constant)		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
Modified Contractors (Rm constant)		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
Modified Utilities (Rm constant)		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
Modified Sundries (Rm constant)		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
Modified Cost 1: On-mine direct central services costs		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
		RiskTriang(0.9,1,1.15,RiskStatic(1))	0.900	1.017	1.150
Modified Project Capex: Mining: Replacement (Rm constant)		RiskTriang(0.95,1,1.15,RiskStatic(1))	0.950	1.033	1.150
Modified US$/ZAR Exchange Rate - real (2014)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Pt price US$/oz (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Pd price US$/oz (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Rh price US$/oz (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Au price US$/oz (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Ni price US$/lb (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Cu price US$/lb (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Co price US$/lb (real)		RiskNormal(1,0.1,RiskStatic(1))	-∞	1.000	+∞
Modified Net smelt and ref recov factor %		RiskTriang(1,1,1.01,RiskStatic(1))	1.00	1.00	1.01

Simulation NPV Results

@RISK Output Report for NPV D78

Performed By: ssahu
Date: Saturday, January 2, 2016 2:00:08 PM





Simulation Summary Information	
Workbook Name	Simplified Financial Model Rev.4.xlsx
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	29
Number of Outputs	548
Sampling Type	Monte Carlo
Simulation Start Time	1/2/2016 13:50
Simulation Duration	00:01:24
Random # Generator	Mersenne Twister
Random Seed	955232690

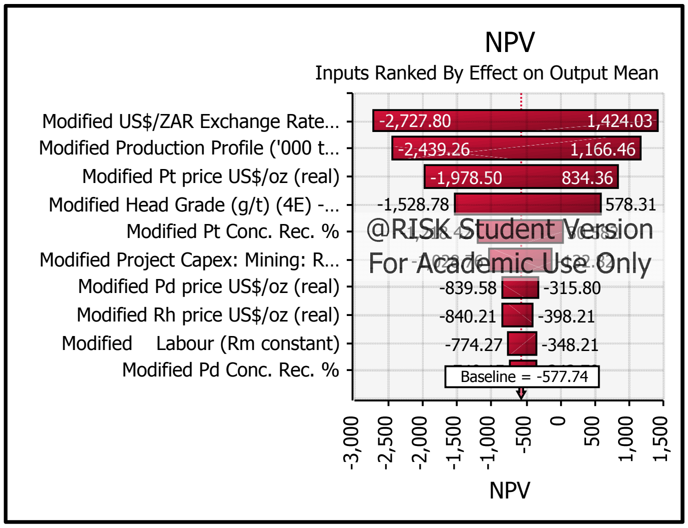
Summary Statistics for NPV

Statistics		Percentile	
Minimum	(8,352)	**5%**	(3,559)
Maximum	8,166	**10%**	(2,968)
Mean	(578)	**15%**	(2,538)
Std Dev	1,941	**20%**	(2,184)
Variance	3769165.801	**25%**	(1,885)
Skewness	0.252710606	**30%**	(1,613)
Kurtosis	3.347129294	**35%**	(1,382)
Median	(679)	**40%**	(1,143)
Mode	(157)	**45%**	(910)
Left X	(3,559)	**50%**	(679)
Left P	5%	**55%**	(422)
Right X	2,707	**60%**	(177)
Right P	95%	**65%**	63
Diff X	6,265	**70%**	370
Diff P	90%	**75%**	661
#Errors	0	**80%**	1,017
Filter Min	Off	**85%**	1,430
Filter Max	Off	**90%**	1,930
#Filtered	0	**95%**	2,707

@RISK Output Report for NPV D78

Performed By: ssahu

Date: Saturday, January 2, 2016 2:00:08 PM



Change in Output Statistic for NPV			
Rank	**Name**	**Lower**	**Upper**
1	Modified US$/ZAR Exchange Rate - real (2014)	(2,728)	1,424
2	Modified Production Profile ('000 tpy) - Mined tonnes	(2,439)	1,166
3	Modified Pt price US$/oz (real)	(1,978)	834
4	Modified Head Grade (g/t) (4E) - Mined	(1,529)	578
5	Modified Pt Conc. Rec. %	(1,218)	31
6	Modified Project Capex: Mining: Replacement (Rm constant)	(1,029)	(133)
7	Modified Pd price US$/oz (real)	(840)	(316)
8	Modified Rh price US$/oz (real)	(840)	(398)
9	Modified Labour (Rm constant)	(774)	(348)
10	Modified Pd Conc. Rec. %	(740)	(344)

Simulation IRR Results

@RISK Output Report for IRR D79

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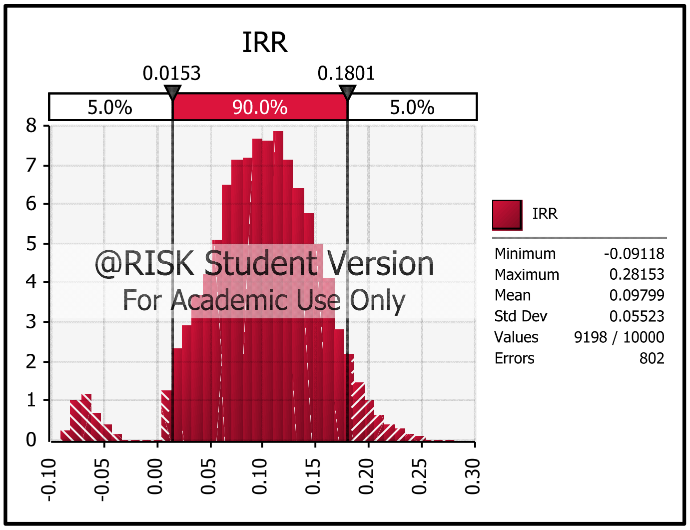
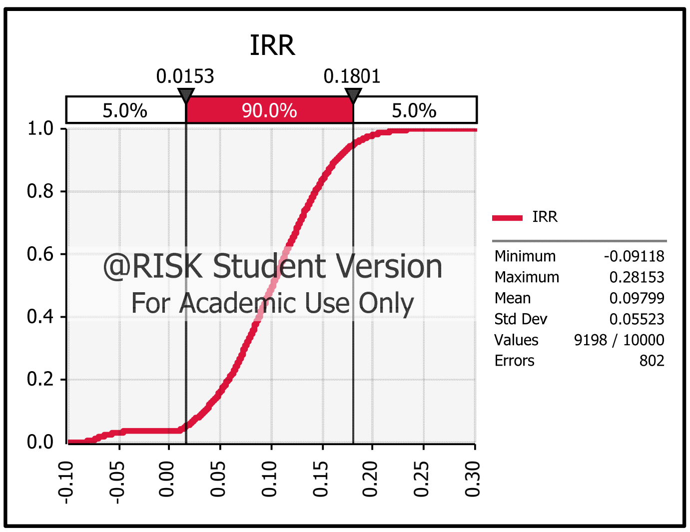


Simulation Summary Information	
Workbook Name	Simplified Financial Model Rev.4.xlsx
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	29
Number of Outputs	548
Sampling Type	Monte Carlo
Simulation Start Time	1/2/2016 13:50
Simulation Duration	00:01:24
Random # Generator	Mersenne Twister
Random Seed	955232690



Summary Statistics for IRR

Statistics		Percentile	
Minimum	-9.12%	**5%**	1.53%
Maximum	28.15%	**10%**	3.39%
Mean	9.80%	**15%**	4.70%
Std Dev	5.52%	**20%**	5.76%
Variance	0.003049913	**25%**	6.64%
Skewness	-0.617511286	**30%**	7.36%
Kurtosis	4.187025583	**35%**	8.06%
Median	10.12%	**40%**	8.77%
Mode	11.04%	**45%**	9.40%
Left X	1.53%	**50%**	10.12%
Left P	5%	**55%**	10.75%
Right X	18.01%	**60%**	11.35%
Right P	95%	**65%**	12.07%
Diff X	16.48%	**70%**	12.74%
Diff P	90%	**75%**	13.48%
#Errors	0	**80%**	14.31%
Filter Min	Off	**85%**	15.24%
Filter Max	Off	**90%**	16.32%
#Filtered	0	**95%**	18.01%

@RISK Output Report for IRR D79

Performed By:
ssahu

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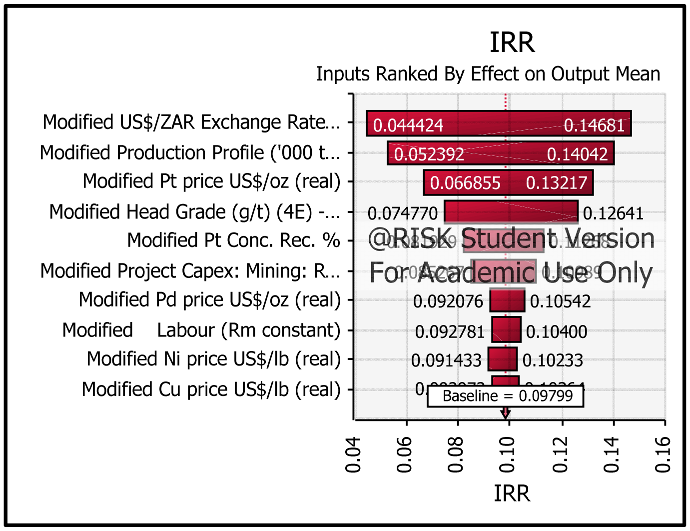

Change in Output Statistic for IRR

Rank	Name	Lower	Upper
1	Modified US$/ZAR Exchange Rate - real (2014)	4.44%	14.68%
2	Modified Production Profile ('000 tpy) - Mined tonnes	5.24%	14.04%
3	Modified Pt price US$/oz (real)	6.69%	13.22%
4	Modified Head Grade (g/t) (4E) - Mined	7.48%	12.64%
5	Modified Pt Conc. Rec. %	8.19%	11.27%
6	Modified Project Capex: Mining: Replacement (Rm constant)	8.53%	10.99%
7	Modified Pd price US$/oz (real)	9.21%	10.54%
8	Modified Labour (Rm constant)	9.28%	10.40%
9	Modified Ni price US$/lb (real)	9.14%	10.23%
10	Modified Cu price US$/lb (real)	9.30%	10.36%

APPENDIX C

Respondents profile

S No.	Respondents	Work Profile	Designation	Interview Date
1	Respondent 1	Project Manager	Project Manager	02.12.2015
2	Respondent 2	Project Manager	Project Manager	07.12.2015
3	Respondent 3	Project Manager	Senior Project Manager	06.01.2016
4	Respondent 4	Project Manager	Senior Project Manager	09.12.2015
5	Respondent 5	Project Manager	Project Manager	09.12.2015
6	Respondent 6	Project Manager	Senior Project Manager	10.12.2015
7	Respondent 7	Project Manager	Senior Project Manager	14.12.2015
8	Respondent 8	Project Manager	Project Manager	04.01.2016
9	Respondent 9	Project Reviewer	Head of Project Reviews	05.01.2016
10	Respondent 10	Project Reviewer	Senior Project Management Specialist	11.12.2015
11	Respondent 11	Project Reviewer	Project Reviewer	10.12.2015
12	Respondent 12	Techno Economist	CET Manager	04.01.2016
13	Respondent 13	Strategy Manager	Senior Strategy Manager	07.12.2015
14	Respondent 14	Strategy Manager	Strategy Manager	11.12.2015
15	Respondent 15	Financial Modeller	Financial Analyst	03.12.2015
16	Respondent 16	Project Reviewer	CET Analyst	07.12.2015
17	Respondent 17	Mining Engineer	Mining Engineer	
18	Respondent 18	General Manager	Head of Project Management Support	07.12.2015
19	Respondent 19	General Manager	General Manager	10.12.2015
20	Respondent 20	General Manager	Head of SP Projects	02.12.2015

Interview template

Name:

Designation:

Interview Date:

Introduction:

1. Explain the model (HSF to Excel)
2. Explain the input parameters and distribution
3. Explain the results

Questions:

1. Are you familiar with Monte Carlo probabilistic modelling technique to model uncertainties?

2. Do you trust that analytical tools such as Monte Carlo for probabilistic modelling dealing with uncertainties help in better decision making?

3. What are your concerns in use of Monte Carlo in mining project evaluation?

   a. Perceived complexity of modelling techniques?

   b. Lack of transparency in modelling input parameters distribution?

   c. Garbage in Garbage out syndrome?

4. Does the MCS model it provide better information on the possible range of outcomes than the static NPV and IRR?

5. Does it provide you with underlying factors that you think you can tweak or manage for better value (flexibility of value)?Do you think it will help boost value by applying appropriate mitigating actions?

Additional Discussion Notes:

APPENDIX D

Consistency matrix

The consistency matrix was created to ensure alignment of the problem, research questions and methodology.

Research problem stated here					
Sub-problem	**Literature Review**	**Hypotheses or Propositions or Research questions**	**Source of data**	**Type of data**	**Analysis**
Determine what the key input parameters are in the NPV and IRR calculations of the Platinum mine projects.	- Martinez & Watson, 2012 - Erdem, Guyaguler & Demirel, 2012 - De Beers Internal Study, 2008 - IPA Reports, 2011-2014	What are the key input parameters that drive the value of Platinum mine business case and what are the respective distribution associated with those parameters.	- AAP Project database - Historical information - Expert opinion, Proxy and Empirical means - Sensitivity analysis	Nominal data	- HSF to Excel model - Sensitivity analysis - Empirical / Proxy modelling
Determine whether the simulated NPV and IRR results provide for better decision making than the NPV and IRR provided from the static DCF results.	- Erdem, Guyaguler & Demirel, 2012 - Cheah & Liu, 2005 - Hoesli et al., 2005 - @Risk Sample cases	Does the simulated NPV and IRR results provide for better decision making than the NPV and IRR provided from the static DCF results.	- Simulated NPV and IRR results will be presented compared to the static NPV and IRR calculations - Unstructured interviews will be done to collect feedback	Qualitative feedback (ordinal data type)	Qualitative analysis.