Application of Techno-economic modelling in the Platinum Mining Industry of Southern Africa

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Abstract

Management does not have an efficient mechanism to test strategic and operational alternatives and to assess the impact of these on the value and underlying trade-off variables of the business. Techno-economic models can be applied for this purpose as they provide a framework for undertaking advanced process simulation and business valuation. The purpose of the research report is to identify key components, principles and best practice as applied in techno-economic models, to improve techno-economic modelling for the purpose of decision-making and business optimization.

The integrated techno-economic model requires a mining model with production planning and scheduling abilities. The half-level system method can be applied to create production profiles for different mining options and only after optimisation the best option is taken forward for graphical design and detailed scheduling. A metallurgical model incorporates the logic and efficiencies of the treatment process into the techno-economic model from which the refined products are determined for revenue and costing purposes. The financial model integrates with the mining and metallurgical elements and uses detailed costing models and sound financial principles for operating and capital cost estimates. An accurate techno-economic model includes key cash flow components and applies rigorous valuation practice for investment analysis.

Techno-economic models are extensively applied in business planning, major project valuations and stay–in-business project valuations. Learnings from the review of these case studies suggest best practice, which allows the models to be applied to different types of business entities and contributes to the accuracy, consistency and efficiency of techno-economic modelling. Integrated techno-economic modelling is also applicable in strategic planning and mine design optimization as it provides a powerful instrument for decision-making and business optimization. The future of the mining business depends on it as an invaluable direction steering tool.

Declaration

I declare that this report is my own, unaided work. I read the university policy on plagiarism and hereby confirm that no plagiarism exists in this report. I also confirm that there is no copying nor is there any copyright infringement. I willingly submit to any investigation in this regard by the School of Mining Engineering and I undertake to abide by the decision of any such investigation.

It is being submitted for the degree of Masters of Science in Mining Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other university.

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Andries Gustav Erasmus

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1 Introduction

1.1 Research Background

After the 2008 world economic crises, mining companies became capital constrained and management had to increase their confidence that available capital funds are allocated to investments with the highest value-creating potential for the business. The mining industry is a long-term capital-intensive industry and it is imperative that techno-economic information supplied to decision makers is accurate, consistent and of a high standard. Techno-economic modelling is a major component of the strategic planning process, which informs executives with regard to the available strategic options and the anticipated outcome of each. Once the strategy has been finalized, the business planning process translates the adopted strategy into an optimized business plan, which is used for short-term planning and to measure business performance. Techno-economic modelling provides a framework for undertaking advanced process simulation and valuation to guide decision-making and business optimization.

1.2 Research Problem

Techno-economic models are used in different applications of the mining industry but are often inadequately accurate, consistent, efficient and flexible to be used for a range of business objectives. This can result in flawed and tardy business information being supplied to decision makers that can lead to poor investments and wasteful business planning.

1.3 Research Questions

The integration and complex inter–relationships between technical and financial variables are questioned to reflect the impact of the model variables on the results in an accurate manner. Simulation of the mining value chain requires a production planning and scheduling system, operating and capital cost estimation mechanisms, as well as the correct application of investment analysis. Elements of these sub-models are interrogated to ensure that the integrated techno-economic model has the ability to be applied for strategic planning, business planning, investment valuations and mine design optimization.

1.4 Research Objectives

This research investigates and recommends key components, principles and best practice to provide practical guidance for the design and application of integrated techno-economic models for the purpose of decision-making and business optimization.

1.5 Research Motivation

Techno-economic modelling is applicable in the field of mining engineering, but will also be beneficial to stakeholders in corporate finance, merchant banks and the investment community. Techno-economic modelling is crucial to the future of the mining business, as it depends on it as an invaluable direction steering tool to ensure the long- term profitability and sustainability of the business.

1.6 Research Methods

Sources of information include formal technical and financial literature, journal articles, conferences proceedings, policies and procedures, personal communication with competent and experienced persons, practical experience and critical reviews of project valuations and business plans.

1.7 Research Limitations

The scope of the research is limited to the platinum mining industry in Southern Africa. The platinum industry plays a pivotal role in the development of fuel cell technology that can significantly alter the world economy and environment. The research focuses mainly on mining and metallurgical modelling, financial modelling and techno-economic investment analysis. Case studies explore the application of techno-economic models in business planning, major project valuations and stay-in-business project valuations.

1.8 Research Report Outline

Chapters 1 and 2 provide a general induction, whilst chapter 3 to 6 contains the core of the research report. Chapter 7 to chapter 9 incorporate the concluding sections.

- Chapter 1 - Introduction

The research background, problem, questions, objective, motivation, methods and limitations are provided and are followed by a report outline.

- Chapter 2 - Literature Review

Related literature that describes current valuation practice and applications of techno-economic modelling in strategic planning, business planning and mine design optimization is reviewed. The critical review aims to identify areas of potential improvement in techno-economic modelling.

- Chapter 3 – Key Components of Mining and Metallurgical Modelling

The half-level system method is explored to generate production profiles for a mine and is demonstrated for underground mining that uses the conventional scattered breast stoping method. Metallurgical process logic and efficiencies are integrated into the techno-economic model to determine the refined metal products for revenue and costing purposes.

- Chapter 4 – Key Components of Financial Modelling

Operating and capital cost estimation methods are assessed together with financial principles and key concepts to ensure the integrity of the financial modelling process.

- Chapter 5 – Key Components of Techno-economic Modelling

The key elements required in the cash flow schedule and the application of the discounted cash flow methodology is studied.

- Chapter 6 – Application of Techno-economic Modelling

Case studies include the application of integrated techno-economic models in the areas of business planning, major project investment valuation and stay-in business project valuations.

- Chapter 7 - Conclusions

The findings are summarized and areas for further research are identified.

- Chapter 8 - Recommendations

The final recommendations of the research report are reflected.

- Chapter 9 - References

Reference is made to the works cited in the research report.

2 Literature Review

The objective of this report is to investigate current practices regarding techno-economic modelling with the aim of recommending practical guidelines that could provide a consistent approach and improve the accuracy of techno-economic modelling. Techno-economic modelling provides a framework for undertaking advanced process simulation and valuation to guide decision-making and business optimization. In line with this objective, a number of related literature documents were consulted and critically reviewed. This chapter presents some of the reviews and provides a summary of the key outcomes.

2.1 Review of Valuation Practice

In the quest to promulgate a consistent mineral asset valuation practice, The South African Code for the Reporting of Mineral Asset Valuations (The SAMVAL Code) was developed to set the minimum standard for public reporting (SAMVAL Working Group, 2009, p. 6). The principles of materiality, transparency and competency are endorsed as the basis of best practice while allowing for flexibility through professional judgment and specific local provisions (SAMVAL Working Group, 2009, p. 7). A mineral asset valuation, completed in accordance with the SAMVAL code, must be signed off by a competent valuator, who is a person registered with a relevant professional organization and possesses the necessary qualifications, ability and sufficient relevant experience in the valuation of mineral assets (SAMVAL Working Group, 2009, pp. 6, 7). A public report must be based on and fairly reflect the mineral asset valuation report and supporting documentation, as prepared by the competent valuator (SAMVAL Working Group, 2009, p. 7). The competent valuator must undertake a site visit to the mineral property being valued and the valuation date must be given, as the value is the present value of all future benefits at a specific time (SAMVAL Working Group, 2009, p. 8). The competent valuator is responsible for choosing the mineral asset valuation approaches and methods and must apply at least two valuation approaches (SAMVAL Working Group, 2009, p. 8). The results from the valuations approaches and methods employed must be weighed and reconciled into a concluding opinion in value (SAMVAL Working Group, 2009, p. 8).

The competent valuator is responsible for providing an accurate mineral asset valuation that considers a range of techno-economic inputs of which any can cause the valuation to be significantly flawed if it contains erroneous information. The techno-economic input information is generated by a number of parties, which includes geology, mining, engineering, metallurgy, finance and strategy. In the case of investment valuations and business planning, it is imperative that the submitted input information is signed off by competent originators and a proper audit trail and version control are maintained by the competent valuator.

According to Lilford and Minnitt (2002, p. 369), a number of countries have introduced codes governing the valuation of mineral assets and securities. Lilford and Minnitt (2002, p. 369) stated that the challenge facing the successful implementation of these valuation codes and the Mineral and Petroleum Resources Development Act (MPRDA), lies in the inability of independent valuators to value mineral properties and projects on a consistent basis. Lilford and Minnitt (2002, p. 369) are of the view that certain valuation principles and methodologies are applicable in all jurisdictions of the minerals industry and claim that it can be incorporated into the development of standard tools, which would encourage mineral valuators to apply valuation methodologies consistently.

According to Njowa and Musingwini (2011, p. 3) the evaluation of a mineral asset includes the assessment of the ore reserves, mining rates, revenues, costs, expected returns, risks and the monetary project value and therefore, a mineral asset valuation can be regarded as the outcome of a mineral asset evaluation. Njowa and Musingwini (2011, p. 1) stated that the monetary value of a mineral asset can be determined in the market or may be estimated by applying a valuation method, which is reliant on the developmental stage of the mineral asset. The applicability of the valuation approaches to mineral assets at the various stages of development is reflected in Table 1 and valuation approaches with their most accepted valuation methods are listed in Table 2. From these, it is clear that the income approach and discounted cash flow (DCF) method is most widely used for development and production properties.

Table 1: Valuation Approaches and Stage of Mineral Assets (Adapted from SAMVAL Working Group, 2009)

Development stage	Exploration properties	Development properties	Production properties	Dormant properties		Defunct properties
Valuation approach				Economically viable	Economically unviable	
Income (Cash flow)	Not generally used	Widely used	Widely used	Widely used	Generally not used	Generally not used
Market	Widely used	Less widely used	Quite widely used	Quite widely used	Widely used	Widely used
Cost	Quite widely used	Not generally used	Not generally used	Not generally used	Less widely used	Quite widely used

Table 2: Valuation Approaches and Methodologies (Adapted from CIMVAL, 2003)

Valuation Approach	Valuation Method	Comments
Income	Discounted cash flow (DCF)	Very widely used
Market	Comparable transactions	Widely used with variations
Market	Option agreement terms	Widely used Option aspect not discounted as it should be
Cost	Appraised value	Widely used but not accepted by all regulators

Njowa and Musingwini (2011, p. 3) indicated the income approach as the most reliable technique of mineral asset valuation, which predominantly uses the discounted cash flow method (DCF). According to Njowa & Musingwini (2011, p. 3), the method relies on the value-in-use principle and determines the net present value (NPV) of future cash flows over the useful life of the mineral asset. Option pricing is another method that falls in the income approach category (Njowa & Musingwini, 2011, p. 3).

Njowa and Musingwini (2011, p. 3) stated that the market approach bases the value of an asset on transactions of comparable mineral assets and describes the method as problematic as it is difficult to find comparable mineral assets, due to the uniqueness of each property. The market approach relies on the principle of willing buyer and a willing seller and that the sale is an arm's length transaction (Njowa & Musingwini, 2011, p. 3).

Njowa and Musingwini (2011, p. 3) explained that the costs approach rely primarily on historical costs spent on exploration and acquisitions to which prospective enhancement multipliers can be applied to derive the mineral asset value. Historical costs spent can be adjusted by deducting any impairment losses to introduce the principle of successful efforts and to capture the change in value due to improved or reduced prospects (Njowa & Musingwini, 2011, p. 3).

Smith and Ballington (2005, p. 295) are of the view that the best application of the discounted cash flow method is from the valuations of mining operations or projects where the mineral reserve is well defined and the extraction has been scheduled over the life of mine.

The discounted cash flow (DCF) method is regarded as the most appropriate valuation method for mining operations or projects where the mineral reserve is well defined and the extraction is scheduled over the life of mine. It allows the attributes of mining production profiles and of metallurgical processes to be incorporated in the analysis. Operating and capital cost estimates, taxes and net working capital changes can be included in the cash flow schedules, which permit the delivery of a number of valuation metrics and sensitivity analyses.

2.2 Review of Applications of Techno-economic Modelling

Techno-economic modelling provides a framework to assess the impact of the changes in the micro and macro-economic environment on the future viability of the company. Some of the key areas of the application of techno-economic modelling include strategic and business planning as well as mine design optimization. The following sub-sections review of how techno-economic modelling is applied in these activities, with an aim to identify best practice and potential areas of improvement.

2.2.1 Application in Strategic Planning

According to Lane, et al. (2010, p. 161), mining executives have a difficult task determining what the strategy of the business should be, as they have no mechanism to quantitatively test the impact of strategic decisions on the business and understand the underlying dynamics. Lane, et al. (2010, p. 161), is of the opinion that techno-economic models should have the ability to test different strategic alternatives rapidly and to determine the impact of these on value, unit costs, reserves and profitability in an attempt to optimize the underlying trade-off variables. Techno-economic modelling of the complete business value chain is a means of linking the operational reality and strategic choices so that the full impact can be assessed (Lane, et al., 2010, p. 161).

According to Smith (2012, pp. 773,774), strategic long-term planning acknowledges the depleting nature of a mineral asset, the importance of a defined and flexible project pipeline, the variability of market conditions and requirements of the legislative environment. The framework for strategic long-term planning provides a logical process that integrates tools and techniques like scenarios, discounted cash flow analysis, value-based management, project value tracking, project ranking and prioritization, option identification and analysis to create order and logic in the business planning process (Smith, 2012, pp. 773, 774).

Smith, et al. (2007, p. 73), is of the view that strategic alignment of capital investments can only be achieved through a structured planning process, which is based on the optimization (NPV maximization) of the mineral assets and the structured competition for financial resources. Discounted cash flow analysis is accepted as the primary methodology of project valuation, investment decision-making and strategic planning (Smith, et al., 2007, p. 73).

Marsh, et al. (2005, p. 291), explained that the implementation of the Hyperion Strategic Finance (HSF) techno-economic model has improved the strategic planning process at Anglo Platinum. HSF has the ability to construct different scenarios quickly and therefore serve as a valuable decision-making tool (Marsh, et al., 2005, p. 291).

Strategic plan modelling is also known as portfolio modelling and is applied to identify and optimize the strategy of a company. A techno-economic model should consequently have the ability to test alternative strategies with reasonable ease and speed, after considering the complex underlying relationships of variables. It should be able to reflect the current operations together with the project pipeline, in terms of production and value. The variation in commodity prices, inflation and the impact of taxes and planning parameters should be incorporated in the discounted cash flow analysis of the techno-economic models. Project ranking metrics, sensitivity analysis and scenario simulation need to be integrated and a structured process should be followed for strategic planning purposes and investment decisions.

2.2.2 Application in Business Planning

Smith (2012, pp. 773, 774) stated that a value-optimized, strategically aligned business plan is delivered from the mineral asset portfolio on a cyclical basis. The strategic plan translates into a business plan and allows a shared understanding of the opportunities and challenges facing a mining company (Smith, 2012, pp. 773, 774).

Marsh, et al. (2005, p. 277), indicated that business planning and investment valuations at Anglo Platinum are conducted on a discounted cash flow basis. Hyperion Strategic Finance (HSF) software are used for techno-economic modelling of investment centres (IC) and consolidations to shaft, mine and group levels (Marsh, et al., 2005, p. 277).

Techno-economic modelling is applied in business planning and investment valuation processes. The techno-economic models should have the capability to reflect the smallest production unit and combine these models to represent shaft, mine and group consolidations.

2.2.3 Application in Mine Design Optimization

According to Ballington, et al. (2004, p. 211), an Economic Optimisation Model (EOM) has been implemented to enhance the mine design process at Gold Fields Ltd.

Lane, et al. (Lane, et al., 2006, p. 2) explained that the rationale for developing an Economic Optimization Model (EOM) at Gold Fields Ltd. was to develop a proper decision-making planning tool to test the economic viability of mineral reserve plans and mining projects and to optimize their net present values (NPV). The techno-economic model uses costing and financial models to generate financial metrics from shaft production schedules and can rapidly generate economics for life of mine schedules, which allow more time to test and optimize production scenarios (Lane, et al., 2006, p. 2).

Lane, et al. (Lane, et al., 2006, p. 2) indicated that in the mining industry, the relationship between controllable and uncontrollable variables and physical and economic outcomes are complex and often non-linear. These relationships constitute an economic system and simple relationships will not suffice to understand the dynamics of an entire mine and therefore, the techno-economic model must be able to represent all the relevant cause-effect relationships between variables in an accurate way (Lane, et al., 2006, p. 2). An accurate techno-economic model is a prerequisite for successful optimization and these techno-economic models must realistically capture the relationships and dynamics between variables (Lane, et al., 2007, p. 2).

Vermeulen (2007) explained that the purpose of the Mine Optimization Tool (MOT) is to have an integrated software tool that can schedule production activities by half-level for a shaft complex and integrate the related economics with the schedule. This allows assessment of multiple scenarios in a relatively short period, after which only the best option is taken forward for graphic design and scheduling (Vermeulen, et al., 2007).

Gabryk, et al. (2012, p. 593) claims the adoption of rule-based design and production schedules allows for the rapid generation of production schedules for mining options. According to Gabryk, et al. (2012, p. 593) activity-based operating costs, labour and capital can be linked to standard templates, such as half-level or decline barrels, which are replicated to reflect the mine structure. For each option, a production schedule is generated per mining activity, the operating and capital costs are estimated and the required financial metrics are determined for decision-making (Gabryk, et al., 2012, p. 593).

Techno-economic modelling is applied in mine design optimization to maximize the value of a mining project by giving valuation feedback to the project engineers during the options analysis and design process. It is important that the techno-economic model links the production schedules with a financial model and accurately reflects the complex relationships between variables to simulate the mining value chain.

2.3 Findings

In the case of investment valuations and business planning, it is imperative that the submitted input information is signed off by competent originators and a proper audit trail and version control are maintained by the competent valuator. The discounted cash flow (DCF) method is regarded as the most appropriate valuation method for mining operations or projects where the mineral reserve is well defined and the extraction is scheduled over the life of mine.

A techno-economic model should have the ability to test alternative strategies with reasonable ease and speed, after considering the complex underlying relationships of variables. It should be able to reflect the current operations together with the project pipeline, in terms of production and value. The variation in commodity prices, inflation and the impact of taxes and planning parameters should be incorporated in the discounted cash flow analysis of the techno-economic models. Project ranking metrics, sensitivity analysis and scenario simulation need to be integrated. The techno-economic models should have the capability to reflect the smallest production unit and combine these models to represent the shaft, mine and group consolidations. It is important that the techno-economic model links the production schedules with a financial model and accurately reflects the complex relationships between variables to simulate the mining value chain.

3 Key Components of Mining and Metallurgical Modelling

3.1 Introduction

According to Smith (2012, p. 761), a mining company needs to create sustainable value from its mineral assets and therefore, it is necessary to optimize the mineral asset portfolio and to align it with strategic and business objectives. Smith (2012, p. 761) stated that this requires a structured integrated approach across all elements of the mining value chain from exploration to the sale of products as illustrated in Figure 1. The solution lies in the systematic application of strategic planning tools and techniques that align decisions and actions across the company (Smith, 2012, p. 761). Techno-economic modelling provides a means of assessing whether operations and mining projects meet the company's financial objectives and support the capital investment decision-making process.

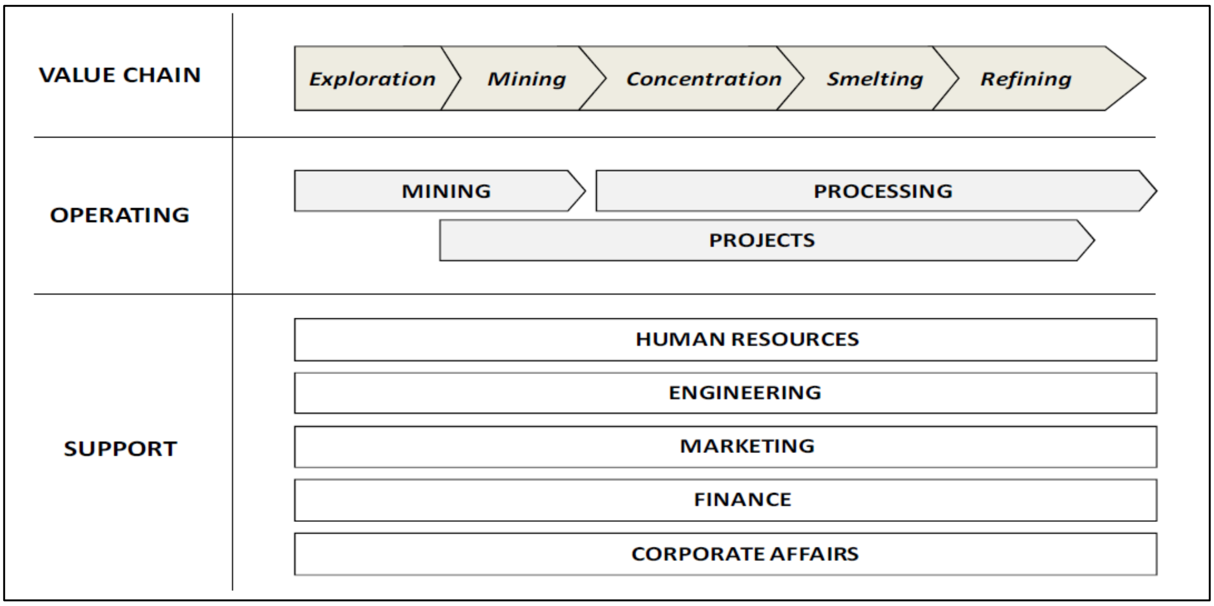


Figure 1: Mining Value Chain (Smith, 2011, p. 221)

The strategic long term planning process requires each operation within the mining group to develop a mining rights plan (MRP) from which the business plan (BP) is extracted (Smith, 2012, p. 768). The lease area (LA) is a surface area where surface rights have been obtained and includes the mining right area (MRA) that is broken up into investment centres as exemplified in Figure 2.

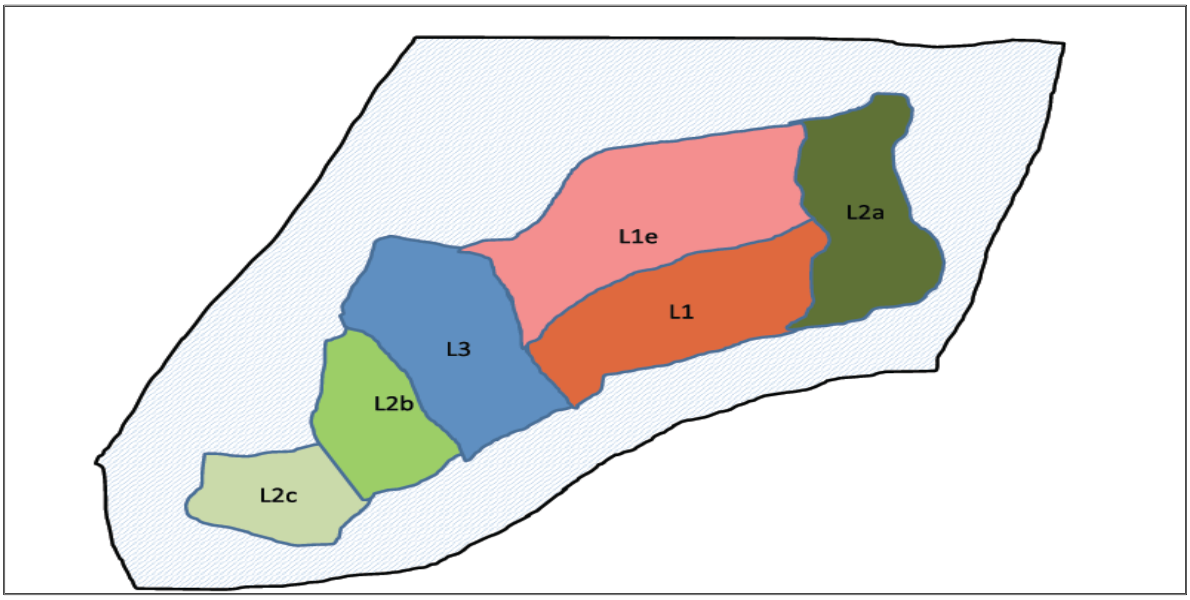


Figure 2: Lease Area, Mining Right Area and Investment Centres (Quaye, 2014, p. 4)

The mining rights area (MRA) is the full area over which a mining right has been granted in terms of the Mineral and Petroleum Resources Development Act (MPRDA) (Smith, et al., 2007, p. 68), whilst the investment centres (IC) are the logical, physical mining extraction blocks of ground within a MRA (Smith, et al., 2009, p. 193). Figure 3 shows a typical MRA, which consists of investment centres (L1 – L3a) that constitute the mineral resources and reserves.

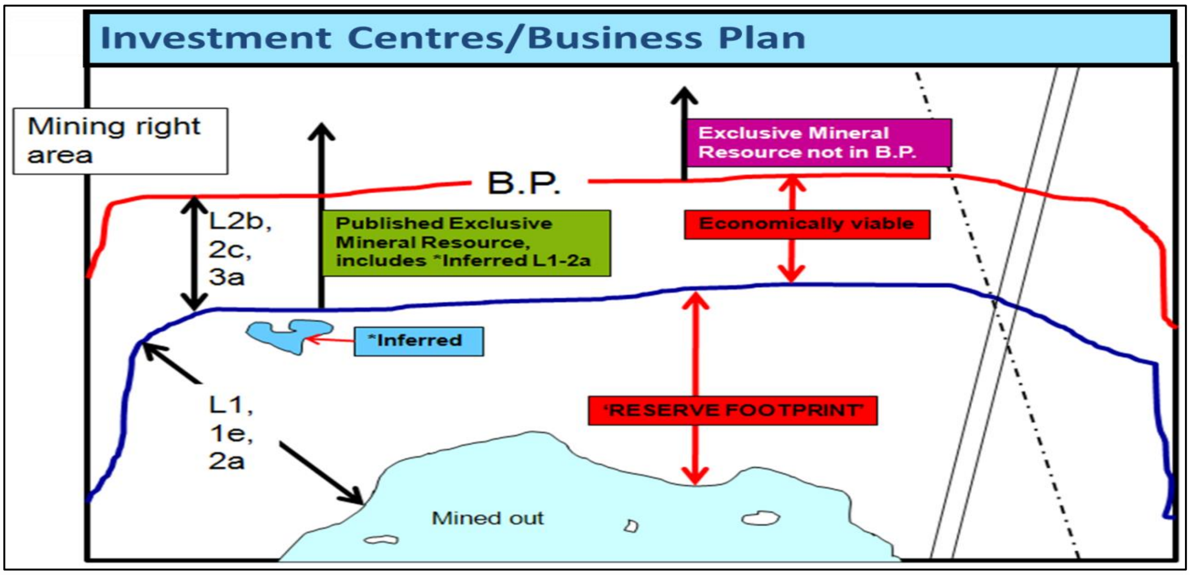


Figure 3: Mining Right Area with Investment Centres (Anglo American Platinum (b), 2014)

An IC or a combination thereof defines a mining operation or a mining project and each IC can be at a different level of planning confidence, as listed in Table 3.

Table 3: Planning Confidence Levels of Investment Centres (Smith, 2012, p. 768)

Level	Operation, Project or IC Phase	Confidence %
L1	Operational Phase	
L1e	Execution Phase	
L2a	Feasibility Phase	+-10%
L2b	Pre-feasibility Phase	+-15% to +-20%
L2c	Conceptual Phase	+-25% to +-30%
L3a	Scoping Phase -	> +-30%
L3b	Scoping Phase – Pre-resource areas	> +-30%
NIB - Eng.	Not in Business Plan – Engineering ICs that may have been subject to engineering study work up to a pre-feasibility phase, but are uneconomical based on current global assumption planning parameters.	
NIB - NW	Not in Business Plan – No Work ICs that have not had any study work done on them or where exploitation is planned well into the future (> 30 years).	

The planning confidence of an IC is increased as the project of which it forms part, progresses through the stage gate process as demonstrated in Figure 4.

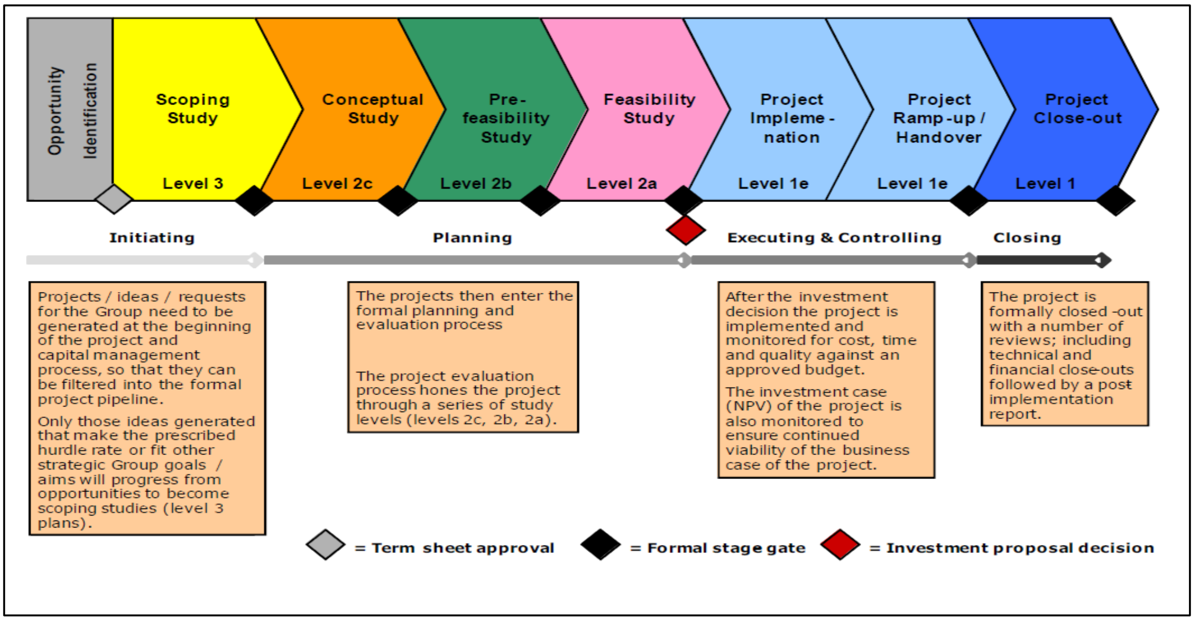


Figure 4: Project Stage Gate Process (Smith, 2011, p. 190)

Smith (2007, p. 68) explained that the mining rights plan (MRP) as displayed in Figure 5 is a physical, long-term depletion plan or schedule that covers the full MRA. Smith stated that the MRP has a lifespan resulting from the optimal scale of operations and is not necessarily economically viable across its full life span. Smith (2007, p. 68) stressed the importance that the full extent of the MRA is planned out in a technically defensible manner, by using appropriate operating and capital cost estimates and prevailing planning parameters (Smith, et al., 2007, p. 68). According to Smith (2012, p. 768), the MRP forms the basis of annual reporting and updating of the mines works program as required by the MPRDA. Several extraction sequencing options should be developed to identify the optimized plan (maximized NPV), which is annually updated and reviewed as part of the business planning process (Smith, et al., 2007, p. 68).

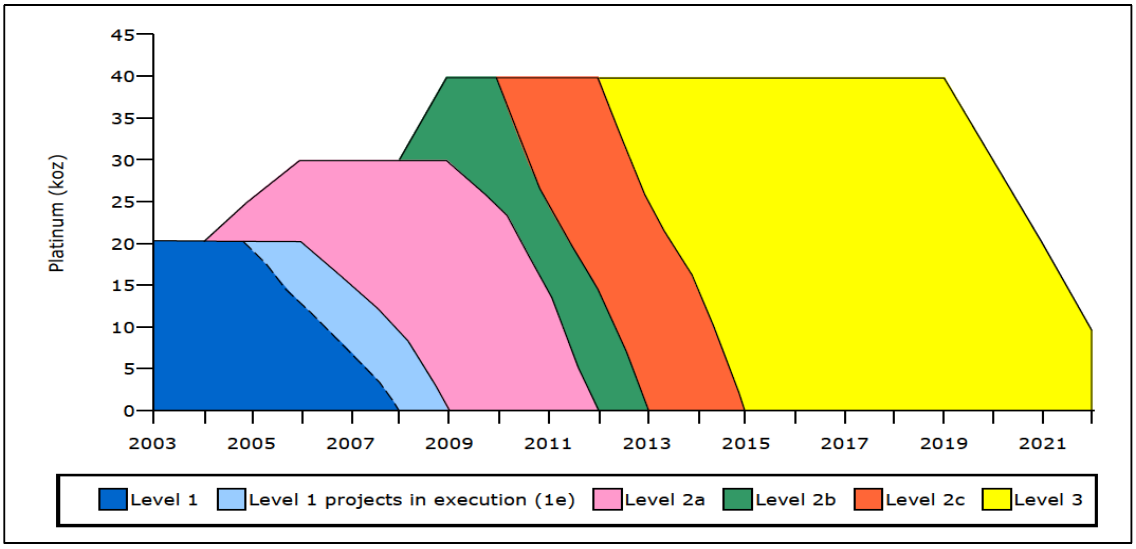


Figure 5: Mining Rights Plan (Smith, 2011, p. 189)

The business plan (BP) is a plan that consists of the budget plan and long-term plan and comprises of production profiles, as well as operating and capital cost estimates, and is used for capital prioritization and value optimization (Smith, 2012, p. 768). Smith (2007, p. 68) explained that the business plan covers the life of the mine or the first 60 years (2 periods of 30 years); whichever comes first. New order mining rights, granted in terms of the MPRDA, are initially granted for 30 years with a right of first refusal for a further 30-year period (Smith, et al., 2007, p. 68).

Figure 6 illustrates a typical business planning cycle, which consists of strategic planning, production planning and scheduling, labour planning, operating and capital cost estimation, as well as the consolidation and valuation of the business plan for the entire group.

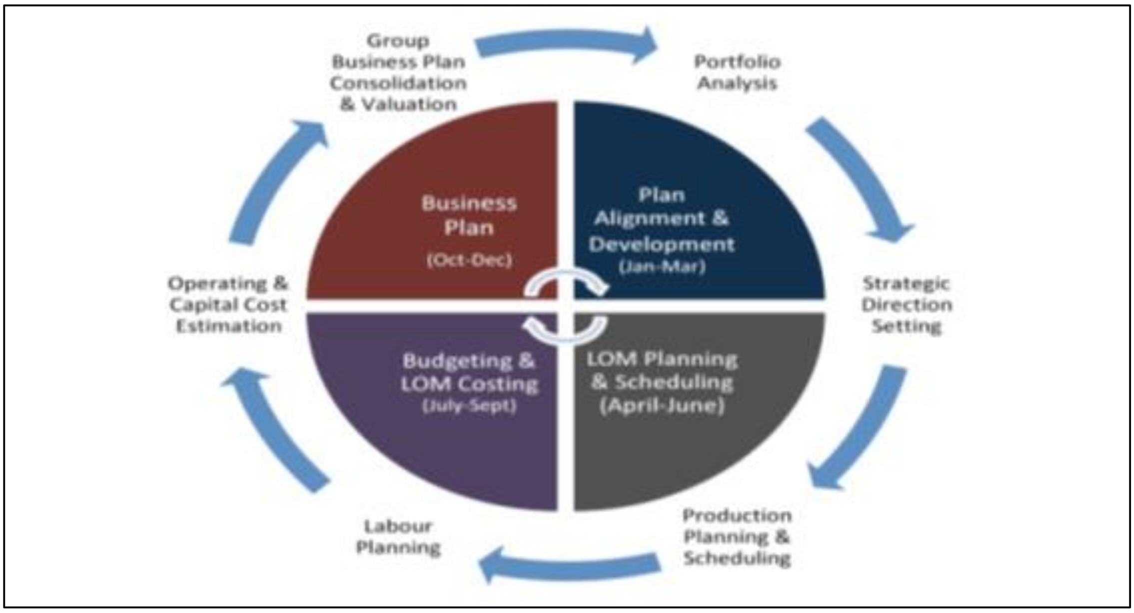


Figure 6: Business-Planning Cycle at Anglo American Platinum (Quaye, 2014, p. 3)

The BP is a full economic plan extracted from the MRP as demonstrated in Figure 7 (Smith, et al., 2007, p. 68).

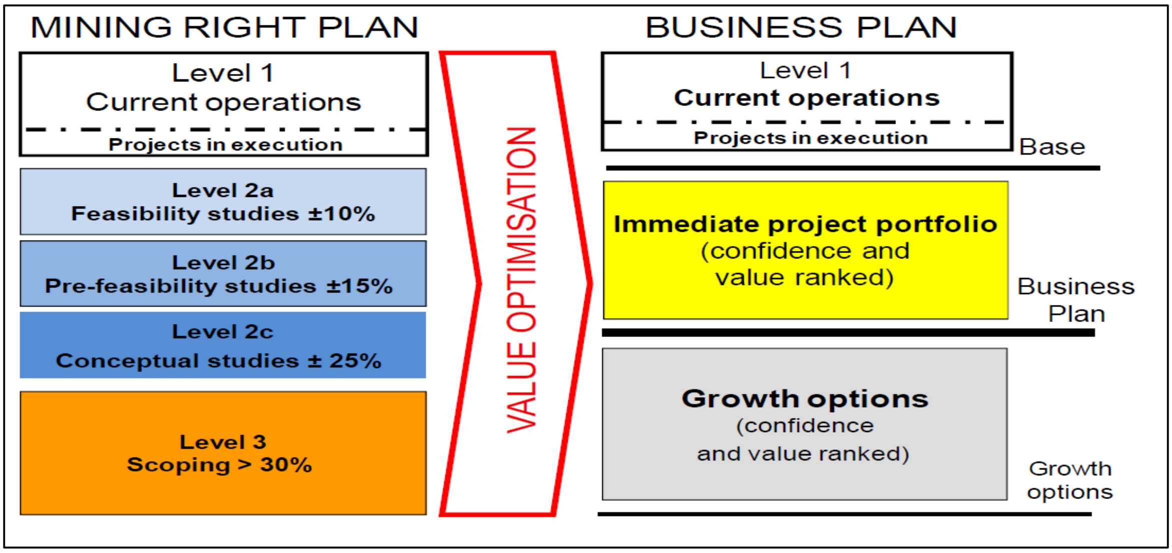


Figure 7: Business Plan extracted from a Mining Right Plan (Smith, 2011, p. 171)

The BP is indicating the optimized exploitation option (maximum NPV) as reflected by the dotted line in Figure 8. The BP production profile provides the basis for strategic planning of human resources, infrastructure and plant capacities (Smith, et al., 2007, p. 68).

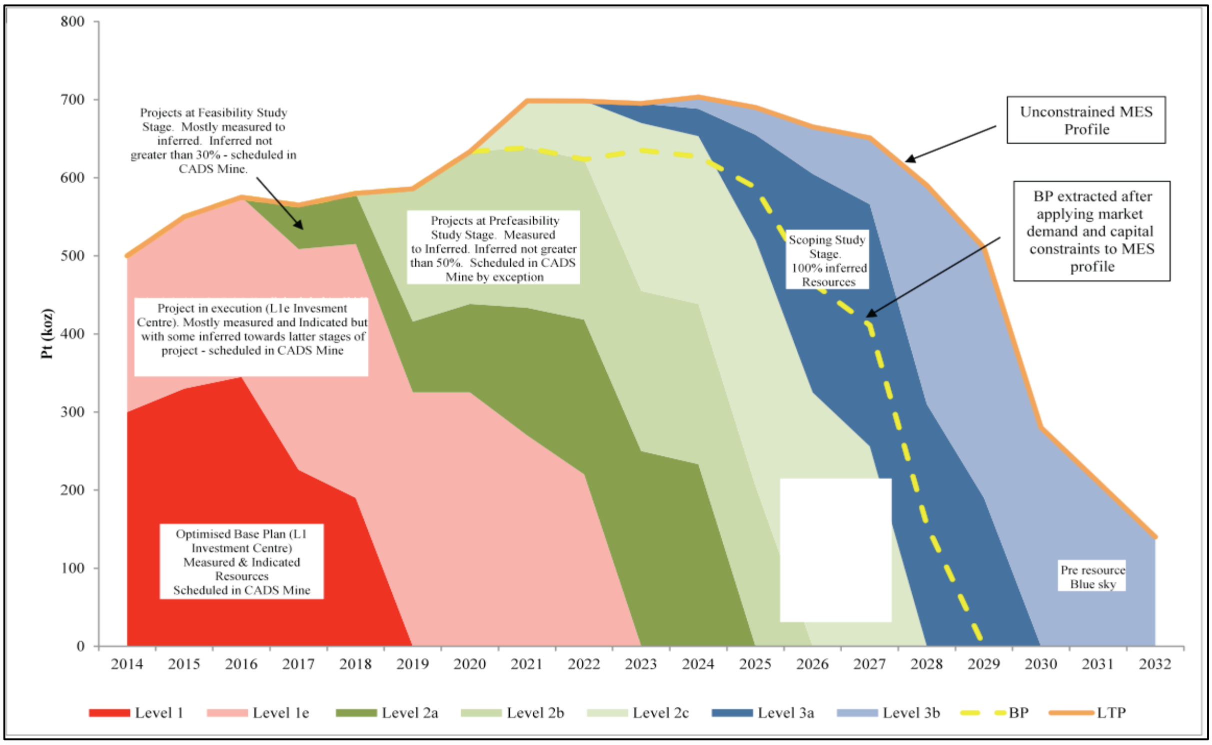


Figure 8: BP Production Profile extracted from MRP Production Profile (Quaye, 2014, p. 18)

3.2 Mining Modelling

3.2.1 Introduction

It is imperative that the integrated techno-economic model contains a mining model to create production profiles for the different mining options and methods. Mining entities and activities, mine design criteria and geological parameters need to be identified for each mining option. These production profiles will be optimized and tested in terms of value and other constraints. This approach allows for the assessment of multiple options in a relatively short period, after which only the best option is taken forward for graphical design and detailed scheduling (Vermeulen, et al., 2007).

Conventional Scattered Breast Mining

A basic understanding of the ore body, underground mining method and relevant mining entities and activities are required before the production planning and scheduling processes are engaged in deriving production profiles. The Bushveld Complex is a platinum group metal (PGM) resource and hosts the economically mineable Merensky, UG2 and Plat reef. The Merensky and UG2 reefs are narrow tabular ore bodies and are mostly exploited, at Rustenburg platinum mines, by means of the conventional scattered breast mining method. Strike footwall haulages provide access from the vertical or decline shaft to the ore body boundary. The haulages are developed approximately 35m below the reef and have crosscuts (x-cuts) developed from them at a spacing of approximately 200m between successive x-cuts. The x-cuts are developed towards the reef, at a 90^{o} angle with the haulage and have a length of approximately 120m. From the end of the x-cut, an inclined travelling way is developed in line with the x-cut to intersect the reef horizon. This is followed by a horizontal, on-reef, 6m step-over, which is developed at a 90^{o} angle with the travelling way. From this point, an on-reef raise of 200m is developed to the upper level and box-holes are developed from the x-cut to intersect with the footwall of the raise, where tips are constructed. This conventional development layout is illustrated in Figure 9.

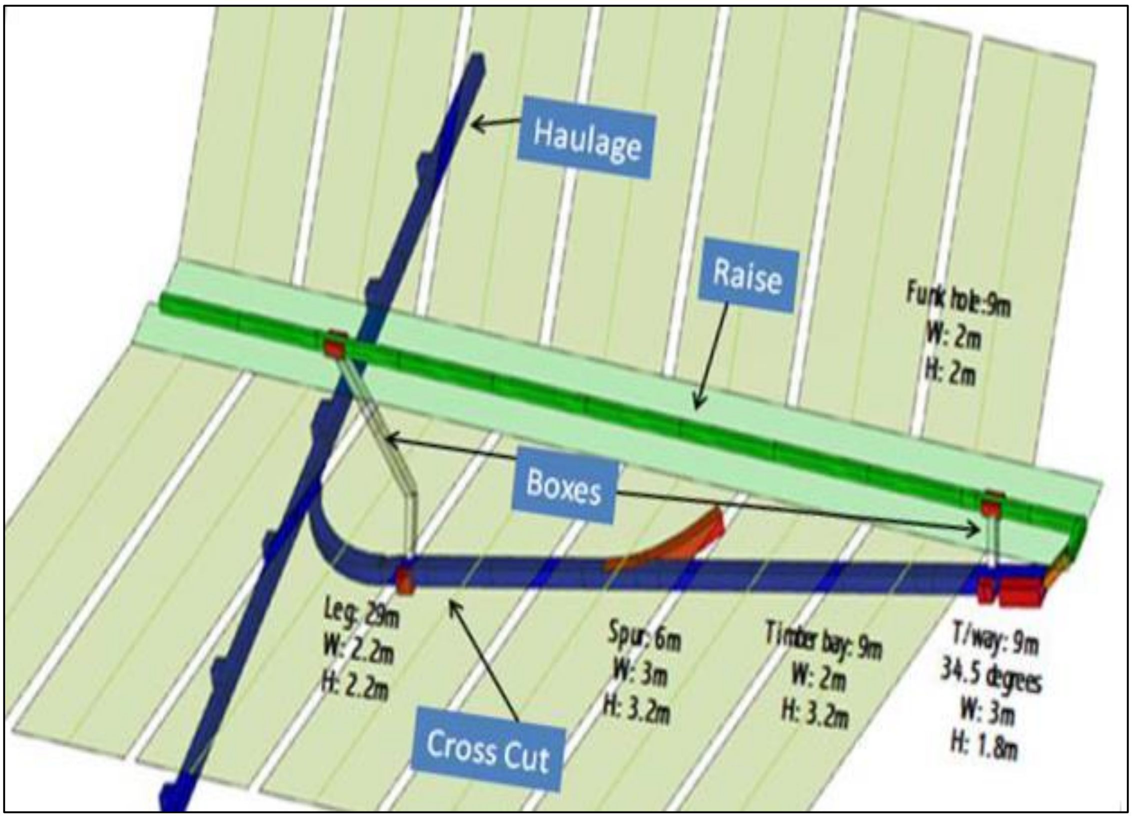


Figure 9: Conventional Development Mining Layout (Anglo American Platinum, 2013)

Ledging of 6m is done on both sides of the raise. For scattered breast stoping, stope gullies are cut approximately every 30m on either side of the raise. Stope breast panels are mined between the gullies and on both sides of the raise. The average stoping width is 1.1m and the rock is drilled with hand-held compressed air drilling machines. In-stope support consists of pre-stressed timber and roof bolts, along with grout packs. Broken ore is cleaned from the stope face to the gullies and box-holes by means of scraper winches and from the box-holes, it is transported to the shaft ore-pass system by rail bound battery locomotives and hoppers. The ore and waste fall down ore passes to the loading station at the shaft bottom, from where they are hoisted to the surface by means of skips (rock conveyances). Figure 10 shows a diagram of a conventional stoping layout.

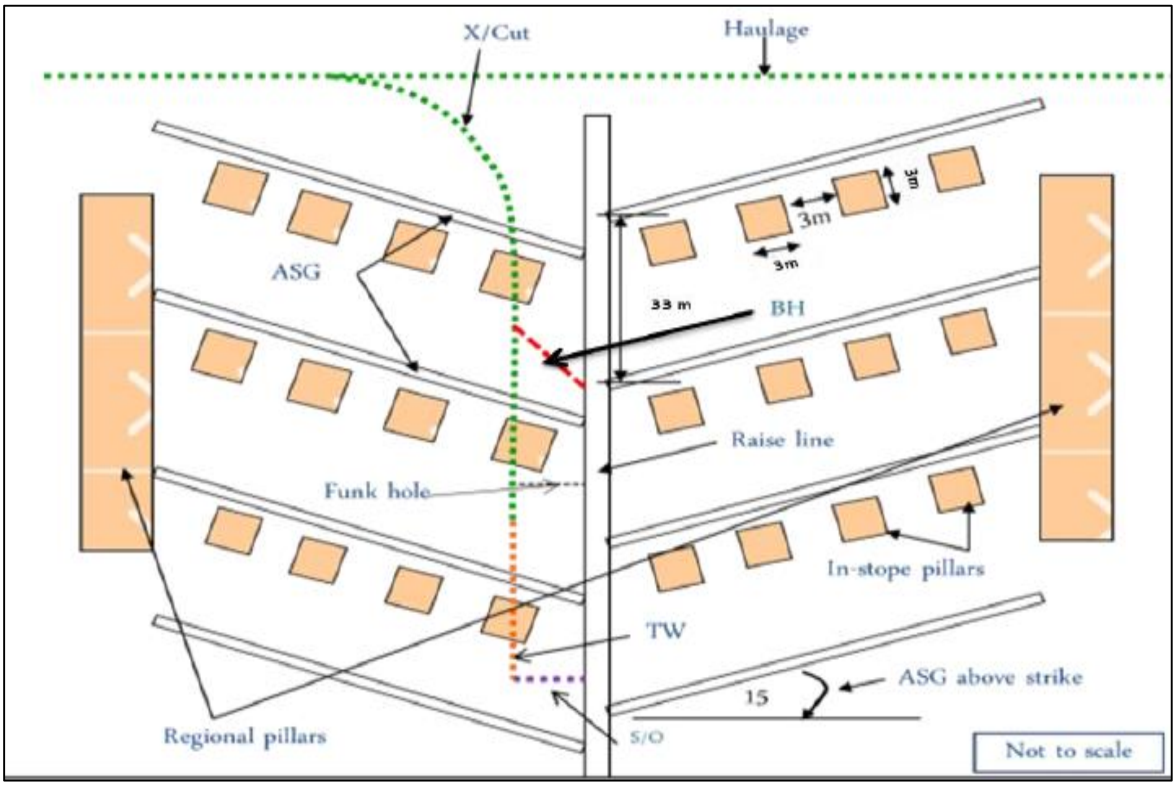


Figure 10: Conventional Scattered Breast Mining Layout (Anglo American Platinum, 2013)

Mining Entities

According to Vermeulen, et al. (2007), the mining model should be able to accommodate different mining methods, shaft layouts and mine designs. Vermeulen, et al. (2007) claim this is achieved by creating a mine structure, which consists of mining entities such as standard mining blocks (SMB) that reports to half-levels (HL), levels, investment centres (IC) and shafts. A standard mining block is the smallest repeatable mining unit on a mine and contains a basic layout that is repeated to form a half-level and requires activities to take place to produce outputs (Vermeulen, et al., 2007). A half-level is the area on either side of the apex on a specific mining level and consists of the standard mining blocks within the specific area together with the rest of the half-level development and infrastructure (Vermeulen, et al., 2007).

An investment centre can contain a number of half-levels as exemplified in Figure 11.

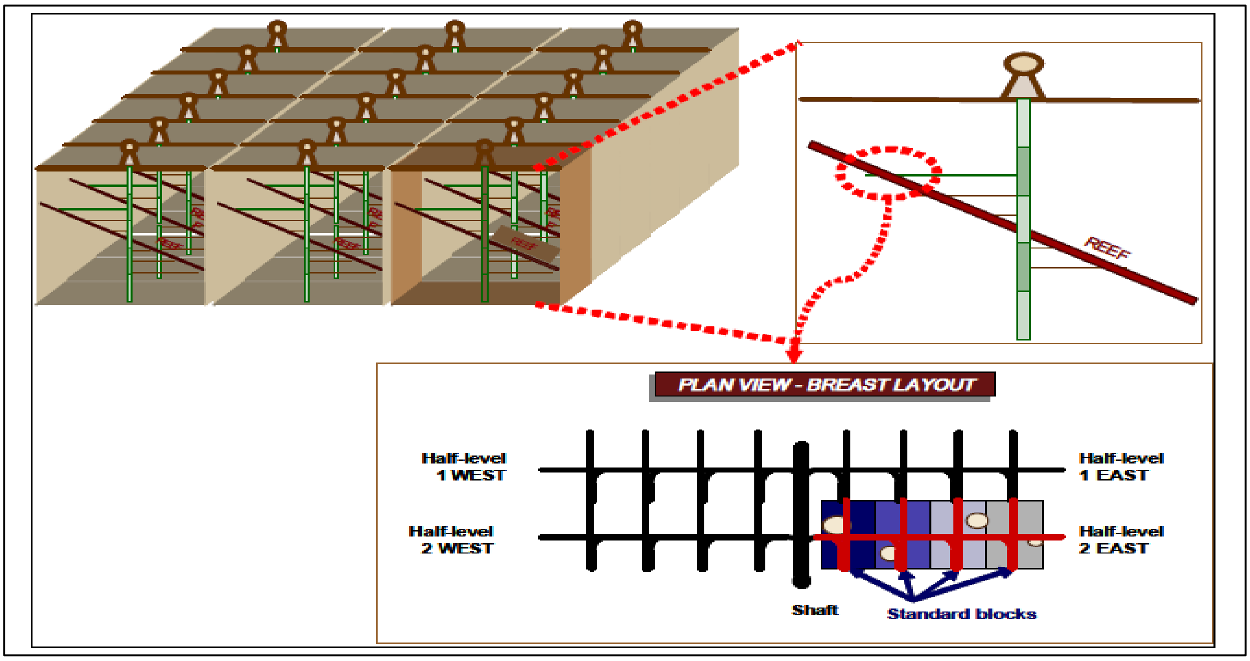


Figure 11: Standard Mining Blocks and Half-levels (Vermeulen, et al., 2007)

Activities

Each mining entity has activities that are performed on it and these activities incur costs from the consumption of resources to produce outputs (Vermeulen, et al., 2007). Vermeulen, et al. (2007) state that the mining model incorporates the relevant activities and sets the scheduling rules between these activities for a particular mining method. The scheduling of various half-levels produces outputs, which are used to determine the required labour complements, equipment and material and allows for capacity testing (Vermeulen, et al., 2007). According to Vermeulen, et al. (2007), activities can be broken up into the following sub-categories:

- Mining activities include development, ledging, equipping, stoping, sweepings, vamping and reclamation.
- Logistical activities include tramming, men and material transportation, conveying and hoisting.
- Engineering activities include maintenance, repairs, modifications and construction.

- Service activities include ventilation, rock engineering, surveying, sampling, geology, finance, human resources, safety and general management.

Figure 12 illustrates a half-level layout with the associated mining activities that occur in sequential order from right to left.

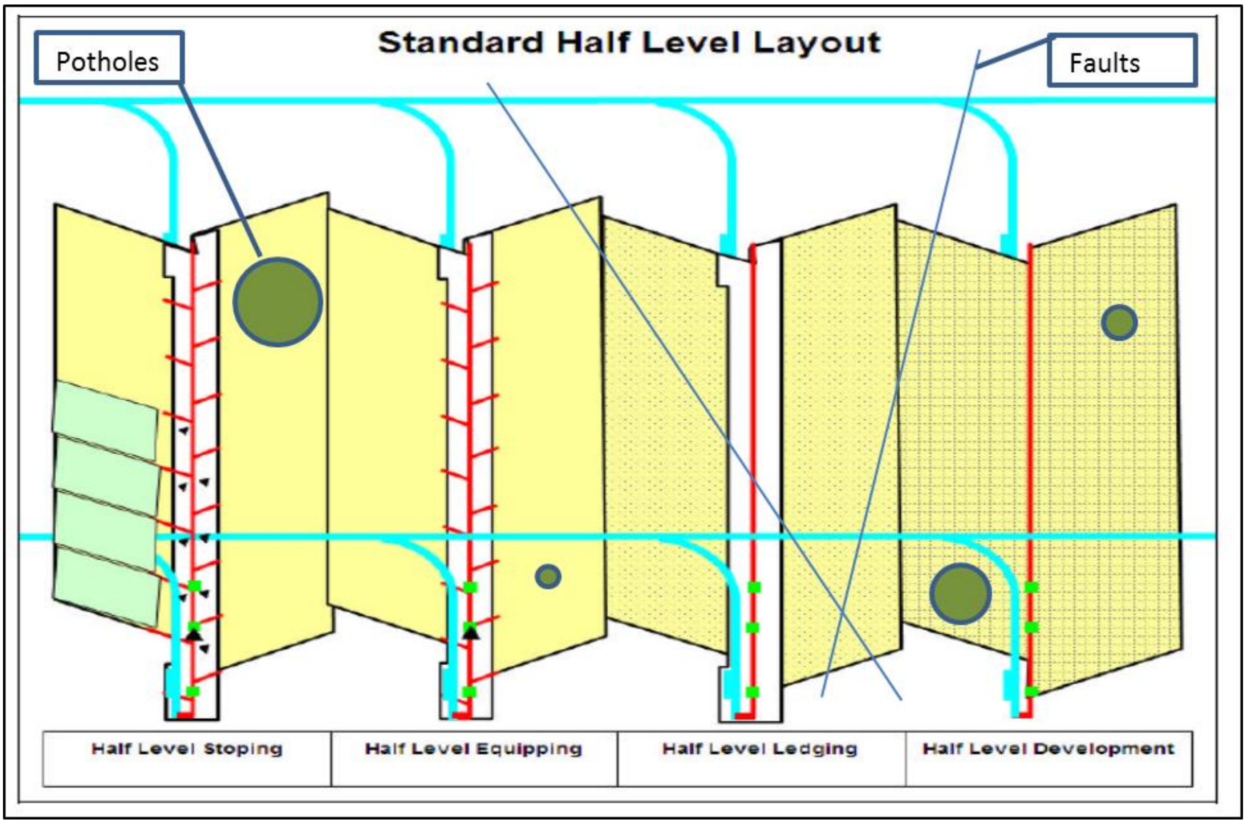


Figure 12: Half-level Layout and Activities (Vermeulen, et al., 2007)

Half-level System

Steady state stoping on a half-level is only achievable if the supporting mining activities take place in a synchronized fashion and at appropriate mining rates. Conventional mining includes the following activities in a sequential order as shown in Figure 13:

1. Flat-end development – Haulage, x-cut, timber bay
2. Flat-end development construction – Rails, ventilation pipes, air and water pipes, drains
3. Non-flat end development – Travelling ways, step-overs, raises and boxes

4. Non-flat end development construction – Tips, box fronts, ventilation pipes, air and water pipes, raise winch, mono-winch, electric cabling and lights
5. Ledging
6. Ledge equipping – Face and gully winches, centre gully winches, electrical cabling and lights, scrapers, ventilation brattices and curtains, blasting barricades, air and water pipes, drilling machines and air legs
7. Stoping and sweepings
8. Vamping
9. Reclamation

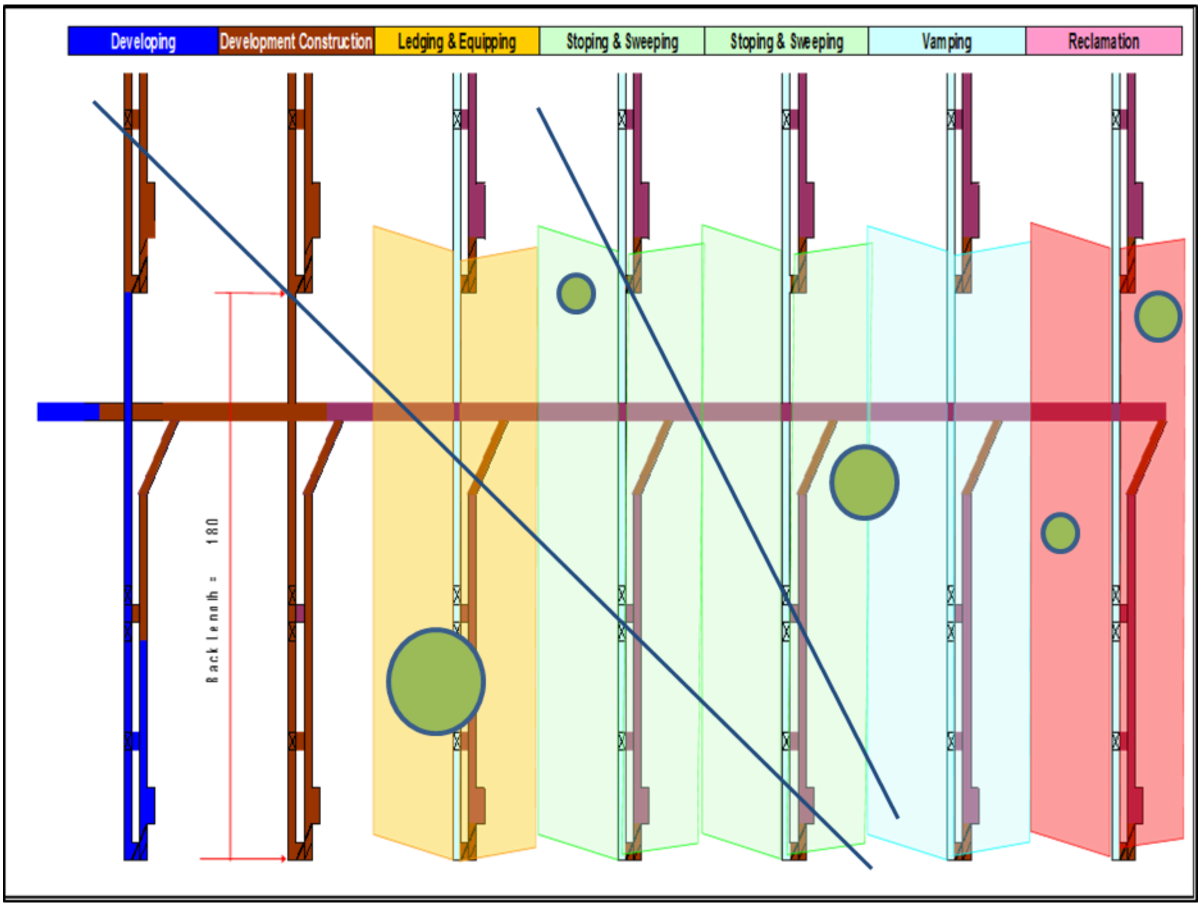


Figure 13: Conventional Mining: Mining Activities and Sequence (Anglo American Platinum (f), 2015)

The iceberg technique is expanded to create the half-level system, which can be applied to determine the appropriate mining rate of all the supporting mining activities on a half-level to maintain the half–level steady state stoping rate.

The total half-level system advance is limited by the advance rate of the haulage. For a given haulage advance rate, the rest of the half-level activities must be done in a synchronized fashion to ensure the associated steady state stoping rate is sustainable. In the sections that follow, this methodology is applied to determine the required production in each of the half-level mining entities and the aggregate of these production profiles will provide the production profile of the total half-level. The half-level system is illustrated in Figure 14.

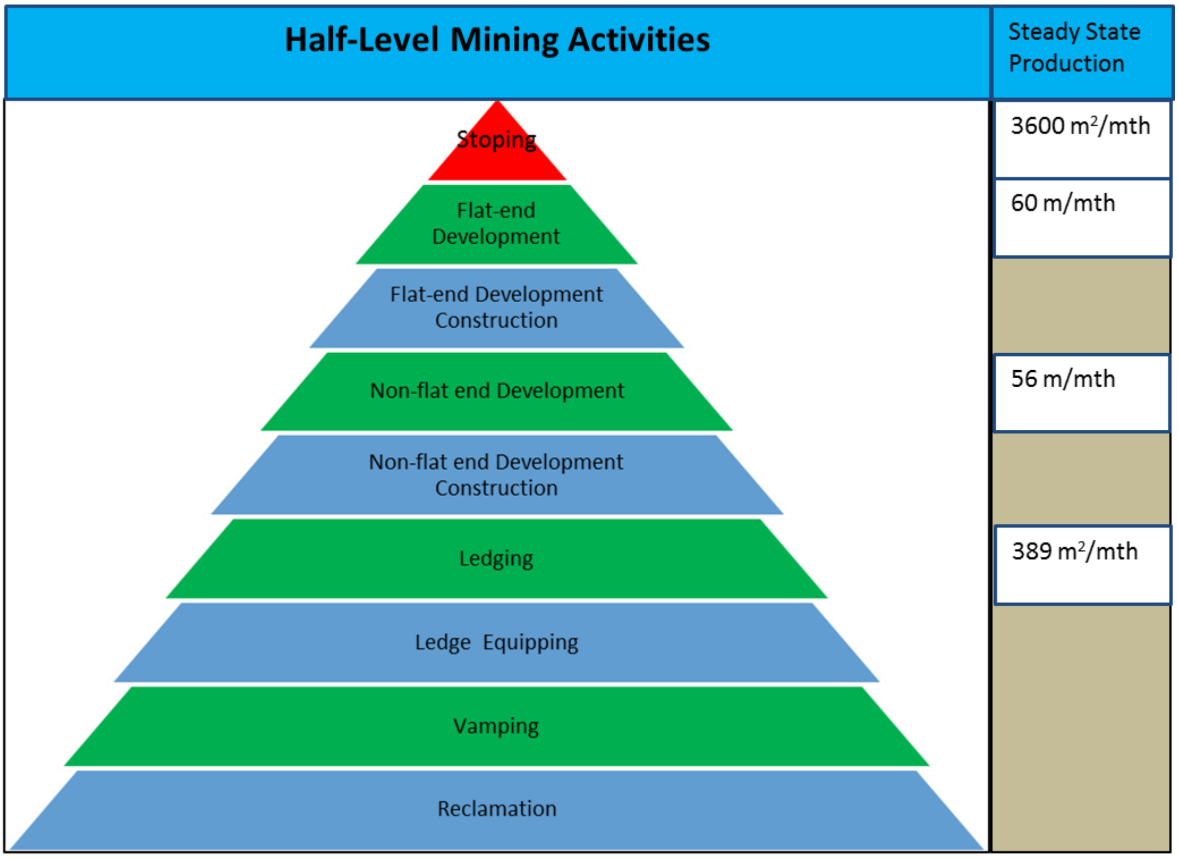


Figure 14: Half-level System

Mine Design Criteria (MDC)

The mineral right plan and investment centres need to be divided into a grid to form the standard mining blocks (SMB). Each SMB, with its ore and waste rock, will belong to a specific half-level. Basic mine layout plans indicate the minable half-levels, half-level layouts and standard mining block layouts and are required to determine the MDC inputs for the mining model.

Mine design criteria are design parameters that can change for a specific mining method based on the ore body characteristics, mining or economic factors.

According to Musingwini (2010, p. 425), optimal extraction broadly requires that the maximum amount of the ore be extracted together with the minimum amount of waste rock and in conventional underground mines, it requires minimizing the waste development that defines the mining grid. This process includes the optimization of vertical level intervals and raise spacing that consequently influences the back length of raises (Musingwini, 2010, p. 425). Musingwini (2010, p. 425) suggested moving back to smaller vertical level intervals and raise spacing and derived the optimal range of vertical level intervals to be 30 – 50m, whilst the optimal raise spacing is 180m to 220m. Musingwini (2010, p. 425) further recommended that the stope geometries should be square and consequently, require the raise spacing and back length to be equal in length.

Typical mine design criteria, as listed in Table 4, are based on historical business planning data from Rustenburg platinum mines and are applied in the sections that follow. From this data, it is evident that the mining layout practice at Rustenburg platinum mines is aligned with the findings by Musingwini (2010, p. 425).

Table 4: Mine Design Criteria (Anglo American Platinum (f), 2015)

Description	Values
True dip of reefs	10-13^0
Geological losses	20%
Mining losses	11%
Pillar losses	12.85%
MCF	98%
Vertical distance between haulage levels or shaft stations	30 - 50m
Back lengths of raises	200m
Strike distance between raises or X/cuts	200m
Panel spacing (Gully to gully)	33.33m
Panel span (Pillar to pillar)	30m
Half-level system or haulage advance / mth	36m

3.2.2 Planning - Stoping

The steady state stoping area per half-level needs to be estimated to produce a stoping production profile and to determine the required activity level of development, ledging and equipping to support the stoping production profile. The area of a SMB can be calculated from Equation 1.

Equation 1: Standard Mining Block Area (SMB m^2)

$$Standard\ Mining\ Block\ Area\ [m^2]$$
$$= SMB\ dip\ distance\ [m] x\ SMB\ strike\ distance [m]$$

Due to geological losses, mining losses and pillars, the full SMB area cannot be extracted and the extraction percentage can be determined from Equation 2.

Equation 2: Extraction

$$Extraction\ [\%] = \frac{SMB\ [m^2] - Total\ Losses\ [m^2]}{SMB\ [m^2]} x\ 100$$

$$Extraction\ [\%] = \frac{Extractable\ Mining\ Block\ Area\ [m^2]}{SMB\ [m^2]} x\ 100$$

$$Extraction\ [\%] = 100\% - Total\ losses\ [\%]$$

Values of losses are shown in Table 5 and are derived from historical business planning data for Rustenburg platinum mines.

Table 5: Extraction (Anglo American Platinum (f), 2015)

Description	Values
Geological losses - Known	8%
Geological losses – Unknown	12%
Mining losses	11%
Pillar losses - Regional	6%
Pillar losses – In-stope	6.85%
Total losses	43.85%
Extraction	56.15%
Total	100%

The area of an extractable mining block (EMB) can be calculated from Equation 3:

Equation 3: Extractable Mining Block Area (EMB m^2)

$$Extractable\ Mining\ Block\ Area\ [m^2] = SMB\ [m^2] x\ \ Extraction\ [\%]$$

$$Extractable\ Mining\ Block\ Area\ [m^2] = SMB\ [m^2]\ - Total\ Losses\ [m^2]$$

The stoping extraction percentage can be computed by deducting the raise area and ledge area from the EMB area according to Equation 4.

Equation 4: Stoping Extraction

$$Stoping\ Extracton\ [\%] = \frac{(SMB\ [m^2]\ x\ Extract.\%) - Raise\ [m^2] - Ledging\ \ [m^2\ ]}{SMB\ [m^2]}$$

$$Stoping\ Extracton\ [\%] = \frac{EMB\ [m^2] - Raise\ [m^2] - Ledging\ [m^2]}{SMB\ [m^2]}$$

$$Stoping\ Extracton\ [\%] = \frac{Stoping\ [m^2\ ]}{SMB\ \ [m^2]}$$

Table 6 provides an example of the stoping extraction percentage calculation based on historical business planning data for Rustenburg platinum mines.

Table 6: Stoping Extraction (Anglo American Platinum (f), 2015)

Description	Values
SMB dip distance (back length)	200m
SMB strike distance	200m
SMB Area	200m x 200m = 40000m^2
Extraction	56.15%
EMB area	40000m^2 x 56.15% = 22460m^2
Raise area	200m x 1.5m = 300m^2
Ledging area	180m x 12m = 2160m^2
Stoping area	22460 - 300 - 2160 = 20000m^2
Stoping extraction	20000 / 40000 = 50.00%

The available stoping area per SMB can be calculated directly from the SMB area if the stoping extraction percentage is known by using Equation 5 as presented in Table 7.

Equation 5: Stoping Area per SMB

$$Stoping\ Area\ [m^2] = Stoping\ Extracton\ [\%]\ x\ SMB\ \ [m^2]$$

Table 7: Stoping Area per SMB (Anglo American Platinum (f), 2015)

Description	Values
SMB dip distance (back length)	200m
SMB strike distance	200m
SMB area	200m x 200m = 40000m^2
Stoping extraction	50%
Stoping area	40000 x 50% = 20000m^2

The steady state stoping rate is dependent on the advance rate of the haulage or the half-level system advance rate and can be calculated from Equation 6 as shown in Table 8.

Equation 6: Steady State Stoping Area per Half-level

$$Steady\ State\ Stoping\ Area\ [m^2] =$$
$$SMB\ dip\ distance\ [m] x\ Haulage\ Advance\ [m] x\ Stoping\ Extraction\ [\%]$$

Table 8: Steady State Stoping Area per Half-level (Anglo American Platinum (f), 2015)

Description	Values
SMB dip distance (back length)	200m
Haulage advance per mth	36m
Stoping extraction	50%
Steady state stoping area / half-level / mth	200 x 36 x 50% = 3600m^2 /mth

The steady state stoping area per half-level can be used to estimate the number of stoping crews required per half-level by applying Equation 7 as shown in Table 9.

Equation 7: Stoping Crews per Half-level

$$Stoping\ Crews = \frac{Steady\ State\ Stoping\ Area\ [m^2]}{Stoping\ Crew\ Productivity\ [m^2]}$$

Table 9: Stoping Crews per Half-level (Anglo American Platinum (f), 2015)

Description	Values
Steady state stoping area / half-level / mth	3600m^2 /mth
Stoping crew productivity / mth	360m^2 /mth
Stoping crews	3600 / 360 = 10 crews

3.2.3 Planning - Development

The development replacement factor is applied to estimate the required steady state development advance from the steady state stoping area and is based on the layout of a standard mining block on a half-level. The calculation of the development replacement factors requires the dimensions of the development ends for a standard mining block (SMB). Characteristic development end dimensions are sourced from historical business planning information for Rustenburg platinum mines and are reflected in Figure 15 and Table 10.

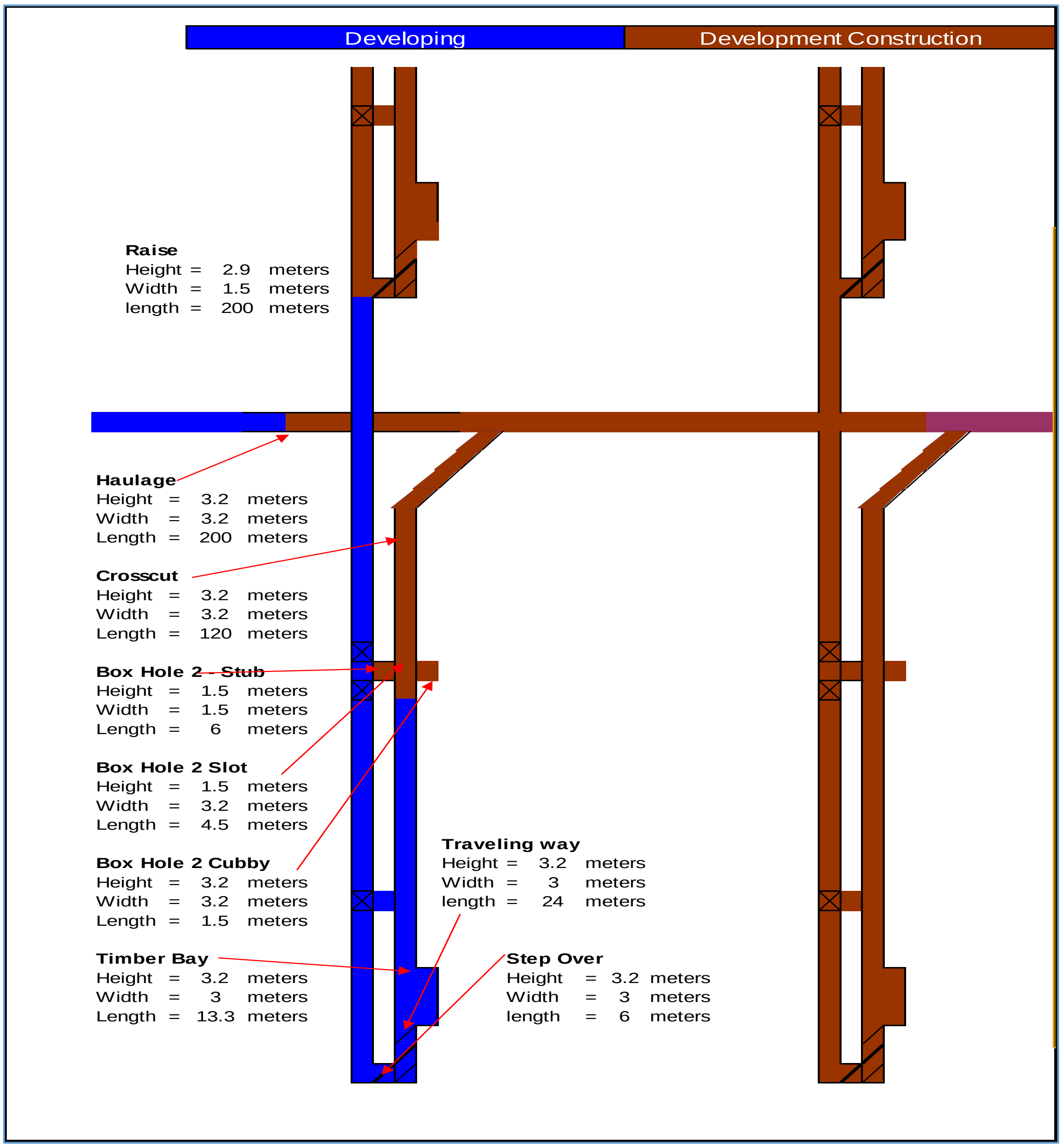


Figure 15: Development Dimensions per SMB (Anglo American Platinum (f), 2015)

Table 10: Development Dimensions per SMB (Anglo American Platinum (f), 2015)

Description	Width (m)	Height (m)	Length (m)	Volume (m^3)
Flat-end Dev.	**3.2**	**3.2**	**333.3**	**3405**
Haulage	3.2	3.2	200	2048
X/Cut	3.2	3.2	120	1229
Timber Bay	3	3.2	13.3	128
Non-flat end Dev.	**1.48**	**2.9**	**311**	**1338**
Travelling Way (TW)	3	3	24	216
Step over (SO)	3	3	6	54
Raise (R)	1.5	2.9	200	870
TW, SO, R	1.71	2.9	230	1140
Box 3 Stub	1.5	1.5	6	14
Box 3 Box Slot	3.2	1.5	4.5	21.6
Box 3 Cubby	3.2	3.2	1.5	15.4
Box 3 Drop raise	1.0	1.0	40	40
Box 2 Stub	1.5	1.5	6	14
Box 2 Box slot	3.2	1.5	4.5	21.6
Box 2 Cubby	3.2	3.2	1.5	15.4
Box 2 Drop raise	1.0	1.0	5	5
Box 1 Stub	1.5	1.5	6	14
Box 1 Box Slot	3.2	1.5	4.5	21.6
Box 1 Cubby	3.2	3.2	1.5	15.4
Box 1 Drop raise	1.0	1.0	0	0
Total Box Stub	1.5	1.5	18	42
Total Box Slot	3.2	1.5	13.5	64.8
Total Box Cubby	3.2	3.2	4.5	46.2
Total Box Drop raise	1.0	1.0	45	45
Total Box-holes	2.06	2.06	36	153
Total Box-drop raise	1.0	1.0	45	45
Total Development	2.454	3	644.3	4743

A development replacement factor can be derived for each development entity in a SMB as demonstrated in

Table 11 by using Equation 8.

Equation 8: Development Replacement Factor

$$Development\ Replacement\ Factor\ [\frac{m^2}{m}] = \frac{Stoping\ Area\ per\ SMB\ [m^2\ ]}{Development\ Advance\ \ per\ SMB\ [m]}$$

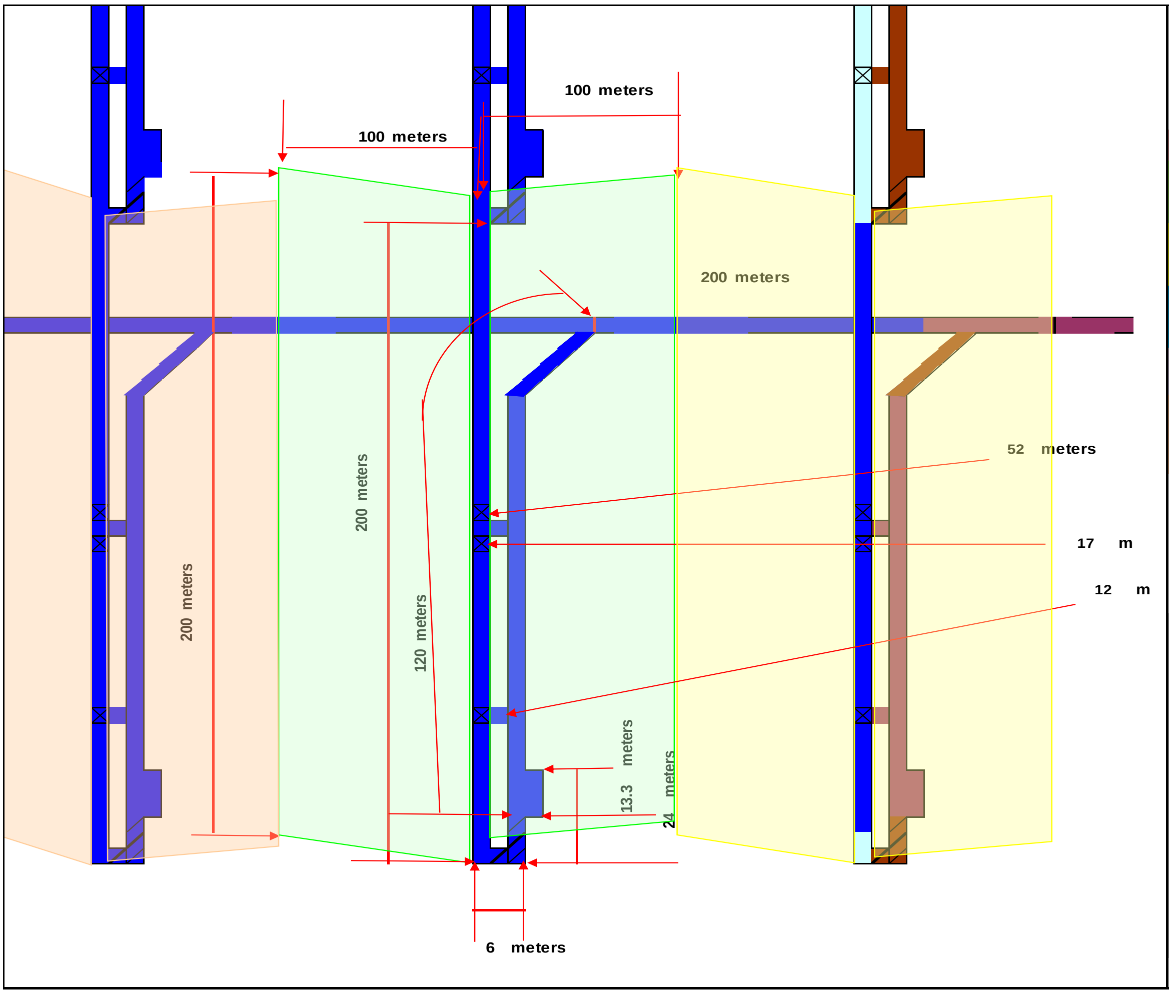


Figure 16: Development Replacement Factor (Anglo American Platinum (f), 2015)

Table 11: Development Replacement Factor (Anglo American Platinum (f), 2015)

Description	Values
Stoping	
Stoping area / SMB	40000m^2 x 50% = 20000m^2
Flat-end Dev.	**20000m^2 / 333.3m = 60 m^2/m**
Haulage	20000m^2 / 200m = 100 m^2/m
X/Cut	20000m^2 / 120m = 166.7 m^2/m
Timber bay	20000m^2 / 13.3m= 1504 m^2/m
Non-flat end Dev.	**20000m^2 / 311m = 64.3 m^2/m**
Travelling way (TW)	20000m^2 / 24m = 833 m^2/m
Step over (SO)	20000m^2 / 6m = 3333 m^2/m
Raise (R)	20000m^2 / 200m = 100 m^2/m
TW, SO, R	20000m^2 / 230m = 87 m^2/m
Box-holes	20000m^2 / 36m = 555.5 m^2/m
Box-drop raise	20000m^2 / 45m = 444.4 m^2/m
Total Development	**20000 m^2 / 644.3m =31 m^2/m**

From the development replacement factor and the steady stoping area, the required steady state development advance for each development entity can be determined according to Equation 9 as demonstrated in Table 12.

Equation 9: Steady State Development Advance per Half-level

$$Steady\ State\ Development\ Advance\ [m] = \frac{Steady\ State\ Stoping\ Area\ [m^2]}{Development\ Replacement\ Factor\ [m^2/m]}$$

Table 12: Steady State Development Advance per Half-level (Anglo American Platinum (f), 2015)

Description	Values
Stoping	
Steady state stoping area / half-level / mth	200 x 36 x 50% = 3600m^2 /mth
Flat-end Dev.	**3600 / 60 = 60m/mth**
Haulage	3600 / 100 =36m /mth
X/Cut	3600 / 166.7 = 21.6m /mth
Timber bay	3600 / 1504 = 2.4m /mth
Non-flat end Dev.	**3600 / 64.3 = 56m /mth**
Travelling way (TW)	3600 / 833 = 4.3m /mth
Step over (SO)	3600 / 3333 = 1.1m /mth
Raise (R)	3600 / 100 = 36m /mth
TW, SO, R	3600 / 87 = 41.4m /mth
Box-holes	3600 / 555.5 = 6.5m /mth
Box-drop raise	3600 / 444.4 = 8.1m /mth
Total Development	**Sum = 116m /mth**
Steady state development advance / half-level / mth	3600 / 31 = 116m /mth

The development volumes can be determined from the dimensions of the development entities by applying Equation 10 as alluded in Table 13.

Equation 10: Steady State Development Volume per Half-level

$$Steady\ State\ Development\ Volume\ [m^3] = Steady\ State\ Development\ Advance\ [m]\ x\ \ Width\ [m]\ x\ \ Height\ [m]$$

Table 13: Steady State Development Volume per Half-level (Anglo American Platinum (f), 2015)

Description	Values
Steady state development advance / half-level / mth	116m /mth
Width (From Table 10)	2.454m
Height (From Table 10)	3m
Steady state development volume / half-level / mth	116 x 2.454 x 3 = 854m^3 /mth

The steady state development-advance per half-level can be used to estimate the amount of development crews required per half-level by applying Equation 11 as shown in Table 14.

Equation 11: Development Crews per Half-level

$$Development\ Crews = \frac{Steady\ State\ Development\ Advance\ [m]}{Development\ Crew\ Productivity\ [m]}$$

Table 14: Development Crews per Half-level (Anglo American Platinum (f), 2015)

Description	Values
Flat End Dev.	
Steady state dev advance / half-level / mth - Haulage	36m /mth
Development crew productivity – Haulage	36m /mth
Development crews - Haulage	36 / 36 = 1 Crew
Steady state dev advance / half-level / mth – X/Cut & TB	21.6+2.4 =24m /mth
Development crew productivity – X/Cut & TB	24m /mth
Development crews - X/Cut & TB	24 / 24= 1 Crew
Non-flat end Dev.	
Steady state dev advance / half-level / mth – TW, SO, R	4.3 + 1.1+36 =41.4m /mth
Development crew productivity – TW, SO, R	22.5m /mth
Development crews - TW, SO, R	41.4 / 22.5 = 1.84 = 2 Crews
Steady state dev advance / half-level / mth – Box-holes	6.5m /mth
Development crew productivity – Box-holes	15m /mth
Development crews – Box-holes	6.5 / 15 = 0.43 = 1 Crew
Steady state dev advance / half-level / mth – Box-drop raise	8.1m /mth
Development crew productivity – Box-drop raise	15m /mth
Development crews – Box-drop raise	8.1 / 15 = 0.54 = 1 Crew

3.2.4 Planning - Ledging

The ledging replacement factor is applied to estimate the required steady state ledging area from the steady state stoping area and is based on the layout of a standard mining block. The ledging replacement factor is computed by using Equation 12 as depicted in Table 15 and is grounded on historical business planning information for Rustenburg platinum mines.

Equation 12: Ledging Replacement Factor

$$Ledging\ Replacement\ Factor\ \left[\frac{m^2}{m^2}\right] = \frac{Stoping\ Area\ per\ SMB\ [m^2]}{Ledging\ \ Area\ per\ SMB\ [m^2]}$$

Table 15: Ledging Replacement Factor (Anglo American Platinum (f), 2015)

Description	Values
Stoping	
Stoping Area / SMB	40000 x 50% = 20000m^2
Ledging	
SMB back length less pillars	200 - 20 = 180m
Ledging Width	12m
Ledging Area	180 x 12 = 2160m^2
Ledging Replacement Factor	20000 / 2160 = 9.26m^2 /m^2

Equation 13 is applied in Table 16 to determine the required steady state ledging area per half-level.

Equation 13: Steady State Ledging Area per Half-level

$$Steady\ State\ Ledging\ Area\ [m^2] = \frac{Steady\ State\ Stoping\ Area\ [m^2]}{Ledging\ Replacement\ Factor\ [\frac{m^2}{m^2}]}$$

Table 16: Steady State Ledging Area per Half-level (Anglo American Platinum (f), 2015)

Description	Values
Stoping	
Steady state stoping area / half-level / mth	200 x 36 x 50% = 3600m^2 /mth
Ledging	
Steady state ledging area / half-level / mth	3600 / 9.26 = 389m^2 /mth

The steady state ledging area per half-level can be used to estimate the number of ledging crews required per half-level as shown in Table 17 by using Equation 14.

Equation 14: Ledging Crews per Half-level

$$Ledging\ Crews = \frac{Steady\ State\ Ledging\ Area\ [m^2]}{Ledging\ Crew\ Productivity\ [m^2]}$$

Table 17: Ledging Crews per Half-level (Anglo American Platinum (f), 2015)

Description	Values
Steady state ledging area / half-level /mth	$389m^2$ /mth
Ledging crew productivity / mth	$200m^2$ /mth
Ledging crews	389 / 200 = 2 crews

3.2.5 Scheduling

Proper scheduling of conventional mining activities on a half-level requires adherence to scheduling rules to deliver a synchronized mining half-level, which will produce without fluctuations and stoppages. The duration of mining activities can be determined from Equation 15, Equation 16 and Equation 17 and the calculations are shown in Table 18.

Equation 15: Stoping Duration

$$Stoping\ Duration\ [Mths] = \frac{Stoping\ Area\ per\ SMB\ [m^2]}{Stoping\ Crew\ Productivity\ [m^2] x\ Stoping\ Crews}$$

Equation 16: Development Duration

$$Development\ Duration\ [Mths] = \frac{Development\ Advance\ per\ SMB\ [m]}{Dev.\ Crew\ Productivity\ [m]\ x\ Development\ Crews}$$

Equation 17: Ledging Duration

$$Ledging\ Duration\ [Mths] = \frac{Ledging\ \ Area\ per\ SMB\ [m^2]}{Ledging\ Crew\ Productivity\ [m^2]\ x\ Ledging\ Crews}$$

Table 18: Mining Activity Duration (Anglo American Platinum (f), 2015)

Description	Values
Stoping	
Stoping area per SMB	20000m^2
Stoping Crew Productivity	12 x 30m = 360m^2 /mth
Number of crews	10
Stoping duration	20000 / (360 x 10) = 5.55 = 6 mths
Flat end Dev.	
Dev. advance per SMB - Haulage	200m
Dev. crew productivity - Haulage	12 x 3m = 36m /mth
Number of crews - Haulage	1
Dev. duration - Haulage	200 / (36 x 1) = 5.55 = 6 mths
Dev. advance per SMB – X/Cuts & TB	120 + 13.3 = 133.3m
Dev. crew productivity - X/Cuts & TB	12 x 2m = 24m /mth
Number of crews - X/Cuts & TB	1
Dev. duration – X/Cut & TB	133.3 / (24 x 1) = 5.55 = 6 mths
Non-flat end Dev.	
Dev. advance per SMB – TW, SO, R	24+6+200 = 230m
Dev. crew productivity - TW, SO, R	15 x 1.5m = 22.5m /mth
Number of crews - TW, SO, R	2
Dev. duration - TW, SO, R	230 / (22.5 x 2) = 5.11 = 6 mths
Dev. advance per SMB – Box-holes	36
Dev. crew productivity – Box-holes	15 x 1m = 15m /mth
Number of crews – Box-holes	1
Dev. duration – Box-holes	36 / (15 x 1) = 2.4 = 3 mths
Dev. advance per SMB – Box- drop raise	45
Dev. crew productivity – Box-drop raise	15 x 1m = 15m /mth
Number of crews – Box-drop raise	1
Dev. duration – Box-drop raise	45 / (15 x 1) = 3 mths
Ledging	
Ledging area per SMB	2160m^2
Ledging crew productivity	6.67 x 30m = 200m^2 /mth
Number of crews	2
Ledging duration	2160 / (200 x 2) = 5.4 = 6 mths

From Table 18 it is evident that the box-hole crew and drop raise crew (diamond drilling crew) will only be utilized for 50% of their time. The box-hole team can be re-deployed to in-stope re-development, which might be required due to geological potholes or massive fall of ground. The diamond drilling crew can be utilized for cover drilling and sealing of water fissures in the haulage.

The mining activities with their respective duration, cumulative duration and year in which the cash outflow will occur can be displayed on an activity line as demonstrated in Table 19.

Table 19: Scheduling of Mining Activities per SMB (Anglo American Platinum (f), 2015)

Activities	Flat dev Flat Constr.	Non-flat Dev	Non-flat Constr.	Ledging	Stope Equip.	Float	Stoping	Vamping Reclam.
Duration (Mths)	6	6	6	6	6	6	6	6
Cumulative duration (Mths)	6	12	18	24	30	36	42	48
Duration (Years)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cumulative duration (Years)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4
Year of cash out flow	1	1	2	2	3	3	4	4

The following scheduling rules should be considered:

- The duration of stoping, development and ledging activities should be calculated and synchronized as demonstrated above.
- A fixed period should be allowed for non-flat end construction, which includes box front construction and tip construction.
- A fixed period should be allowed for stope equipping, which includes installation of mono-winches, scraper winches, water and compressed air pipes, electrical cabling and other required equipment.
- A fixed period should be allowed as a float to cater for unforeseen delays, which might occur before the commencement of stoping.
- A fixed period should be incorporated for vamping and reclamation.

Managerial judgement is required to determine the fixed periods, as scheduling tools do not always incorporate sufficient detail. Rules of thumb are applied in support of these managerial decisions, hoping the errors will have a negligible impact. The fixed periods should be revised on a regular basis to minimize variances and to keep them realistic.

3.2.6 Mining Equation

Stoping

Geological information is required per resource block to estimate the production tonnage, content and grade. Typical geological information as required for stoping and ledging are provided in Table 20 and are sourced from historical business planning data for Rustenburg platinum mines.

Table 20: Stoping and Ledging Entity Information (Anglo American Platinum (c), 2015)

Half-level	Resource Block	Best Cut		Over-breaking		Stope Waste	SG
		Stoping width [m]	4E Grade [g/t]	Stoping width [m]	4E Grade [g/t]	[%]	[t/m^3]
32 E Mer	PM3220	1.00	6.0	0.1	0	3%	3.1
32 E Mer	PM3221	1.05	5.74	0.05	0	3%	3.1
32 E Mer	PM3222	0.9	7.41	0.2	0	3%	3.1
32 E UG2	PU3220	0.85	7.03	0.25	0	3%	3.8
32 E UG2	PU3221	0.95	4.79	0.15	0	3%	3.8
32E UG2	PU3222	1.0	4.9	0.1	0	3%	3.8

From the stoping area production profiles and geological information, the stoping tonnage, content and grade can be estimated for a SMB as listed in Table 21.

Table 21: Stoping Production per SMB (Anglo American Platinum (f), 2015)

Description	Value		Description	Value
Location			**Planned**	
Half-level	3 E Mer		Stoping width	1.1m
Geological Block	PM3220		Volume broken	1980m^3
			SG	3.8t/m^3
Production			Tonnes broken	7524t
Stoping crew productivity /mth	360m^2		4E Grade	5.45g/t
Stoping crews / SMB	5		4E Content	41040g
Stoping area broken /mth	1800m^2			
			Stope Waste	
Best cut			Dilution	3%
Stoping width	1		Volume broken	60m^3
Volume broken	1800m^3		SG	3.8t/m^3
SG	3.8t/m^3		Tonnes broken	226t
Tonnes broken	6840t			
4E Grade	6g/t		**Stoping**	
4E Content	41040g		Tramming width	1.133m
			Volume broken	2040m^3
			SG	3.8g/t
Over-breaking			Tonnes broken	7750t
Stoping width	0.1m		4E Grade	5.3g/t
Volume broken	180m^3		4E Content	41040g
SG	3.8t/m^3			
Tonnes broken	684t			
4E Grade	0g/t			
4E Content	0g			

Development

From the development production profiles (in advance meters) and the development entity information (as listed in Table 22), the development production profiles in terms of tonnage, grade and content can be estimated for each of the mining entities. A calculation for haulage production is provided in Table 23.

Table 22: Development Entity Information (Anglo American Platinum (f), 2015)

Description	SG	4E Grade	Dimensions		Reef / Waste
	t/m^3	g/t	Height [m]	Width [m]	
Mer-Haulage	3.0	0	3.2	2.7	Waste
Mer-X/Cut	3.0	0	3.2	2.7	Waste
Mer-Trav way	3.0	0	2.7	1.8	Waste
Mer-Box-hole	3.0	0	2.0	1.5	Waste
Mer-Raise	3.0	1.9	2.4	1.4	Reef

Table 23: Development Production per Entity (Anglo American Platinum (f), 2015)

Description	Value
Location	
Half-level	3E Mer
Entity	Haulage
Production	
Dev. crew productivity m /mth	36m
Dev. crews / half-level	1
Advance / month	36m
Planned	
Height	3.2m
Width	2.7m
Volume broken	311m^3
SG	3.1t/m^3
Tonnes broken	964t
4E Grade	0g/t
4E Content	0g

Mining and Concentrator Production

The production tonnage, content and grade can be determined per half-level by combining the production data of the mining entities on a half-level. This process can be repeated to calculate the production per investment centre, shaft and mine. Throughout this data consolidation process, segregation between the respective reef types and waste production must be maintained. The ore delivered to the respective concentrators can also be determined with a similar consolidation, but consideration should be given to the reef type treated at a specific concentrator, together with the mine call factor (MCF) and tonnage discrepancy factor (TDF).

3.2.7 Case Study

A case study at Thembelani shaft in Rustenburg investigated the performance of the half-level system by comparing planned and actual production and labour productivity data on a number of half levels. The location of Thembelani shaft as part of the Rustenburg platinum mines are illustrated in Figure 17.

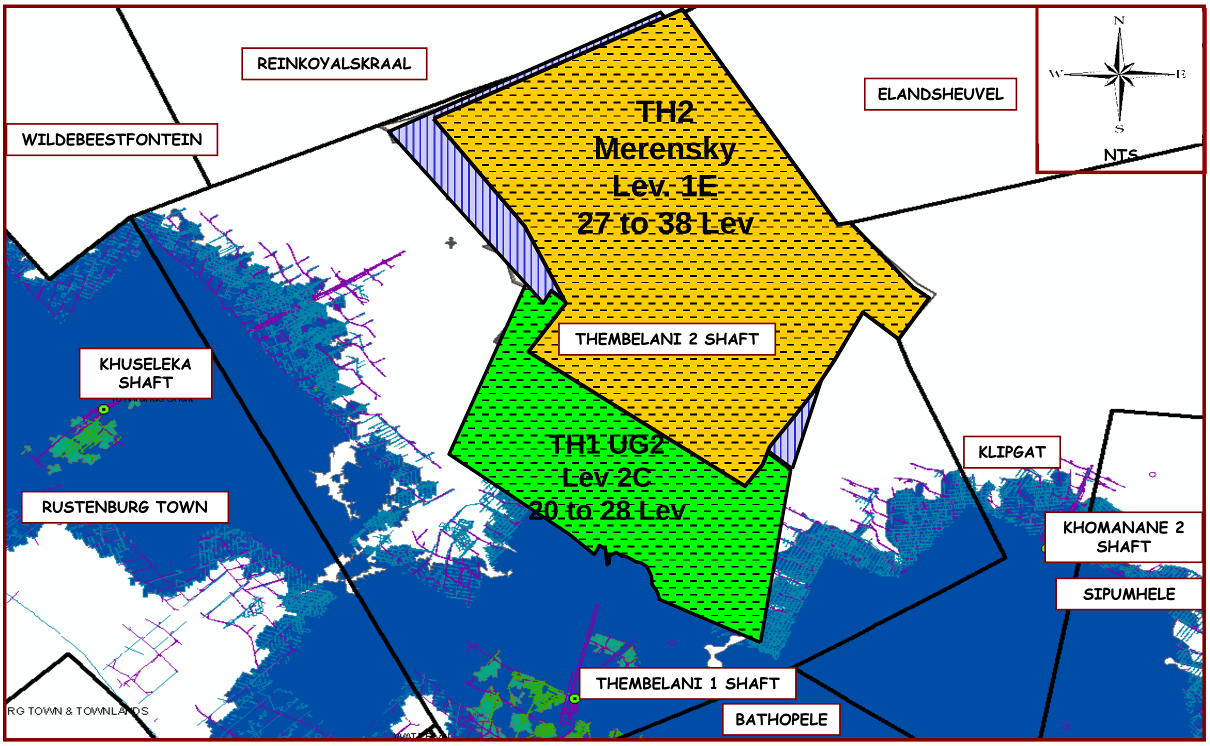


Figure 17: Location Plan of Thembelani Shaft (Anglo American Platinum (f), 2015)

Production variances were detected that include the under or over performing of complete half-levels and individual mining entities. The half-level system advance (haulage advance) varied between 24 and 48 m/month, against a planned advance of 36 m/month. In the case of stoping, the crew productivities varied between 270 and 450 m^2/crew compared to the planned 360 m^2/crew per month.

The production variances of the mining entities caused them to lag behind or advance ahead of the synchronised half-level schedule. Interventions were required to restore the desynchronised mining entities with the rest of the half-level entities. Remedial steps included stoppage of mining entities, providing additional resources or prioritization of critical mining entities. The synchronization status of the mining entities on a half-level was reviewed on a monthly basis during the production planning sessions.

The root causes of these over and under performances were determined and either the planned crew productivities or the planned half-level system advance (haulage advance) was modified in cases where the root causes could not be eliminated in the short term. The root causes were found to include factors such as short face times, low air or water pressures, inadequate material and equipment, absenteeism, poor ground conditions and logistical constraints. This adjusted planned crew productivities and modified half-level system advance altered either the number of crews required per half-level or the half-level production output.

3.2.8 Findings

The mining rights area is broken down into investment centres, of which the planning confidence increases as the project investment centres progress through the stage gate process. A mining rights plan consists of the production profiles of the investment centres within a mining rights area. The optimized business plan is extracted from the mining rights plan and is used to prioritize capital investments, measures business performance and serves as the basis for future strategic planning.

The integrated techno-economic model requires a mining model with production planning and scheduling abilities. The half-level system method can be applied to create production profiles for different mining options and after optimisation; the best option is taken forward for graphical design and detailed scheduling. In the case of conventional underground mining, the half-level system method is applied to determine the steady state stoping, development and ledging rates per half-level. From the steady state production and crew productivities, the number of crews is determined and the durations of mining activities are estimated and synchronized to deliver a mining plan for a half-level. This half-level mining plan can be replicated to create a mining plan for an investment centre and shaft, which should be pressure tested against logistical and economic constraints. From the mining model, the tonnes milled and 4E grade are derived and incorporated into the metallurgical model. The case study also stressed the importance to review the synchronisation status of half-level mining entities and to implement mitigating steps.

3.3 **Metallurgical Modelling**

3.3.1 Introduction

Platinum mines produce ore that contains platinum group metals (PGM) and base metals (BM), which is processed sequentially at concentrators, smelters and a precious metal refinery (PMR) or base metal refinery (BMR). At the concentrators, the ore is crushed, milled and concentrated via a flotation process. The concentrate is transported to the smelters where the concentrate is smelted in electric arc furnaces. From the furnace, the product is further refined in Pierce-Smith converters to produce a converter matte. The converter matte is milled to produce matte slurry, which is passed over wet magnetic separators to produce a rich magnetic PGM matte and a nickel-copper matte (NCM). The magnetic PGM matte is leached to remove any residual base metals. The final PGM matte is then transported to the precious metal refinery where it is processed and refined to produce the 7E metals that consist of platinum, palladium, rhodium, gold, ruthenium, osmium and iridium. The nickel-copper matte (NCM) is processed and refined at the base metal refinery (BMR) to produce nickel, copper and cobalt. (Anglo American Platinum (a), 2014). Figure 18 displays the platinum value chain together with a basic metallurgical process flow.

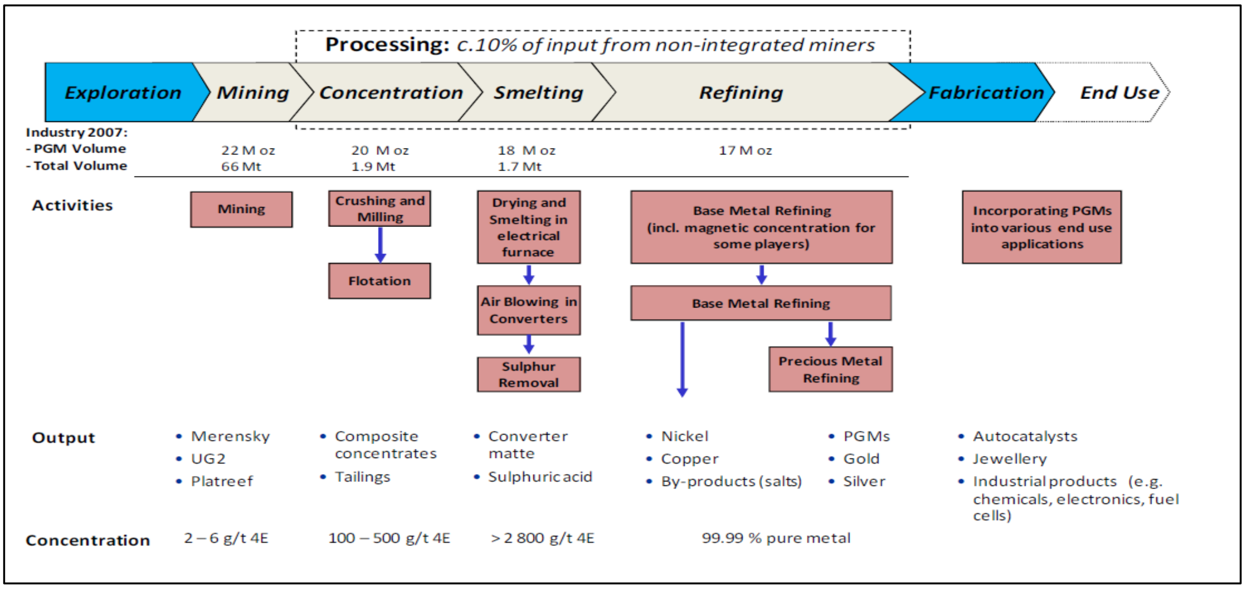


Figure 18: Platinum Value Chain with Metallurgical Process Flow (Smith, 2011, p. 36)

3.3.2 Concentrators

Mass Pull

Mass pull provides a method to determine the mass of the concentrate product from the concentrators after processing the tonnes milled received from the mines. Based on historical business planning data for Anglo American Platinum, typical mass pull values range between 1% and 4% and can be calculated from Equation 18.

Equation 18: Mass Pull

$$Mass\ Pull\ [\%] = \frac{Concentrate\ Mass\ [t]}{Tonnes\ Milled\ [t]} x\ 100$$

For production profiles, the concentrate mass is determined from the product of the mass pull percentage and the tonnes milled as alluded in Equation 19.

Equation 19: Concentrate Mass

$$Concentrate\ Mass\ [t] = Mass\ Pull\ [\%]\ x\ Tonnes\ Milled\ [t]$$

Metal Split (Prill Split)

The head grade is given as a four-element grade (4E) and is measured in grams per ton (g/t). The sum of the metallurgical split percentages of platinum (Pt), palladium (Pd), rhodium (Rh) and gold (Au) are equal to 100%, whilst the metal split percentages of iridium (Ir), osmium (Os) and gold (Au) are also based on the 4E grade. These metals are all precious metals and collectively they are termed 7E metals. Base metals (BM) recovered in the platinum industry include nickel (Ni), copper (Cu) and cobalt (Co) and their metal split percentage are based on tonnes milled. Typical Merensky and UG2 reef values are shown in Table 24 and Table 25.

Table 24: Metal Split: Merensky (Anglo American Platinum (e), 2015)

Metal Split – Merensky	2015	2016	2017	2018	2019	2020
Pt Metal Split [%]	62.861	62.867	62.863	62.862	62.864	62.867
Pd Metal Split [%]	28.331	28.339	28.333	28.334	28.332	28.339
Rh Metal Split [%]	5.793	5.794	5.791	5.796	5.795	5.792
Au Metal Split [%]	3.011	3.014	3.018	3.013	3.014	3.015
Ir Metal Split [%]	2.018	2.015%	2.013	2.012	2.011	2.016
Os Metal Split [%]	0.000	0.000	0.000	0.000	0.000	0.000
Ru Metal Split [%]	10.139	10.132	10.138	10.134	10.133	10.132
Ni Metal Split [%]	0.156	0.156	0.153	0.159	0.155	0.154
Cu Metal Split [%]	0.056	0.052	0.055	0.054	0.053	0.051
Co Metal Split [%]	0.021	0.023	0.024	0.023	0.022	0.019

Table 25: Metal Split: UG2 (Anglo American Platinum (e), 2015)

Metal Split - UG2	2015	2016	2017	2018	2019	2020
Pt Metal Split [%]	59.464	59.435	59.398	59.204	59.234	58.894%
Pd Metal Split [%]	28.845	28.775	28.747	28.967	28.898	29.297
Rh Metal Split [%]	10.220	10.419	10.535	10.319	10.432	10.024
Au Metal Split [%]	1.472	1.371	1.320	1.510	1.436	1.786
Ir Metal Split [%]	3.988	4.043	4.076	4.021	4.051	3.946
Os Metal Split [%]	0.000	0.000	0.000	0.000	0.000	0.000
Ru Metal Split [%]	17.238	17.429	17.533	17.253	17.376	16.853
Ni Metal Split [%]	0.126	0.124	0.123	0.119	0.120	0.111
Cu Metal Split [%]	0.028	0.025	0.024	0.028	0.025	0.034
Co Metal Split [%]	0.021	0.020	0.020	0.020	0.020	0.019

For production profiles, the content of each metal in the tonnes milled is determined by applying Equation 20 for 7E metals and Equation 21 for base metals.

Equation 20: Tonnes Milled Metal Content (7E Metals)

$$Tonnes\ Milled\ Metal\ Content\ (7E)\ [Oz]$$
$$= Met\ Split\ [\%]\ x\ Head\ Grade\left[\frac{g}{t}\right] x\ Tonnes\ Milled\ [t]\ x\ Conversion\left[\frac{Oz}{g}\right]$$

Equation 21: Tonnes Milled Metal Content (Base Metals)

$$Tonnes\ Milled\ Metal\ Content\ (BM)\ [t] = Met\ Split\ [\%]\ x\ Tonnes\ Milled\ [t]$$

Concentrating Recoveries

The recovery percentage is an indication of the efficiency of the concentrating process and the residue metals are lost in tailings. Characteristic values for the respective Merensky and UG2 reefs are displayed in Table 26 and Table 27.

Table 26: Concentrating Recoveries: Merensky (Anglo American Platinum (e), 2015)

Concentrating Recoveries -Merensky	2015	2016	2017	2018	2019	2020
Pt Conc. Rec. [%]	89.440	90.260	89.680	90.670	90.540	90.360
Pd Conc. Rec. [%]	89.000	90.090	87.970	90.490	90.350	90.180
Rh Conc. Rec. [%]	88.070	88.840	88.370	89.320	89.180	89.000
Au Conc. Rec. [%]	80.080	80.280	78.840	81.340	81.210	81.020
Ir Conc. Rec. [%]	80.280	80.970	80.590	81.550	81.400	81.210
Os Conc. Rec. [%]	0.000	0.000	0.000	0.000	0.000	0.000
Ru Conc. Rec. [%]	69.610	70.170	69.910	70.850	70.720	70.530
Ni Conc. Rec. [%]	65.440	65.800	65.720	66.670	66.580	66.390
Cu Conc. Rec.[%]	86.410	87.210	86.680	87.580	87.500	87.350

Table 27: Concentrating Recoveries: UG2 (Anglo American Platinum (e), 2015)

Concentrating Recoveries -UG2	2015	2016	2017	2018	2019	2020
Pt Conc. Rec. [%]	83.700	86.210	83.850	83.230	83.210	84.880
Pd Conc. Rec. [%]	82.000	84.660	82.700	82.390	82.370	83.410
Rh Conc. Rec. [%]	81.110	83.260	81.730	81.570	81.570	81.990
Au Conc. Rec. [%]	67.640	69.230	68.700	68.970	68.980	68.220
Ir Conc. Rec. [%]	79.110	81.100	78.900	78.110	78.070	80.390
Os Conc. Rec. [%]	0.000	0.000	0.000	0.000	0.000	0.000
Ru Conc. Rec. [%]	80.580	83.360	80.160	79.090	79.040	82.090
Ni Conc. Rec. [%]	18.460	20.210	17.350	15.930	15.860	20.290
Cu Conc. Rec. [%]	67.730	71.530	64.700	61.870	61.740	70.600
Co Conc. Rec. [%]	0.000	0.000	0.000	0.000	0.000	0.000

The concentrator recoveries are computed from Equation 22 and are derived by means of a metallurgical simulation, which is based on the relevant business plan (BP) production profiles that feed the respective concentrator.

Equation 22: Concentrating Recovery

$$Concentrating\ Recovery\ [\%] = \frac{Concentrate\ Metal\ Content\ [Oz\ or\ t]}{Tonnes\ Milled\ Metal\ Content\ [Oz\ or\ t]}\ x\ 100$$

For production profiles, the metal content in the concentrate is calculated from the product of the concentrator recoveries and the metal content in the tonnes milled using Equation 23.

Equation 23: Concentrate Metal Content

$$Concentrate\ Metal\ Content\ [Oz\ or\ t]$$
$$= Concentrating\ Recovery\ [\%]\ x\ Tonnes\ Milled\ Metal\ Content\ [Oz\ or\ t]$$

The grade of the concentrate is computed from Equation 24 after converting the metal content back to grams.

Equation 24: Concentrate Grade

$$Concentrate\ Grade\ \left[\frac{g}{t}\right] = \frac{Concentrate\ Metal\ Content\ [g]}{Concentrate\ Mass\ [t]}$$

From these calculations, a concentrate production profile is generated, which indicate the mass, metal content and the grade of the concentrate that is transported to the smelters.

3.3.3 Smelters

Smelting Recoveries

The recovery percentage is an indication of the efficiency of the smelting process, whilst the residue metals are lost in slag. Representative smelting recovery values are provided in Table 28.

Table 28: Smelting Recoveries (Anglo American Platinum (e), 2015)

Smelting Recoveries	2015	2016	2017	2018	2019	2020
Pt Smelt Rec. [%]	99.06	99.06	99.02	99.03	99.04	99.02
Pd Smelt Rec. [%]	99.06	99.06	99.02	99.03	99.04	99.02
Rh Smelt Rec. [%]	99.08	99.08	99.04	99.05	99.05	99.03
Au Smelt Rec. [%]	98.93	98.93	98.88	98.89	98.90	98.88
Ir Smelt Rec. [%]	98.78	98.78	98.74	98.75	98.75	98.73
Os Smelt Rec. [%]	-	-	-	-	-	-
Ru Smelt Rec. [%]	99.09	99.09	99.06	99.06	99.07	99.05
Ni Smelt Rec. [%]	92.15	92.14	91.98	92.03	92.04	91.94
Cu Smelt Rec. [%]	89.86	89.85	89.59	89.65	89.68	89.53
Co Smelt Rec. [%]	31.50	31.49	31.28	31.33	31.35	31.24

The smelting recoveries are computed from Equation 25 and are derived by means of a metallurgical simulation, which is based on the relevant business plan (BP) production profiles that feed the smelters.

Equation 25: Smelting Recovery

$$Smelting\ Recovery\ [\%] = \frac{Smelter\ Matte\ Metal\ Content\ [Oz\ or\ t]}{Concentrate\ Metal\ Content\ [Oz\ or\ t]}\ x\ 100$$

For production profiles, the metal content in the matte is calculated from the product of the smelter recoveries and the metal content in the concentrate using Equation 26.

Equation 26: Smelter Matte Metal Content

$$Smelter\ Matte\ Metal\ Content\ [Oz\ or\ t] = Smelting\ Recovery\ [\%]\ x\ Concentrate\ Metal\ Content\ [Oz\ or\ t]$$

These computations enable the creation of a smelter-matte production profile, which reflects the matte metal content that is fed to the refineries.

3.3.4 Refineries

Refining Recoveries

The recovery percentage is an indication of the efficiency of the refining process as the residue metals are lost. Typical refining recoveries are listed in Table 29.

Table 29: Refining Recoveries (Anglo American Platinum (e), 2015)

Refining Recoveries	2015	2016	2017	2018	2019	2020
Pt Refin. Rec. [%]	99.78	99.78	99.78	99.78	99.78	99.78
Pd Refin. Rec. [%]	99.12	99.12	99.12	99.12	99.12	99.12
Rh Refin Rec. [%]	96.00	96.00	96.00	96.00	96.00	96.00
Au Refin. Rec. [%]	99.03	99.03	99.03	99.03	99.03	99.03
Ir Refin. Rec. [%]	93.46	93.46	93.46	93.46	93.46	93.46
Os Refin. Rec. [%]	-	-	-	-	-	-
Ru Refin. Rec. [%]	90.27	90.27	90.27	90.27	90.27	90.27
Ni Refin. Rec. [%]	98.91	98.91	98.91	98.91	98.91	98.91
Cu Refin Rec. [%]	97.06	97.07	97.22	97.19	97.21	97.19
Co Refin. Rec. [%]	94.95	94.95	94.73	94.71	94.69	94.71

The smelting recoveries can be determined from Equation 27 and are derived by means of a metallurgical simulation, which is based on the relevant business plan (BP) production profiles that feed the respective refinery.

Equation 27: Refining Recovery

$$Refining\ Recovery\ [\%] = \frac{Refined\ Metal\ Content\ [Oz\ or\ t]}{Matte\ Metal\ Content\ [Oz\ or\ t]}\ x\ 100$$

For production profiles, the refined metal content in the matte is estimated from the product of the refining recoveries and the metal content in the matte as depicted in Equation 28.

Equation 28: Refined Metal Content

$$Refined\ Metal\ Content\ [Oz\ or\ t] = Refining\ Recovery\ [\%]\ x\ Matte\ Metal\ Content\ [Oz\ or\ t]$$

These refined production profiles are utilized to estimate revenue and costs as alluded in the financial modelling section that follows.

3.3.5 Findings

The metallurgical model integrates the process efficiencies and logic for concentrators, smelters and refineries into the techno-economic model to determine the refined metal products for revenue and costing purposes.

4 Key Components of Financial Modelling

4.1 Introduction

Operating costs include depreciation and amortization, but for free cash flow purposes, these are excluded from calculating cash operating costs. In the case of Anglo American Platinum, cash working costs are typically grouped as indicated in Table 30.

Table 30: Cash Working Costs (Anglo American Platinum (b), 2015)

On-Mine / Off-Mine Costs	Basic Financial Equation (BFE) Category	Category	Costs	Sub-Costs
On-Mine Costs	Cost 1	Mine Costs	Shaft head	Labour
On-Mine Costs	Cost 1	Mine Costs	Shaft head	Contractors
On-Mine Costs	Cost 1	Mine Costs	Shaft head	Materials & Services
On-Mine Costs	Cost 1	Mine Costs	Shaft head	Utilities
On-Mine Costs	Cost 1	Mine Costs	Shaft head	Sundries
On-Mine Costs	Cost 1	Mine Costs	Central Services	Direct
On-Mine Costs	Cost 1	Mine Costs	Central Services	Allocated
On-Mine Costs	Cost 2	Metallurgical Costs	Concentrator	
Off-Mine Costs	Cost 2	Metallurgical Costs	Smelter	
Off-Mine Costs	Cost 2	Metallurgical Costs	Precious Metal Refinery	
Off-Mine Costs	Cost 2	Metallurgical Costs	Base Metal Refinery	
Off-Mine Costs	Cost 2	Central Costs	Group Central Services (GCC)	
	Cost 3 = Cost 1+ 2			
Off-Mine Costs		Central Costs	Other Indirect Costs (OIC)	
Off-Mine Costs		Central Costs	Transport – Prec. Metals	
Off-Mine Costs		Central Costs	Transport – Base Metals	
Off-Mine Costs		Central Costs	Marketing	
Closure Costs		Closure Costs	Retrenchment Costs Rehabilitation Costs	

On-mine costs consist of mining and concentrator costs, while off-mine costs comprise of the smelter, refinery and central costs. In the case of mining companies, capital costs are often classified as project or stay-in-business (SIB) capital costs.

In both cases, it is important to distinguish between capital expenses, which qualify for full redemption in terms of Section 15(a) of the Income Tax Act (ITA), and capital expenses that qualify for partial annual redemption (PAR) in terms of Section 36.11(d) of the ITA, as the income tax treatment of these two categories are not similar. Capital expenses can be categorized as illustrated in Table 31 and Table 32. A distinction is made between the mine, process and central capital cost categories to enable the application of different capital cost escalation rates to the respective capital costs, as the composition of the various capital cost baskets are not similar.

Table 31: Stay-in-Business Capital Cost Categories (Anglo American Platinum (b), 2015)

On / Off Mine	Capital	Tax Legislation
On-Mine Costs	Mine	Section 15(a)
On-Mine Costs	Mine – Waste Stripping	Section 15(a)
On-Mine Costs	Concentrator	Section 15(a)
Off-Mine Costs	Smelter	Section 15(a)
Off-Mine Costs	Refinery – Precious Metals	Section 15(a)
Off-Mine Costs	Refinery – Base Metals	Section 15(a)
Off-Mine Costs	Central	Section 15(a)
Off-Mine Costs	Central - Housing	Section 36.11(d)
Off-Mine Costs	Central - Vehicles	Section 36.11(d)

Table 32: Project Capital Cost Categories (Anglo American Platinum (b), 2015)

On / Off Mine	Capital	Tax Legislation
On-Mine Costs	Mine	Section 15(a)
On-Mine Costs	Mine – Waste Stripping	Section 15(a)
On-Mine Costs	Concentrator	Section 15(a)
Off-Mine Costs	Smelter	Section 15(a)
Off-Mine Costs	Refinery – Precious Metals	Section 15(a)
Off-Mine Costs	Refinery – Base Metals	Section 15(a)
Off-Mine Costs	Central	Section 15(a)
Off-Mine Costs	Central - Housing	Section 36.11(d)
Off-Mine Costs	Central - Vehicles	Section 36.11(d)

4.2 Operating Cost Modelling

4.2.1 Introduction

Consideration of a number of costing fundamentals is required to ensure accurate and realistic cost modelling of production profiles.

Fixed and Variable Costs

An understanding is required of how costs will vary at different activity levels, which can be measured mainly in terms of production units and hours worked. According to Drury (1996, pp. 41-42), it is unlikely that fixed costs will remain constant across all activity levels and a distinction between fixed costs and variable costs must be made relative to the period under consideration. Drury (1996, pp. 41-42) stated that over a sufficiently long period, nearly all costs are variable and the shorter the period, the greater the probability that a specific cost will be fixed. Fixed costs are assumed to stay constant with activity level changes, but can change in response to other factors and management interventions (Drury, 1996, pp. 41-42). Ross, et al. (1996, p. 248), claimed that fixed costs are not fixed forever, but are only fixed for a specific period and any fixed costs can be modified or eliminated if given enough time. All costs can therefore be regarded as adjustable (Ross, et al., 1996, p. 248). From observations and critical reviews of cost estimates for project valuations and business plans, the adjustment of fixed costs, during the ramp-up or ramp-down phase of a project, has been identified as problematic. This can lead to serious overstatement or understatement of costs that will subsequently affect the accuracy of investment valuations and business plans. The application of fixed and variable costing ratios to perform high-level cost estimates should be approached with care and if possible, substituted with cost estimates from first principles by means of detailed costing models.

Overhead Cost Allocation

Drury (1996, p. 296) stated that activity-based costing (ABC) seeks to understand the forces that cause costs to change over time and assumes that investment centres require activities that cause costs. It assigns the costs of activities to investment centres based on the consumption of each activity (Drury, 1996, p. 296). Activity-based costing can be applied to allocate overhead costs to investment centres (Drury, 1996, pp. 296, 518). Drury (1996, pp. 84-87) explained that specific overhead rates need to be determined for each overhead department and the overhead rates are determined by dividing the costs of the relevant overhead department by an appropriate allocation base or cost driver. According to Drury (1996, pp. 84-87), the costs allocated to the investment centre are calculated by multiplying the specific overhead rate with the cost driver quantity as consumed by the investment centre. The objective is to choose a cost driver that provides a reasonable measure of the resources consumed by the investment centre (Drury, 1996, pp. 84-87).

Incremental and Average Costing

Computation of unit costs for overhead allocation or reporting purposes can be performed by means of the average or incremental costing method. Average costing is determined by dividing the total absolute costs by the total production so that each production unit carries the same unit cost rate. Incremental costs are the additional costs generated from the production of a group of additional units and are also known as differential costs (Drury, 1996, p. 45). Marginal cost is the additional costs generated from the production of one additional unit (Drury, 1996, p. 45) or is the change in costs that occurs when there is a small change in output (Ross, et al., 1996, p. 249). The incremental or marginal unit cost rate is calculated by dividing the incremental costs by the incremental production, which might differ from the base unit costs. The applicability of the two methods is illustrated in Section 6.2.

Full Absorption and Variable Costing

Full absorption costing refers to a system where all the fixed and variable costs are allocated to products. The alternative and opposite system to this is variable costing, which refers to a system where only the variable costs are allocated to products (Drury, 1996, p. 199). The application of full absorption costing is discussed in Section 5.6 and Section 6.3.

Cost Estimation

Activity-based budgeting (ABB) provides a framework for understanding the amount of resources that are required according to a planned level of activity and are useful for estimation of future expenditure (Drury, 1996, pp. 296, 518,519). Costs blue printing involves building up a cost structure from a zero base by providing a blueprint for each cost component (Wits Mining, 2013).

Cost Estimation - Engineering Method

Engineering methods of analysing cost behaviour are based on the use of an engineering work-study to analyse the relationships between inputs and outputs (Drury, 1996, p. 672). The procedure in these studies is to make direct observations of the underlying physical quantities required for an activity and to convert the results into a cost estimate (Drury, 1996, p. 672). Drury (1996, p. 672) stated that engineers, who are familiar with the technical requirements, estimate the quantities of material, labour and machine hours that is required and thereafter, prices and rates are applied to obtain the cost estimate. The engineering method is useful for estimation of direct costs for repetitive processes where input and output relationships are clearly defined (Drury, 1996, p. 672). A disadvantage of the method is that it can be time-consuming and expensive and therefore, it is appropriate to use when the direct costs forms a large portion of the total costs (Drury, 1996, p. 672). This method is suitable for on-mine cost estimation from first principles through the application of detailed costing models.

Cost Estimation - Inspection of Accounts Method

According to Drury (1996, p. 672), this method requires inspection of each item of expenditure within the accounts and classifies it as fixed, variable, semi-fixed or semi-variable costs. For variable cost items, unit costs are used and absolute or total costs are preferred for fixed cost items. For semi-fixed and semi-variable costs, agreement is required on a cost equation that best describes the cost behaviour (Drury, 1996, p. 672).

Cost Estimation - High-low Method

Drury (1996, p. 673) claimed that the high-low method can be used to determine a reasonable fixed-variable ratio of a cost item. Drury (1996, p. 673) explained that the method consists of selecting the highest and lowest activity levels for a period and to divide the changed cost amount by the differential in activity levels to obtain the variable unit costs. The fixed costs can be estimated at any activity level (assuming a constant variable unit cost) by subtracting the total variable costs from the total costs (Drury, 1996, p. 673).

4.2.2 Mine Costs

In the modelling of mine costs, it is imperative to determine the main cost drivers and their relationship with activity levels. Labour and equipment make up a large portion of costs on mines and the determination of labour complements and equipment requirements will be a good starting point for operating and capital cost estimates.

Equipment Utilization

The equipment productivity, efficiency and utilization should be considered when specifying the production capacity of machines to determine the number of machines required for a given production profile. The equipment utilization is impacted by the time allocation of the equipment as shown in Table 33.

Table 33: Equipment Time Allocation Matrix (Anglo American Platinum (a), 2015)

<table>
<tr><td colspan="10">Calendar Time</td></tr>
<tr><td colspan="8">Controllable Time
(Available Time)</td><td colspan="2">Uncontrollable Time
(Not Available Time)</td></tr>
<tr><td colspan="5">Uptime
(Running Time)</td><td colspan="3">Downtime
(Non-Running Time)</td><td rowspan="3">Uncontrollable Events</td><td rowspan="3">Not available for Production</td></tr>
<tr><td colspan="2">Operating Time
(Working Time)</td><td colspan="3">Non-Operating Time
(Lost Time)</td><td rowspan="2">Scheduled Maintenance
▪ Planned Maintenance
▪ Repairs
▪ Modifications</td><td rowspan="2">Non-Scheduled Maintenance
• Repairs
• Modification</td><td rowspan="2">Operational stops</td></tr>
<tr><td>Primary Production</td><td>Secondary Production</td><td>Delays</td><td>Stand-by</td><td>Consequential</td></tr>
</table>

Material Costs

A standard bill of material can be generated for each activity to determine the material costs, but the Pareto's principle, which states that 20% of the items account for 80% of the value should be applied. Fixed-variable ratios, which can be determined from historical costs analyses, can also be applied to estimate material costs. Fixed costs are assumed to remain constant during steady state production, except if the operation changes significantly. For variable material costs, the product of the quantity driver (units/production unit) and the unit cost rate (R/unit) will provide a variable cost driver (R/production unit). The estimated costs should be benchmarked against historical costs at a similar production level. An adjustment factor needs to be applied to calibrate the estimated costs in line with actual historical costs before it can be extrapolated, based on the future production profile, to estimate future material costs.

Labour Availability

In the case of certain labour designations, a distinction should be made between labour at-work and labour in-service. The labour at-work complement is determined based on crew sizes, crew productivity and the production profile, whereas the labour in-service complement is calculated by adding an in-service factor to the at-work labour complement. The addition of the factor is required, as a significant percentage of the workforce is not available in the workplace, primarily due to annual leave, sick leave, maternity leave and training. Equation 29 is used to calculate the in-service labour complement from the at-work labour complement.

Equation 29: In-service Labour Complement

$$In\ service\ Labour\ Complement = At\ work\ Labour\ Complement\ x\ \ In\ Service\ Factor$$

Typical in-service factor value is 1.15 for conventional labour intensive mines (Anglo American Platinum (b), 2015).

Cash Labour Costs

Cash labour costs include the following elements, which should be used in the labour cost calculation:

- Cash salary
- Cash car allowance
- Retirement funding
- Housing allowance payments
- Regional allowance payments
- 13th Cheques payments
- Leave day payouts
- Shift and standby allowance payments
- Overtime payments
- Performance bonus payments

The following elements should be excluded from the cash labour costs:

- Company housing benefits – Non-cash costs
- Leave day provisions – Non-cash costs
- Cell phone costs – Already part of Sundry costs
- Shares payments – Already part of Other Indirect Costs (OIC)

Mine Departments

It is advisable to estimate the cost elements per department on a mining shaft to ensure completeness and reasonability, through benchmarking with previous budgets and actual information.

The departments and sub-departments as depicted in Table 34 are often found in platinum mines.

Table 34: Mine Departments (Anglo American Platinum (b), 2015)

Mine Departments	Sub-departments
Mining	Conventional Development Conventional Development Construction Conventional Ledging Conventional Ledge Equipping Conventional Stoping Conventional Supervision
Logistics	Horizontal Logistics (per half-level) Decline Logistics Vertical Logistics Surface Logistics
Engineering	Horizontal Engineering (per half-level) Decline Engineering Vertical Engineering Surface Engineering
Direct Central Services	General Management Mineral Resources Finance Human Resources Engineering Safety

Shaft head Costs

Shaft head costs can be broken down into the costs elements of labour, contractors, stores (material), utilities (water, electricity and compressed air) and sundries. For each activity on the mine, the sub-activities should be interrogated to determine the required resources and cost drivers. In the costing models, assumptions are made concerning staffing, equipping and material consumption, which varies from mine to mine and even between sections within a mine. What is important is to develop a detailed costing model in which these parameters can easily be changed and applied to filter through the cost estimates. The production and associated cost estimates are done per half-level, which is combined with other relevant half-levels to provide cost estimates per investment centre and shaft.

4.2.3 Metallurgical Costs

General

Metallurgical costs are estimated from either a costing model or average costing methods. For a costing model, the relevant circuits in the metallurgical process should be considered to determine the costs from first principles. Within each circuit, the required labour, equipment and material must be established. In the case of average costing methods, yearly unit costs are calculated from the absolute plant operating costs and the strategic production profile as determined during the business planning period. It is assumed that the strategic production profile will be maintained regardless of whether a specific project will continue or not.

Concentrator Costs

It is standard practice to determine the concentrate costs for a given production profile from a detailed costing model. Concentrator unit costs (R/ton milled) are calculated and applied to the production profiles of the contributing investment centres to allocate these costs to these investment centres.

Smelter Costs

The smelter costs as determined during the business planning process are divided by the smelter production to derive the average smelter unit costs. The smelter costs per investment centre are determined from the product of the average smelter unit costs and the production of the relevant investment centre. The average smelter unit costs (R/concentrator ton) are based on the concentrate tonnage received by the smelter.

Precious Metal and Base Metal Refinery Costs

The refinery costs as determined during the business planning process are divided by the refinery production to derive the average refinery unit costs. The refinery costs per investment centre are computed from the product of the average refinery unit costs and the production of the relevant investment centre. The average base metal refinery unit costs (R/BM ton) are based on the refined base metal tonnage, whilst the average precious metal refinery unit costs (R/6E Oz) are based on the refined precious metals ounces.

4.2.4 Central Costs

General

Average unit costs are determined for each component based on the absolute cost forecast as determined during the business planning process and the associated strategic production profile. The cost drivers for each component of central costs are displayed in Table 35.

Table 35: Central Costs (Anglo American Platinum (b), 2015)

Description	Cost Drivers
Group centralized costs (GCC)	R / Pt Oz sold
Other indirect costs (OIC)	R/ Pt Oz sold
Transport - Precious metal sold	R / 4E Oz sold
Transport - Base metals sold	R / 4E Oz sold
Marketing	R / Pt Oz sold

Due to the process pipeline effect, which considers the delay to convert metals produced to cash, a distinction is made between refined metals produced and refined metals sold, which serve as a denominator in the calculation of central unit costs. For each investment centre, the central costs are determined from the product of the respective unit cost and the relevant production profile.

Royalties

For financial accounting purposes, royalties are included in central costs, but for cash flow estimation, it is excluded due to sequential calculation reasons. It is important to note that group centralized costs (GCC), other indirect costs (OIC), transport and marketing costs are excluded from the royalty earnings before interest and tax (EBIT) calculation. For this and other reasons, the financial accounting EBIT definition differs from the royalty EBIT definition as discussed in Section 5.8.

4.2.5 Closure Costs

Mine closure costs consist of environmental rehabilitation costs and labour retrenchment costs. In the case of closure costs, care should be taken not to double account for items already included in other indirect costs (OIC) as listed in Table 35.

Environmental Rehabilitation Costs

Regulation 41(3) of the MPRDA requires that the closure liability in terms of environmental rehabilitation costs of mining operations must be assessed on an annual basis (DMR, 2002). Regulation 54(2) indicates that the holder of a prospecting right, mining right or mining permit must annually update and review the quantum of the financial provision for rehabilitation liability in consultation with a competent person (DMR, 2002). On an annual basis, in terms of the commitments of its approved Environmental Management Program (EMP) and rehabilitation objectives, each operation should estimate the total expenditure required for the final rehabilitation and remediation of its operations (DMR, 2002). The use of a standardized Rehabilitation Cost Estimation Model (RCEM) is suggested, as this standardizes the approach to rehabilitation costing and makes the annual revision easier and less costly (Anglo American, 2013). The establishment of an environmental trust fund to finance the estimated environmental rehabilitation liabilities of operations should be considered and the contributions into the fund are based on the estimated environmental obligation over the life of the mine, to a maximum of 30 years (Anglo American, 2013). Where a trust fund is used, the cash outflows will reflect as annuities instead of a lump sum at project closure date.

Labour Retrenchment Costs

Agreement on the underlying assumptions is required to provide a consistent way to estimate labour retrenchment costs. Significant reductions in the labour complements form the basis to determine retrenchment costs after considering the following factors (Kriek, 2014):

- Notice pay – usually 1 month's salary
- Severance allowance – usually salary of 2 weeks per year in service and assume an average of 10 service years per employee
- Housing – usually 3 month's housing allowance
- Bonuses and shares – as negotiated and agreed
- Long service awards – fixed amount per employee
- Labour attrition rate – approximately 1% per year

4.2.6 Findings

Fixed-variable cost estimation ratios should be applied with care and the adjustability of fixed costs should be incorporated in cost estimates of long-term production profiles. Activity–based costing can be applied to determine the appropriate cost drivers to allocate overhead costs to investment centres. These unit cost drivers can be determined from average costing or incremental costing methods. The cost estimation method is mainly driven by the required details, accuracy and available time to perform the estimate. Mining and metallurgical plant costs are dependent on the equipment, material and labour used in the process and vital costing features, as discussed, should be incorporated to ensure realistic cost predictions.

The on-mine cost forecasts of investment centres require estimations from first principles by means of detailed costing models, in which parameters and assumptions can easily be modified to filter through the cost estimates. The use of average costing rates is suitable to determine the off-mine costs of an investment centre. Closure cost estimates need to be supported by appropriate estimation models and assumptions.

4.3 **Capital Cost Modelling**

4.3.1 Introduction

Capital costs can be classified as either project or stay-in-business (SIB) capital costs.

Expansion capital expenditure is incurred to increase the:

- Current mining production profile; or the
- Current processing capacities and efficiencies.

Replacement project capital expenditure is required to maintain the:

- Current mining production profile; or the
- Current processing capacities and efficiencies.

In the case of mining projects, the project capital costs are largely made up of new excavation and equipment costs within the capital footprint, which includes vertical shafts, decline shafts and the associated development. For processing projects, the project capital costs are usually incurred for new infrastructure and equipment. Stay-in-business capital costs are utilized to maintain, improve or replace existing excavations, infrastructure and equipment. It can also be applied to mitigate risks or for business improvement purposes as shown in Table 36. Both project and SIB capital costs should be estimated and included for investment valuation and business planning purposes.

Table 36: Capital Cost Classification (Smith, 2011, p. 164)

<table>
<tr><th colspan="2">Projects</th><th colspan="7">Stay in Business Capital Categories</th></tr>
<tr><td>Expansion (Proj E)</td><td>Replacement (Proj R)</td><td rowspan="2">Replacement of Equipment (RE)</td><td rowspan="2">Business Improvement (BI)</td><td colspan="3">Risk</td><td rowspan="2">Ore Reserve Development (ORE)</td><td rowspan="2">Shared Infrastructure (SI)</td></tr>
<tr><td>Production Increases Capacity</td><td>Maintain Production Capacity</td><td>Safety (RS)</td><td>Legislation (RL)</td><td>Business (RB)</td></tr>
<tr><td>Expansion Capital</td><td colspan="8">Ongoing Capital</td></tr>
</table>

4.3.2 Escalation

Escalation is the allowance made in an estimate to provide for the variance between estimated costs (in real money terms) and actual costs (in nominal money terms) due to inflation (Da Vinci Institute, 2009, p. 3.43). Project cost escalation can be based on general escalation rates or project specific escalation rates as referred to in Section 5.7

4.3.3 Capital Cost Estimates

Projects advance through a number of project phases during their life cycles and the accuracy of capital cost estimates increases as it progresses. The different types of capital cost estimates, with their associated accuracies and contingency attributes, are listed in Table 37.

Table 37: Capital Cost Estimation Types (Da Vinci Institute, 2009, pp. 3.42, 3.45)

Type	Project Phase	Class	Accuracy	Contingency
Order of magnitude (OoM)	Conceptual (FEL 1)	0	+-35%	+20%
Preliminary Cost Estimate (PCE)	Pre-feasibility (FEL 2)	1	+25% to -15%	+15%
Control Budget Estimate (CBE)	Feasibility (FEL 3)	2	+15% to -5%	+10%
Latest Cost Forecast (LCF)	Execution (Detailed design)	3/4	+10% to -10% or +5% to -5%	
Latest Cost Forecast (LCF)	Execution (Construction)	3/4	+10% to -10% or +5% to -5%	
Latest Cost Forecast (LCF)	Execution (Commissioning)	3/4	+10% to -10% or +5% to -5%	

4.3.4 Contingencies

Cost estimation methods do not provide 100% accurate estimates and therefore, contingencies are added to the basic estimates (Nel, 2006, p. 330). The contingency allowance provides the estimate with a high probability of realisation (Da Vinci Institute, 2009, p. 3.43).

The required contingency can be derived from the estimate's level of accuracy as calculated from Equation 30.

Equation 30: Approximate Contingency

$$Approximate\ Contingency\ [\%] = 100\% - Estimate\ Accuracy\ [\%]$$

Cost estimation of long-term projects may result in less accurate estimates due to the increased uncertainty and consequently, requires a larger contingency provision. The estimate's accuracy can be improved by involving representatives from departments such as purchasing, engineering, production and finance to produce a joint estimate (Nel, 2006, p. 327).

4.3.5 Capital Expenditure Footprint

Typical mining project capital costs include:

- Future study costs
- Future execution costs
    - Project management and engineering costs
    - Vertical and decline shaft development and equipment
    - Development and equipment that form part of the shaft infrastructure
    - Haulage development and equipment up to the apex or first crosscut

All future capital costs required to establish the initial capital footprint should form part of the project capital costs for valuation purposes. A map of the capital footprint should be interrogated to distinguish between capital costs and working cost development. Development excavations from the shaft to the apex or first crosscut are usually regarded as capital cost development, whilst the remainder of the development to the investment centre boundary are working cost development. The classification of development costs is important, as it will determine the timing of the excavation, which will affect the cash flow schedule and investment valuation. Capital development or infrastructure outside the investment centre area might be for the benefit of the investment centre, in which case the capital costs should be included for valuation purposes. In complex situations, where development is done from an adjacent investment centre to give early access to a new investment centre, the incremental valuation methodology, which considers the base and extended business cases as alluded in Section 5.3, should be considered to determine the treatment of this capital development costs for valuation purposes. Figure 19 provides an illustration of the development footprint for two investment centres of a new vertical shaft.

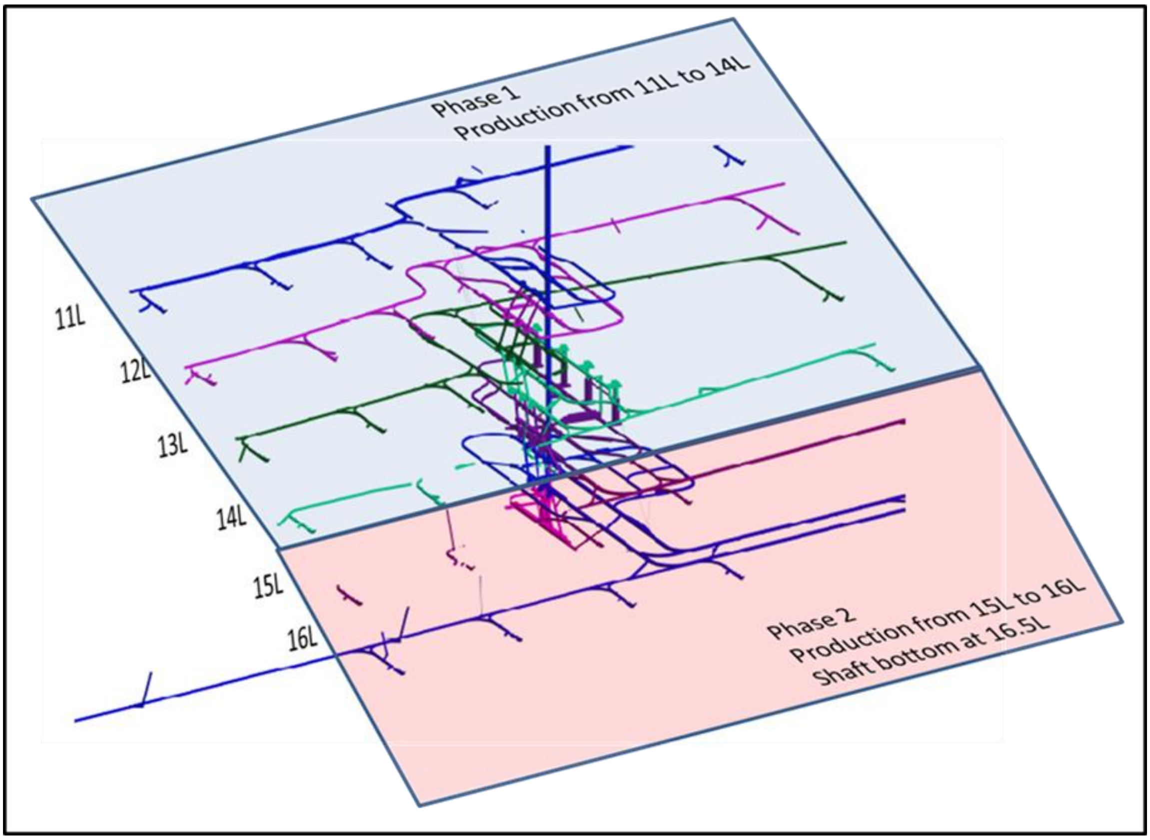


Figure 19: Development Footprint per Investment Centre (Anglo American Platinum (g), 2014)

4.3.6 Findings

Capital expenditure can be categorized as either project or SIB capital costs according to the nature of the expense and both should be estimated and included in the investment valuations. Capital cost estimates increase their accuracy as the project progresses through the project phases. Contingencies are added to capital cost estimates due to the inherent forecasting inaccuracies and the effect of inflation is incorporated by means of escalation. Project capital costs can consist of study and execution capital costs and all future incremental capital costs relevant to an investment centre should be considered in the investment valuation.

5 Key Components of Techno-economic Modelling

5.1 Introduction

Ross, et al. (1996, p. 180), explained that capital investment decisions are concerned with the choice of fixed assets in which the business should invest and these decisions will determine the nature of a firm's operations and products for years to come. The growth of an economy is critically dependent on new investments that create value (Ross, et al., 1996, p. 180).

Capital investment decisions form part of the capital budgeting process, which includes the following decisions (Drury, 1996, p. 383):

1. Determine the composition of the project portfolio.
2. Determine the amount of capital expenditure required for the project portfolio.
3. Determine how the capital expenditure will be financed.

According to Drury (1996) the capital investment decision-making model includes the following steps:

1. Identify strategic business objectives.
2. Search for investment opportunities.
3. Gather information about possible future business environments.
4. List outcomes for each anticipated business environment.
5. Measure the investment returns in terms of shareholder value for each of the possible outcomes.
6. Select the investment projects that maximize value and include them in the optimized business plan.
7. Obtain investment authorization for the selected projects and implement projects.
8. Review capital investment decisions.

5.2 Concepts and Principles

Correct application of concepts and principles in discounted cash flow analysis is important for accurate investment valuations and business planning.

Relevant Cash Flow

Relevant cash flow consists of all changes in the firm's future cash flow, that has a direct consequence of taking the project (Ross, et al., 1996, p. 209) or that will be affected due to a specific decision, whilst irrelevant cash flow will not be affected by a specific decision (Drury, 1996, p. 43). Sunk cash flows are irrelevant for decision-making as it has already occurred and cannot be removed (Ross, et al., 1996, p. 210). It can also be described as cash flows that have been created by a decision in the past and cannot be changed by any future decision (Drury, 1996, p. 44).

Incremental Cash Flow

Drury (1996, p. 394) stated that investments decisions should be analysed in terms of the cash flows that can be directly attributable to them and should only include the incremental cash flows that will occur in the future, because of the accepted investment. It will include cash inflows and outflows, as well as savings in cash outflows (Drury, 1996, p. 394). Incremental cash flow is the difference in a firm's future cash flow due to the project (Ross, et al., 1996, p. 209). The project could have a positive or negative side effect or spillover effect onto current operations or projects, and these adjustments should be incorporated in the incremental cash flow, as it is a relevant cash flow (Ross, et al., 1996, p. 211).

Opportunity Costs

Opportunity costs are the most valuable alternative that is given up if a specific investment is undertaken (Ross, et al., 1996, p. 211). Drury (1996, p. 45) explained that these costs measure the opportunity that is lost when a decision to take a specific course of action implies that an alternative course of action has to be sacrificed. Opportunity cost only applies to scarce resources and is a relevant cost (Drury, 1996, p. 45). A business should only invest in capital projects that yield a return in excess of the opportunity costs which are also known as the minimum rate of return, the cost of capital, discount rate or interest rate (Drury, 1996, p. 387).

Cash Flow Identity (CFI)

Ross, et al. (1996, p. 31) stated that the discounted cash flow analysis is based on the cash flow identity, which is derived from the balance sheet identity as reflected in Equation 31 and Equation 32.

Equation 31: Balance Sheet Identity (BSI) (Ross, et al., 1996, p. 31)

$$Assets = Equity + Liabilities$$

Equation 32: Cash Flow Identity (CFI) (Ross, et al., 1996, p. 31)

$$Cash\ flow\ from\ Assets = Cash\ flow\ to\ Suppliers\ of\ Capital$$

$$Cash\ flow\ from\ Assets = Cash\ flow\ to\ Shareholders + Cash\ flow\ to\ Lenders$$

The CFI says that the cash flow from assets is equal to the cash flow paid to suppliers of capital or alternatively, the cash generated by the assets is used to pay the shareholders and the lenders (Ross, et al., 1996, p. 31). Ross, et al. (1996, p. 212) indicated that the cash flow schedule should only include cash flow from assets and not cash flow to shareholders and lenders. Repayment of principal loan amounts and financing costs, which includes interest paid and dividends paid are excluded from the cash flow schedule (Ross, et al., 1996, p. 212).

Ross, et al. (1996, pp. 22, 34) stated that the cash flow from assets consists of operating cash flow, net capital spending and changes in net working capital as shown in Table 38.

Table 38: Cash Flow Identity (Ross, et al., 1996, pp. 22, 34)

Cash Flow Identity	
Cash flow from Assets = Cash flow to Shareholders + Cash flow to Lenders	
Cash Flow from Assets	
	Operating Cash Flow (OCF)
Less	Net Capital Spending
Less	Additions to Net Working Capital (NWC)
Equal	**Cash Flow from Assets**
Operating Cash Flow (OCF)	
	Gross Sales Revenue
Less	Commissions
Equal	**Net Sales Revenue**
Less	Cash Working Costs
Less	Depreciation & Amortization
Equal	**Operating Profit** (Profit before Interest and Tax [PBIT]) or (Earnings before Interest and Tax [EBIT]
Plus	Depreciation & Amortization (Add back)
Equal	**Operating Cash Flow before Tax** (Profit before Interest, Tax ,Depreciation and Amortization [PBITDA) (Earnings before Interest, Tax, Depreciation and Amortization [EBITDA])
Less	Tax
Equal	**Operating Cash Flow (OCF)**
Net Capital Spending	
	Ending Fixed assets
Less	Beginning Fixed assets
Plus	Depreciation
Equal	**Net Capital Spending**
Changes in Net Working Capital	
	Ending Net Working Capital
Less	Beginning Net Working Capital
Equal	**Changes in Net Working Capital**
Cash Flow to Shareholders	
	Dividends paid
Less	Net new equity raised
Equal	**Cash Flow to Shareholders**
Cash Flow to Lenders	
	Interest paid
Less	Net new borrowings
Equal	**Cash Flow to Lenders**

Operating Cash Flow

According to Ross, et al. (1996, p. 31), operating cash flow (OCF) is the cash flow that results from the normal business activities of producing and selling products or services. Financing expenses of assets, which includes interest paid and dividends paid, are not included as they are not operating expenses, but royalties and taxes are taken into account (Ross, et al., 1996, p. 31).

Accounting profit differs from cash flows because the income statement contains non-cash items of which depreciation and amortization of fixed assets are the most significant (Ross, et al., 1996, pp. 27-28). Depreciation is a non-cash expense and has a cash flow consequence only because it influences the tax calculation (Ross, et al., 1996, p. 217). Wear and tear allowance is the depreciation claimed as an expense for tax purposes and the yearly allowable amount is determined according to the guidelines laid down by the Receiver of Revenue. The Receiver prescribes rates for wear and tear allowances for different assets (Ross, et al., 1996, p. 217). Tax shield is the tax saving resulting from the wear and tear allowances (depreciation deductions) and equals the wear and tear amount multiplied by the tax rate (Ross, et al., 1996, p. 226). If an asset is sold for a price higher than the tax book value, the difference (profit) should be included as a taxable income and when the asset is sold at a price lower than the tax book value, the difference (loss) is included as a tax deduction (Ross, et al., 1996, p. 217).

Net Working Capital

Net working capital (NWC) is the amount spent on working capital as measured by the increase in current assets over current liabilities (Ross, et al., 1996, p. 32). Investment in working capital will increase (negative cash flow) due to an increase in cash required to pay expenses, material inventory (stock in stores) and accounts receivable (trade debtors or customers) to cover credit sales. Investment in working capital will decrease (positive cash flow) due to an increase in accounts payable (trade creditors or suppliers) for credit purchases and an increase in tax liabilities (tax creditors). The balance for each item above should be estimated at year-end and the balance movement between two successive years will determine the net cash flow movement of the working capital. All nominal net working capital invested in a project should be recovered before the end of the project (Ross, et al., 1996, p. 211).

A frequently used approach to forecasting working capital funding requirements is the percentage-of-sales method. This model assumes there is a direct relationship between the level of sales and the working capital components (Correia, et al., 1993, p. 472). The value from credit sales might also not be readily available from the financial statements and consequently, assumptions could be made that credit sales equal a certain percentage (e.g. 90%) of total sales (Correia, et al., 1993, p. 186). The debtor's collection period is calculated using Equation 33.

Equation 33: Debtors Collection Period

$$Debtors\ Collection\ Period\ [Days] = \frac{Accounts\ Receivable\ (Debtors)[R]}{Credit\ Sales\ [R]}\ x\ 365$$

The value of credit purchases might also not be available from the financial statements and assumptions could be made that the credit purchases is equal to a certain percentage (e.g. 70%) of the costs of sales (Warren, 1991, p. 68). The creditor's payment period is calculated using Equation 34.

Equation 34: Creditors Payment Period

$$Creditors\ Payment\ Period\ [Days] = \frac{Accounts\ Payable\ (Creditors)[R]}{Credit\ Purchases\ [R]}\ x\ 365$$

Stocks are recorded at cost price, but sales are recorded at selling price and for this reason, the closing inventory should preferably be divided by the costs of sales and not sales (Correia, et al., 1993, p. 186) (Warren, 1991, p. 66). The average inventory age is calculated using Equation 35.

Equation 35: Average Inventory Age (Stock Days)

$$Average\ Inventory\ Age\ [Days] = \frac{Closing\ Inventory\ [R]}{Cost\ of\ Sales\ or\ Total\ Purchases\ [R]}\ x\ 365$$

Application of these net working capital methods and assumptions are demonstrated in Section 5.10.

Stand-alone Principle

Valuation of a project is based on the project's incremental cash flow. Once the incremental cash flow is determined, the project can be viewed as a mini-firm with its own future revenues, costs, assets and cash flows, which will be evaluated purely on its own merit in isolation from other activities or projects (Ross, et al., 1996, p. 210). The application of this principle in used to exhibit the difference between differential and stand-alone incremental modelling in Section 6.3.

Cash Flow Timing Convention

It is implicitly assumed that cash flows occur at the end of each period unless explicitly told otherwise (Ross, et al., 1996, p. 123). Drury (1996, p. 394) stated that the underlying mathematics in discounting factors is based on the assumption that cash flows in future years will occur in one lump sum at year end. Drury (1996, p. 394) explained that this is an unrealistic assumption as cash flows occur throughout the year and consequently, a more accurate method would be to use monthly discount tables or tables based on continuous compounding. The year-end lump sum discounting does however, reduce the number of computations and provide results that are normally accurate enough for decision-making purposes (Drury, 1996, p. 394).

Cash Inflow and Outflow Convention

Cash flow convention requires cash inflows to be indicated as positive values and cash outflows to be indicated as negative values in the cash flow schedule (Nel, 2006).

Discount Rates and Rate of Return

Real discount rates exclude inflation and apply to real cash flows, while nominal discount rates include inflation and apply to nominal cash flows (Ross, et al., 1996, p. 212) (Drury, 1996, p. 427). A real rate of return is the return on an investment excluding the effects of inflation and is the percentage change in the buying power (Ross, et al., 1996, pp. 12, 276, 277). The nominal rate of return is the return on an investment including the effects of inflation and is the percentage change in the currency one has (Ross, et al., 1996, pp. 12, 276, 277).

5.3 Valuation Methodology

Discounted Cash Flow

Valuations need to be performed on an incremental basis using a discounted cash flow model. The incremental cash flow is determined by the differential between the base and extended (base plus project) business cases.

A production schedule in terms of tonnes milled and associated 4E head grade is used as the basis for both the base and extended discounted cash flow schedules. After calculation of the 4E metal content in the tonnes milled, the metal split percentage (prill split %) is applied to determine the respective metal content in the tonnes milled. The concentrator recovery percentage per metal is multiplied with the tonnes milled metal content to provide the metal content in the concentrate. Thereafter, the smelter recovery percentage per metal is multiplied with the concentrate metal content to reflect the metal content in the smelter matte. The refined metal produced is determined from the product of the refinery recovery per metal and the metal content in the smelter matte.

The metal pipeline effect takes into consideration the delay in cash revenue inflow due to the time to process the tonnes milled to refined metals and to convert the refined metals to actual cash in the bank. The metal pipeline effect, as measured in months, is applied to the refined metal produced to determine the refined metal sold, which can be used to calculate the revenues per metal by applying the long-term economic parameters. The cash inflows of revenues are delayed between one and five months due to the metal pipeline effect. Chrome is produced as a by-product from UG2 ore if economically viable.

Revenue is generated from sales of the three major platinum group metals (PGM) (platinum, palladium and rhodium), gold, nickel, copper and cobalt. Revenue is subject to commissions and discounts in terms of existing marketing and sales agreements. The nominal gross revenue in ZAR is calculated from the product of nominal metal prices in USD and nominal ZAR/USD exchange rates.

On-mine cash operating costs include the mine and concentrator costs. Mine costs include shaft-head, direct central services and allocated central services costs. Mine costs in constant terms (Year 0) are escalated by underground escalation rates to provide mine costs in nominal terms, whilst concentrator costs in constant terms are escalated by concentrator cost escalation rates to convert it to nominal terms. Off-mine operating costs are determined from constant average unit costs and are based on the metals produced. The off-mine unit costs are updated via the global assumptions. It includes smelting, refining, group central services (GCC), other indirect (OIC), transport and marketing costs. Process costs in constant terms are escalated by the process cost escalation rates to calculate process costs in nominal terms. The rest of the off-mine costs and closure costs are escalated by the SA CPI to provide the costs in nominal terms.

The SIB capital costs for the mine and concentrator are determined by means of a detailed SIB capital cost estimation model, whilst the SIB capital costs for smelters, refineries and the central services are often based on a percentage of their respective operating expenditure, as determined in the latest business planning cycle. Mine and process SIB capital costs, in constant (Year 0) money terms, are escalated by the respective general mine or process capital cost escalation rate, whilst central SIB capital costs are escalated by the SA CPI, to convert them to nominal terms. Project capital expenditure includes an allowance for contingencies and is escalated using, general capital cost escalation rates or project-specific capital cost escalation rates, depending on the project phase. A project classified as a replacement project does not increase metal production above current processing capacity and in this case, no allocation of processing expansion capital costs must be included in these valuations.

Nominal cash operating profit before interest and tax, capital expenditure and metal inventory changes are used to calculate the company’s tax payable. The cash flow effect due to changes in nominal net working capital must be incorporated in the valuation of the project. The nominal net cash flows are de-escalated by SA CPI factors to obtain the net cash flow in real money terms (Year 1) to which a real hurdle rate is applied to calculate the project NPV. The base and extended cases are optimized by a tail management procedure as alluded in Section 6.3.

Money Terms and Conversion

Constant and real values are both present values cash flows, which are reflected in money terms of a specific year (Year 0 or 1), while nominal values are escalated values to cater for inflation and are reflected in the money terms of the specific year in which the yearly cash flow will occur. For the purpose of the recommended practice, a distinction will be made between constant and real money terms. In the mine planning environment, the business plan is done in the input year (Year 0), which is prior to the base or first year (Year 1) of the life of mine business plan.

Constant Money Terms (Present Values in Year 0)

Constant money terms can be described as the present value of an item in today's money terms (Year 0) without considering any inflation or escalation. Mineral commodity prices, operating costs and capital costs are initially forecasted and estimated in constant money terms, as the actual prices of these commodities are available in today's money terms.

Nominal Money Terms (Future Values)

Nominal cash flows are determined by escalating the constant cash flows by the applicable escalation rate factor. Different escalation rates are applicable to the various cash flow line items, while other values like unredeemed capital are not escalated when carried forward to the following year. It is also imperative to perform certain calculations, like taxes, net working capital changes and dividend withholding tax in nominal terms to determine an accurate and realistic estimate of future cash flows.

Real money terms (Present Values in Year 1)

Cash flows in real money terms are calculated by de-escalating the nominal cash flows with a SA CPI factor to convert it back to present values in year 1 of the cash flow schedule.

The process of money term conversion is illustrated in Figure 20.

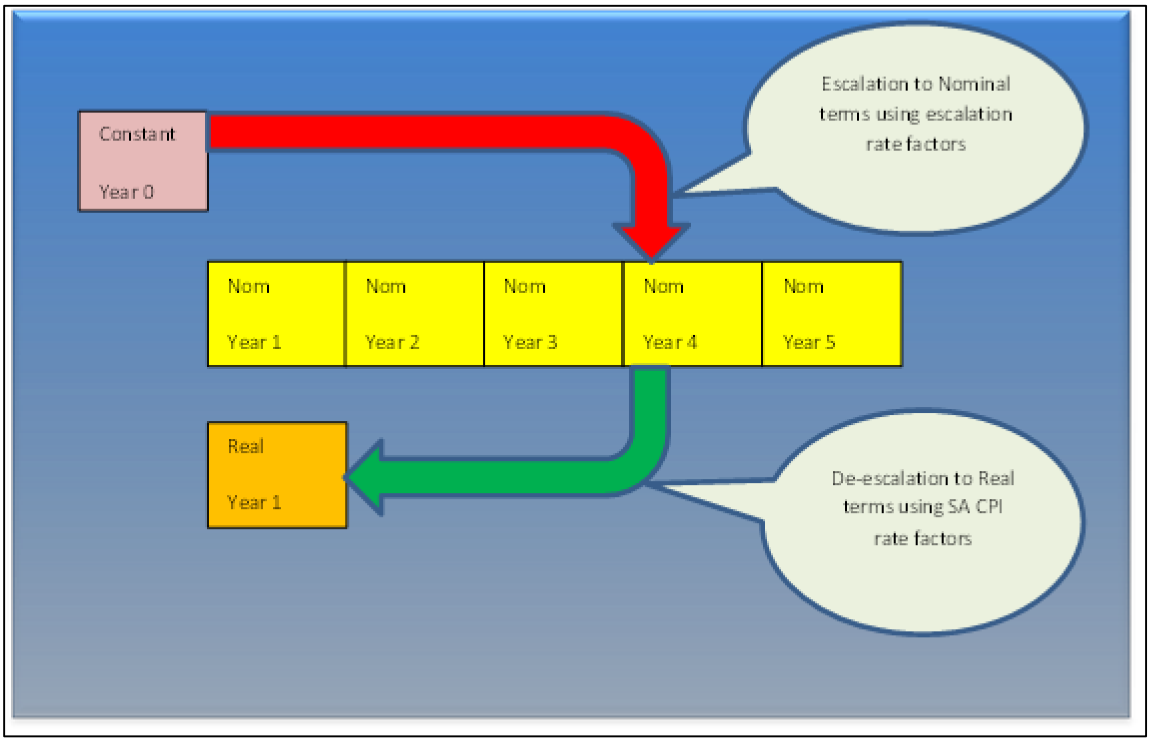


Figure 20: Process of Money Term Conversion

It is advisable to repeat the complete cash flow schedule in constant, nominal and real money terms to ensure accuracy and integrity of the cash flow results. The methodology to achieve this is incorporated in the sections that follow.

5.4 **Global Assumptions**

Global assumptions are a set of yearly information that contains long-term economic and planning parameters. Global assumptions are influenced by key drivers in the macro-economic environment as exhibited in Figure 21.

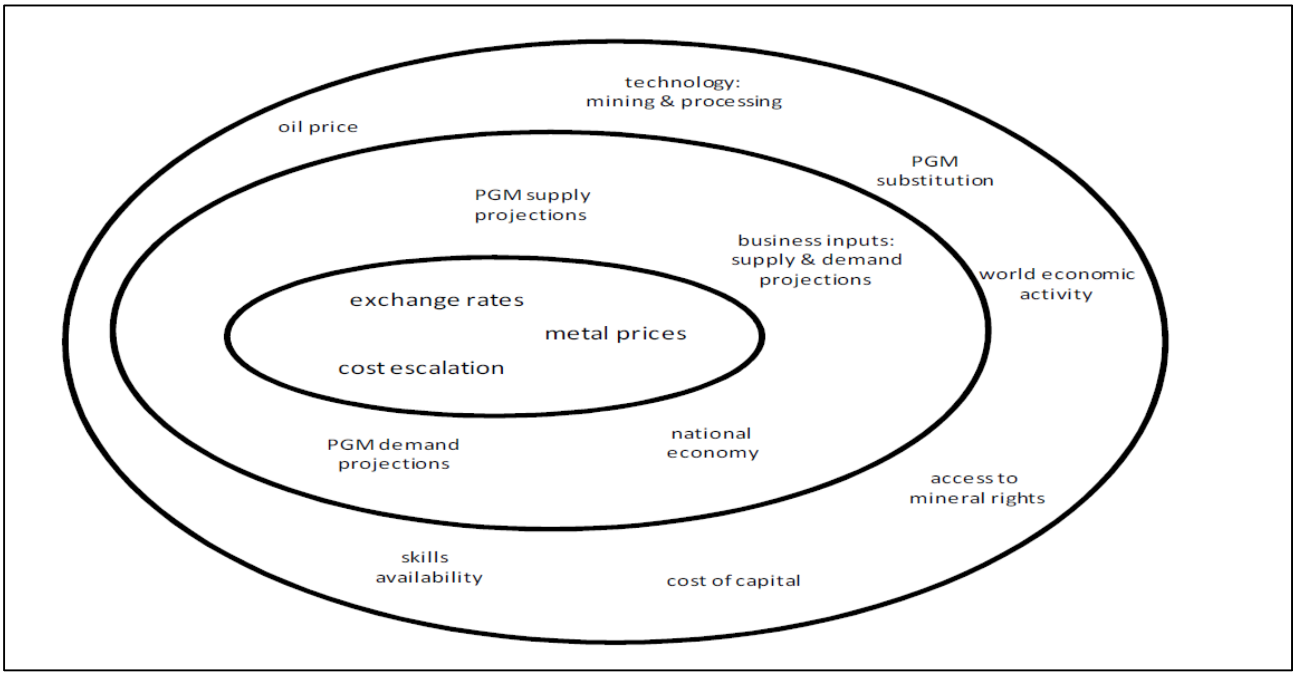


Figure 21: Key Drivers of Global Assumptions (Smith, 2011, p. 128)

The assumptions consist of consumer price indexes (CPI), exchange rates, escalation rates and metal prices, as exemplified in Table 39, Table 40 and Table 41.

Table 39: Global Assumptions: CPI, R/$, Tax and Discount rate (Anglo American Platinum (d), 2015)

CPI, R/$, Tax, Discount Rate	2015	2016	2017	2018	2019	2020
SA CPI growth [%]	5.90	5.50	5.20	5.20	5.20	5.20
USA CPI growth [%]	2.20	2.30	2.20	2.20	2.20	2.20
R/US$ Exchange Rate - constant	11.098	11.229	11.591	12.364	12.364	12.361
R/US$ Exchange Rate - nominal	11.500	12.000	12.750	14.000	14.410	14.830
R/US$ Exchange Rate - real	11.500	11.636	12.011	12.812	12.811	12.809
Tax Rate [%]	28.00	28.00	28.00	28.00	28.00	28.00
Dividend withholding tax rate [%]	5.00	5.00	5.00	5.00	5.00	5.00
Discount Rate (real) [%]	11.50	11.50	11.50	11.50	11.50	11.50

Table 40: Global Assumptions: Escalation Rates (Anglo American Platinum (d), 2015)

Escalation Rates	2015	2016	2017	2018	2019	2020
On-mine Opex (Undergr.) escalation [%]	8.65	8.24	6.63	7.38	7.38	7.38
On-mine Opex (Open pit) escalation [%]	6.78	5.85	5.40	5.20	5.20	5.20
Off-mine Opex (Conc.) escalation [%]	8.06	7.71	7.20	7.35	7.35	7.35
Off-mine Opex (Smelting) escalation [%]	9.20	9.52	8.87	8.10	8.10	8.10
Off-mine Opex (Refining) escalation [%]	8.08	8.26	7.10	7.09	7.09	7.09
Capital (Mining) escalation [%]	6.11	6.84	6.66	7.76	6.66	6.28
Capital (Process) escalation [%]	7.07	6.87	6.58	7.02	6.88	6.80

Table 41: Global Assumptions: Metal Prices (Anglo American Platinum (d), 2015)

Metal Prices US$ (Constant)	2015	2016	2017	2018	2019	2020
Pt price US$/Oz	1,586.22	1,665.62	1,646.44	1,656.89	1,708.09	1,731.71
Pd price US$/Oz	853.83	869.92	877.45	868.62	879.99	915.49
Rh price US$/Oz	1,156.90	1,191.69	1,226.48	1,261.27	1,296.05	1,330.84
Au price US$/Oz	1,272.02	1,252.98	1,249.41	1,300.00	1,300.00	1,300.00
Ir price US$/Oz	-	-	-	-	-	-
Os price US$/Oz	-	-	-	-	-	-
Ru price US$/Oz	-	-	-	-	-	-
Ni price US$/lb.	10.36	11.17	11.01	10.57	9.75	9.53
Cu price US$/lb.	3.18	3.27	3.19	3.21	3.27	3.49
Co price US$/lb.	13.22	12.76	12.41	12.40	12.40	12.40

Metal Prices

For illustrative purposes, it is assumed that the metal prices are forecasted in constant money terms (Year 0) and then converted to nominal and real (Year 1) money terms.

- Constant metal prices quoted in USD/unit are converted to nominal metal prices in USD/unit, by escalating them with a US CPI factor as per Equation 36.
- Nominal metal prices quoted in nominal USD/unit are converted to real metal prices in USD/unit, by de-escalating them with a US CPI factor as per Equation 37.

Equation 36: Nominal Metal Prices

$$Nominal\ Metal\ Prices\ [\frac{USD}{Unit}] = Constant\ Metal\ Prices[\frac{USD}{Unit}]\ x\ US\ CPI\ Factor$$

Equation 37: Real Metal Prices

$$Real\ Metal\ Prices\ \left[\frac{USD}{Unit}\right] = \frac{Nominal\ Metal\ Prices\ \left[\frac{USD}{Unit}\right]}{US\ CPI\ Factor}$$

From the equations above it is clear that the only difference between the constant (Year 0) and real (Year 1) metal prices, is the year in which it is stated, as in both cases escalation and de-escalation are done by means of a US CPI factor.

Exchange Rates

For illustrative purposes, it is assumed that the exchange rates are forecasted in constant money terms (Year 0) and then converted to nominal and real (Year 1) money terms.

- Constant exchange rates quoted in ZAR/USD are converted to nominal exchange rates in ZAR/USD, by escalating it with a SA CPI factor and de-escalating it with a US CPI factor as per Equation 38.
- Nominal exchange rates quoted in ZAR/USD are converted to real exchange rates in ZAR/USD, by de-escalating it with a SA CPI factor and escalating it with a US CPI factor as per Equation 39.

Equation 38: Nominal Exchange Rate

$$Nominal\ Exchange\ Rate\ \left[\frac{ZAR}{USD}\right] = Constant\ Exchange\ Rate\ [\frac{ZAR}{USD}]\ x\ \frac{SA\ CPI\ Factor}{US\ CPI\ Factor}$$

Equation 39: Real Exchange Rate

$$Real\ Exchange\ Rate\ \left[\frac{ZAR}{USD}\right] = Nominal\ Exchange\ Rate\ [\frac{ZAR}{USD}]\ x\ \frac{US\ CPI\ Factor}{SA\ CPI\ Factor}$$

It is also evident that the only difference between the constant (Year 0) and real (Year 1) exchange rates, is the year in which it is stated, as in both cases escalation and de-escalation are done by means of a SA-US CPI factor.

Uncertainty and Risks

Uncertainty and risks in the macro-economic environment can be addressed through the application of global assumption scenarios in the valuation model. It is required to develop the following sets of global assumption scenarios on a bi-annual basis:

- S1 - Base (B)
- S2 - Investment Economic Scenario – Base (IES-B)
- S3 - Investment Economic Scenario – Upside (IES-U)
- S4 - Investment Economic Scenario – Downside (IES-D)
- S5 - Consensus Scenario

Scenario 1 contains the strategic parameters that are aligned with the budget parameters for the 5-year budget period and are used for business planning purposes. Scenario 2 includes the strategic parameters for the purpose of investment valuations. Scenario 3 contains optimistic strategic parameters and used for upside sensitivities of investment valuations. Scenario 4 includes pessimistic strategic parameters and applies to downside sensitivities of investment valuations. Scenario 5 contains parameters as agreed with joint venture (JV) partners and is used for JV-view investment valuations. Scenario 3 and 4 valuations are conducted to illustrate the envelope of the value of the investment project if the macro-economic environment were to change as shown in Figure 22.

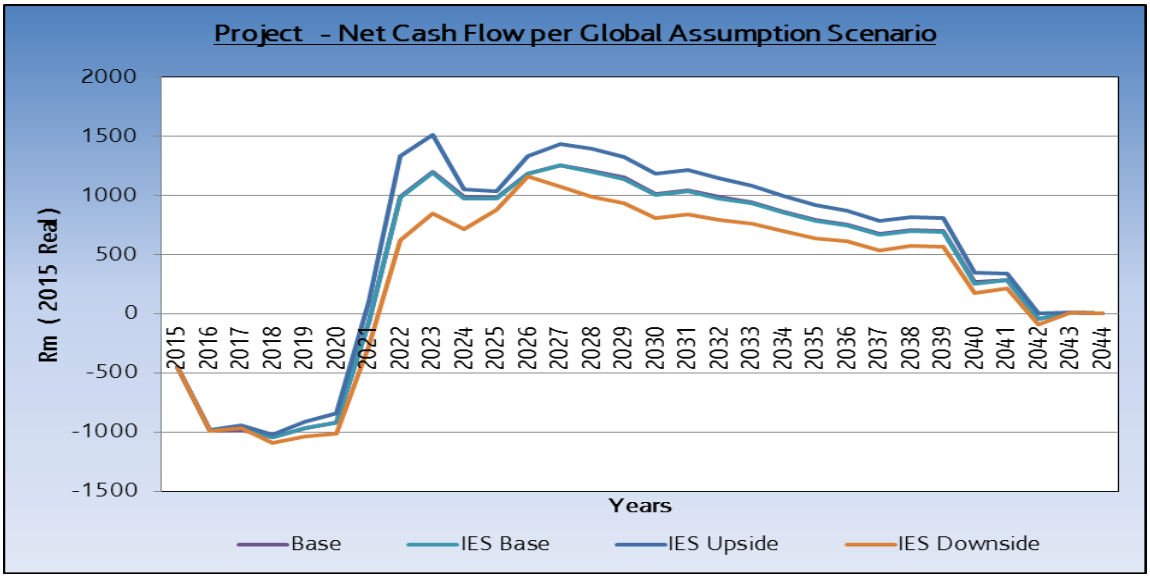


Figure 22: Net Cash Flow per Global Assumption Scenario (Anglo American Platinum (g), 2014)

5.5 Revenue

Gross Revenue

Gross revenue should be calculated in constant, nominal and real money terms for the purposes of the respective cash flows. The gross revenue must be calculated per mineral based on the mineral commodity prices and exchanges rates as indicated in the global assumptions. Equation 40 can be applied for the gross revenue calculations in constant, nominal and real money terms. The gross revenue in real terms real can also be calculated by discounting the nominal gross revenue by SA CPI factors.

Equation 40: Gross Revenue

$$Constant\ Gross\ Revenue\ [R]$$
$$= Mineral\ Content\ [Unit] x\ Constant\ Metal\ Price\ [\frac{\$}{Unit}]\ x\ Constant\ Exchange\ Rate\ [\frac{R}{\$}]$$

$$Nominal\ Gross\ Revenue\ [R]$$
$$= Mineral\ Content\ [Unit]\ x\ Nominal\ Metal\ Price\ \left[\frac{\$}{Unit}\right]\ x\ Nominal\ Exchange\ Rate\ [\frac{R}{\$}]$$

$$Real\ Gross\ Revenue\ [R]$$
$$= Mineral\ Content\ [Unit] x\ Real\ Metal\ Price\ \left[\frac{\$}{Unit}\right]\ x\ Real\ Exchange\ Rate\ [\frac{R}{\$}]$$

$$Real\ Gross\ Revenue\ [R]\ = \frac{Nominal\ Gross\ Revenue\ [R]}{SA\ CPI\ Factor}$$

Commissions and Discounts

Commissions and discounts are based on the agreements with the respective selling agents per metal as depicted in Table 42. Incorporation of this functionality is useful when modelling different take-off price agreements in the case of joint ventures as mentioned in Section 6.3.

Table 42: Commissions and Discounts (Anglo American Platinum (d), 2015)

Commission Discounts %	2015	2016	2017	2018	2019	2020
Pt Comm. Disc. [%]	-	-	-	-	-	-
Pd Comm. Disc. [%]	-	-	-	-	-	-
Rh Comm. Disc [%]	1.34	1.12	1.12	1.12	1.12	1.12
Au Comm. Disc. [%]	-	-	-	-	-	-
Ir Comm. Disc. [%]	-	-	-	-	-	-
Os Comm. Disc. [%]	-	-	-	-	-	-
Ru Comm. Disc. [%]	-	-	-	-	-	-
Ni Comm. Disc. [%]	-	-	-	-	-	-
Cu Comm. Disc. [%]	-	-	-	-	-	-
Co Comm. Disc. [%]	-	-	-	-	-	-

Commissions and discounts are determined as a percentage of gross revenue and are calculated from Equation 41. The real commissions and discounts can also be calculated by discounting the nominal commissions and discounts by SA CPI factors.

Equation 41: Commissions and Discounts

$$Constant\ \ Commissions\ \&\ \ Discounts\ [R]$$
$$= Constant\ Gross\ Revenue\ [R]\ x\ \ Commisions\ \&\ Disc.[\%]$$

$$Nominal\ Commissions\ \&\ Discounts\ [R]$$
$$= Nominal\ Gross\ Revenue\ [R]\ x\ Commisions\ \&\ Disc.[\%]$$

$$Real\ Commissions\ \&\ \ Discounts\ [R]$$
$$= Real\ \ Gross\ \ Revenue\ [R]\ x\ Commisions\ \&\ Disc.[\%]$$

$$Real\ Commissions\ \&\ Discounts\ [R] = \frac{Nominal\ Commissions\ \&\ Disc.[R]}{SA\ CPI\ Factor}$$

Net Revenue

Net revenue is determined from the difference between the gross revenue and the value of commissions and discounts and is calculated using Equation 42. The real net revenue can alternatively be determined by discounting the nominal net revenue by SA CPI factors. Net revenue matches gross sales as defined in the Royalty Act and discussed in Section 5.8.

Equation 42: Net Revenue

$$Constant\ Net\ Revenue\ [R] = Constant\ Gross\ Revenue[R] - Constant\ Commisions\ \&\ Discounts\ [R]$$

$$Nominal\ Net\ Revenue\ [R] = Nominal\ Gross\ Revenue[R] - \ Nominal\ Commisions\ \&\ Discounts\ [R]$$

$$Real\ Net\ Revenue\ [R] = Real\ Gross\ Revenue[R] - Real\ Commisions\ \&\ Discounts\ [R]$$

$$Real\ Net\ Revenue\ [R] = \frac{Nominal\ Net\ Revenue\ [R]}{SA\ CPI\ Factor}$$

5.6 Operating Costs

The valuation methodology incorporates the full pricing revenue from the sold metals and consequently full absorption costing should be applied to determine the value added. Full absorption costing methodology requires that all costs in the full mining value chain, from mining to selling of final products, should be taken into account during the valuation. It is essential to determine the costs for the base and extended business cases in the following areas:

- On-mine
  - Mine
  - Concentrator
- Off-mine
  - Smelter
  - Refineries
  - Central

In the case of an existing mine and concentrator, the determination of the incremental costs, due to the addition of an extension project, can be quite intriguing due to the inherent complexity of a mine and concentrator operation. It is therefore advisable not to estimate the incremental mining and concentrator costs directly, but to perform a detailed cost estimate for each of the base and extended business cases. In these cases, cost estimation should be done from first principles by applying appropriate cost estimation techniques as alluded in Section 4.2.1. The respective mine costs and concentrator costs of an extension project will alter if the project is deferred by a year as the allocation ratio of fixed costs with the existing mine or concentrator will change. The incremental costs for the project are calculated during the incremental valuation, which determines the differential between the costs of the base and extended business cases.

Another, more simplistic, method of determining the costs is by means of the average costing method. The methodology derives yearly unit costs for the facility from the quotient of its strategic cost forecast and the strategic production profile of the relevant cost driver. The respective base and extended case costs are determined from the product of the unit costs and the production profiles of the investment centres in the respective base and extended business cases. This methodology assumes that the strategic production profile will be sustained from other sources if the project under consideration is not approved and the series of estimated unit costs will consequently remain unchanged. This average costing method can be applied to estimate the off-mine costs as shown in Table 43. The incremental off-mine costs for the project are calculated during the incremental valuation.

Table 43: Global Assumptions: Off-mine Costs (Anglo American Platinum (d), 2015)

Off-Mine Costs - Opex (constant)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Off-Mine Costs - Opex (constant)						
Smelting - R/t conc (constant)	2000	2000	2000	2000	2000	2000
PM refining - R/Oz 6E (constant)	160	160	160	160	160	160
BM refining - R/t Ni, Cu, Co (constant)	25000	25000	25000	25000	25000	25000
GCC - R/Oz Pt sold (constant)	450	450	450	450	450	450
OIC (Own mines) - R/Oz Pt sold (constant)	350	350	350	350	350	350
OIC (JVs) - R/Oz Pt sold (constant)	0	0	0	0	0	0
PM transport - R/Oz 4E (constant)	10	10	10	10	10	10
BM transport - R/t Ni & Cu (constant)	1500	1500	1500	1500	1500	1500
Marketing - R/Oz Pt sold (constant)	350	350	350	350	350	350

The valuation model will escalate the input costs in constant terms (Year 0) to nominal terms by applying the relevant operating cost escalators and then discount it back to real terms (Year 1) by applying SA CPI factors to the nominal cash flows by employing Equation 43 and Equation 44.

Equation 43: Nominal Operating Costs

$$Nominal\ Operating\ Costs\ [R] = Constant\ Operating\ Costs\ [R]\ x\ \ Opex\ Escalation\ Factor$$

Equation 44: Real Operating Costs

$$Real\ Operating\ Costs\ [R] = \frac{Nominal\ Operating\ Costs\ [R]}{SA\ CPI\ Factor}$$

5.7 Capital Costs

Stay-in-Business (SIB) Capital Costs

In the financial valuation model, the SIB capital costs can be entered per classification (as illustrated in Table 31) as either absolute costs in constant (Year 0) money terms or as a percentage of the relevant constant operating costs. Absolute costs can be estimated from a detailed SIB capital cost model, which contains a list of all equipment items scheduled to be replaced or other identified SIB capital projects. The percentage of the relevant operating costs is determined from an analysis of historical operating costs and the associated SIB capital costs. The absolute cost method is normally used for on-mine SIB capital costs, in the case of mines and concentrators, whilst the percentage methodology is applied to estimate off-mine SIB capital costs as shown in Table 44.

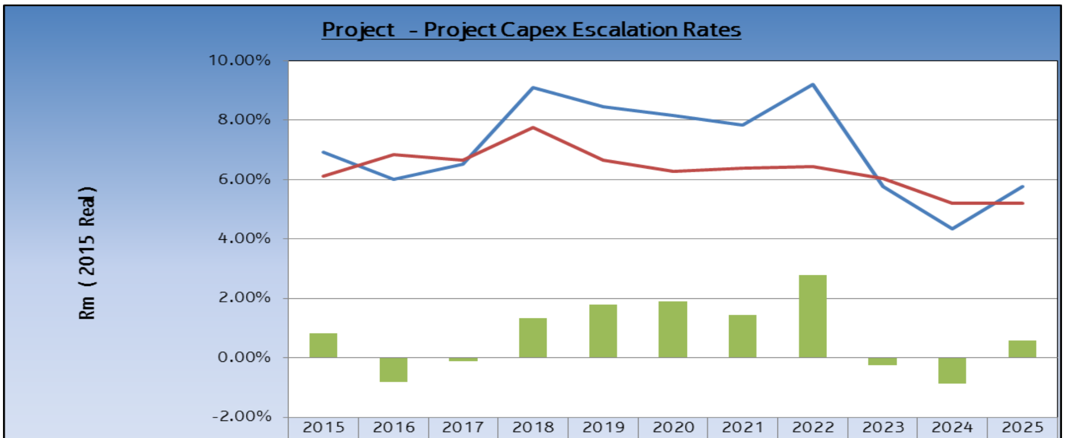
Table 44: SIB Capital Cost Percentages (Anglo American Platinum (c), 2014)

SIB Capital Factor	2015	2016	2017	2018	2019	2020
Mine SIB capital: % of Mine Opex	-	-	-	-	-	-
Concentrator SIB capital: % of Conc. Opex	-	-	-	-	-	-
Smelter SIB capital: % of Smelting Opex	11.70	11.16	29.65	11.25	11.25	11.25
BM Refinery SIB capital: % of BMR Opex	14.03	13.44	8.92	12.00	12.00	12.00
PM Refinery SIB capital: % of PMR Opex	9.13	9.25	5.90	8.02	8.02	8.02
Central SIB capital: % of Central Opex	5	5	5	5	5	5

Project Capital Costs

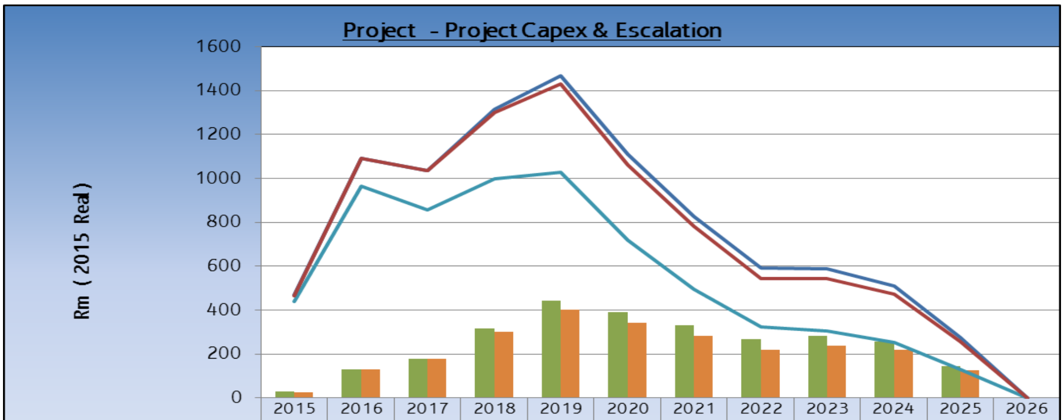
The financial valuation model requires project capital costs to be entered as a constant absolute value per classification as indicated in Table 32. The project capital costs should be estimated from a detailed capital cost estimation model, which incorporates a properly defined work breakdown structure (WBS) and a project schedule. The estimation types as presented in Table 37 are used to create project capital cost estimates based on the project phase and associated required accuracy. The project capital costs value should include contingencies to compensate for estimation uncertainties.

At conceptual and pre-feasibility study levels, generic capital cost escalation rates are applied to escalate constant project capital costs to nominal terms, whilst project-specific capital cost escalation rates are used for escalation to nominal terms during the feasibility phase of a project. Project-specific capital cost escalation rates are generally in line with the general capital cost escalation rates as published via the global assumptions. The difference arises due to the composition of the project capital costs, which is different from the basket used to determine the general capital cost escalation rates. Figure 23 illustrates the variance between the project specific and general escalation rates, whereas Figure 24 provides a comparison between the general escalation and project specific escalation values for a reviewed project.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Variance	0.81%	-0.82%	-0.13%	1.33%	1.78%	1.89%	1.43%	2.78%	-0.25%	-0.87%	0.58%
Escalation Rate (Spec Esc)	6.92%	6.02%	6.53%	9.09%	8.44%	8.17%	7.83%	9.22%	5.78%	4.33%	5.78%
Escalation Rate (Gen Esc)	6.11%	6.84%	6.66%	7.76%	6.66%	6.28%	6.40%	6.44%	6.03%	5.20%	5.20%

Figure 23: Project Capital Cost Escalation Rates (Anglo American Platinum (g), 2014)



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Escalation (Spec Esc)	30	129	178	317	441	392	331	266	283	256	146	0
Escalation (Gen Esc)	27	129	179	303	401	342	284	219	236	220	125	0
Constant Capex	437	963	857	998	1028	718	497	325	306	254	130	0
Nom Capex (Spec Esc)	467	1092	1035	1315	1469	1109	827	591	588	510	276	0
Nom Capex (Gen Esc)	464	1092	1037	1301	1429	1060	780	543	542	474	255	0

Figure 24: Project Capital Cost Escalation (Anglo American Platinum (g), 2014)

Money Terms Conversion

Capital costs in constant money terms are converted to nominal money terms by escalating them with the appropriate capital cost escalation rates according to Equation 45. Nominal capital costs are converted back to real money terms by de-escalating them with SA CPI factors as per Equation 46.

Equation 45: Nominal Capital Costs

$$Nominal\ Capital\ Costs\ [R] = Constant\ Capital\ Costs\ [R]\ x\ \ Capex\ Escalation\ Factor$$

Equation 46: Real Capital Costs

$$Real\ Capital\ Costs\ [R] = \frac{Nominal\ Capital\ Costs\ [R]}{SA\ CPI\ Factor}$$

5.8 **Royalties**

Introduction

Cawood (2010, p. 199) stated that the Mineral and Petroleum Resources Royalty Act 28 of 2008 (Royalty Act) was promulgated in November 2008 and the main purpose of it is to collect royalties from South African mines holding mining rights granted in term of the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA). The intention is to compensate the State for its custodianship over South Africa's non-renewable mineral resources when exploited by mining companies for their own benefit (Cawood, 2010, p. 199). Old order mineral rights still exist but are worthless as the state is now the custodian of mineral rights and consequently have the right to royalties (Wits Mining, 2013).

Through the Royalty Act, the following philosophies were embedded (SARS, 2008):

- Recognizing that South Africa's mineral resources are non-renewable and are part of the common patrimony of all South Africans, thereby entitling the nation to consideration for the value of those resources when extracted and transferred.
- Acknowledging that S.A.'s mineral resources belong to the nation and the State is the custodian thereof.
- Affirming the State's obligation to provide for economic and social development
- Considering the need to create an internationally competitive and efficient mineral resource regime that contains rules seeking (SARS, 2008):
    i. Maximum certainty for the investor community in support of sustainable economic growth; and
    ii. Royalty rate stability for the foreseeable future.

Royalty Act - Section 2

Section 2 of the Royalty Act establishes the imposition of royalties by stating that a person must pay for the benefit of the National Revenue Fund in respect of the transfer of a mineral resource extracted from within S.A. (SARS, 2008).

Royalty Act - Section 3

Section 3 of the Royalty Act clarifies the determination of royalties by affirming it is determined by multiplying the gross sales of the extractor during the year of assessment by a percentage determined in accordance with the formula in Section 4 of the Royalty Act (SARS, 2008).

Equation 47: Royalty Payable

$$Royalty\ Payable\ = Royalty\ Rate\ (Y\%)\ x\ Gross\ Sales$$

Royalty Act - Section 4

Section 4 of the Royalty Act provides the royalty formula and determines (SARS, 2008):

- The royalty rate (Y %) calculation is based on two formulas, which caters for refined and unrefined minerals respectively.
- The minimum royalty rate is 0.5%.
- The maximum royalty rate is 5% for refined minerals.
- The maximum royalty rate is 7% for unrefined minerals.

Equation 48: Royalty Rate – Refined Minerals (Y_R)

$$Y_R\,\% = \left(0.5\% + \frac{EBIT}{Gross\ \ Sales\ x\ 12.5}\%\right)$$

Equation 49: Royalty Rate - Unrefined Minerals (Y_U)

$$Y_U\,\% = \left(0.5\% + \frac{EBIT}{Gross\ Sales\ x\ 9}\%\right)$$

Royalty Act - Section 5

Section 5 of the Royalty Act defines that Earnings before Interest and Tax (EBIT), for royalty calculation purposes, is equal to (SARS, 2008):

- Gross sales;
- Less tax deductible expenses to recover mineral resources to its saleable state;
- Less capital expenditure to develop mineral resources;
- Less unredeemed capital expenditure carried forward;
- Plus capital recoupments; and
- Add back transport, insurance and handling expenses incurred after producing the saleable product or to effect disposal of mineral resources.

Cawood (2010, pp. 204, 205) stated that capital recoupments deal with capital amounts already allowed as deductions from income and explained that the general rule is that the recovery for tax purposes is limited to the original costs of the asset. Cawood (2010, pp. 204, 205) indicated that capital expenditure includes unredeemed amounts from capital redemption deductions, but excludes amounts from capital redemption allowances (for gold mines) and stated that the same capital expenditure cannot have a double impact on reducing royalty obligations. For the purpose of the royalty calculation, capital expenditure includes the full redemption per Section 15(a) and the partial annual redemption (PAR) in terms of Section 36.11(d) of the Income Tax Act (ITA) (Cawood, 2010, pp. 204,205).

Section 5 of the Royalty Act determines that Earnings before Interest and Tax (EBIT), for royalty calculation purposes, specifically exclude (SARS, 2008) , (Cawood, 2010, pp. 204, 205):

- Deduction of financial instruments (interest payments on debt, costs of carrying derivatives and currency hedges), except for option or forward contract costs (price hedging) which can be included.
- Deduction of general expenses allowed in terms of Section 11(a) of the ITA.
- Deduction of transport, insurance and handling expenses incurred after producing the saleable product as per Schedule 1 or 2, or to effect disposal of mineral resources.
- Deduction of any assessed loss carried forward as mentioned in Section 20(1) (a) of the ITA unless the assessed loss arises in respect of capital expenditure taken into account for the purposes of paragraph 5(1) of the Tenth Schedule of the ITA.
- Deductions of foreign currency losses allowed in terms of Section 24I of the ITA.
- Any determination in respect of an impermissible tax avoidance arrangement contemplated in Part IIA of the ITA.
- Any deduction contemplated in paragraph 5(2) of the 10th Schedule of the ITA, which refers to costs uplifts allowed in the petroleum sector.

Section 5 of the Royalty Act provides for a reasonable apportionment for the purposes of determining EBIT in the case of composite refined and unrefined mineral resources (SARS, 2008). It also makes provision for sole treatment, if the value of the refined or unrefined mineral resources does not exceed 10% of the total value of that composite mineral resource and states that a negative EBIT will be deemed zero (SARS, 2008).

Royalty Act - Section 6

Section 6 of the Royalty Act states that gross sales are (SARS, 2008):

- The amount received or accrued in respect of the transfer of the mineral resource;
- and is determined without any regard to transport, insurance and handling expenses incurred after producing the saleable product as per Schedule 1 or 2 or to effect disposal of mineral resources.

Gross sales serve to be the denominator of EBIT to determine the profitability ratio and to establish a base for the royalty calculation (Cawood, 2010, p. 205). For royalty purposes, gross sales are regarded as the amount received and are calculated by deducting the commissions and discounts from gross revenue and therefore, equate to the net revenue as previously defined in Section 5.5.

Royalty Act – Schedule 1 & 2 and Exceptions

Schedule 1 and 2 of the Royalty Act provide criteria conditions of refined and unrefined mineral resources. Communities that previously received royalties will continue to receive such royalties and farmers that can prove hardship due to mining close to their farms are entitled to royalties. In both these cases, the state royalties will still apply and the mine is liable for both royalties (Wits Mining, 2013).

Royalties in Zimbabwe

Royalties in Zimbabwe are charged at a rate of 2.5% of net revenue. An additional beneficiation penalty of 15% is added if the operation does not process the metals through a smelting plant.

5.9 **Tax**

Company Tax

Introduction

Section 5 of the Income Tax Act 58 of 1962 (ITA) determines that subject to the provisions of the Fourth Schedule (PAYE and Provisional tax), there shall be paid annually for the benefit of the National Treasury Fund, an income tax in respect of taxable income received by or accrued to in favour of (SARS, 1962):

- Any person (other than a company) during the year of assessment ended the last day of February each year; and
- Any company during every financial year of such company.

In terms of Section 26 of the ITA, company tax is levied on taxable income at a rate of 28% (SARS, 1962) (SARS, 2014). According to Van Blerck (1992), mining capital expenditure is expenditure that includes the following:

- Expenditure on shaft sinking, mine equipment and pipelines
- Expenditure on development, general administration and management
- Expenditure on assets qualifying for partial annual redemption (PAR)
- Capital allowances in the case of gold and natural oil mines

Mining capital expenditure incurred is the amount that remains after deducting mining capital recoupments from current mining capital expenditure (Van Blerck, 1992, pp. 12-5, 6).

Capital Redemption

In terms of Section 15(a) and Section 36.11(d) of the ITA an allowance in respect of certain capital expenditure is granted in lieu of various other allowances, to be deducted from the income derived by a taxpayer from mining operations (Van Blerck, 1992, pp. 12-2, 3). Van Blerck (1992, pp. 12-2, 3) indicated that the deductions may be categorized as follows:

- Capital redemption deduction
    - Full redemption – Section 15(a)
    - Partial annual redemption (PAR) – Section 36.11(d)
- Capital allowance deduction – Gold mines and natural oil mines

Capital Redemption Deduction

Section 15(a) states that mining companies are entitled to deduct from their mining taxable income all the mining capital expenditure incurred during the year of assessment, except for Section 36.11(d) mining capital expenditure, which is subjective to partial annual redemption (PAR) (Van Blerck, 1992, pp. 12-2, 3, 20). If these deductions exceed the mining taxable income in the year of assessment, the balance is carried forward as unredeemed mining capital expenditure to the following years to reduce future mining taxable income (Van Blerck, 1992, pp. 12-2,3,20).

Capital Redemption Amount

For assets qualifying for the full capital redemption deduction in terms of Section 15 (a), the deduction amounts to the capital expenditure incurred (Van Blerck, 1992, pp. 12-2, 3, 21). In the case of assets qualifying for the partial annual redemption (PAR) in terms of Section 36.11(d), the capital redemption deduction is spread in equal instalments over 10 years in the case of items i to v below, or 5 years for item vi below (Van Blerck, 1992, pp. 12-2, 3, 21). If a Section 36 asset is disposed of, the remaining tax book value shall be redeemed in the year of disposal and the full selling price will be recouped in the same year’s taxable income (Van Blerck, 1992, pp. 12-2, 3, 21).

Section 36 Assets

The PAR system in terms of Section 36.11(d) applies to mining capital expenditure in respect of the acquisition, erection, construction and improvement of (Van Blerck, 1992, pp. 12-19, 20):

i. Housing for residential occupation by the taxpayer’s employees and furniture for such housing; and
ii. Infrastructure in respect of residential areas developed for sale to the taxpayer’s employees; and
iii. Any hospital, school, shop, garage, carport or similar amenity owned and operated by the taxpayer mainly for the use of his employees; and
iv. Recreational buildings and facilities owned and operated by the taxpayer mainly for the use of his employees; and

v. Any railway line, conveyor, road or pipeline for the transport of minerals from the mine to the nearest public transport system or outlet (plant or marketplace); and

vi. Motor vehicles intended for the private use or partly private use of the taxpayer's employees.

Full redemption is applicable in the case of infrastructure for residential areas of housing mentioned in item i above (Van Blerck, 1992, pp. 12-19, 20).

<u>Ring fencing</u>

ITA legislation creates six different types of ring fences in the mining industry, which include (Van Blerck, 1992, pp. 12-3, 28-31):

1. Taxpayer ring-fence

   Each corporate entity is a separate taxpayer and no corporate group system exists.

2. Mining income ring-fence – Section 36.7(e)

   Mining income is calculated and taxed separately from non-mining income and therefore, prohibit the offset of the mining capital redemption deductions against non-mining income.

3. Capital expenditure ring-fence – Section 36.7(f)

   The mining capital redemption deductions of a specific mine cannot exceed the mining taxable income generated by that mine. This restriction is subject to qualifications:

   - The restrictions do not apply where the taxpayer was carrying on mining operations on two or more mines on December 5, 1984, as these mines are deemed as one mine and are conveniently called "old mines".
   - A provision enacted in 1990 overrides the restriction in part and is only applicable where a "new mine" commences mining operations after March 14, 1990. It states that mining capital redemption/allowance deductions of a specific mine cannot exceed the taxable income generated by that mine by more than 25% and consequently a breach in ring fence is allowed of up to 25% of the capital redemption allowance.

4. Capital expenditure per mine ring-fence – Section 36.10

Where separate and distinct mining operations are carried on in mines that are not contiguous, the capital redemption deduction shall be computed separately.

5. Gold formula ring-fence

   The Gold formula is applied on a mine by mine basis and is based on the taxable income derived from mining for gold.

6. Prospecting ring-fence – Section 15(b)

   The Commissioner has the power to ring fence prospecting expenditure partially by providing that it should be deductible in instalments or by restricting the deductions to the particular class of mining income to which the prospecting relates.

<u>Pre-production and Non-production Expenditure Provisions</u>

According to Van Blerck (1992, pp. 12-3. 28-31), the mining capital redemption deduction is claimable before a mine commences with production and it may generate assessed taxable losses, which may be offset against the taxpayer's mining income from other mines. If the following categories of expenditure are incurred prior to the commencement of production, or during any period of non-production, they should be included in the definition of mining capital expenditure (Van Blerck, 1992, pp. 12-3. 28-31):

- Development
- General administration and management
- Interest and charges on loans utilized for mining purposes

<u>Dividend Withholding Tax</u>

Dividend payments should be excluded from the cash flow schedule as it is already incorporated in the weighted average costs of capital (WACC) portion of the hurdle rate. It also forms part of financing costs paid to shareholders and is not part of cash flows from assets as alluded in Section 5.2. Dividend withholding tax (DWT) should be included in the cash flow schedule as the hurdle rate is an after-tax rate that is applied to after-tax cash flows. DWT is levied on net dividends paid at a statutory rate of 15% (SARS, 2014). The dividends paid are determined from the free cash flow after net working capital changes and the quantum is dictated by the company's dividend policy. In the case where the shareholder is a foreign investor or due to inter-group savings, a reduced DWT rate (e.g. 5%) can be incorporated in the project valuation to represent cash flows more realistically.

Capital Gains Tax (CGT)

The Eighth Schedule of the Income Tax Act 58 of 1962 (ITA) deals with the determination of taxable capital gains and assessed capital losses. These should be included in gross income at a rate of 33.3% for natural persons, with a maximum effective tax rate of 13.32% and 66.6% for companies, with a maximum effective tax rate of 18.648% (SARS, 2014). The majority of mining capital assets qualifies for a capital redemption deduction and is therefore not subject to the Eighth Schedule of the ITA (Wits Mining, 2013). Specific assets that are excluded from the capital redemption deduction include mineral rights and land and consequently these assets are subject to the Capital Gains Tax (Wits Mining, 2013).

Carbon Tax

Carbon taxes have not yet been imposed on mines in S.A. and the impact of it on the project value can be incorporated as part of a sensitivity analysis.

Tax in Zimbabwe

An effective tax rate of 27.71% is used to model mining operations and projects in Zimbabwe. Table 45 provides a breakdown of this tax rate.

Table 45: Effective Tax Rate – Zimbabwe (Anglo American, 2012)

Base	Percentage [%]
Zimbabwe corporate tax	15
Aids levy: 3% of corporate tax rate	0.45
Zimbabwe withholding tax on dividends	8.46
Netherlands corporate tax: exempt in Netherlands	0
Netherlands withholding tax on dividends: 5%	3.8
SA corporate tax rate: exempt is SA	0
Total effective tax rate	27.71

5.10 Net Cash Flow

Net Working Capital

An increase in the balance of current assets will cause a cash outflow, while an increase in the balance of the current liabilities will cause a cash inflow. The end of the year balance on the working capital items can be derived by employing the equations below. Typical planning parameters used to estimate the end of the year balances, as portrayed in Table 46, are based on historical analysis.

Table 46: Global Assumptions: Net Working Capital Parameters (Anglo American Platinum (d), 2015)

Working Capital	2015	2016	2017	2018	2019	2020
Trade Debtors Collection Days	12	12	13	13	13	13
Stores Inventory [%]	5.73	6.45	6.04	6.04	6.04	6.04
Other Current Assets [%]	7.29	7.67	7.49	7.49	7.49	7.49
Trade Creditors Payment Days	46	47	46	46	46	46
Company Tax Creditor [%]	55.64	55.64	20.00	20.00	20.00	20.00
Dividend withholding Tax Creditor [%]	-	-	-	-	-	-
Employee Services Benefits [%]	0.77	0.86	0.74	0.74	0.74	0.74

Current Assets

Equation 50: Current Assets

$$Current\ Assets\ [R] = Trade\ Debtors\ [R] + Stores\ Inventory\ [R] + Other\ Current\ Assets\ [R]$$

Equation 51: Trade Debtors (Trade Accounts Receivable)

$$Trade\ Debtors\ [R] = \frac{Trade\ Debtors\ \ Collection\ Days}{365}\ x\ Net\ Revenue\ [R]$$

Trade Debtors Collection Days = as specified in Global Assumptions

Equation 52: Stores Inventory

$$Stores\ Inventory\ [R] = Stores\ Inventory\ [\%]\ x\ (Mine\ Cost + Concentrator\ Cost + Smelter\ Cost + Refinery\ Cost)[R]$$

Stores Inventory [%] = as specified in the Global Assumptions

Equation 53: Other Current Assets

$$Other\ Current\ Assets\ [R] = Other\ Current\ Assets\ [\%]\ x\ (Mine\ Cost + Concentrator\ Cost + Smelter\ Cost + Refinery\ Cost)[R]$$

Other Current Assets [%] = as specified in the Global Assumptions

<u>Current Liabilities</u>

Equation 54: Current Liabilities

$$Current\ Liabilities\ [R] = (Trade\ Cred. + Company\ Tax\ Cred. + Dividend\ wh.Tax\ Cred. + Employ.\ Serv.\ Cred.)[R]$$

Equation 55: Trade Creditors (Trade Accounts Payable)

$$Trade\ Creditors\ [R] = \frac{Trade\ Creditors\ Payment\ Days}{365}\ x\ (Opex + Capex)[R]$$

Trade Creditors Payment Days = as specified in the Global Assumptions

Equation 56: Company Tax Creditor

$$Company\ Tax\ Creditor\ [R] = Company\ Tax\ Creditor\ [\%]\ x\ Tax\ Payable[R]$$

Company Tax Creditor [%] = as specified in the Global Assumptions

Equation 57: Dividend withholding Tax Creditor

$$Dividend\ wh.\ Tax\ Creditor = Dividend\ wh.\ Tax\ Creditor\ [\%] x\ Dividends\ \ Payable[R]$$

Dividend wh. Tax Creditor [%] = as specified in the Global Assumptions

Equation 58: Employee Services Creditors

$$Employee\ Services\ \ Creditors = Empl.\ Serv.Cred.[\%]\ x\ (Mine\ Cost + Conc\ Cost + Smelt\ Cost + Ref\ Cost)[R]$$

Employee Services Creditor [%] = as specified in the Global Assumptions

Net Cash Flow Schedule

The net cash flow schedule of each investment centre and consolidated business case (base, extended and incremental) can be structured as exhibited in Table 47. This net cash flow schedule needs to be repeated in the required currencies and in constant, nominal and real money terms for information integrity and reporting purposes.

Table 47: Net Cash Flow Schedule (Anglo American Platinum (b), 2015)

Description	Positive / Negative Cashflow
Gross revenue	Positive
Commissions and discounts	Negative
Net Revenue	
Shaft head Costs - Labour	Negative
Shaft head Costs - Contractors	Negative
Shaft head Costs - Stores	Negative
Shaft head Costs - Utilities	Negative
Shaft head Costs - Sundries	Negative
Cash Shaft head Costs	
Central Services - Direct	Negative
Central Services - Allocated	Negative
Cash Mine Costs	
Concentrator Costs	Negative
Smelter Costs	Negative
Refinery –Precious Metals	Negative
Refinery – Base Metals	Negative
Cash Process Costs	
Group Central Services Costs (GCC)	Negative
Other Indirect Costs (OIC)	Negative
Transport – Precious Metals	Negative
Transport – Base Metals	Negative
Marketing Costs	Negative
Closure Costs	Negative
Cash Central Costs	
Royalties	Negative
Cash Operating Costs	
Cash Operating Profit before Tax (EBITDA)	
Company Tax	Negative
Cash Operating Profit after Tax	
SIB Capital Costs	Negative
Project Capital Costs	Negative
Free Cash Flow (FCF) after Capital	
Net Working Capital	Positive / Negative
Dividend Withholding Tax	Negative
Net Cash Flow	

For completeness, the summary of the associated metals produced and sold can be reported with the cash flow schedule as displayed in Table 48.

Table 48: Schedule of Metals Produced and Sold (Anglo American Platinum (f), 2015)

Description	Units
Tonnes Milled	kt
4E Head Grade	g/t
Concentrate Tonnes	kt
Metals Produced	
Refined Metal - Pt	kOz
Refined Metal - Pd	kOz
Refined Metal - Rh	kOz
Refined Metal - Au	kOz
Refined Metal - Ir	kOz
Refined Metal - Os	kOz
Refined Metal - Ru	kOz
Refined Metal - Ni	t
Refined Metal - Cu	t
Refined Metal - Co	t
Metals Sold	
Refined Metal - Pt	kOz
Refined Metal - Pd	kOz
Refined Metal - Rh	kOz
Refined Metal - Au	kOz
Refined Metal - Ir	kOz
Refined Metal - Os	kOz
Refined Metal - Ru	kOz
Refined Metal - Ni	t
Refined Metal - Cu	t
Refined Metal - Co	t

Hurdle Rate

General

The valuation approach calls for opportunity costs and project specific risks to be considered in valuations. The hurdle rate is calculated from the weighted average cost of capital (WACC) as well as the country and technical risk premiums. The hurdle rate reflects the expected return on an investment. A real hurdle rate is a real discount rate that is applied to real cash flows to calculate the Net Present Value (NPV). The application of a real discount rate is preferred as the SA CPI forecast might not be constant over all future years. The calculation of the NPV from nominal cash flows is a two-step process consisting of discounting the nominal cash flows by a SA CPI factor to calculate real cash flows and discounting these real cash flows by a real hurdle rate to determine the discounted cash flows and NPV.

Country Risk Premium

The country premium allows for risks that have not been captured in the cash flow forecast. The cumbersome process of identifying and quantifying country risks should consider the risks of expropriation, the possibility that profits cannot be freely remitted and other unforeseen events like power shortages and corruption. The country risk premium consists of two components (Anglo American, 2014):

- A basic premium derived from a quantitative risk model, which utilizes the probabilities that certain events might take place as inputs and then calculates the expected positive and negative cash flows from each of these country risk events. The cash flows are then introduced into the discounted cash flow (DCF) model of a typical mine. Subsequently, the DCF models are compared with and without the country risk cash flows and it is possible to derive an equivalent risk premium to be included in the hurdle rate. The method assumes that cash flows reflect normal operating conditions in the country and consequently, only makes allowance for unexpected events that would typically not be envisaged and are not incorporated in the DCF model (Anglo American, 2014).
- An additional premium that is recognizing volatility caused by extreme or once-off events and typically has a low probability, but a high impact. More comprehensive information is typically publicly available for member countries of the Organization

for Economic Co-operation and Development (OECD) and consequently an additional premium of +0.5% to +1% is included for non-member countries (Anglo American, 2014).

Every project brings its own unique risks and rewards and the premium is intended to guide management with regard to the appropriate additional returns due to country risks. To aid consideration, it is helpful to show the internal rate of return (IRR) of the investment compared to the hurdle rate with and without the inclusion of the country risk premium (Anglo American, 2014).

Technical Risk Premium

For technical risk purposes, projects can be classified as either green field or brown field projects. Greenfield projects are projects planned to be established in an area where no or limited basic infrastructure such as power, water, sanitation, roads and housing exists to support the project. This type of project is usually the start of a new mine complex. Brownfield projects are planned for establishment in areas where basic infrastructure exists to support the project. This project type is usually the extension of an existing mine complex (Anglo American, 2013).

Hurdle Rate

Typically, a base rate (real) of 7.5% per annum is adopted for operating assets to cater for opportunity costs and is based on the company's weighted average cost of capital (WACC) (Anglo American, 2013). A country risk premium of 2.5% for South Africa and 6% for Zimbabwe is added to the base rate. (Anglo American, 2013) A further project technical risk premium of 1.5% for brownfield projects or 2.5% for greenfield projects is added in the case of major projects (Anglo American, 2013). In line with these guidelines, a real hurdle rate of 11.5% per annum is used to value major brownfield projects and 12.5 % for major greenfield projects in South Africa. (Anglo American, 2013).

5.11 Findings

The valuation methodology calls for the project valuation to be based on the incremental cash flow of the project that will be the determined from the base and extended business cases. The calculation of the cash flow schedule line items for a single investment centre was established and it is recommended that the cash flow schedule is repeated in constant, nominal and real money terms to ensure accurate money terms conversions. Calculation of taxes, net working capital and dividend withholding tax are required in nominal terms and the conversion of these line items to real money terms will only be done by discounting the nominal values with SA CPI factors and not from re-calculating it from the constituent real line items. The business planning process requires a distinction between constant money terms and real money terms. The conversion process applies escalation factors to compute nominal values from constant values and SA CPI factors to discount nominal values back to real values. Global assumptions include constant metal prices and exchange rates that can be converted to nominal and real money terms. Uncertainty and risks in the macro-economic environment are accommodated by introducing different sets of global assumption scenarios to illustrate the envelope of investment value.

The constant gross revenue, commissions and net revenue can be calculated from the production and metal profiles as determined in the mining and metallurgical models and need conversion to nominal and real terms for downstream computations. The full pricing revenue of the metal products is recognized in the cash flow schedule and this requires the application of full absorption costing, which incorporates costs over the full mining value chain, to avoid overstatement of business cases.

For on-mine costs, application of detailed costing models is proposed to estimate the base and extended business case costs from first principles. Off-mine costs for the base and extended business cases are calculated in the valuation model by applying average cost rates to the respective production and metal profiles. The costs in the cost estimation model are computed in constant money terms and then converted to nominal and real terms in the valuation model. Mining capital costs require classification under either Section 15(a) capital, which qualifies for full redemption, or

Section 36.11(d) capital, which qualifies for partial annual redemption (PAR) in terms of the ITA. On-mine SIB capital costs are often estimated from a detailed SIB capital costs model and populated in the valuation model in constant absolute values. Off-mine SIB capital costs are based on a percentage of the relevant off-mine operating costs in constant money terms, as derived from historical analysis and are calculated within the valuation model. Project capital costs are determined from a detailed cost estimation model and project specific escalation rates are applied in the feasibility phase to convert the constant absolute inputs to nominal terms.

Specific royalty formulas should be applied in the case of refined and unrefined minerals and the allowable elements of EBIT and gross sales for royalty calculations are crucial. In the case of mining capital expenditure, full redemption is allowed in terms of Section 15(a) and partial annual redemption (PAR) is allowed in terms of Section 36.11(d) of the ITA. The ITA specifies the Section 36 assets and creates ring-fences to be applied when performing tax calculations of group consolidations. Dividend withholding tax should be included as a cash outflow and net working capital requirements can be determined from the provided equations and global assumption parameters. In nominal terms, the sum of net working capital changes will equate to zero over the life of the project, but this will not hold in real terms. Cash flow schedules are created for investment centres and consolidations. A real hurdle rate must be applied to the incremental real net cash flow to determine the project NPV. The hurdle rate must incorporate the WACC, as well as country and technical risk premiums to cater for opportunity costs and risks.

6 Application of Techno-economic Modelling

6.1 Introduction

Techno-economic modelling has been applied to perform business planning, major project valuations and SIB project valuations. In these areas, the alternatives were paralleled and reviewed to identify pitfalls and benefits for recommending best practice.

6.2 Business Planning

Business Entity Consolidation Structures

During the business planning process, investment centres are planned and scheduled to deliver mining plans. An integrated techno-economic model consists of a user-defined consolidation structure, which links to consolidation (Cons) and investment centre (IC) files. Each of the investment centre and consolidation files contains the same calculation logic and standard reports. Both these files are updated with the global assumption data, whilst production and financial data are only uploaded to investment centre files. A consolidation file consolidates the data from the subordinate investment centres according to the consolidation structure. Based on the consolidated data it re-calculates specific values, according to on-off calculation settings within the consolidation file. The norm is to recalculate taxes, royalties, net working capital, dividend withholding tax and net cash flow at each consolidation file. Different scenarios can be created within each investment centre and consolidation file to cater for the various global assumption views and mining options. The consolidation percentage, method and scenario of each investment centre and consolidation file can be specified in the consolidation structure. The consolidation start date and end date can also be altered and are applied to perform tail management (tail cutting) of the base and extended business cases to optimize them. The combination of investment centre and consolidation files, as dictated by the consolidation structure, provides the required flexibility to model different business entities. These mine consolidations can be consolidated into different tax entities and group consolidations for group valuations, cash flow forecast and capacity testing.

Recurring and Solitary Consolidation Structures

Two types of consolidation structures are possible for business planning purposes, which are conveniently called recurring and solitary consolidation structures. The purpose of the structures is to provide the consolidated technical and economic information for the different planning levels (L1 – L3) of each operation and at the group level. For illustrative purposes, it is assumed that the MRA only contains L1, L1e and L2a investment centres. The layouts of the two consolidation structures are provided in Table 49 and Table 50.

Table 49: Recurring Consolidation Structure (Anglo American Platinum (f), 2015)

Cons Files	IC Files	Scenario	Cons %
Incremental Cons		Base	
L2a Cons		Base	0
	Project - Merensky (L2a)	Base	100%
	Project – UG2 (L2a)	Base	100%
	Project - Merensky (L1e)	Base	100%
	Project – UG2 (L1e)	Base	100%
	Operation - Merensky(L1)	Base	100%
	Operation – UG2 (L1)	Base	100%
L1e Cons		Base	100%
	Project - Merensky (L1e)	Base	100%
	Project – UG2 (L1e)	Base	100%
	Operation - Merensky(L1)	Base	100%
	Operation – UG2 (L1)	Base	100%
L1 Cons		Base	-100%
	Operation – Merensky (L1)	Base	100%
	Operation – UG2 (L1)	Base	100%

For the recurring structure, the L1e consolidation already provides the progressive L1e plan as the L1 investment centres are repeated under the L1e consolidation. The L1 consolidation is subtracted from the L1e consolidation to perform the incremental valuation of the L1e investment centres. The same average off-mine unit cost rate is applied to all the investment centres (L1 and L1e) within the L1e consolidation, which is based on the progressive L1e off-mine costs and production profile. The L1 IC files carry a L1 off-mine unit cost rate (higher) in the L1 consolidation, whilst the L1 IC files carry a L1e off-mine unit cost rate (lower) in the L1e consolidation. During incremental valuation (L1e Cons minus L1 Cons) where the above-mentioned two sets of L1 IC are subtracted from each other, negative costs or positive cash flow will be generated that gives rise to unrealistic value creation.

Table 50: Solitary Consolidation Structure (Anglo American Platinum (f), 2015)

Cons Files	IC Files			Scenario	Cons %
Incremental Cons				Base	
Extended Case					
L2a Cons				Base	100%
	Project - Merensky (L2a)			Base	100%
	Project – UG2 (L2a)			Base	100%
L1e Cons				Base	100%
	Project - Merensky (L1e)			Base	100%
	Project – UG2 (L1e)			Base	100%
L1 Cons				Base	100%
	Operation – Merensky (L1)			Base	100%
	Operation – UG2 (L1)			Base	100%
Base Case					
L2a Cons				Base	100%
	Project - Merensky (L2a)			Base	100%
	Project – UG2 (L2a)			Base	100%
L1e Cons				Base	100%
	Project - Merensky (L1e)			Base	100%
	Project – UG2 (L1e)			Base	100%
L1 Cons				Base	100%
	Operation – Merensky (L1)			Base	100%
	Operation – UG2 (L1)			Base	100%

In the case of the solitary consolidation structures, the investment centres are listed once (initially) on the structure for business planning purposes. The L1 consolidation needs to be added to the L1e consolidation file to provide the progressive L1e plan. Where it is required to perform incremental project valuations on the same consolidation structure utilized for business planning, the investment centres and consolidation files must be repeated to form a base and extended consolidation, which are reporting to an incremental consolidation. Incremental costing of off-mine costs is required in the case of solitary consolidation structures and the unrealistic negative off-mine costs, as detected in recurring consolidation structures due to the application of average costing, are eliminated to enhance the accuracy of business plans and valuations. The implementation of solitary structures will also increase the modelling efficiency due to a significant reduction in the size of the business planning structures and the associated setup time, run time, consolidation errors and required computing capacity.

6.3 Major Project Valuations

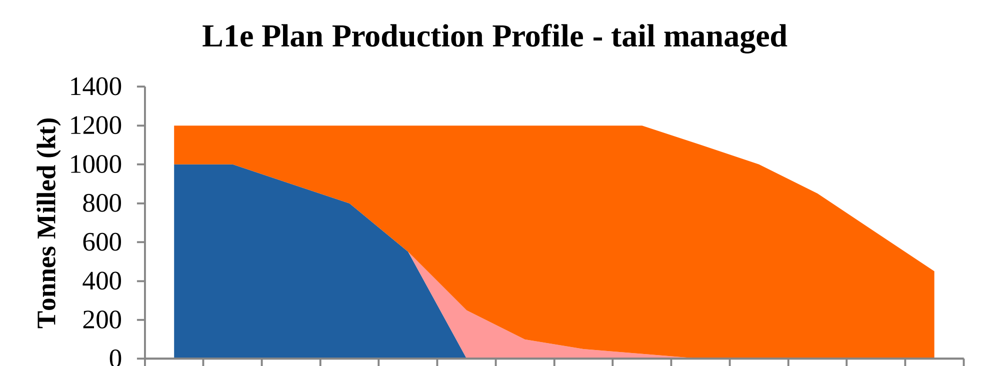
Consolidations and Tail Management

Tail management (tail cutting) is based on the assumption that the operation will be shut down when it becomes uneconomical. It is the process to optimize the base and extended business cases by curtailing the production profile when it becomes cash flow negative on a continuous basis. This task can be executed by either deleting the input data after the tail cut year or by entering the tail cut year on the consolidation structure. This method is briefly discussed by means of an incremental consolidation structure of a 100% owned mine project as reflected in Table 51.

Table 51: Consolidation Driven Tail Management (Anglo American Platinum (f), 2015)

Cons Files	IC Files	Scenario	Cons Method	Cons Start Year	Cons End Year	Cons %
Incremental Cons (Differential or Stand-alone)		IES-B				
Extended Cons -TC		IES-B	Full Cons	2015		100%
Extended Cons		IES-B	Full Cons	2015	2030	100%
	Project - Merensky (L2a)	IES-B	Full Cons	2015		100%
	Project – UG2 (L2a)	IES-B	Full Cons	2015		100%
	Operation - Merensky(L1)	IES-B	Full Cons	2015		100%
	Operation – UG2 (L1)	IES-B	Full Cons	2015		100%
Base Cons - TC		IES-B	Full Cons	2015		-100%
Base Cons		IES-B	Full Cons	2015	2020	100%
	Operation – Merensky (L1)	IES-B	Full Cons	2015		100%
	Operation – UG2 (L1)	IES-B	Full Cons	2015		100%

The base consolidation file (Base Cons) consolidates 100% of the two operational IC files. The consolidated net cash flows of the base consolidation file are examined to determine the last year of continuous positive cash flow (i.e. 2020). This year is entered as the last consolidation year in the base consolidation file (Base Cons). The base consolidation – tail cut file (Base Cons - TC) will consolidate 100% of the information from the base consolidation file for the period 2015 to 2020. The base consolidation – tail cut file will consequently reflect the optimized base case. The same consolidation logic is applied to determine the optimized extended case in the extended consolidation – tail cut file. The true incremental value is determined from the differential between the optimized extended case and optimized base case. Care should be taken during the consolidation system design that only the input data like production, operating expenses and capital expenses are terminated after the tail cut year and the downstream cash flow calculations comprising of process pipeline revenue, tax and net working capital movements should be allowed to run its course into the following year or two. The tail managed production profiles for L1 and L1e plans are illustrated in Figure 25.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
L1e	200	200	300	400	650	950	1100	1150	1175	1100	1000	850	650	450
L1 Tail						250	100	50	25	0				
L1	1000	1000	900	800	550									

Figure 25: Tail Management (Quaye, 2014, p. 7)

The consolidation driven tail management has the advantage that the original input data is not tampered with. It also eliminates the requirement of having two sets of input files, which can become misaligned. The tail management cut off year can easily be adjusted on the consolidation structure when the models are updated with new global assumptions. Standardization of the tail management process by means of consolidation structures will ensure the integrity of input data and provide an efficient method of modifying the cut-off date.

Full and Partial Mining Value Chain Modelling

The valuation methodology of 100% models applies to own mine valuations and determines the value added by a project over the full mining value chain, from the mining of ore, to the sale of refined metals. The full sales revenue is recognized in the base case and extended case cash. This practice necessitates the application of full absorption costing and consequently all operating and capital costs over the full mining value chain (on-mine and off-mine costs) are considered in the cash flow schedule to avoid overstatement of the base and extended business cases.

In the case of joint ventures, the valuation methodology of on-mine models applies to “sale of concentrate” valuations and determines the value generated by a project over the on-mine (mining and concentrator) portion of the mining value chain. Only the take-off price revenue, on-mine costs and on-mine capital costs are incorporated in the cash flow schedules of the base and extended business cases.

The valuation methodology of off-mine models applies to “purchase of concentrate” valuations for joint ventures and determines the value created by a project over the off-mine (smelter, refineries and other) portion of the mining value chain. The full sales revenue, purchase of concentrate costs (equal to take-off price revenue mentioned above), off-mine costs and off-mine capital costs are incorporated in the cash flow schedules of the base and extended business cases.

The ability to model the full mining value chain and parts of it enables the creation of 100%, on-mine and off-mine models, which can be combined in different consolidation arrangements to perform techno-economic modelling for own mines, joint ventures and associates. This method and functionality provide the valuation accuracy and flexibility required in techno-economic models.

Stand-alone and Differential Incremental Valuations

The differential incremental valuation (DIV) determines the pure differential between the optimized extended case (base plus project) and the optimized base case, without recalculation of tax on the incremental cash flow. In the extended business case, the project capital costs from the project investment centres (L1e) is used as a tax shield for the profits derived from the operational investment centres (L1). When compared to the stand-alone incremental valuation as described below, the tax shield or saving occurs earlier in the cash flow schedule and has a positive impact on the NPV.

The stand-alone incremental valuation (SIV) requires that any value arising from external tax shields, because of the project being part of a broader tax group, must be excluded from the project's net cash flow and net present value to reflect the pure value from the project on its own. The modelling is carried out in such a way that ensures the tax shield from the project IC (L1e) is isolated from the profits of the operational IC (L1) and the rest of the broader tax group. The stand-alone incremental valuation only redeems the tax shield created by the project capital costs against profits generated by the project IC and not against profits generated by the operational IC or the mining group. Consequently, it will only be redeemed at a later stage in the project's life once the project investment centres start to generate profits. This later redemption of the tax shield creates a delayed positive cash flow profile compared to the differential incremental valuation method. This method is implemented by re-calculating the tax after the incremental operating profit before tax is determined to deliver a stand-alone incremental value, which is aligned with stand-alone valuations principles as described in Section 5.2.

Due to tax entity and ring-fencing legislation, a group consolidation is required for realistic tax calculations but is usually a complicated and time-consuming modelling process. It is consequently not practical to create a group model, containing all the investment centres of an entire mining group, during project valuations. The alternative SIV method is a practical and conservative method that delivers a lower NPV value compared to the DIV method. The SIV method has the additional benefit that green field and brown field project valuations are comparable when applying this method, as the brownfield project will not enjoy an earlier tax benefit due to the operational investment centres being part of the extended business case. The standalone incremental valuation method offers a consistent, objective valuation approach that is being proposed for project valuation purposes. The difference between the differential incremental and stand-alone incremental valuation methodology are illustrated in Figure 26.

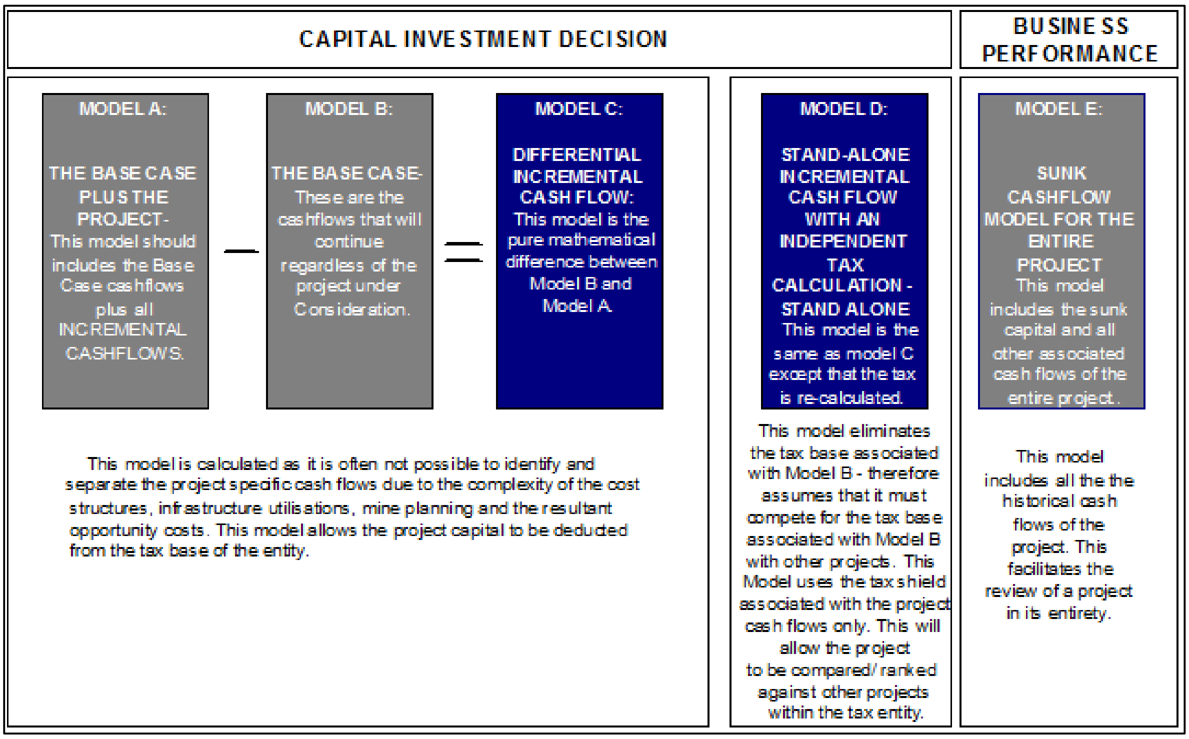


Figure 26: Incremental Valuation Methodologies (Smith, 2011, p. 194)

6.4 **Stay-in-Business Project Valuations**

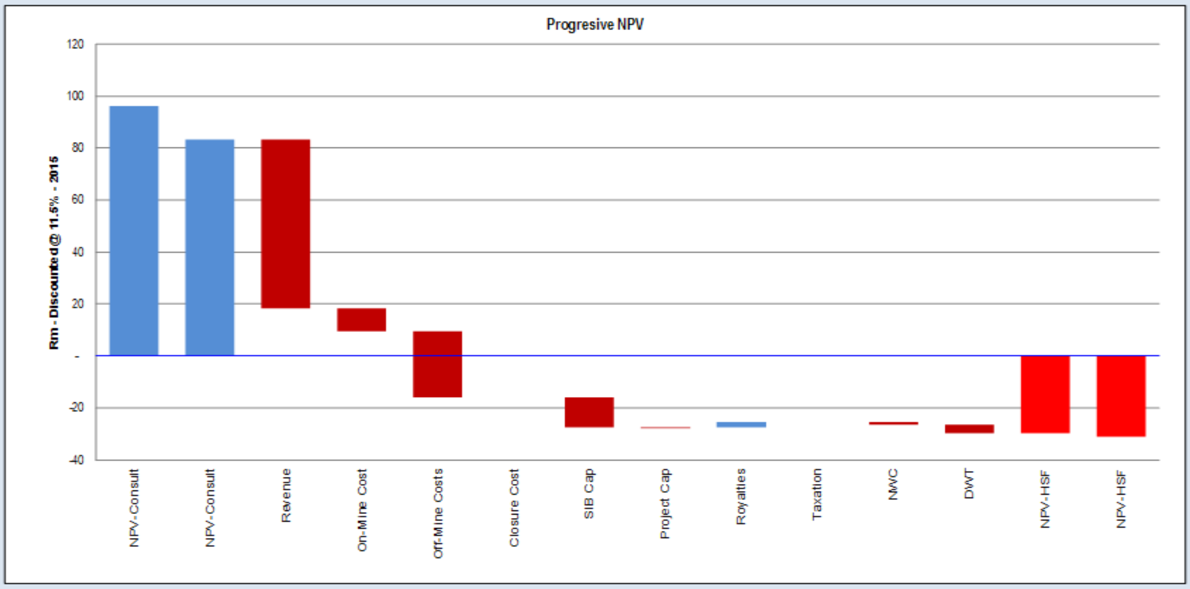
The yearly stay-in-business capital expenditure is traditionally of the same magnitude as the yearly capital expenditure on major projects, but no project valuation tools existed to value and rank these projects. Compared to major projects, the number of SIB projects is usually large, while the capital amounts are relatively low. These SIB projects do not have dedicated project teams, whom can source the relevant information to perform techno-economic valuations, as this is not viable from an economic and complexity perspective. The fact that SIB projects compete for the same capital funds as major projects, requires that the same valuation logic and accuracy should be applied to SIB project valuations and major project valuations to make them comparable.

A capital excellence project was initiated, which implemented a scrubbing process to ensure optimized and value creating SIB capital projects. A business case model was developed, which included pre-populated tables of techno-economic input information for each operation. These tables are updated on a yearly basis from the business planning system. The business case development consequently only requires basic model input i.e. incremental tonnage, efficiency improvement percentages and capital cash flow relevant to the anticipated SIB capital project. The business case model also allows the top three options to be contained within the model reports for decision-making visibility. Once the best business case option for a specific project is identified, key business case data, including valuation metrics and cash flow schedules, are exported to a SIB portfolio model. The portfolio model reflects information of all the SIB capital projects in a graphical manner that facilitates the project ranking and approval process.

Standard valuation practice, as defined for major project valuations, was consistently applied to techno-economic modelling of SIB capital projects. The incorporation of pre-populated information tables improved the efficiency of techno-economic modelling, as it enabled the tool to be used by the SIB project teams and engineers for optimization and evaluation of alternative options.

6.5 **Case Study**

A case study was done to compare the results obtained from two different techno-economic models. Anglo American Platinum implemented a customized Hyperion Strategic Finance (HSF) model for business planning and project valuation purposes. This highly sophisticated model with excellent consolidation abilities applies the best practices and logic as discussed in this document. The alternative techno-economic model is a basic spreadsheet based discounted cash flow model, which was used by a mining consulting firm for project valuation during the mine design and schedule optimization. A small open cast project with a lifespan of two years was used for the analysis. The same production, grade, operating costs and capital costs was used as inputs in constant money terms for both models. The spreadsheet model had a positive NPV of 96 million ZAR, whilst the HSF model delivered a negative NPV of 31 million ZAR. Figure 27 below illustrates the major elements that account for the differences in NPV value.



	NPV-Consult Mthly@11.5%	NPV-Consult Yearly@11.5 %	Revenue	On-Mine Cost	Off-Mine Costs	Closure Cost	SIB Cap	Project Cap	0	Royalties	Taxation	NWC	DWT	NPV-HSF Full Year Disc@ 11.5%	NPV-HSF Mid Year Disc@11.5%
Prog NPV	96	83	18	9	-16	-16	-27	-28	-28	-26	-26	-27	-30	-30	-31
Movement	96	-13	-65	-9	-25	-	-11	-0	-	2	-	-1	-3	-	-1

Figure 27: NPV Waterfall Analysis (Anglo American Platinum (h), 2015)

The spreadsheet model only considered the cash flows in constant money terms without catering for inflation, whilst the HSF model escalated the constant money terms to nominal terms. This enabled the calculation of realistic royalties, taxes and net working capital changes in nominal terms.

The biggest difference occurred in the revenue calculation. The spreadsheet model used the same metallurgical split and concentrator, smelter and refinery recoveries for all years instead of sourcing the information from a metallurgical simulation, where these values will vary slightly from year to year, as applied in the HSF model. The HSF model also considered the pipeline effect of refined metal that delayed some of the revenue to the following year. The spreadsheet model assumed constant metal prices and exchange rates and does not take anticipated future fluctuations, due to supply and demand fundamentals and purchasing parity, into account.

Although the same constant operating and capital cost inputs were used, a further value reduction can be seen in these areas as mining and process escalation are usually higher than CPI and this impact is reflected in the HSF results. The spreadsheet model did not account for changes in net working capital and dividend withholding tax.

A simplified model is in most cases suitable for mine design and scheduling optimization where only the relevant NPV is important to guide the mining engineer. These simplified models would not suffice to support investment decisions, determine the company's cash flow forecast during the business planning process or to guide management through the evaluation of strategic options.

6.6 Findings

Business Planning – Business Entity Consolidations Structures

The combination of investment centre and consolidation files as dictated by the consolidation structure provides the required flexibility to model different business entities. These mine consolidations can be consolidated into different tax entities and group consolidations for group valuations, cash flow forecast and capacity testing.

Business Planning – Recurring and Solitary Consolidation Structures

Incremental costing of off-mine costs is required in the case of solitary consolidation structures and the unrealistic negative off-mine costs, as detected in recurring consolidation structures due to the application of average costing, are eliminated to enhance the accuracy of business plans and valuations. The implementation of solitary structures will also increase the modelling efficiency due to a significant reduction in the size of the business planning structures and the associated setup time, run time, consolidation errors and required computing capacity.

Major Project Valuations – Consolidation and Input Tail Management

The consolidation driven tail management has the advantage that the original input data is not tampered with. It also eliminates the requirement of having two sets of input files, which can become misaligned. The tail management cut off year can easily be adjusted on the consolidation structure when the models are updated with new global assumptions. Standardization of the tail management process by means of consolidation structures will ensure the integrity of input data and provide an efficient method of modifying the cut-off date.

Major Project Valuations – Full and Partial Mining Value Chain Modelling

The ability to model the full mining value chain and parts of it enables the creation of 100%, on-mine and off-mine models that can be combined in different consolidation arrangements to perform techno-economic modelling for own mines, joint ventures and associates. This method and functionality provide the valuation accuracy and flexibility required in techno-economic models.

Major Project Valuations – Standalone and Differential Incremental Modelling

Due to tax entity and ring-fencing legislation, a group consolidation is required for realistic tax calculations but is usually a complicated and time-consuming modelling process. It is consequently not practical to create a group model, containing all the investment centres of an entire mining group, during project valuations. The alternative SIV method is a practical and conservative method that delivers a lower NPV value compared to the DIV method. The SIV method has the additional benefit that green field and brown field project valuations are comparable when applying this method, as the brownfield project will not enjoy an earlier tax benefit due to the operational investment centres being part of the extended business case. The standalone incremental valuation method offers a consistent, objective valuation approach that is being proposed for project valuation purposes.

Stay-in-Business Project Valuations

Standard valuation practice, as defined for major project valuations, was consistently applied to techno-economic modelling of SIB capital projects. The incorporation of pre-populated information tables improved the efficiency of techno-economic modelling, as it enabled the tool to be used by the SIB project teams and engineers for optimization and evaluation of alternative options.

Case Study

A simplified model is in most cases suitable for mine design and scheduling optimization where only the relevant NPV is important to guide the mining engineer. These simplified models would not suffice to support investment decisions, determine the company's cash flow forecast during the business planning process or to guide management through the evaluation of strategic options.

7 Conclusions

7.1 Summary of Findings

Key components of Mining and Metallurgical Modelling

The mining rights area is broken down into investment centres of which the planning confidence increases as the project investment centres progress through the stage gate process. A mining rights plan consists of the production profiles of the investment centres within a mining rights area. The optimized business plan is extracted from the mining rights plan and is used to prioritize capital investments, measures business performance and serves as the basis for future strategic planning.

The integrated techno-economic model requires a mining model with production planning and scheduling abilities. The half-level system method can be applied to create production profiles for different mining options and after optimisation; the best option is taken forward for graphical design and detailed scheduling. In the case of conventional underground mining, the half-level system method is applied to determine the steady state stoping, development and ledging rates per half-level. From the steady state production and crew productivities, the number of crews is determined and the durations of mining activities are estimated and synchronized to deliver a mining plan for a half-level. This half-level mining plan can be replicated to create a mining plan for an investment centre and shaft, which should be pressure tested against logistical and economic constraints. From the mining model, the tonnes milled and 4E grade are derived and incorporated into the metallurgical model. The case study also stressed the importance to review the synchronisation status of half-level mining entities and to implement mitigating steps.

The metallurgical model integrates the process efficiencies and logic for concentrators, smelters and refineries into the techno-economic model to determine the refined metal products for revenue and costing purposes.

Key Components of Financial Modelling

Fixed-variable cost estimation ratios should be applied with care and the adjustability of fixed costs should be incorporated in cost estimates of long-term production profiles. Activity–based costing can be applied to determine the appropriate cost drivers to allocate overhead costs to investment centres. These unit cost drivers can be determined from average costing or incremental costing methods. The cost estimation method is mainly driven by the required details, accuracy and available time to perform the estimate. Mining and metallurgical plant costs are dependent on the equipment, material and labour used in the process and vital costing features, as discussed, should be incorporated to ensure realistic cost predictions.

The on-mine cost forecasts of investment centres require estimations from first principles by means of detailed costing models, in which parameters and assumptions can easily be modified to filter through the cost estimates. The use of average costing rates is suitable to determine the off-mine costs of an investment centre. Closure cost estimates need to be supported by appropriate estimation models and assumptions.

Capital expenditure can be categorized as either project or SIB capital costs according to the nature of the expense and both should be estimated and included in the investment valuations. Capital cost estimates increase their accuracy as the project progresses through the project phases. Contingencies are added to capital cost estimates due to the inherent forecasting inaccuracies and the effect of inflation is incorporated by means of escalation. Project capital costs can consist of study and execution capital costs and all future incremental capital costs relevant to an investment centre should be considered in the investment valuation.

Key Components of Techno-economic Modelling

The valuation methodology calls for the project valuation to be based on the incremental cash flow of the project that will be the determined from the base and extended business cases. The calculation of the cash flow schedule line items for a single investment centre was established and it is recommended that the cash flow schedule is repeated in constant, nominal and real money terms to ensure accurate money terms conversions. Calculation of taxes, net working capital and dividend withholding tax are required in nominal terms and the conversion of these line items to real money terms will only be done by discounting the nominal values with SA CPI factors and not from re-calculating it from the constituent real line items. The business planning process requires a distinction between constant money terms and real money terms. The conversion process applies escalation factors to compute nominal values from constant values and SA CPI factors to discount nominal values back to real values. Global assumptions include constant metal prices and exchange rates that can be converted to nominal and real money terms. Uncertainty and risks in the macro-economic environment are accommodated by introducing different sets of global assumption scenarios to illustrate the envelope of investment value.

The constant gross revenue, commissions and net revenue can be calculated from the production and metal profiles as determined in the mining and metallurgical models and need conversion to nominal and real terms for downstream computations. The full pricing revenue of the metal products is recognized in the cash flow schedule and this requires the application of full absorption costing, which incorporates costs over the full mining value chain, to avoid overstatement of business cases.

For on-mine costs, application of detailed costing models is proposed to estimate the base and extended business case costs from first principles. Off-mine costs for the base and extended business cases are calculated in the valuation model by applying average cost rates to the respective production and metal profiles. The costs in the cost estimation model are computed in constant money terms and then converted to nominal and real terms in the valuation model. Mining capital costs require classification under either Section 15(a) capital, which qualifies for full redemption, or

Section 36.11(d) capital, which qualifies for partial annual redemption (PAR) in terms of the ITA. On-mine SIB capital costs are often estimated from a detailed SIB capital costs model and populated in the valuation model in constant absolute values. Off-mine SIB capital costs are based on a percentage of the relevant off-mine operating costs in constant money terms, as derived from historical analysis and are calculated within the valuation model. Project capital costs are determined from a detailed cost estimation model and project specific escalation rates are applied in the feasibility phase to convert the constant absolute inputs to nominal terms.

Specific royalty formulas should be applied in the case of refined and unrefined minerals and the allowable elements of EBIT and gross sales for royalty calculations are crucial. In the case of mining capital expenditure, full redemption is allowed in terms of Section 15(a) and partial annual redemption (PAR) is allowed in terms of Section 36.11(d) of the ITA. The ITA specifies the Section 36 assets and creates ring-fences to be applied when performing tax calculations of group consolidations. Dividend withholding tax should be included as a cash outflow and net working capital requirements can be determined from the provided equations and global assumption parameters. In nominal terms, the sum of net working capital changes will equate to zero over the life of the project, but this will not hold in real terms. Cash flow schedules are created for investment centres and consolidations. A real hurdle rate must be applied to the incremental real net cash flow to determine the project NPV. The hurdle rate must incorporate the WACC, as well as country and technical risk premiums to cater for opportunity costs and risks.

Application of Techno-economic Modelling

Business Planning

The combination of investment centre and consolidation files as dictated by the consolidation structure provides the required flexibility to model different business entities. These mine consolidations can be consolidated into different tax entities and group consolidations for group valuations, cash flow forecast and capacity testing. Incremental costing of off-mine costs is required in the case of solitary consolidation structures and the unrealistic negative off-mine costs, as detected in recurring consolidation structures due to the application of average costing, are eliminated to enhance the accuracy of business plans and valuations. The implementation of solitary structures will also increase the modelling efficiency due to a significant reduction in the size of the business planning structures and the associated setup time, run time, consolidation errors and required computing capacity.

Major Project Valuations

Standardization of the tail management process by means of consolidation structures will ensure the integrity of input data and provide an efficient method of modifying the cut-off date. The ability to model the full mining value chain and parts of it enables the creation of 100%, on-mine and off-mine models that can be combined in different consolidation arrangements to perform techno-economic modelling for own mines, joint ventures and associates. This method and functionality provide the valuation accuracy and flexibility required in techno-economic models. The SIV method is a practical and conservative method that delivers a lower NPV value compared to the DIV method. The SIV method has the additional benefit that green field and brown field project valuations are comparable when applying this method, as the brownfield project will not enjoy an earlier tax benefit due to the operational investment centres being part of the extended business case. The standalone incremental valuation method offers a consistent, objective valuation approach that is being proposed for project valuation purposes.

Stay-in-Business Project Valuations

Standard valuation practice, as defined for major project valuations, was consistently applied to techno-economic modelling of SIB capital projects. The incorporation of pre-populated information tables improved the efficiency of techno-economic modelling, as it enabled the tool to be used by the SIB project teams and engineers for optimization and evaluation of alternative options.

Case Study

A simplified model is in most cases suitable for mine design and scheduling optimization where only the relevant NPV is important to guide the mining engineer. These simplified models would not suffice to support investment decisions, determine the company's cash flow forecast during the business planning process or to guide management through the evaluation of strategic options.

7.2 Further Research

Areas identified for further research include the advanced techno-economic modelling to determine the optimum take-off metal prices in the case of joint venture agreements in the platinum mining industry of South Africa.

8 Recommendations

Key components of Mining and Metallurgical Modelling

The half-level system is recommended to create production profiles for various mining options and only after final evaluation the best option should be taken forward for graphical design and detailed scheduling. This method can also be implemented to generate mining production profiles for strategic work and mining studies where a number of options have to be considered in a relatively short space of time to maximize value. Incorporation of the metallurgical process logic and the metal pipeline effect are advised to determine the metal quantities for revenue and costing purposes.

Key Components of Financial Modelling

It is suggested that on-mine operating costs are estimated from first principles and off-mine costs are determined from average or incremental unit costs. Cost estimates should be calibrated in line with historical costs before they are extrapolated for production profiles. Closure costs need to be based on defensible estimation models and assumptions. Capital cost estimation methods must be aligned with the required level of accuracy as per project stage gate and proper segregation between capital and working cost development requires consideration of the capital footprint. Contingencies must be included in the capital cash flow, whilst application of project specific escalation rates is required during the feasibility study of a project.

Key Components of Techno-economic Modelling

An incremental valuation methodology is recommended, which is based on cash flow schedules for base and extended business cases. Repetition of cash flow schedules in constant, nominal and real money terms are advised to ensure the integrity of calculations and correct money term conversions. Different sets of global assumptions should be created to establish the envelope of value because of macro-economic uncertainty and risks.

In the case of own mine modelling (100% models), the full revenue of products is recognized in the cash flow schedule and consequently, the application of full absorption costing is required to avoid overstatement of the project value. Mining capital expenditure must be classified as either Section 15(a) or Section 36.11(d) capital to ensure correct computation of taxes. It is proposed that project capital costs and on-mine SIB capital costs are estimated from detailed cost estimation models, whilst off-mine SIB capital costs are determined by applying the percentage of operating cost method.

Royalty settings should allow for activation and switch between refined and unrefined metals, whilst care should be taken to incorporate only allowable items in the calculation of EBIT and gross sales for royalty purposes. Tax computations need to consider Section 15(a) and Section 36.11(d) of the ITA, which allow for full and partial redemption of capital expenses against the taxable income and for the unredeemed capital to be carried forward to the following year. It is also necessary to perform the tax calculations in nominal terms and to avoid re-calculating it from constituent line items in real terms. The inclusion of dividend withholding tax in the cash flow schedules is advised, as the net cash flow is an after-tax cash flow to which an after-tax hurdle rate is applied.

The inclusion of net working capital changes are proposed and should be computed in nominal terms based on ratified assumptions, with the sum of the nominal net working capital changes to equal zero over the life of the project. Application of a real hurdle rate to real cash flow is preferred above the methodology of applying a nominal hurdle rate to nominal cash flows, as the anticipated inflation that is included in a nominal discount rate might not be constant in all years. A set of valuation metrics and sensitivity analysis should be applied, together with a portfolio view and valuation reconciliations, to provide comprehensive information to stakeholders. It is recommended that cash flow schedules be created for investment centres that can roll up into consolidations to re-calculate royalties, tax and net working capital when required.

Application of Techno-economic Modelling

Business Planning

The functionality to create user defined consolidation structures is recommended for the purpose of business planning and incremental valuations of various business configurations. Models must periodically be updated with global assumptions to reflect changes in the macro-economic environment. The use of solitary structures is proposed as it increases the modelling efficiency, whilst the associated incremental costing of off-mine costs will enhance the accuracy of project valuations.

Major Project Valuations

Standardization of the tail management process by means of consolidation structures is endorsed as it ensures the integrity of input data and provides an efficient method of modifying the cut-off date. The ability to model the full mining value chain and parts of it is advocated as it enables the creation of 100%, on-mine and off-mine models that can be combined in different consolidation arrangements to perform techno-economic modelling for own mines, joint ventures and associates. This method and functionality provide the valuation accuracy and flexibility required in techno-economic models. The SIV method is proposed in order to comply with the stand-alone principle and allow green field and brown field project valuations to be comparable.

SIB Project Valuations

The consistent application of standard valuation practice, as defined for major projects, is recommended for SIB capital projects. The incorporation of pre-populated information tables is advised as it improves the efficiency of techno-economic modelling in the case of SIB capital projects.

Case Study

Only techno-economic models that apply the correct principles and best practice should be applied to support investment decisions, business planning and strategic option analysis.

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