Establishing a new metric for mineral resource management
by A.S. Macfarlane*

Introduction
The concept of mineral resource management (MRM) was developed initially at the Vaal Reefs Exploration and Mining Company, in 1996, where it was created as part of a business process re-engineering initiative that was being run at the time, aimed at redefining and improving the structure of the company, which at the time was part of the Gold and Uranium Division of the Anglo American Corporation.

At the time, the principle objective of this initiative was to improve the liaison between geology, survey, evaluation and planning activities, in order to create more integrated plans, that were more aligned to value.

Subsequently, with the formation of AngloGold Limited, the initiative was taken to a corporate level, and implemented at a company level, spread across all the operating units.

Since then, MRM has developed within AngloGold Ashanti, to the extent that it is now being spread to the company’s Africa operations, as a result of the successes obtained in the South African operations.

Meanwhile, the author continued to research and consult in the field through the University of the Witwatersrand, at the School of Mining Engineering. This work has allowed the author to assist other companies in their approach to MRM, notably Gold Fields Limited, Kumba Resources, Anglo Platinum, and BHP Billiton, among others, at corporate level and/or at individual mine sites.

This extensive exposure to current practice has allowed the author to develop insight into the degree of success of MRM in achieving its objectives, while also being able to identify shortcomings in current practice and application.

These observations have allowed the author to come to the conclusion that MRM has achieved only marginal success on average, although there are notable centres of excellence that are the exception to this generality.

The reason behind this conclusion are principally that MRM has operated in a vacuum where, on the one hand there has been no real and appropriate measure of the success of MRM and, on the other, operating and company management have often perceived MRM and its activities as an unnecessary expense, because the metric to identify its value-add is not present.

Judgements therefore tend to be subjective, and often influenced by short-term reporting imperatives such as cost and profit.

**Definition of MRM**
In work that the author conducted for BHP Billiton at their Hotazel Manganese Mines in 2002, the following definition for MRM was developed.

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Establishing a new metric for mineral resource management

‘MRM is an integrated activity which identifies, evaluates and provides an optimal extraction plan of the mineral resource, to produce a quality product which satisfies the business objectives of the company, and the requirements of the customer, in a dynamic environment.

It performs an audit and quality assurance function to ensure compliance to the business plan, and customer satisfaction in terms of quality and quantity.

Overall, effective MRM is an essential component of Operational Excellence along the value chain.’

The definition includes materially important concepts of integration, economic focus aligned to the business objectives, quality assurance and customer satisfaction, by aligning MRM work to the value chain.

Importantly, this focus requires that the mineral resource is recognized as the most important economic asset of the company, and that it is treated as an asset. This requires that its value be ascertained, and that this value is optimized, through each stage of the mining process.

The subject of the valuation of the mineral asset for public reporting and public valuation purposes is the subject of other papers and debates, but in principle the fundamental net asset value of a mining company should be a function of the value of the mineral asset in present value terms, less liabilities.

Thus, MRM has the role of identifying, optimizing and realizing the value of the mineral asset, through converting it from an initial inferred resource, through to a proved Reserve, and ultimately to saleable product.

The increase in value, in moving from exploration through resources, into reserves and to mined and beneficiated product, is accompanied by a decreasing level of uncertainty and risk associated with the various categories of resource and reserve, which means that the activity of MRM is principally to do with the reduction of risk and the realization of value associated with the exploitation of the mineral asset.

In work that has been published elsewhere, the author has identified that this focus on value and risk translates into the following focus areas for MRM:

➤ Integration of (previously) functional disciplines in a value chain approach, to ensure that maximum value is extracted through the combined efforts of activities in the value chain
➤ Integration of short, medium and long-term planning and optimization studies, so that short planning, which may be driven by short-term objectives, does not compromise the realization of longer-term value
➤ Strong economic focus on maximizing the value of the mineral asset and minimizing the risks associated with its extraction
➤ Real, measureable ‘triple bottom line’ improvement, in the area of responsibility and influence of MRM, which matches issues of sustainability that the company has recognized
➤ Unlocking real value through free cash flow, for the shareholder through constant search for added value, beyond the cost of capital of the company
➤ Identification of, and focus on, the real drivers of value in the company, in the MRM field
➤ An independent, professional and consistent audit and quality assurance role on the product throughout the value chain, aligned to the corporate governance principles of the company
➤ Establishment of confidence in the market that the company can deliver on its promises of value extraction from the resource, both in terms of projects, operating entities and acquisition targets.
➤ Identification of targets, operations and projects that have the potential to deliver value in excess of the cost of capital, and the application of cost-effective strategies to realize this value
➤ Interrogation, analysis and application of corrective plans and actions to operations or projects that do not deliver returns in excess of the cost of capital
➤ Divestment from operations and projects that cannot deliver value to the company.

Most companies seem to have placed some degree of focus on these aspects, but with varying degrees of success.

All too frequently, there is a disjoint between the short-term requirements of companies, and the longer-term, more strategic assessments that are required.

Corporate and market concerns

The capital markets continue to perceive mining as high risk business, with exploration and deep level mining carrying particularly high risk premiums.

Such perceptions are backed up by various studies that have been conducted, such as the following:

➤ A CIM survey conducted in 2000 over 18 projects showed that 78% had problems of non-delivery (Vallee, 2000)
➤ In a survey conducted by the North West Mining Association, of 60 projects since 1980, there was an average overrun of 22% on costs or time, with half of these having overruns of more than 20% (Gypton, 2002)
➤ A CMMI survey conducted in 1998 of 55 projects showed 40% had problems associated with grade estimates, and 24% had problems with tonnage estimates
➤ An Anglo American study of 11 of its major projects showed that errors were most commonly due to grade estimates, price forecasts and valuation methodologies being incorrect (Croll, 1999)
➤ A recent global benchmarking study of mining and petroleum projects by BHP Billiton has shown that the most frequent source of error in project estimates arises from inadequate ‘front-end loading’, or inadequate information accuracy levels at the feasibility stage. These observations have recently been backed up by a study conducted by De Jager (2005) of Anglo American, who has also concluded that projects do not realize or deliver optimum capital efficiency through output, often being highly overcapitalized.

A conversation between the author and RBC Capital markets in London (2004) further revealed the following opinion of South African mining ventures, that enter the capital market for financing:

➤ South African companies do not manage capital well: they tend to employ too much capital on very large, long-life projects that do not deliver early returns to the shareholder.
Establishing a new metric for mineral resource management

- They have a tendency to value life of mine, rather than financial returns
- They have unnecessary concerns about security of tenure and political risk; the real concern is about their ability to deliver superior returns to the shareholders.

Interestingly, these perceptions arise from the situation where South African companies have traditionally relied upon internal equity funding, whereas now they need to raise finance from global markets, where the competition for finance does not carry the same legacy.

These observations and concerns give rise to a number of familiar criticisms of the mining industry in general and the South African one in particular, that manifest themselves in a CEO's 'worry list' that could be summarized as follows:

- Excellent plans are created, but they don't deliver results
- Projects are financed and constructed, but they do not deliver to expectations
- Having to find innovative accounting ways to formulate year end or quarterly results that satisfy the market's expectations and 'whispers', when it cannot be done through the real results
- Having to constantly think up new excuses for non-performance
- Analysts and investors start to lose confidence in your announcements, and your company in general
- Having to make shock announcements about material changes in resource estimates, plans, designs or production levels attainable
- The market discovers a non-compliance issue in a public report on resources, reserves or valuations
- Share weakening as a result of market discounts to the extent you become subject to a hostile takeover
- Coming to the realisation that your assets are not what you thought they were.

To add to this worry list, the auditing community has, through the KPMG and PricewaterhouseCoopers surveys of 2005, concluded that companies do not report on long-term value, instead concentrating on short-term earnings as the principle focus area.

Such a focus ignores long-term value, and treats investment in long-term value as an expense, in the accounting period at hand.

The PWC view of the 'Earnings Game', and the tendency that it encourages short-term focus as opposed to long-term value creation, is based on the following:

- Accounting rules allow that items such as R&D, information technology, marketing, branding and other intangibles can be treated as expenses
- This results in manipulation of P/E ratios, and creates a false picture of value when multiples are used for valuation
- This results in the expensing of long-term, value adding investment, which should rather be capitalized
- The result is a mismatch of the time of the expense and the realization of the value.

The criticisms developed through the KPMG and PWC audits, especially those of mining companies, emphasized an apparent disconnection between short-term earnings reporting, and long-term value reporting, that is extensively dealt with in the book The Value Reporting Revolution (Eccles, Her. Keegan & Phillips, 2001).

The principle theme of the book is the following:

- Companies do not publish information about value creation
- Companies focus on short-term earnings in public reporting
- Public reporting does not address the needs of investors and analysts
- Reporting often lacks transparency.

The 'needs' referred to here are for the reporting of value, value creation and value drivers in the business.

To illustrate this point, a recent quarterly report, published as a two-page broadsheet newspaper release, emphasized a 35% improvement in headline earnings. However, close scrutiny revealed the following as the drivers of this performance:

- Forex earnings up
- Received prices up
- Opex up
- Depreciation up
- Mine production down
- Increased debt
- No development result published
- No reference to ore reserves
- No grades reported on
- No recoveries reported on
- No capital charge.

The actual improvements in reported earnings were mainly due to accounting measures, and a new assessment of inventories. The real performance, in terms of real value drivers, showed no improvement over the previous quarter.

It should be realized that where project delivery is concerned, and where the creation of value from the resource is a key element of success, both in the short and the long-term, this is a matter of concern aimed not only at the way in which operations and projects are managed, but also the way in which MRM is applied.

Current application of MRM

As mentioned previously in this paper, it is the opinion of the author that MRM implementation has realized only marginal levels of success.

Certain companies have managed to identify, develop and achieve reasonably high levels of integration, in both work practices and systems, and to align these to value chain activity. These successes have been reported by authors such as Visser.

These, and others, have concentrated on integrity issues related to the reporting of resource and reserve estimates, and the disclosures that associated with these in annual reports. There is no doubt that significant improvements have been made in these areas, and in the reconciliations that must be present in these estimates and reports.

Other companies have made significant strides in areas of process optimization, process control and constraint analysis.

Such improvements have been reported by authors such as Diedricks (2003) and Bye (2005), who has reported on some of these improvements in this conference.
Establishing a new metric for mineral resource management

De Jager has reported on findings and developments from the Anglo American perspective, and Mullins has reported on risk assessment and management in BHP Billiton.

Work conducted by the software suppliers has supported the development of MRM to the state where it currently stands, which, in the field of IS and IT is well advanced of its position some years ago.

Other technology initiatives have significantly impacted upon the success of MRM to date, in areas such as seismic reflection studies, geological modelling, borehole radar, information capture and process monitoring and control.

Most of the initiatives developed in the industry have allowed practitioners to assess the value of their plans in terms of discounted cash flow (DCF) techniques, assessing the value of plans on the basis of net present value (NPV) or Internal rate of return (IRR). The development of basic mining equation (BME) formats has helped to facilitate this move towards valuation.

In some companies, interventions have been initiated, aimed at establishing parts of MRM, or even MRM as a whole, but these have often failed because a lack of executive support, suboptimality, constraints that were not dealt with adequately, or lack of continuity and sustainability.

While many of these initiatives have delivered significant results, they have delivered limited success, being in many cases suboptimal solutions, or solutions that do not translate into measurable economic value.

As a result of these observations, the author has developed the following list of areas where MRM practice must be improved, or where new solutions must be developed.

- The planning and exploitation of mineral resources is subject to at least three opposing forces. Reporting routines require that companies report on short-term performance in terms of earnings. This, accompanied by the fact that managers are rewarded according to short-term profits, tends to place emphasis on profit and cost, rather than value. The result is that value adding activities, such as exploration, development and the creation of flexibility, are often compromised in the drive for profit.

Classical mineral economics, on the other hand, relies on theories of exhaustion, and may direct companies to preserve the stock of wealth in the ground, through the application of pay limits and mining to average grades.

Issues of sustainability support this approach. The MRM approach is a modern business approach, which requires that maximum value is extracted from the resource early in the life of the project, so that free cash flow generated from early returns can be reinvested into the mine or project, in order to create flexibility and growth. It also requires that projects that cannot meet the criterion of creating returns in excess of the cost of capital be abandoned.

These three opposing forces create tension in the planning process, resulting in a disconnect between short-term planning based on profit, and longer-term planning for value. Furthermore, flexibility, which is essential to manage economic cycles and to deal with risks inherent in the resource (such as potholes, faults, grade variability), is seen as a cost and is minimized with the result that operations are constantly constrained, and have to resort to short-term reactive plans that are themselves not sustainable.

- There is no measure that allows integration of short and long-term planning or operation. Generally, companies measure short-term performance through profit, and longer-term value using DCF measures. However, there is no connection between the two, and DCF techniques are usually applied and measured as static, single point analyses, with many shortcomings, as explained below. A more dynamic measure is required.

- Flexibility, ore reserve development and exploration can be seen as options available to the manager, either to be increased, maintained or decreased. Clearly, increasing levels of these activities result in decreased risk to the operation, but increased cost. Appropriate levels of these activities, assessed on a cost-benefit basis, must be defined, which address the value added by these activities, and the costs associated with them. (This important issue is the subject of another paper)

- The value of the mineral resource is calculated only as an NPV value, and used only as an investment criterion. This means that the value of the asset is ‘off-the-book’, and typically only assessed annually when new long-term plans are developed. Even, so, continuity of value is not guaranteed, and there is no formal way of establishing whether value is being created, destroyed or optimized. A means is required that values the asset and keeps it on the book.

- Similarly, capital investment tends to be a one-off event, whereby capital, through the appropriation method applicable in South Africa, is written off after it has been incurred. The result of this practice has been that projects tend to be over capitalized, and that returns on invested capital are neither monitored nor realized. Many examples of mega-shafts that have never reached their design capacities litter the South African countryside, representing wasted capital.

- Risk analysis is not given sufficient attention, and tends to be a one-off event, without due consideration of the quantum of risk. In projects, the observations of BHP Billiton and Anglo American reflect a lack of adequate risk analysis and management of the inputs into mine projects or plans, with the result that risk is often factored into discount rates rather than dealt with at source. A model is required that assesses downside risk, and quantifies it in terms of economic value loss. Its mitigation requires investment, based on financial valuation criteria, to ensure that the expenditure involved is value adding. Thus, an integrated model that combines risk and value within a single metric is required.

- An essential aspect of MRM is optimization of plans. This level of optimization is strategic mine planning, which must be factored into the planning processes and models at the right level and sequence, and be based on the common metric. This essential activity is usually given inadequate attention, with the result that plans tend to remain static and suboptimal.

Cost/volume/profit modelling, used to assess optimal...
operating levels under changing economic circumstances, is an essential tool in the MRM toolkit, which has the potential to release significant value to the shareholder, through the application of dynamic cut off grades and planning profiles, under varying constraints. The value of this approach has been recognized in the work of Lane (1998), and has been incorporated into most open pit planning and optimization packages. The potential to develop such models and algorithms in the underground situation requires investigation.

Process optimization is an area that also has the potential to unlock unrealized value, where investment into process optimization opportunities can be justified on a value add basis.

While these issues appear numerous, the focus of this paper is to provide a single solution to these issues, incorporated into a single model for business improvement and value creation.

The profit approach to planning

Plans based purely on profit or contribution are unlikely to optimize value. Clearly profits are driven by revenue and costs, and these then provide the levers by which to maximize profit.

Profits themselves, in accounting terms, are single period measures, related to a particular reporting period. Value adding expenditure, by contrast, realizes value in another, future accounting period, and is therefore treated as expense in the profit based plan. As a result it is at risk.

Profit based plans are often the result of margin squeezes and other pressure, which causes the mine planner to move to options that release profit or contribution. The most commonly applied of these are high-grade options, and low cost.

Such a movement has been seen in the gold mining sector over the last ten years, where margin squeezes have moved companies from high volume, low cost options into higher grade, lower volume plans, to combat the margin squeeze.

This cyclicity is clearly seen in Figure 1 below, which shows that in times of high prices, mining companies have tended to move to lower grades at higher volume. However, costs have usually risen in these high price cycles.

Conversely, in low price cycles, companies have tended to move to higher grades.

The grade graph, however, despite showing these swings, shows an overall downward trend, illustrating that such short-term reactive planning is not sustainable.

Conventional economic wisdom would question such behaviour: why should a business deliberately under produce when prices are high, and conversely supply their most valuable products into a low price market?

The answer to the question is simply that it is a matter of necessity that, where flexibility to deal with changing economic cycles has not been created (as a value-adding decision), reactive planning has to be undertaken, which is value destroying.

Of course, older operations will be forced to move towards profit based planning, since there is no further life to optimize. However, this should be done as part of the progression from strategic to tactical, to operational planning that should be part of the whole planning life cycle of wasting assets.

DCF approach to planning

Most longer-term plans for operations and projects are based on DCF valuation. While DCF techniques are reasonable well understood, there are some serious misgivings associated with the use of DCF. Some of these are that:
Establishing a new metric for mineral resource management

➤ The usefulness of a DCF analysis is only as good as the quality of the many technical inputs
➤ The correct discount rate has to be chosen, which should reflect only systematic risk associated with the financing structure. All too often discount rates chosen are too high, with the result that viable projects are rejected on the basis of NPV or IRR
➤ DCF tends to yield single point answers, reliant on expected values
➤ There is an inherent assumption that the plan is inflexible, with the result that flexibility is not included in the analysis
➤ The interpretation of the results of DCF analysis needs some insight into the mechanisms and mathematics of the method
➤ Conflicting rankings can occur between NPV and IRR, which can lead to misleading conclusions
➤ Discounting tends to hide future opportunities for expansions and other value adding activities
➤ While maximizing NPV relies on creating high early cash flows, this is not the same as maximizing profit in these years. Thus a conflict exists between maximizing NPV and maximizing profit.
➤ Traditional measures can encourage the acquisition of capital, which reduces cash costs but destroys value.

The concerns over the disconnect between profit and NPV are magnified when consideration is given to the many other metrics that are used for various other purposes, as is shown in Figure 2 below.

This complex and confusing management system is not conducive to the realization of value for shareholders.

The result of the misgivings of DCF analysis as a measure of value, and those of profit based planning define the need for an MRM metric that overcomes these, and provides a linkage between the two.

Economic value added as an alternative metric

EVA was developed by the management consulting firm Stern Stewart Incorporated, which was founded in 1982 by Joel M. Stern, and G. Bennett Stewart (Ehrbar, 1998). It was developed as a performance management system, aimed at increasing focus on behavioural and organizational change in management, and at operationalizing the notion of increasing shareholder value. (It should be noted that EVA is a copyright of Stern Stewart Inc.)

It became popular in the 1990s, being employed by companies such as Coca Cola, General Electric and AT&T. However, until now it has not been accepted widely in the mining industry, since the market value of mining companies is assessed in accounting terms, excluding the value of resources and reserves, while fundamental analysis has relied on the traditional measures such as DCF. Although some mining companies have briefly turned their attention to EVA, they have generally abandoned this foray, after finding it difficult to align non-financial parts of the organization to it, especially the operational parts of the business.

This has been partly due to it being seen merely as a financial management tool, rather than part of a holistic and strategic process of improvement in the company as a whole. It has therefore needed a recognizable and acceptable vehicle that links it firmly into the planning and production processes, while allowing a reporting function that satisfies the market’s needs.

Essentially, EVA is net operating profit minus an appropriate charge for the opportunity cost of all capital invested in an enterprise. As such, EVA is an estimate of the true ‘economic’ profit or the amount by which earnings exceed or fall short of the required minimum rate of return that shareholders and lenders could get by investing in other securities of comparable risk.

Peter Drucker stated in Harvard Business Review ‘Until a business returns a profit that is greater than its cost of capital, it operates at a loss. Never mind that it pays taxes as if it had a genuine profit. The enterprise still returns less to the economy than it devours in resources. Until then, it does not create wealth: it destroys it’.

The intent of EVA is to ensure that managers recognize this, and recognize that they must ensure returns on the capital that has been employed, and for which the investors invested in the first place, by keeping capital on the books as a charge. Effectively, it charges the company rent for tying up investor’s cash to support operations, since there is a hidden opportunity cost that goes to investors to compensate them for forfeiting the use of their own cash. EVA captures this hidden cost of capital that conventional measures ignore.

Figure 2—Current complex arrangement and relationships of different value metrics.(Cadle 2003)
The calculation of EVA is done in four steps, namely:

➤ Calculate net operating profit After Tax (NOPAT)
➤ Calculate total invested capital (TC)
➤ Determine the cost of capital (WACC)
➤ Calculate EVA.

In other words:

\[
\text{Sales} - \text{Operating Costs} = \text{NOPBT} - \text{Taxes} = \text{NOPAT} - \text{WACC} \times \text{Capital} = \text{EVA (value creation)}.
\]

The term WACC \( \times \) Capital, represents the capital charge, or opportunity cost of capital. In this term, capital refers to total balance sheet minus non-interest bearing debt, at the beginning of the year.

The WACC clearly must be estimated. The cost of debt is calculated as the after tax true cost of finance, whereas the cost of equity must be either estimated (in the case of a non-listed company), or calculated using the Capital Asset Pricing Model (CAPM), or the Gordon Constant Growth Model.

In more familiar terms, where Return on investment is incorporated,

\[\text{EVA} = (\text{ROI} - \text{WACC}) \times \text{Capital Employed} - \]

Thus, EVA is represented as Figure 3.

Where EVA is zero, if the WACC has been calculated correctly, the shareholders will have received the returns that they expected. The real value, however, is represented by the extent to which EVA is positive. This in effect is free cash flow, available for payment to shareholders, or reinvestment into the company into projects that will provide returns in excess of the cost of capital.

EVA is essentially a single period measure, in that it estimates the value addition from a single accounting period.

Stern Stewart have identified that if the total market value of a company is more than the amount of capital invested in it, the company has managed to create shareholder value. If the case is the opposite, the market value is less than the invested capital, and shareholder value has been destroyed.

The difference between market value, and the company book value, is described by Stewart as market value added (MVA).

\[\text{Market Value Added} = \text{Company Total market Value} - \text{Capital Invested}\]

Where the market and book value of debt are equal, this means that:

\[\text{Market Value Added} = \text{Market Value of Equity} - \text{Book Value of Equity}\]

The book value of equity represents all items that are equity equivalents. This includes items such as reserves and retained earnings. In the world of accounting, reserves in this case refer to cash and capital reserves, although it would equally refer to mineral reserves, if these were reflected in the balance sheet.

Even though they are not, they do represent the principle asset of the company, probably accounting for 60% of its market value.

This principle is carried forward into the examination of the usefulness of EVA and MVA as MRM performance measures, and as a measure of value for mineral projects.

This examination capitalizes the mineral asset in terms of the resource and reserve, and estimates the effectiveness of management in terms of its value creation from the asset.

The MVA is thus a measure of the value that has been added to the capital invested in the company, from the time of the investment, provided it is positive.

Mathematically, Stewart has shown that MVA is the present value of all future EVA. Thus,

\[\text{Market Value Added} = \text{Present Value of all future EVA}\]

Or,

\[\text{MVA} = \sum_{n=10}^{\infty} \left( \frac{\text{EVA}}{(1 + i)^n} \right)\]

The principle of MVA can be represented graphically as in Figure 4.

The figure shows that where the objective of the firm is to maximize EVA, this can be used as a measure of performance. Additionally, continued EVA improvement, manifested as MVA provides a longer-term performance measure, linked to the creation of value of longer-term capital projects.

Returning to the issue of reserves, the SEC rule 10 requires companies to account for reserves, but in a note, off the books. This benefits the company for accounting purposes, but is not an accurate reflection of the company’s economic position.

MVA brings the reserves into the value assessment, and does so in a proactive way, in that it encourages the optimal use of the reserves, through optimal planning and extraction, in such a way as to maximize EVA.

In order to do this, the MVA of reserves is calculated as the market value of reserves less the capitalized costs. Changes in the market value added to reserves can then be added to NOPAT and an accumulated capital account.

EVA of reserves is then calculated utilizing this data.

The theory of EVA and MVA can be translated into the application of these metrics as appropriate value measures in MRM, based on the following:
Establishing a new metric for mineral resource management

EVA and MVA capitalize the mineral resource, thereby keeping it on the books, and retaining the capital that has been applied to exploit it.

Short-term performance is directed by maximizing EVA in the first year, whereas longer-term plans are measured in terms of maximizing MVA.

EVA and MVA are linked directly, and therefore planning can be based on maximizing EVA from the first mining increment (equated to year 1 in the plan), and maximizing MVA from the remaining resource.

Value adding expenditures such as exploration, development, etc. are capitalized, and form part of the EVA/MVA equation, so that they are optimized in terms of value, and not seen solely as an expense.

EVA and MVA management rely on the identification and control of the key value drivers in the company, specifically those related to MRM and the mineral asset.

Overall, the approach allows the company to treat the mineral asset like an asset, and to constantly search for added value, which will be manifested through free cash flow generation.

The approach encourages reporting in terms of value creation, and value drivers, which is what the market wants.

Finally, the approach simplifies the management structure, in that a single metric can now be used for all of the above purposes, especially in the field of MRM, as shown in Figure 5.

The work of Hotelling

Hotelling (1931) developed the ‘r-per cent’ rule of extraction, which states that the price of an exhaustible resource must grow at a rate equal to the rate of interest, both along an efficient extraction path, and in a competitive resource industry equilibrium.

This would indicate that a competitive resource owner would deplete at a socially acceptable rate.

In terms of returns, or rent, the Hotelling rule implies that the present value of a unit extracted must be the same in all periods, if there is to be no gain in shifting production between periods. If this is to be the case, the undiscounted value must be growing at exactly the rate of interest.

Hotelling took this theory and applied it to a number of conditions, including monopolies, demand and cost dependent on cumulative production and uncertainty.

In the case of monopoly, he found that marginal revenue, as opposed to price, grows at the rate of interest.

He also recognized that profits relate not only to current production, but also to that remaining in the ground, and that future production is likely to take place at higher costs. To take account of this, he came to the conclusion that the
Establishing a new metric for mineral resource management

The present value of extraction must take into account the higher extraction costs experienced in future time periods. The rate of increase in rent must therefore equal the opportunity cost of deferred extraction (interest, \( r \)) less the savings in future extraction costs.

Hotelling did not adequately cover the aspect of uncertainty, instead indicating only that uncertainty in exploration could lead to outright failure or unrealistic prices and expectations, which should result in intervention of one sort or another.

A mathematical representation of Hotelling’s rule, which is based on the maximization of profit over the life of the mine, and which uses the critical assumption that marginal profit is the same in each time period, is as follows:

\[
\tau = \left[ p - MC(q_{t+1}) \right] - \left[ p - MC(q_{t}) \right] \frac{\delta V}{dT}
\]

In this expression, called the \( \tau \) per cent rule of expression, equality of marginal profit across periods implies that, across two periods, \( p - MC(q_{t}) \) is increasing at a rate equal to \( r \) per cent. In other words, rent on the marginal ton extracted in period \( t \) equals discounted rent on the marginal ton extracted in the next period. (Rent is user cost, royalty or Hotelling rent).

In order to assess the optimal extraction path, Hotelling requires that to maximize the present value of profits, first the rate of extraction must be selected that satisfies the \( \tau \)-per cent rule on rent \( p - MC(q_{t}) \); and secondly that the number of periods of extraction be assessed, such that the end condition \( p - MC(q_{t}) \) is as large as possible. He suggests this be done using a process of backward induction.

The work of Lane

In his book *Economic Definition of Ore*, Ken Lane (1998) has developed the mathematics that define the basis for cut off grade optimization for mining companies, taking into account the effects of mining, processing and market constraints, on a resource that is finite.

The basic premise of the book is that, under different conditions of these constraints, there is an opportunity cost to be factored into the calculation of cut off grades, in order to optimize the returns achievable within these constraints, in terms of planning.

Lane has identified that the opportunity cost factor is derived from the premise that capital carries two penalties, firstly, the interest that could be earned by investing the capital elsewhere \( (\delta V) \), and secondly, decline in value due to deteriorating economic conditions \( (-dV/dT) \), where \( \delta \) is the cost of capital, \( V \) is the capital, and \( T \) is time.

These components of opportunity cost have been combined to form a general expression that maximizes the value of an exhaustible resource.

According to Lane, the optimum exploitation strategy for maximizing the present value of an operation based on a finite resource can be determined by maximizing the expression:

\[
\tau = \tau \left( \delta V' - dV' /dT \right) = c - F \tau
\]

Where \( \tau \) is the time taken to process a unit decrement of resource which yields cashflow \( c \), and \( V' \) is the maximum present value at that stage.

This expression contains two components, namely the cash-flow, and the opportunity cost factor.

Lane defines the opportunity cost as the value of \( F \) which sets NPV to zero when the resource is depleted by a complete optimum exploitation strategy. Indeed, this is the further premise of Lane’s work, that says that there exists an optimal exploitation strategy for the depletion of a finite mineral resource, which is defined as a path of maximum NPV, by realizing that each successive increment of depletion should maximize the NPV of the remaining resource.

In terms of defining this optimal strategy, Lane proposes that at each decrement of depletion, a re-examination of the existing constraints, the opportunity cost and the associated cut off grade be made, so that an optimal cut off grade policy be defined over the life of the mine.

Examination of this expression shows that it closely resembles the EVA equation, in that \( c \) represents cashflow, or NOPAT in EVA terms, and \( F \) represents the capital charge, since \( V \) in the Lane expression is the capital value of the resource, less the capital applied to it.

Lane does not specifically mention EVA in his book, but this examination illustrates that his dynamic cut off grade optimization model is in fact based on the principles of EVA and MVA.

Lane varies his expressions for the calculation of NPV under differing constraint conditions, such that three expressions are derived, which define the NPV under conditions of each constraint being dominant. From these expressions, optimal cut off grades can be defined, which then define an optimal exploitation strategy.

The three expressions for NPV under conditions of mining, processing and market constraints, respectively, are shown below.

\[
\begin{align*}
V_c &= (p - k)xyg' - xh - m - \left( f + F \right) / M \\
V_e &= (p - k)xyg' - (h + \left( f + F \right) / H) - m \\
V_e &= (p - k - \left( f + F \right) / K)xyg' - xh - m
\end{align*}
\]

where

- \( m \) = mining variable cost
- \( M \) = mining capacity
- \( h \) = treatment variable cost
- \( H \) = treatment capacity
- \( F \) = opportunity cost
- \( X \) = ongoing capital expenditure
- \( p \) = price
- \( k \) = variable marketing cost
- \( K \) = market capacity
- \( Y \) = yield
- Cutoff grade = g mineral/unit of ore
- Average grade = g’ mineral/unit of ore

Lane has further refined this work, to develop the concept of ‘balancing cut off grades’, applicable where constraints are in balance, and the mining, processing and marketing systems work in balance, such that capacity is fully utilized, and that grade is optimized within residual constraints.

The expressions so derived yield the following conclusions:

- Under conditions of constraints, cut off grades are elevated as a result of the opportunity cost, resulting in higher returns, as long as the constraint exists. It is
Establishing a new metric for mineral resource management

likely that such conditions exist early in the life of the operation, thus forcing the mine to fill its capacity with high grade material in the early years. This approach is consistent with maximizing NPV, and with the theory of constraints, which dictates that where constraints exist, companies should optimize within the constraint.

➤ The opportunity cost includes the capitalized value of the mineral resource, which is higher at the beginning of the life of the project than at the end (when it diminishes to zero). This means that the grade profile that is defined as optimal is elevated in the early years and reduces towards the end, ultimately being driven only by marginal costs.

The result of this iterative optimization process is that a grade profile is produced, based on dynamic cut off grade optimization, such as that shown in Figure 6.

Minnitt (2003) has used the work of Lane in application to a Wits-type underground gold mine, where the mine is the principal constraint. He has shown that balanced optimal cut off grades can be calculated, but did not take this on to a life of mine profile.

Various MSc students have also attempted to apply Lane’s work with varying degrees of success.

The work of Camus

In his book, Management of Mineral Resources, creating value in the mining business, Juan Camus (2002) has identified that EVA appears to be an appropriate metric for MRM, in that it ‘places the value creation notion as the compass of the business and defines a metric to guage the ongoing true value generated by the firm. It also addresses the incentive issue with innovative schemes, which mitigate the agency problems that occur when the interests of the employees and the interests of the shareholders are not aligned’.

Camus has examined the issue of the optimal strategy to exploit an exhaustible resource, by defining that for a given resource, of value \( V \), in NPV terms, the first increment \( r \) that is mined from the resource should maximize the value of the cash flow \( c \) for that period.

Once this increment is mined, the next increment to be mined should maximize the subsequent cash flow, and thus the progressive path of depletion maximizes the value of the remaining resource.

This approach is consistent with the work of Lane, in that it ensures that firstly the best value is sought, and thereafter, within the constraints of the resource and the infrastructure, the plan seeks out the next best unit, after each decrement.

Mathematically, Camus defines the strategy as follows;

\[
\text{Maximum Present Value } V = \frac{C + W}{(1 + k)t}
\]

Where  
- \( k \) = cost of capital
- \( t \) = time to exploit fraction \( r \)

When \( t \) is approximately 1 year,

\[
(1 + k)r = 1 + k.t
\]

Thus replacing this in the expression above for \( V \),

\[
\nu = V - W = C - k.V.t
\]

(This is the EVA equation).

\( \nu \) is the increment of value of exploitation of \( r \), or the value added by mining that fraction.

Camus has thus shown that EVA, which is equivalent to \( \nu \) in this expression, is a function of the current decrement’s cash flow value, \( C \), less a capital charge.

In this case, the capital charge (which is the opportunity costs) is a function of the net value of the resource, and the cost of capital.

Once again, this is consistent with the work of Lane.

Camus further identifies that time must be taken account of as a variable, whereby changes over time due to price fluctuations are factored into the mathematics. In this case, the maximum value is found by maximizing the above expression. Thus,

\[
\nu = \frac{dV}{dR} = Max_{\nu}(c + F.\nu)
\]

where

\( \nu = \text{EVA when mining and processing a unit of resource} \)

\( F = \text{fixed cost } (k.V - dV/dT) \)

\( \nu = \text{time taken to process a unit of resource } (t/r) \)

---

**Figure 6—Dynamic cut off grade optimization**

**Figure 7—Depletion of a finite resource**
Establishing a new metric for mineral resource management

The time dependency thus brought into the expression ensures that high early returns are sought, since the opportunity cost is high at the start of the project. A planning profile developed using these mathematics will result in a cut off grade profile that is further optimized, whereby cut off grades are elevated by the opportunity cost in the early years, diminishing eventually to purely marginal cut off grades in the later years.

Value is thus created early in the life, which is then reinvested into flexibility in the operation, so that the optimal path of extraction can be created through the removal of constraints.

Camus has applied this logic to a large Chilean copper Mine, where the optimized plan has realized an increase in NPV of $610 million.

The world of accounting

PWC have produced two documents, and KPMG have also conducted a survey of the way in which mining companies report. The PWC studies are directly the result of the global surveys referred to in the previous section. Essentially, they are therefore aimed at understanding the degree to which mining companies report value and risk.

In the report published in 2003, PWC states: ‘More than 70% of mining company executives surveyed believed that their companies are under valued. Furthermore they recognize that the market’s continued focus on short term earnings is a problem. In an industry characterised by long lead times and extended project life spans, it is worrying to find that approximately half of all three participant groups (companies, analysts and investors) feel that a focus on short term earnings discourages mining companies in general from investing in long-term value creation.’

The survey found that the investment community feels it needs better indicators to fully understand and value mining companies. Most of these that were identified were non-financial, especially relating to the resources and reserves, and the plans for their extraction. In this regard, the survey found that investors and analysts put emphasis on matters relating to markets and the strategies that the companies intend to adopt to supply those markets, whereas company executives feel that emphasis should be placed on reporting softer issues, which is surprising, given the fact that they feel their companies are under valued (where the fundamental value lies in the resource and the company’s ability to extract it). It is also interesting that companies admit that in a number of indicators they are struggling to put the right data management and other performance management systems in place to provide adequate quality of information.

This is a extreme admission of failure of MRM implementation, and can only be ascribed to a disjoint between operating and financial management, and MRM, or a lack of MRM at all.

EVA and MVA as a combined reporting measure, provides both short-term value measures (EVA) and long-term measures of value creation (MVA), based on identified key value drivers, especially those associated with MRM and the resources and reserves.

EVA as a metric for MRM

The above paragraphs have shown that EVA and MVA provide tools that satisfy the requirements of a measure that combines short and long-term value, both for reporting and for planning purposes.

It also pulls together work done by Lane, Hotelling and Camus in providing a methodology for optimizing the value from finite resources, through the application of dynamic cut off grades, and optimum levels of production, which realize operating leverage opportunities.

In terms of strategic mine planning, the EVA approach encourages mineral resource managers to:

- Improve the returns earned on existing capital, by comparing cash flow to capital
- Invest in projects as long as the returns exceed the cost of capital
- Divest from projects or operations that fail to achieve the cost of capital.

The latter may mean that projects that fail to deliver returns in excess of the cost of capital should be harvested, such that there is no further investment, and costs are gradually reduced to marginal levels only.

This indicates that over project life, although EVA remains the overall management system for MRM, its application is more critical in the planning and early stages of new projects, whereas in older projects, NPV or even pure profit become leading indicators, as the investment opportunities decrease, and flexibility is not an affordable option.

A planning model for EVA

The application of EVA and MVA as metrics for MRM require that a dynamic approach to planning is adopted, which incorporates and allows a constant search for value adding opportunities.

Companies such as AngloGold Ashanti, AngloPlatinum and Gold Fields Limited, have realized benefits from the development and implementation of dynamic planning cycles, which allow continuity and integrity to be established in their annual business cycles.

These cycles are generally based on profit and NPV as the value measures, and carry a limited amount of risk analysis and management.

The EVA approach requires that further opportunities for optimization studies and risk management be created in the cycle, and that the cycle becomes truly dynamic.

The author has developed such a cycle, which appears in Figure 8.

In addition, this model requires that short-term and long-term planning are done concurrently instead of sequentially, so that there are corrective loops available to ensure that no disconnects exist.

Conclusions

The paper follows previous publications by the author, (Macfarlane, 2000, 2002, 2005) and has shown that EVA and MVA are tools that satisfy the requirements of establishing a measure that relates to value creation in mining ventures, and that it is a workable measure for MRM.

It has been successfully applied in mines in South America, and elements of it, such as cut off grade optimization have been applied in South Africa.
Establishing a new metric for mineral resource management

As a trial, it will now be applied to a new platinum operation, to assess the value potential that exists, compared to the use of standard metrics. It is envisaged that it will provide a valuable method, which focuses on real value and free cash flow generation. It will also bring about focus on the value added through risk management and flexibility creation, which are subjects of another two papers.

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