Technical risk assessment techniques in Mineral Resource Management with special reference to the junior and small-scale mining sectors.

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ABSTRACT

Title of treatise: Technical risk assessment techniques in Mineral Resource Management with special reference to the junior and small-scale mining sectors

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The junior and small-scale mining sectors in South Africa play an important role in the livelihoods of numerous communities. Mining is an opportunity, in the post-1994 democratic era, for many individuals to obtain access to much required empowerment and socio-economic development. These sectors are, however, not without numerous characteristics that pose problems for operators, legislators, and other role-players. Mining is inherently risky, with operators experiencing numerous difficulties throughout the life of mine.

This critical analysis provides understanding relating to the junior and small-scale mining sectors of South Africa, as well as how mineral resource management issues impact these sectors. The different phases within the risk management cycle are described together with key techniques available to reduce the associated risks. The applicability of these techniques for use in the junior and small-scale mining sectors is highlighted. Opportunity does exist for junior and small-scale prospects and operations to include such techniques in either the search for funding or monthly planning and functioning.

It is, therefore, the risk management cycle and how it currently applies to a mineral resource suitable for exploitation by the junior and small-scale mining sectors that are the core focus. No management process can create additional value in the ground, but various available mechanisms can go a long way to quantifying the inherent risk that exists, highlighting the need to manage the risks and hopefully allowing the entrepreneur access to the intrinsic opportunities of the emerging mining sector in South Africa.

LIST OF ABBREVIATIONS

3D	Three-dimensional
APCOM	Applications for Computers in Mining
ARM	African Rainbow Minerals
ASSM	Artisanal Small-scale mining
AUS	Australian
AusIMM	Australian Institute of Mining and Metallurgy
AVMIN	Anglovaal Minerals
BEE	Black Economic Empowerment
BRP	Business Risk Period
CASM	Communities and small-scale mining
CGS	Council for Geosciences
CIM	Canadian Institute of Mining
CMMI	Council of Mining and Metallurgical Institutions
CPR	Competent Persons Report
CSIR	Council for Scientific and Industrial Research
DCF	Discounted Cash Flow
DME	Department of Minerals and Energy
DRC	Democratic Republic of Congo
DSCR	Debt Service Cover Ratio
DTI	Department of Trade and Industry
EVA	Economic Value Add
GDP	Gross Domestic Product
GMSI	Graphic Mining Solutions International
HDSA	Historically Disadvantaged South African
IDC	Industrial Development Corporation
ILO	International Labour Organisation
IMF	International Monetary Fund
IMM	Institute of Mining and Metallurgy
IPR	Independent Peer Review
IRR	Internal Rate of Return
JORC	Joint Ore Reserve Committee
JSE	Johannesburg Securities Exchange

LIB	Long Inclined Borehole
LOM	Life of Mine
MES	Mineral Economics Society
MPRDA	Mineral and Petroleum Resources Development Act 28 of 2002
MRM	Mineral resource management
MRF	Mineral Resources Forum (of UNCTAD)
MQA	Mine Qualifications Authority
NAMF	New African Mining Fund
NPV	Net Present Value
NSC	National Steering Committee of Service Providers to the SSM Sector
NYSE	New York Stock Exchange
RC	Reverse Circulation (drilling)
RD	Relative Density
R&D	Research and Development
ROM	Run of Mine
RQD	Rock Quality Designation
SAIMM	South African Institute of Mining and Metallurgy
SAMREC	South African Mineral Resources Committee
SD	Standard Deviation
SG	Specific Gravity
SMU	Small Mining Unit
SSM	Small-scale mining
UN	United Nations
UNCTAD	United Nations Conference on Technology and Development
UNDP	United Nations Development Program
USD	United States Dollar
VAC	Value Area Curve
ZAR	South African Rand

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1 INTRODUCTION

1.1 Objectives of the study

The research question addressed in this study may be phrased as: How do participants in the junior and small-scale mining sectors identify and control technical risk within the Mineral Resource Management arena?

Mineral Resource Management (MRM) considers the mine-based disciplines of survey, evaluation, geology, and planning as a single entity rather than as discrete functional domains, and has a critical role to play within successful and profitable mining. MRM-related issues impact significantly on all stages of the mining cycle. Often, MRM-related decisions are difficult to quantify but remain the basis for all mining operations, never the less.

In subsequent sections some of the influential changes that have occurred since the launch of the “new South Africa” in 1994 will be discussed and this discussion provides the platform for a detailed introduction to the junior and small-scale mining sectors and some of its inherent characteristics. The concept of mineral resource management is introduced and the importance of SAMREC and other corporate compliance is shown as particularly relevant to the junior and small-scale mining sectors. The treatise then looks at MRM-related risk issues in particular, and exposes some of the quantifiable and probabilistic techniques available to quantify such issues. Risk concerns need to be addressed for exploration programmes, mining projects, as well as for mining operations. This treatise defines the concept of risk across the mining sector and identifies and describes the key aspects of the risk management cycle, which combines the critical aspects of risk identification, analysis and control. The applicability of various elements of the risk management cycle to the junior and small-scale mining sectors is commented upon.

The junior and small-scale mining sectors have emerged to be a potentially important role-player within the South African mining sector and this work sets out to address certain implications of mineral resource-related risk for this sector. MRM is a concept developed by large multinationals, but is often not holistically applied to the junior and small-scale sectors. For successful mining outcomes, the ability to combine and holistically appraise the impact of risk, especially within the MRM environment, is critical. The ability to tailor solutions for the small and junior sectors is paramount to the success of these sectors.

1.2 Delimitations

It is important to note that this treatise will concentrate on technical risk as it relates to mineral resource risk issues, and the related impact on the junior and small scale mining sectors of South Africa. It is implicitly understood in this industry that various types of risks prevailing in the mining industry interact, and that no project can progress without a holistic assessment of all the particular risks affecting the potential operation. For example, mineral resource risk could be well defined and be considered favourable but other risk domains, for example, country risk, financial risk, or market related-risk could be overriding factors that limit the possibilities of subsequent development. Therefore, for completeness, various risk types are presented although briefly. A detailed assessment of these other risk areas and related interactions is beyond the scope of this treatise.

1.3 Defining junior and small-scale mining

This treatise deals with the junior and small-scale mining sectors, as they pertain to the South African minerals and mining sector. Unfortunately, various other mining-intense countries have similar terms, with slightly different associated definitions. The gradation of operation size is provided in Figure 1, with the position of the junior and small-scale mining sectors.

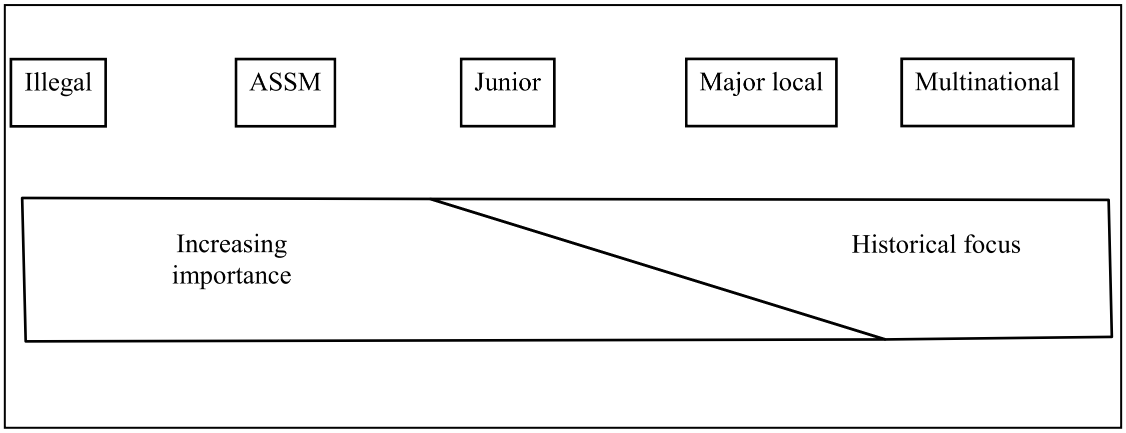

Figure 1: Components of the minerals sector showing where most of the historical industry research focus has been directed

In the Australian and Canadian context junior mining companies primarily identify, explore, and delineate new mineral deposits. Once this is achieved, the entire or only a portion of the prospect is sold to a major or multinational company for mine development (Cooper, 2004). In South Africa, however, an entirely different approach is taken to "junior mining". South African junior mines are role-players in the emerging mining sector, a sector that is characterised by the development of BEE. In the current dispensation such juniors often acquire marginal deposits, as outliers to large well-understand deposits mined by the majors (AngloGold Ashanti, Harmony, Goldfields, to name a few). Examples of current junior mining companies include Sebilo Resources, Retsibogile Mining and Nozala Diamonds.

Small-scale mining has been defined in a variety of ways (see Section 3). The term "small-scale mining" is often interchanged with "artisanal mining" or even "artisanal small-scale mining". Artisanal and small-scale mining encompasses all mining operations that, by virtue of their size and overall turnover *etc*, are categorised as small. Small-scale mining also sometimes includes illegal miners or the West African, South American "garimpero's" or "galamsey". The illegal sector is a high priority to be eliminated in most countries, but this is not without difficulty. In the South African context the boundaries between each category are not distinct, hence the confusion that is often expressed. This concept of small-scale mining is fully defined in Section 3.

1.4 Defining the concept of risk

The Oxford Complete Wordfinder (1993) defines risk as "a chance or possibility of danger, loss, injury or other adverse consequences", while risk within an operational environment is defined by Kerzner (2001) as "a measure of the probability and consequence of not achieving a defined goal". The King Report on Corporate Governance (Institute of Directors, 2002; Terblanche, 2002) defines risk as "uncertain future events which could influence the achievement of a company's objectives. The Institute of Directors (2002) states that these "could include strategic, operational, financial and compliance objectives" and that "some risks must be taken in pursuing opportunity, but a company should be protected against avoidable losses". Conversely, opportunity can be viewed as the opportunity or likelihood of doing better than a specified goal. Achieving an outcome, therefore, represents the most likely scenario in terms of the interaction of risk and opportunity factors evaluated.

Specific to the mining sector, Agricola (1556), in his famous treatise on mining, De Re Metallica, refers to the need for understanding the geology of a particular deposit for successful mining, while Krige in 1955 also developed many aspects of mining risk in his work on risk analysis in mining ventures. The mining industry in South Africa exhibits some unique characteristics when compared with other industrial sectors. These factors (Table 1) result in a very interesting and difficult sector, responsible for underpinning the entire South African economy.

Table 1: Characteristics of the South African Mining Sector

Typical Characteristics
High risk versus reward
Capital intensive procurement
Price taker
Cyclical profits and losses
Remote locations
Finite life of a non renewable resource
Reclamation and rehabilitation liabilities
State ownership of the mineral resource

The Warren Study of 1991 in Glacken (2002) assessed the percentage of -over- versus underestimation of various parameters in Australian gold mining operations. These parameters included capex, opex, gold recovery and grade estimation. Grade was shown to have been 95% overestimated in the study, which equated to a value, at that time, of AUS $95 million. Croll (1999) undertook a study of 11 projects ranging over some 30 years to assess how well various factors (mineral reserves, tonnages, grade, capex and opex) were estimated. The results revealed that three factors carried the greatest risk of accurate determination. These factors are:

- Grade estimation of the mineral reserve;
- The valuation methodology; and
- Forecasting the metal price.

The first two of these factors are considered in this treatise.

2 THE SOUTH AFRICAN MINING SECTOR SINCE 1994

Prior to the democratisation of South Africa in 1994, junior and small-scale mining had been largely ignored or regarded as a troublesome activity that did not contribute towards the attainment of national objectives. The practice was largely confined to the alluvial diamond sector. Furthermore, an exclusionary legislative framework restricted access to minerals rights and active participation in the minerals sector to a small privileged proportion of the country's population and greatly favoured the entrenched mining houses. With the establishment of a new government, a realisation occurred that junior and small-scale mining could be a vehicle for creation of economic activity in remote communities, a mechanism of job creation, and a basis for skills development that could be transferable to other sectors of the economy (McGill, 2004).

Government, and particularly the DME, has therefore sought to actively encourage the growth of small-scale mining ventures. It is one of the key pillars of DME policy to promote small-scale mining, and the DME has been instrumental in establishing several initiatives, partly through the national science and technology system, which can stimulate responsible small-scale mining activity. The intent is to cover the entire range of smaller-scale operations, from truly small-scale mining currently in the second economy, to what, in South Africa, would be termed "junior mining companies", i.e. those fledgling mining companies that are one of the keys to attainment of the goal of broad-based participation in the minerals sector.

It was recognised in the development of the new framework for governing the minerals sector that the rich national heritage of minerals should be accessible for the benefit of all South Africans without regard to ethnic background or gender (Cawood, 2003). A significant process of reform in the legislative and governance framework has therefore been undertaken, and this has culminated in the passing of various new laws. An inclusive, participative and consultative approach was followed in re-drafting the framework.

A cornerstone of the new framework is the broad-based socio-economic charter for the South African mining and minerals industry, commonly referred to as the "Mining

Charter" (Cawood, 2003). It was recently subscribed to with commitment from all of the major stakeholders in the mining and minerals sector. These stakeholders include state, labour, the major mining companies, and organisations representing smaller and developing mines and mining companies.

The first objective of the Charter (Cawood, 2003) is to promote equitable access to the nation's mineral resources for all the people of South Africa. The Charter is founded on seven pillars of social and economic development, these being:

- Human resource development;
- Employment equity;
- Community upliftment;
- Housing and living conditions;
- Procurement;
- Beneficiation; and
- Ownership.

While the Mining Charter is subscribed to voluntarily as an appropriate route for the development of the sector, it is also backed up in law by Act no 28 of 2002, the Mineral and Petroleum Resources Development Act, which provides for the conversion of old-order minerals rights to new-order rights. Under this Act, mining companies will be required to report, using a scorecard against defined performance targets, in each of the seven pillars as a pre-requisite for renewal of mining rights.

A fundamental shift in philosophy under the new legislation is the move to ownership of minerals rights by the state, with prospecting and mining rights being granted to organisations that comply with specified conditions, and certain preferences being granted to HDSAs and small enterprises. The state may provide assistance as required to HDSAs to support them in conducting prospecting or mining operations. The Mining Charter commits the state to providing institutional support and other measures for supporting HDSA companies in exploration and prospecting endeavours (Government Gazette, 2004). Various means of financial support exist to fund feasibility studies, the development of mining plans, and skills development.

A specific provision of the new governance framework is that the granting of a mining right is required to develop opportunities for historically disadvantaged persons, including women, to enter the mineral and petroleum industries and to benefit from the exploitation of the nation's mineral and petroleum resources. The new Minerals Act also provides for mining permits to be issued for small-scale (<1.5 ha), short-duration (<2 yrs) mining operations under an administratively less burdensome protocol (Section 4 (27) MPRDA, 2002). This will make it easier for small-scale mining operations to become incorporated into the formal sector of the economy, but will nevertheless increase the extent of regulation of the small scale mining sector in the national interests, particularly relating to the protection of the environment and the securement of decent, safe and healthy employment conditions for the workforce in such operations.

A further provision of the new legislation is that preference is to be given to local communities in the granting of prospecting and mining rights (MPRDA, 2002). The rights of indigenous peoples whose lives and communities are affected by mining activities to share in the financial returns have been upheld in landmark rulings, such as those in favour of the indigenous population in the Richtersveld that have been allocated 10% of the Alexcor Mine (Nxumalo, 2003). The mining companies are also committed to supporting socio-economic development in labour-sending areas in terms of the Charter and associated scorecard requirements. (This case is again currently in court.)

The change in philosophy also provides for the "use it or lose it" principle, under which major players can no longer retain rights to prospect or mine indefinitely without actively and responsibly exploiting the minerals resource. Specific time periods are prescribed for which a prospecting or mining company may hold rights before advancing a mining project through its natural phases. This development in law will also provide more equitable access to minerals deposits to smaller role-players, emerging companies, and small-scale operations (MPRDA, 2002).

While many portions of the governance framework of the minerals sector are not directly relevant to small-scale mining itself, the new requirements subscribed to by the established players should have major ramifications for the emerging smaller players in the minerals sector, as well as for those currently engaged in the minerals sector through the second economy. In South Africa, as well as other developing nations, the concept of 'two economies' has been developed to consider both the dominant and competitive 'first economy' as well as the marginalised 'second economy'. The second economy is characterised by isolated practices that do not contribute to the first and global economies. For a single economy to prevail targeted initiatives are required that overcome poverty and unemployment (SARPN, 2004).

Some of the major mining companies are responding to this challenge by identifying portions of the minerals resources over which they have mining rights that they cannot mine effectively and that would be suitable for exploitation by smaller operators. (An example of such a "take off agreement" exists in the Northern Cape where marginal Sishen iron-ore deposits are mined by local BEE miners, but with a fixed sales (ore supply) contract to the Sishen Mine (Noetstaller *et al.,* 2004, Sihlali, *pers comm*). The mining companies provide technical assistance and access to markets for such smaller operators. These initiatives vary significantly in size, but include some projects at a scale where they could be regarded as poverty-reduction initiatives at micro scale. From industry's side, there is also agreement to assist HDSA companies in securing finance to fund participation through equity in an amount of R100 billion within the first five years. Examples of existing funds are the Anglo-Khula fund, the Bakubung initiative, as well as the New African Mining Fund. In addition, government provides further funding via entities or organisations like the IDC, the National Empowerment Fund (administered by the DTI) and the National Steering Committee of Services Providers to the small-scale mining sector (administered by the DME).

The success of such support initiatives is continually in the spotlight (Sihlali, *pers comm).*It is a common complaint that governments burden small-scale operators with unrealistic regulatory requirements and often fail in adequately providing the much needed aid, training, and support (Hilson, 2002).

Transformation within the South African mining industry context has resulted in numerous landmark transactions such as the establishment of African Rainbow Minerals by AngloGold, the Harmony/Armgold merger, and the Gold Fields/Mvelaphanda deal. All these transactions have been based on asset valuations, internal feasibility studies, and competent persons report, all of which fall within the ambit of the MRM practitioner. Joint venture arrangements are also reliant on reconciliations of tonnage, grade and product, also within the MRM domain.

In summary, the new governance framework for the granting of prospecting and minerals rights is fundamentally friendlier towards the needs of junior and small-scale operators. The objectives of the new government policy, supported by the newly developed legislative framework, are to attract greater participation by individuals from historically disadvantaged backgrounds into responsible mining activities that are appropriate to national interests. In addition, this policy should facilitate integration, through legitimising, of illicit mining operations into the regulated formal sector of the economy. Enhanced levels of partnership between big and small business will develop during the journey towards sustainable community development centred on mining operations.

There remain major challenges, many of these in common with other sectors of the economy, in supporting the transition of small-scale mining for poverty reduction from the second economy into the formal economy of the country, where it can contribute optimally to the national benefit. Integration remains an essential objective to ensure that the nation’s mineral wealth can be transformed optimally into other forms of capital that will support the sustainable development of communities. Appropriate regulation of small-scale mining is vital to avoid the erosion of value in the mineral resources or even the creation of significant net liabilities due to irresponsible mining activity. In terms of the current legal and administrative framework, inadequate provision is made for assisting the small-scale mining sector in the identification, quantification and management of mineral resource-related risk.

3 INTRODUCTION TO THE SMALL-SCALE MINING SECTOR

Small-scale mining is an essential activity in many developing countries, as it provides an important source of livelihood, particularly in regions where economic alternatives are critically limited. This form of mining is a livelihood strategy adopted primarily in rural areas. In many cases, mining represents the most promising, if not the only, income opportunity available (MMSD, 2002; Hilson, 2002; McGill, 2004).

Many governments consider this sector as a source of problems that relate to non-compliance with mine health and safety laws as well as environmental, labour and tax laws (among others). In the eyes of critics, the sector is seen as a remnant of an antiquated way of doing things, swept away by the forces of corporate capitalism (Danielson, 2003). The concept of artisinal and small-scale mining has been debated at length in the literature (Peake, 1998a; ILO, 1999; Drechsler, 2001). In addition, it has been revealed that many stakeholders have a definition of small-scale mining, which may suit a specific requirement, or viewpoint (Drechsler, 2001, p 147):

- To poverty stricken and hungry people in both rural and urban areas, small-scale mining is a "God-given answer to their woes";
- To individuals involved in gold and semi-precious minerals (e.g. emeralds and diamonds), small-scale mining is the "fast track process to their earthly riches"; and
- To independent observers, small-scale mining is the "greatest environmental disaster-in-making".

Most formal definitions attempt to categorise mines in terms of one or more physical criteria. These criteria may include: mineral type; annual production (tons mined or minerals produced); the value of commodity produced or capital invested; or the number of people employed (Peake, 1998b). In effect, nations develop their own definitions as to what constitutes smallness depending upon their mixes of sociological, geographical, financial, and technical factors. An example of an individual country and an organisations efforts to define small-scale and small-scale mining are set and the problems, constraints and omissions in the definitions are apparent.

- Ghana: "Small-scale mining refers to operations of individual Ghanaians or organised groups of Ghanaians (4 -8) or cooperatives (>10), which are entirely financed by Ghanaian resources at a certain time limit, and carried out on a full-time basis using simple equipment and tools" (MRF, 2005, p1).
- United Nations: "Small-scale mining is any single unit mining operation having an annual production of unprocessed materials of 50 000 tons or less as measured at the entrance of the mine" (MRF, 2005, p1).

In this treatise, within the South African context, small-scale mining is defined as small operations operating at the lower end of the cost curve with limited employees. For the purposes of this treatise and to limit overlap and confusion this definition will also include artisanal operations, which are often transitory and/or illegal. In addition, this definition implicitly includes holders of a "mining permit" as defined in the Minerals and Petroleum Resources Development Act, 2002. A mining permit "may only be issued if:

> a) The mineral in question can be mined optimally within a period of two years; and
> b) The mining area in question does not exceed 1.5 hectares in extent (Section 4(27)(1), MPRDA (2002)).

A breakdown of operation size is given in Table 2 below, where this treatise applies in effect to all the categories, as many South African juniors are in fact medium-scale operations. Unfortunately the matter is further complicated by a second definition (Table 3), which is applied by the DME and based on the following (Sihlali, *pers comm*).

Table 2: Guidelines for a small-scale mine definition (Peake, 1998a)

Category	Employment	Capex (R'000)	Annual Tonnage
Small-scale	<5	<5	< 2000
Micro Small	6 – 20	5 – 99	2000 – 9999
Very small	21 – 49	100 – 7999	10 000 – 99 999
Small	50 – 99	8000 – 24999	100 000 – 249 999
Medium scale	100 - 999	> 25000	> 250 000

Table 3: Current DME classification (Sihlali, pers comm)

Category	Employment	Turnover (R)	Gross Assets (R)
Micro	<5	150 000	100 000
Very Small	6 – 20	3 million	1.8 million
Small	21 – 49	7.5 million	4.5 million
Medium	<200	30 million	18 million

It must be stressed that each subdivision should not be viewed as an isolated cut-off. Rather, an entire size spectrum exists with definite overlap between the individual categories. In addition, often these category names are applied very loosely in the press and in discussion. One person's existing formal small mine may be another's aspiration with regard to a large operation. The true impact of junior and small-scale mining is associated with development nodes that have been instigated through mining activities. The numbers of individuals relying indirectly on small-scale mining operations are therefore even greater.

Small-scale mining is a poverty-driven activity, most often practised by the poorest of the population sector. Often the practice is migratory in nature (Ghose, 2003). This is particularly true in the South African context in the alluvial diamond sector. When undertaken as a subsistence activity, growth opportunities will not exist and escape from the cycle of poverty is considered unlikely (Peake, 1998b). Literacy levels of small-scale miners are low and often mining is conducted in below-standard safety, environmental and occupational health conditions. It is commonly associated with informal, undercapitalised and under-equipped operations. It does, however, have the potential to enrich and economically empower disadvantaged communities (Drechsler, 2001). The UNDP believes that to improve the livelihoods of the small-scale miners, alternative livelihood opportunities need to be developed and the entire sector needs to be formalised. For this reason, an in depth knowledge of the underlying resource/reserve that will underpin such developments is essential.

An important realisation is that some ore bodies may not lend themselves to small-scale mining practices. This lack of suitability could be attributed to depth, mineralogical complexity, or mode of extraction required. The South African mining sector cannot afford to lose the big players and the two sectors (large and small) actually need to develop side by side. Often junior and small-scale mining entrants require money "now" and considering long-term impacts, cash flows and risks to MRM related decisions are not seen as important.

Approximately six million people and some 30 million dependants are involved (UNDP, 2004) in small-scale mining activities worldwide, and roughly half of these are in China (Table 4). 90% of India's mines are operated on a small-scale (Ghose, 2003). Recent research by the ILO suggests that throughout the world small-scale mining involves in the order of 13 million people directly, mainly in developing countries, and that it affects the livelihoods of a further 80 – 100 million (Hinton *et al.,* 2003). It is estimated than in Southern Africa alone some 1.5 million people are directly employed by this sector (Drechsler, 2001).

Table 4: Small-scale mining at global and regional levels (UNDP, 2004)

Region/Country	Employment ('000's)	Commodities
AFRICA		
Burkino Faso	60	Gold
Burundi	10	Gold, Tin
Central African Republic	10	Diamonds
DRC	500	Gold, Diamonds
Ethiopia	10	Gold
Ghana	30	Gold, Diamonds
Guinea	60	Gold, Diamonds
Madagascar	10	Gold
Mali	100	Gold
Namibia	1	Tin

Niger	15	Gold
Rwanda	10	Tin
Senegal	3	Gold
Sierra Leone	100	Gold, Diamonds
Tanzania	100	Gold
Zambia	30	Gemstones
Zimbabwe	30	Gold, Chromite
Total Africa	1,079	
ASIA		
China	3,000	Iron, Coal, Tin, Tungsten
India	500	Iron, Coal, Tin, Borates
Indonesia	465	Gold, Tin
Philippines	250	Gold, Chromite, Coal
Total Asia	4,215	
Latin America		
Brazil	1,000	Gold,Chromite, Gemstones
Bolivia	70	Lead, Gold, Sulphur
Peru	20	Lead,Diatomite,Gold, Copper
Total Latin America	1,090	
TOTAL WORLD	**6,384**	

In South Africa, provinces with relatively high levels of small-scale mining activity are the Northern Cape, NorthWest, Mpumalanga, and KwaZulu-Natal. Table 5 (below) was compiled in 1998 from a variety of sources. It must be remembered that operating conditions are constantly fluctuating and these numbers can only be regarded as an indication of the situation. Through the current formalisation process for small-scale miners at the DME a more up-to-date indication may be possible, especially after the promulgation of the MPRDA (2002).

Many people are involved in the mineral sector, even at a rudimentary level, and the key to successful, sustainable operations is a crucial understanding of mineral resource issues. Certain commodities are more ideally suited to small-scale extraction than others. Examples include: alluvial diamonds, aggregates (dolerite and granite), clay, and surface coal. Beneficiation is, of course, crucial for downstream value addition and suitable avenues include clay bricks, cement bricks, and pottery. Small-scale mining does have the ability to produce minerals from deposits that are not economic to mine on a larger scale. This is largely due to the economies of scale associated with these smaller endeavours, that may not be as capital intensive as larger operations. Therefore, junior and small-scale mining are not sectors which should continue to be ignored as they have been.

Table 5: Estimate of the small-scale miner population by province (Peake, 1998a)

Province	NCape	NWest	M'langa	KZN	Limpopo	Gauteng	WCape	ECape
SSM	410	?	200-250	461	20-30	?	?	?
Diggers[1]	500	1100	n/a	n/a	n/a	n/a	n/a	n/a

It is very difficult to obtain conclusive figures pertaining to the contribution of the junior and small-scale mining sectors to GDP, or figures on the exports from the small-scale mining sector, as it is largely unregulated. Most often, production is from "hand-to-mouth". The underlying need is to link this second economy to the primary economy, which will enhance economic growth and result in such economic contribution data being more readily available. Studies have revealed that the small mines category contributes 1.1% to mining sector employment and 2.5% to sector revenue (Noetstaller *et al.,* 2004). A more current figure relating to small-scale diamond miners considers some 1000 miners, with about 25,000 people being employed by the sector as a whole. The purchasing power of the community is estimated to be in the order of R7.7 billion per annum (Coetzee, 2004).

Mining is a very technical and costly endeavour. As certain initiatives require only limited start-up capital, prolonged financial support is often neglected (Hilson, 2002). If such operations are going to perform throughout a reasonable LOM then increased access to funding mechanisms will result in the ability to upgrade equipment and improve efficiencies. Due to the small-scale mining permit only being valid for two years, the level of funding available to operators is limited. Not many mechanisms are

[1] *Diggers = Registered diamond diggers*

available for potential operators as a result of the inherent risk in investing in mines with shorter lifecycles. This ultimately means that less capital is available for technical assistance in the form of contractors or consultants. Often, only the legal requirements, such as survey, are covered by the junior operators. This results in most aspects of MRM, which could sustain an operation over a longer period, being ignored.

For the small-scale sector the function of MRM resides with the state as the owner of the minerals. The state should thus develop the sector to the level where the MRM responsibility could be passed on to the operators. In addition, it could be the function of the small-scale mining directorate within the DME to support MRM-related capacity-building initiatives. This treatise describes many of the risk techniques relating to different parts of the risk management cycle and provides evidence to support the potential application of the methods to this sector.

4 INTRODUCTION TO MINERAL RESOURCE MANAGEMENT

Harrison (2000, p1) states that MRM refers to "professionally (managing) the exploitation of mineral resources or reserves to meet company objectives". MRM is therefore an integrated activity, including the application of sound management principles that maximise the value of the mineral asset, in order to grow shareholder wealth (Macfarlane, 2000). In recent times a change in organisation structure to embrace this holistic approach has resulted in a more process-driven and value-added approach to MRM. MRM considers the mine-based disciplines of survey, evaluation, geology and planning as a holistic entity rather than separate functional domains. On smaller operations the need for such disciplines is no less important. Functionally, most of the MRM-related decisions become the responsibility of a single mineral resource practitioner, rather than an entire department.

How, therefore, is risk management undertaken within MRM? The concept of risk management is no longer the sole domain of the health and safety department, corporate office, or legislative enforcement. In the past few years it has become more apparent that the mineral resource manager (practitioner) needs to be responsible in dealing with the risk to the overall business risk that is grounded in the orebody (Macfarlane, 2004). To be effective, MRM requires a system that will identify, quantify, and manage the risks associated with the orebody. To be able to do this the person responsible for MRM needs to possess the requisite skills and competencies to undertake quantitative risk management and to report accordingly.

Internationally, MRM is a concept that is not considered in such detail as in South Africa. Internet research on the topic provides links to mainly government sites that have information relating to mineral rights ownership, deeds offices, and environmental issues. This "type" of MRM-related work is, however, commonly carried out by the mining engineering department. Certain overseas operations are managed by South African multinational mining houses. Therefore, it is the opinion of the author that through effective MRM and related successes the approach will take root in many more operations. The main difference between current MRM and previous operational techniques is that the current approach considers MRM as a "seamless" approach, with total integration being the key to the process, while traditional international practice is to add important issues of optimisation onto already established mining engineering structures.

Macfarlane (2000) suggests that besides the integration of survey, evaluation, geology and planning functionalities a further integration with certain financial functionalities will allow MRM to maximise shareholder wealth. In reality, this linkage is between strategic and operational planning, where overriding corporate goals are translated into operational mining plans, which can achieve the required growth.

In the bigger picture MRM has a role to play within corporate governance. Corporate governance is important as it provides the guidelines and platform for companies to operate internally and interact externally (PriceWaterhouseCoopers, 2003). As the Institute of Directors (2002, p 18) states: "Corporate governance, is essentially about leadership". The extent to which companies adopt and demonstrate good principles of corporate governance will impact on investment decisions (OECD, 1999). This premise is particularly relevant for junior operators within the South African context who often seek financing. The ability to display sound corporate governance practices will go a long way in securing funding. MRM corporate governance issues relate, in particular, to the following (Macfarlane, 2004):

- Diligent management of the mineral assets (i.e. to add value and reduce risk);
- Compliance with public reporting requirements (see section 4.1);
- The management of risks associated with the mineral asset; and
- Contribution to operating within a context of sustainable development.

The SAMREC code of South Africa underpins all mineral resources issues and is the code that all reporting and corporate governance within the minerals sector must adhere to. The true challenge involves how this code could be applied to the small and junior mining sectors. Section 4.1 provides the background and describes features of this code in more detail.

4.1 The SAMREC code

Globalisation of the mining industry has resulted in the need for public (standard) reporting codes in the major countries associated with mining related capital funding.

In October 1997 the CMMI's International Definitions Group met in Denver, Colorado, and reached a provisional agreement (the Denver Accord) on definitions of mineral resources and mineral reserves. This agreement went a long way to providing the platform of requirements stipulated by the NYSE. Concurrently, and since 1992, the United Nations Economic Commission for Europe has also been developing an international framework classification for mineral resources and mineral reserves. Agreement was reached to incorporate the CMMI standard reporting definitions for mineral resources and mineral reserves into the UN Framework Classification, thus giving truly international status to the CMMI definitions (SAMREC, 2000). It is this platform that the various individual country-specific codes are built on.

The first such code to be established was the JORC code of Australia in 1999. This was followed by the SAMREC Code of South Africa in 2000, the CIM Code of Canada in 2000 and the European Reporting Code in 2001 (Mullins *et al.,* 2003). This section describes in more detail the background and critical issues contained within the South African SAMREC Code. The definitions in the SAMREC Code are consistent with those agreed at the Denver Accord by the CMMI participants. This section also highlights the impact the code has had on small and junior scale operators.

The compilation of the South African code began in 1998. SAMREC was tasked by the SAIMM to compile a South African reporting code for reporting mineral resources and mineral reserves (the SAMREC Code). The code was finalised after a long consultative process with key role-players including government institutions, law societies and the AusIMM Joint Ore Reserve Committee (JORC). The code is therefore endorsed both locally and overseas. The SAMREC code is the required minimum standard for public reporting of exploration results, mineral resources, and mineral reserves in South Africa (Camisani–Calzolari, 2000). The code has officially been adopted by the JSE as a portion of requirements for new resource sector listings.

Even though many of the small-scale operators will never list on the JSE and the juniors may only strive for a listing, the need to attract funding from various available sources, such as banks and aid agencies/funds, makes striving for SAMREC compliance prudent.

The code requires the proper disclosure of all factors likely to affect the accuracy of the resource and reserve estimates made. Such information becomes part of the competent person's report where the "competent person" is someone who has a minimum of five years experience relevant to the evaluation of resources and reserves for the style of mineralisation and type of deposit under consideration. In addition, the person must be a member of a statutory body recognised by SAMREC such that conduct contrary to the code of ethics can be dealt with. Similar requirements are also stipulated in other codes like JORC and "The Reporting Code" representative of the IMM, as well as of London's and Ireland's Geological societies (IMM, 2001). In Canada, the CIM's terminology merely refers to a "qualified person" but the same requirements are stipulated (Goscoe, 2001).

The relationship between the key concepts of the SAMREC Code is shown in Figure 2. From greenfields exploration mineral resource estimates are made and are classified according to the corresponding level of confidence in the estimate. Through the application of various "modifying factors", the mineral resource categories displaying the highest confidence (indicated and measured) can be "converted" to actual mineable reserves. This progression is schematically provided in Figure 3.

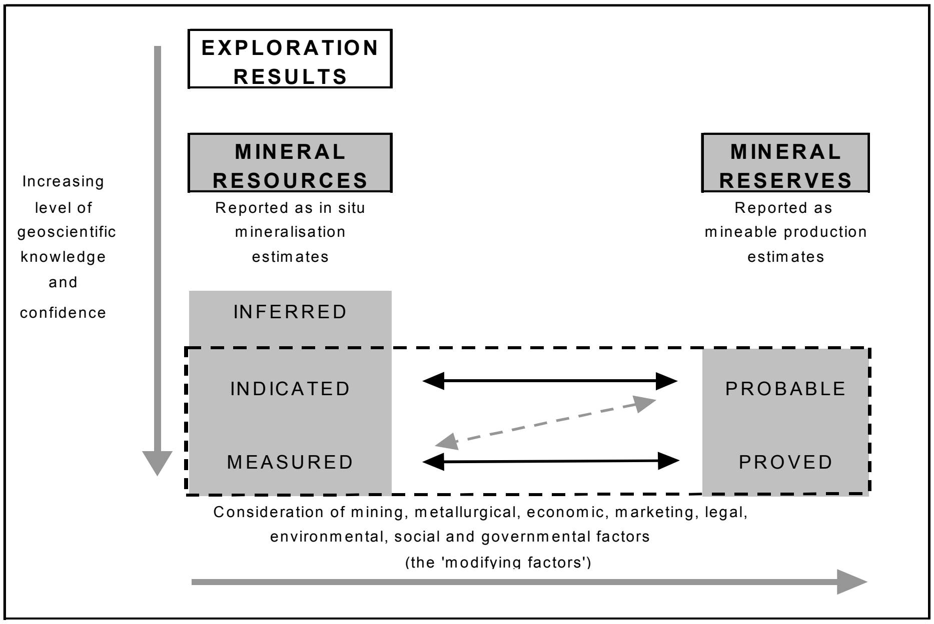

Figure 2: Key concepts of the SAMREC code (SAMREC, 2000)

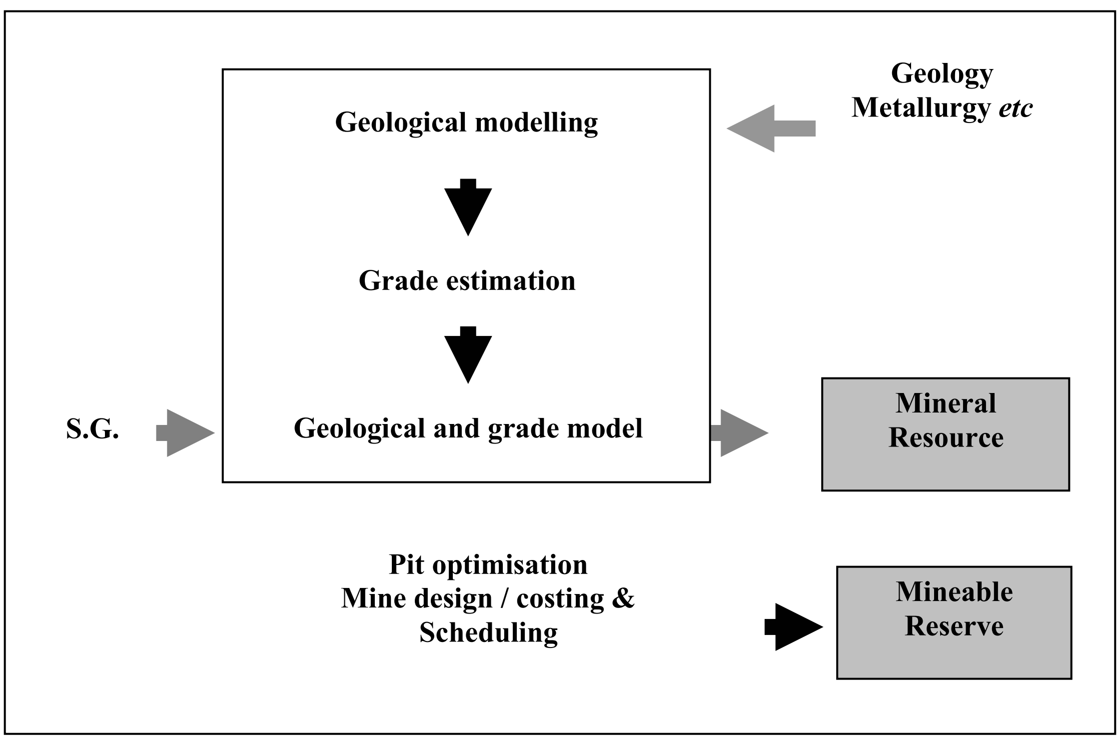

Figure 3: Schematic representation of the relationship between mineral resource and reserves (Carey, 2002)

The level of confidence in ore grade values becomes very important and underpins the classification of resources and reserves. Geostatistics, therefore, provides the only basis for estimates with the lowest expected error variance and is free of biases. SAMREC also requires estimates of tonnages and grades for resources and reserves and the provision of confidence levels (SAMREC, 2000). Confidence should be expressed in terms of both accuracy (the absence of biases) and precision (limits of error). The confidence in a project will depend largely on the lower confidence limit for the grade (Camisani–Calzolari, 2000). Where statistical and/or geological uncertainty exists the categorisation is downgraded accordingly. Risk can therefore be reflected by the likelihood of having certain grade values, within appropriate impact limits of the predicted grades:

- Low risk
  90% probability of quarterly grade within 10% of prediction
- Medium risk
  80% probability of annual grade within 20% of prediction
- High Risk
  70% probability of global grade within 30% of prediction

This incorporation of low, medium, and high risk “categories” is, however, not a stated requirement of SAMREC. An illustration of various possible conditions and the resultant classification, based on the categories described above (Dewar, 2001) is provided in Table 6.

Although the estimates of mineral resources are not dependent on the economics of exploiting the deposit, uncertainties in their estimation (risk) impact directly on the mineral reserves that are derived from them. To understand the concept of risk fully a critical distinction between uncertainty and variability is required.

Natural variability is a fundamental characteristic within a variable and cannot be reduced with further study. (An example of this is the nugget effect of diamond and other precious mineral deposits.) Uncertainty is created by lack of knowledge regarding a particular system and can be decreased with further study and associated understanding (Glacken, 2002). Therefore, uncertainty needs to be reduced through gaining of more information. This process will have an associated cost-benefit trade off (e.g. the use of 3D seismics for data acquisition or not) and to quantify uncertainty using available techniques, one which is conditional simulation (refer to Section 5.3.9.).

Table 6: Application of risk categorisation and SAMREC classification

Condition	***Classification***
Limited exploration data and only global estimates.	Inferred mineral resource
Data permits some estimates on the spatial relationship. Provisional estimate on expected global tonnages and grade above any cut-off are possible. Level of estimates is suitable for long-term planning and feasibility studies.	Indicated mineral resource Lower confidence limit – 15%
Valuation of individual blocks of ore, SMU (small mining unit) or larger. However, smoothing effect occurs during kriging as a result of limited data.	Measured mineral resources with modifying factors: probable reserves Lower confidence limit – 10%
Final selection and valuation of SMU blocks	Measured mineral resources with proven reserves Lower confidence limit – 5%

Smaller operations can often not meet the required density of data required for proper resource/reserve classification due to the overriding costs in obtaining such data. They therefore operate with much higher resource-risk profiles. Producing high ore grades is obviously not as significant, risk wise, as intersected low grades and associated discontinuities. Owing to the lack of background data it is very difficult to predict accurate grade distributions. Risk reduction should be addressed as a continuous process. Financial strength and associated grade trends during "good times" should be used to reduce the risk regarding the mining of the remaining resources.

4.2 Corporate reporting of resource risk

The ability to accurately identify and report mineral resource and technical risk-related issues goes a long way to ensuring good standards of corporate governance. At the forefront of corporate governance reporting standards is the Sarbanes-Oxley Act of 2002 from the USA, as well as the King Report on Corporate Governance for South Africa, 2002, which set directives for reporting on risk. The King Report of 2002 was a second version of the groundbreaking King Report of 1994, which introduced the need for reporting of the triple-bottom line (Institute of Directors, 2002). This concept involved the reporting of all economic, environmental and social aspects of a company's activity. The Sarbanes-Oxley Act meant the "tightening of restrictions, expanding disclosures and toughening penalties" (PriceWaterhouseCoopers, 2003).

A working group commissioned by the London Stock Exchange to address risk-management issues resulted in the Turnbull process. This approach has been adopted as the process to follow by various listed South African companies, including AngloGold Ashanti(Dewar, 2001). The first steps of the Turnbull process are to identify "headline risk areas" and to define the business objectives in these key areas (Appendix C). In other words, high-level business objectives are subdivided into smaller and very specific success factors. Associated with this process is the identification of key performance indicators that can be monitored (Hiles, 2005). Key factors that may affect achieving company goals are then identified and evaluated according to a numerical scale in terms of impact and probability of occurrence. This aspect of the Turnbull process occurs in two steps: first without controls in place; and then again with controls in place. Finally control, reporting, and monitoring systems that are in place to manage the risks are documented.

In the process of this research various annual reports of the major role-players in the South African mining industry were accessed so that a perspective could be obtained on the reporting aspects of mineral resource and reserve related risk. In the AngloGold annual report (2001a) no reference is made to mineral resource risk issues but the report does clearly highlight the contingent of competent persons responsible for signing off the ore resource and reserve statements. Harmony (2002, p 24) states that "gold reserve figures are estimates based on a number of assumptions and may yield less gold under actual production conditions than (they) currently estimates". The report goes on to state that "the reserve estimates contained in the report should not be interpreted as assurances of economic life of Harmony's gold deposits or the profitability of its future operations". The competent person responsible for the South African operations is also mentioned. AVMIN (2001) clearly describes the process undertaken by the competent persons to evaluate the resources and reserves as well as the gold price *etc*. No issues specific to potential MRM risk are highlighted. Placer Dome Group (2001) sets out the competent person contingent together with the variety of cut-off grades applied to their suite of deposits. Placer Dome Group mentions that various potential projects exist in the pipe-line however warns investors that in keeping with the corporations strategy of maximising returns on investment, there is no guarantee that any of the projects will be developed.

The importance of good corporate governance and reporting techniques has evolved from 2001/2002 to the current situation where Ernst and Young in South Africa compiles an "excellence in corporate reporting" report, which surveys the annual reports of South Africa's Top 100 companies. Two mining companies (AngloGold Ashanti and Impala Platinum) are listed in the top 10 places in the 2005 survey (Ernst and Young, 2005). This is clear evidence for improved reporting of mineral resources and reserves as a measure of improved cognisance of mineral resource management issues. This shift in MRM reporting is particularly evident from the Goldfields website where more information is available when compared to 2001/2002. Mineral reserve and resource issues are collated into a separate document (Goldfields, 2004). The objective for Impala Platinum when reporting resources and reserves is "to focus attention on reporting reserves in a clear and credible manner (as) investors are buying into the future cash flows related to those reserves and resources" (Business Day, 2005a). The company makes careful use of diagrams and maps to ensure the reader understands these issues perfectly. The AngloGold Ashanti annual report "carefully explains the business and lays out the risks that the company faces" (Business Day, 2005b).

While issues of corporate governance, Turnbull definitions and transparency are high on the priority list of public companies most junior and small-scale operations are not as conscientious. This fact should, however, not make them any more complacent in these compliance issues. Juniors should especially practise high company standards as a means to achieving overall growth. It is strongly recommended that individual mine operators highlight risk areas in the business plans or mine works programmes.

4.3 MRM and the business model

Good MRM should embody a deeper understanding of the overall business objectives of a company and/or operation, such that the overriding business objective of the MRM function becomes "maximising shareholder wealth through effective utilisation of the assets *viz.* the mineral resource" (Macfarlane, 2000). However, as previously emphasised, the concept of MRM is very much the domain of large-scale operations. In smaller operations, this role is often fulfilled by the geologist and/or outside consultant, where/if such people can be afforded. MRM is not a discipline that should be viewed as the prerogative of larger operations but as a practice that needs to be applied to all operations within the entire minerals sector.

In terms of the sustainable development concept, good MRM requires a balance to be achieved between complete exploitation of a deposit, irrespective of the financial implications and the "rape and escape" attitude of picking the "eyes" out of a deposit. Stakeholders, including the ultimate owners of the operation, the local community, as well as the government all need to be convinced that the exploitation process is beneficial to all. The same considerations also need to be applied by the junior and small-scale operators, such that affected parties, authorities, investors, and downstream buyers of beneficiated products know that these mines have also been operated in a sustainable manner.

As alluded to in the introduction to this treatise, the mining business environment is considered to be unique in that margins are narrow, operations are capital intensive, ventures are costly, and risk levels are high. These features are even more apparent within the junior and small-scale mining sectors. Gitman (1994, p 225) reveals that "return and risk are the key determinants of share price, which represents the wealth of the owners". It may then be interpreted that to achieve shareholder wealth, improved value or profit maximisation, overriding risk should be kept at a minimum. At the Denver World Gold Summit in 1999 Mr Cockerill of Goldfields International stated that: "shareholders get value in two ways. They get value in terms of money today and money tomorrow. Money today is clearly in the form of dividends and money tomorrow is in the form of capital growth." Careful MRM is therefore required to optimally extract ore for maximising shareholder wealth. Within the small-scale mining sector the ability to achieve optimal growth is even more difficult.

4.3.1 Mine value chain

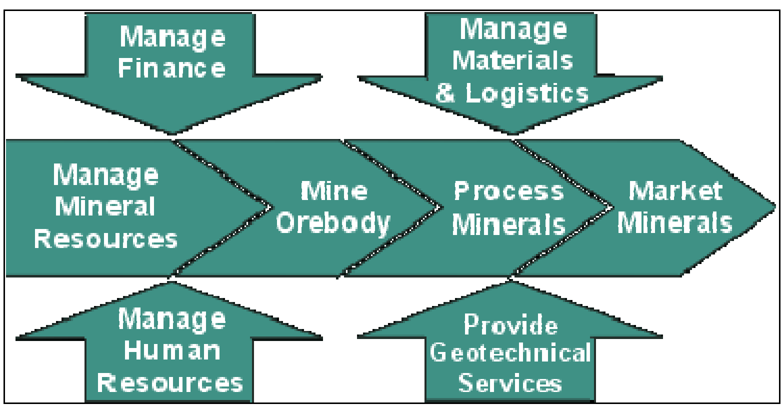

Figure 4: Schematic diagram representing the mine value chain and its associated inputs (Crecy, 2002)

Prior to delineating the orebody for mining purposes it is the role of the exploration geologist to identify the deposit through exploration and prospecting activities. MRM considers the delineation of mineral resources and their conversion to mineral reserves, as described in the previous section. According to the value chain concept the mining company/operation may be modelled as a series of primary activities that are responsible for the generation of value, together with a range of supporting activities that do not directly generate value but support value generating activities. The mine value chain concept establishes a continuum from MRM to production and finally processing aspects (Figure 4). Planning integration is required and, finally, the quality control of the saleable product through to marketing and sales is ensured. Macfarlane (2004) defines the mining value chain as representing sequential work flow, as it relates to the mining process. Intrinsic to this "chain" is the feedback loop to the orebody, which relates to the ability of the orebody to deliver now as well as in the future.

The level of corporate involvement will also adjust during the different phases of the project and mine value chain, as well as according to the overall monetary value of the potential investment (Figure 5). BHP Billiton considers detailed review by a customer selected board together with independent peer reviews, undertaken by a variety of different committees, as an integral part of the investment approval process (Mullins *et al.,* 2003). This process assists in understanding all the risks associated with individual investment opportunities.

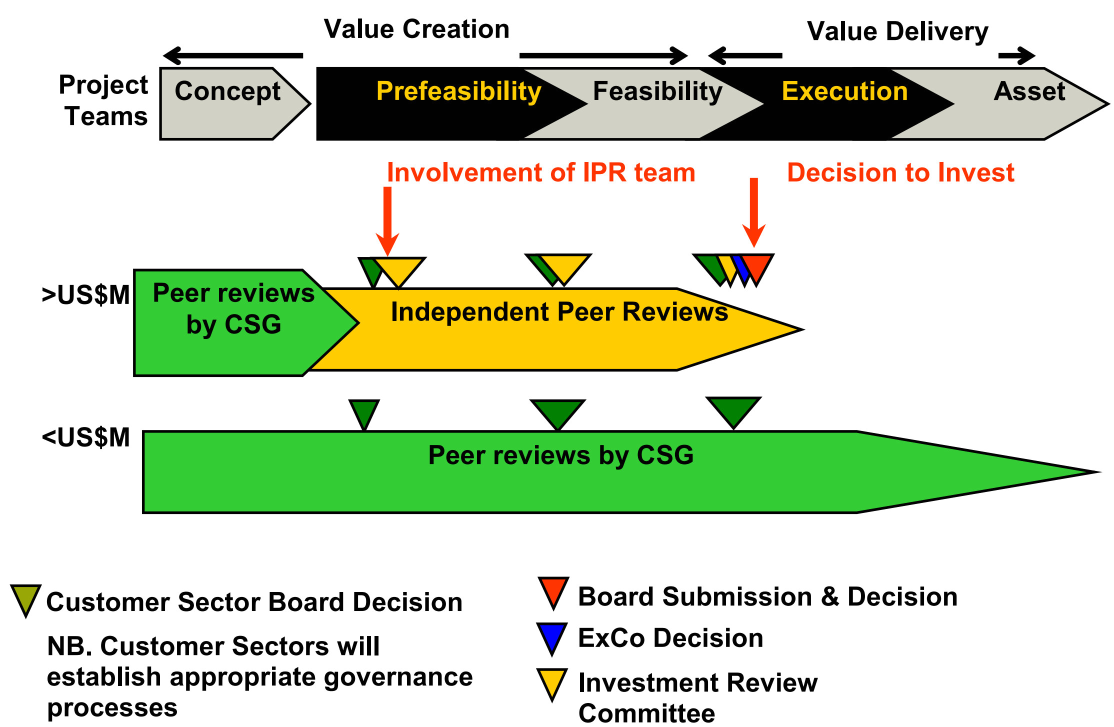

Figure 5: Schematic diagram of the relationship between the mine value chain and levels of governance (Carey, 2002)

The mining value chain can therefore be used to identify critical MRM competencies. These would include (MacFarlane, 2004):

- The ability to integrate value chain activities and technical inputs;
- The ability to interface with production and processing and to analyse variance when it occurs;
- The need to have a sufficient understanding of the other departments, to be able to add value;
- The assurance of technical quality; and
- The development of competencies at lower levels so as to allow data integration, information flow and action.

The mining value chain operates within the overall business environment. The generic fundamental requirements of a mine-related business model are:

- Both short-term and long-term value must be balanced;
- Growth in shareholder value must be achieved;
- A balance between revenue and available resources, which are not generating revenues, needs to be achieved; and
- Cash generated now must be put to work to generate wealth tomorrow

Unfortunately these requirements are often not formally adhered to by the junior and small-scale operators. Small-scale mining has particular difficulties with subscribing to such requirements because most operations emerge from impoverished environments and are often managed by poorly skilled operators. The need to survive for today overrides any call to save for tomorrow. It is therefore the challenge of the government and technical assistants alike to instil the groundwork for such a shift in attitude to enable smaller operations to continue to be sustainable into the future.

4.3.2 Short and long-term value

The interaction between long-term and short-term value within the mining company is very relevant to the junior-scale operations whose aim it is to list on the JSE, or to be viewed on the "radar screen" of larger national operators. Components of short and long-term value should be items that small-scale operators are encouraged to consider. Typical components of short and long-term value are given below:

Short-term value:

- The associated value of the resource and the reserve base, including the ability of the operation to produce earnings from these assets in the short term;
- The liquidity position of the operation;
- The cost level of the operation;
- The operational performance of the operation;
- The level of free cash flow;
- The ability to utilise opportunities that can add short term value; and
- Flexibility in operation to switch to higher grade portions.

A measure of short-term performance, and a predictor of future performance, is provided in the use of standard financial ratios. Values evident in balance sheets and income statements are used to calculate the following typical ratios for listed companies:

- Earnings per share;
- Price/earnings per share;
- Cash flow per share; and
- Net asset value per share.

Long-term value:

- The relationship between the resource and the reserve base;
- Optimal time-based utilisation of the mineral base to ensure a balance between resource utilisation and profitability;
- Long-term viability through commodity price fluctuations; and
- Negating sterilisation induced through achieving short-term objectives.

Long-term value is assessed through a discounted cash flow model (DCF) incorporating concepts of Net Present Value (NPV), Rate of Return (IRR), growth rate and payback period. (Refer to section 5.4.2.)

Linking short and long-term value:

The concept of Economic Value Add (EVA) balances short-term profitability with the long-term objectives contained within the DCF analysis and feasibility study. It measures the success of a company as the rate of cash generation (after interest, tax and the cost of capital) compared to the use to which the cash has been put. This concept is illustrated in Figure 6.

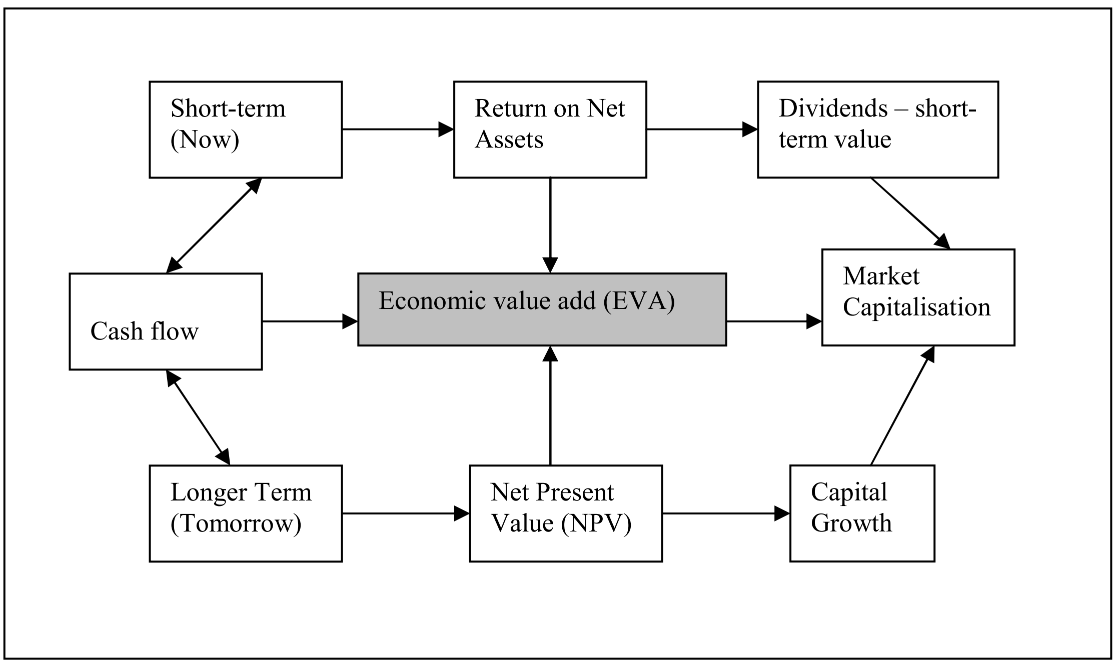

Figure 6: EVA - The linkage between short and long-term value addition (Macfarlane, 2000)

EVA can be incorporated into the MRM arena in the follows ways:

- The inherent value of a mining company is reflected in the balance sheet. This value is based in terms of the overriding mineral asset and its valuation. This valuation, by definition, incorporates the geological model, grade evaluation, application of modifying factors and planning of extraction (the mine plan). All of these are fundamental to effective MRM.

- Cost reductions can lower cut-off grades, which, according to MacFarlane (2000), can increase the underlying ore body value. However, it can be argued that if costs are cut, then profits would increase, benefiting the shareholders. Therefore, careful consideration to ensure that such decisions are economically viable is required before lowering cut-off grades.
- An effective response, through efficient MRM, to changing external factors such as variations in commodity price, must be adopted.
- MRM Managers need to know which factors contained within a DCF can be controlled and, therefore, where best value addition estimates can be achieved.

4.3.3 MRM for the junior and small-scale mining sectors

Macfarlane (2004) has provided a breakdown of what the MRM practitioner should identify within the corporate MRM framework (Table 7). It should be emphasised that the processes provided are cyclical and require constant feedback and evaluation throughout the LOM.

In addition to the elements in Table 7, adaptability of the mining plan and product spread to certain products (where the ore allows) is also important. Within the coal sector, certain less quantifiable but important elements of MRM exist. Van Wyk (2000, p 5) states "that the MRM practitioner has to (have) a deep understanding of the colliery and any neighbouring areas". Furthermore when market conditions change or new markets develop the MRM practitioner needs to be proactive in the inclusion of such aspects as the impact of new technology, associated impact on cut-off grades and reserve definition, So that the colliery product spread and mining plan best suits the requirements of the market.

Finally, it is prudent for mining role-players, to establish where the MRM functionality resides in junior and small-scale operations. Ultimately, the strategic responsibility lies with the board of directors or the mine owner. At an operational level MRM competency is often provided by a consultant to the operation, or an independent consultancy firm. Obviously the proviso is that the operation can afford such expenses. For many of the smaller operations this is not possible, resulting in issues of MRM largely being ignored, to the detriment of the deposit and future of the mine. One suggestion is that annual MRM sessions are facilitated by the South African science councils and/or the Chamber of Mines and other interested stakeholders to address these issues in a structured way, for the benefit of all junior and small-scale mines.

Table 7: MRM framework and related key objectives (MacFarlane, 2004)

Application of international and national protocols and codes applicable to MRM
A risk mitigation strategy document
A risk register
An area risk plan which relates specific area risks to the planning horizons, the extraction sequence, and the geological models
A set of company specific protocols for the following areas: Resource and reserve estimation Planning Feasibility studies Mine design (codes of practice) Sampling Assaying Valuation Metal accounting A holistic audit protocol
A set of controls on key risk areas and key variables
An audit schedule
An audit review and progress document

5 RISK MANAGEMENT

5.1 The risk management cycle

An example of where the decision to ignore certain critical risks resulted in complete failure presents in the case of the Manville Corporation, a role player in the asbestos industry. When this company deliberately chose to ignore the health risks associated with asbestos they subsequently became responsible to fund a personal injury settlement worth USD 150 million in cash, USD 1. 6 million in bonds, 80% of its stock, and 20% of the company profits since 1992, as long as there are claims to settle (Oosthuizen *et al.,* 1998). If a sound risk management process had been adopted such a liability may have been avoided. Nowadays, there are safe ways to use asbestos, where there are no other alternatives, but the safe use of asbestos came 50 years too late to save this sector of the minerals sector.

Dealing with risk requires that risk management be viewed as part of a dynamic, competitive process rather then just a static management activity or, as in the example above, something that is completely ignored. There are three distinct aspects to successful risk management. These include (Toll, 1994):

- Risk identification: both internal and external to the operation;
- Risk analysis: using any of a variety of techniques; and
- Risk response: based on the identification and analysis a response to the risk can be formulated prior to the problem occurring.

All business development initiatives involve elements of risk. The appropriate identification and management of these risks should be seen as the key to effective and sustainable growth, if effectively managed. Risk identification, as the first phase of the risk management cycle, can be completed by consulting objective (past experience) and/or subjective (knowledgeable experts) sources (Kerzner, 2001). Various different risks can also be identified during the life-cycle phases of a project or operation. Risk management assists with the improvement in decision making as the entire cycle/process (risk identification, assessment, and response/management) contributes towards a greater understanding of all risks and potential opportunities and losses. The risk management process is as much about identifying opportunities as it is about avoiding loss exposure. The risk management cycle as applied to mineral reserves and resources is discussed in subsequent paragraphs.

5.2 Risk identification within the mining environment

5.2.1 Introduction

This statement by Mr A. Levitt (Chairperson of the US Securities Exchange Commission) is particularly relevant for the mining sector: "The average company today is a complex enterprise engulfed by rapid technological change and fierce global competition. You have to assess exposure to risk on an ever changing landscape." The underlying importance of a mining organisation accurately identifying all risks is obvious. This section deals with describing the principal types of risks present within the mining environment, irrespective of scale of operation. An introduction to this section is provided in Table 8.

Table 8: Summary of risk areas that impact on the MRM function and possible analysis techniques

Risk Area	Methods of Analyses
Business Risk	
High level of economic uncertainty exists Dynamic, constantly changing business environment.	Cash flow models (scenario planning) Discounted Cash Flow models Sensitivity analysis Monte Carlo Simulation
Natural Risk	
Geological uncertainty More difficult to quantify and dependable on availability, relevance and quantity of information.	Geotechnical risk assessment Conditional simulation Other techniques based on repeatability and variance of sampling results.

From the financial institution viewpoint (Simonsen and Perry, 1999) the key to lending money for projects is not simply to be a source of funding, but to determine which projects have risk profiles that will provide adequate assurance for the repayment of the loans according to plan. Unfortunately, the plight of most small-scale operators is that the majority of financing needs are viewed as highly risky by banking institutions. The impact of project risk can be equated to cash flow parameters, as provided in Table 9.

Table 9: Risk parameters related to common cash flow parameters (Simonsen and Perry, 1999).

Cash flow parameters	***Risk parameters***
Commodity recovered	Reserves Technical
Times	
Revenue received	Market Infrastructure
Equals	
Gross revenue	
Less	
Royalties, fees Operating costs Interest expense Depreciation/Amortisation Taxes	Political Cost Management Funding Completion Political Legal
Equals	
Net after tax	
Plus	
Depreciation/Amortisation	Completion
Less	
Capital costs Loan repayment	Engineering Debt/Equity Ratio Funding Foreign exchange

The cyclical behaviour associated with the expansion, extraction and duration phases of commodity prices impacts on the volatility of the sector. A basic management tool for commodity cycle management has been cost reduction (Simonsen and Perry, 1999). The key to identifying mineral resource-related risks is to be aware of the typical commodity market characteristics, as well as potential impacts on price risk. Price risk can be attributed to the following factors:

- Commodity price fluctuations over time;
- Market share variances;
- Demand inconsistencies; and
- Variability in quality of the sales product.

As most mining operations are, in fact, operating within a much larger environment the concept of business risk period (BRP) may be a more appropriate consideration (SRK, 2001). BRPs will be distinctive throughout the time of the project or operation and will, therefore, impact on the risking of capital accordingly. The BRP encompasses the following factors:

- New discoveries that create competitive changes in the market;
- The time taken for new mines to be brought into production;
- Changes in technology of geological, metallurgical and mining applications;
- The position on the world producer cost curve of the operation; and
- Pay-back period requirements, which would include political risk.

In any mining venture it is possible to categorise the risk environment that the investor is willing to allow. These risk preference behaviours are shown in Figure 7. As risk increases (along the x-axis) the risk-indifferent venture will require no change to the return. The risk-averse sector will expect proportionally higher rates of return for increased risk. Because this approach considers risk "bad", higher returns are expected in compensation for taking the greater risk. For the risk-seeking portion the required return may actually decrease for a given risk. Companies are willing to sacrifice some returns in order that they can take higher risks. In practice, one tends to only take on the risks one feels comfortable with (Gitman, 1994). The opportunity to invest in a risk-seeking project may be viewed favourably as a company either has information or expertise that would result in reducing the risk exposure or, alternatively, the initial cost of investing in such a project is low, and value may be added to the project that exceeds the investment required to the reduce the risk.

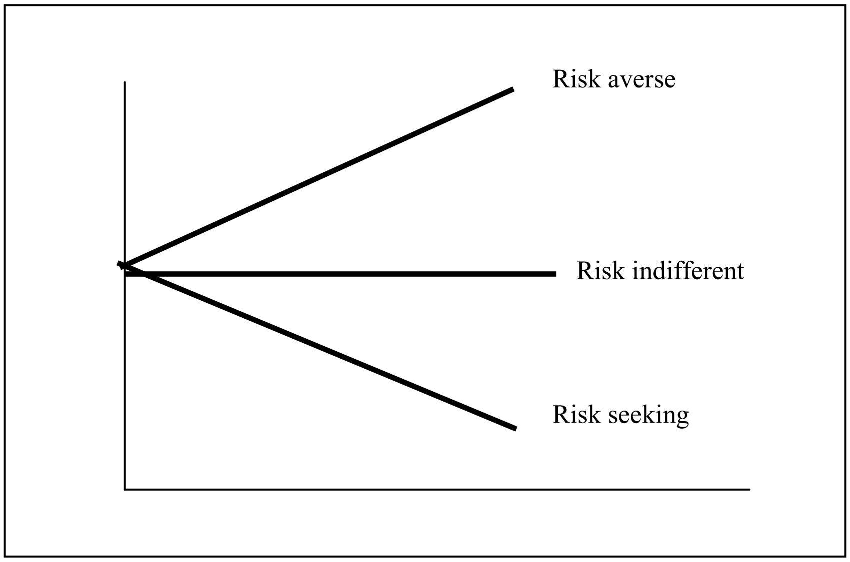

Figure 7: Schematic diagram showing the relationship between how risks are handled depending on the expected rate of return for a project (Gitman, 1994).

Beside mineral resource-related risk areas various other risk areas exist within the mining sector. Turnbull identifies only four main areas of risk: business, financial, compliance, and operational (Hiles, 2001). These, and certain other risk types, are briefly described here to provide necessary background to this section of the treatise.

5.2.2 Management risk

Any mining-related project or aspect of operation, irrespective of scale, requires careful management techniques. Management positions are often viewed as high profile and challenging, with equivalent financial reward in the offering. Certain downside risks (Kerzner, 2001) are not always apparent at the outset of the initiative but could pose a significant threat to the expected outcomes if they are not fully assessed. Work hours are often long and involved, and research shows that most family relationships could be at risk at same time. Mining ventures have longer lifecycles than other business ventures and will therefore take longer to produce successes and failures. Quick successes are few. Success in the junior and small-scale mining sectors will come through experience obtained by managing similar operations effectively. This management risk needs to be adequately addressed so that overall goals are still achieved.

5.2.3 Financial risk

Mining is known to be very risky. This is largely due to the long planning horizon, the project and/or LOM duration, the large amount of capital that must be invested, and the financial risks of the markets. Risk is usually incorporated into the investment decision by adjusting the discount rate within a DCF model. (Refer to section 5.4.2.) Companies generally place risk categories on investments (Briers, 2002). Other DCF considerations include the capex and opex requirements and need to be estimated for particular operating periods. The accuracy of these estimates is therefore critical to the overall outcome of the DCF model.

Studies have shown that ranges of costs estimated within feasibility studies can vary between -5 to +15% (Nell and Burks, 1999).This variation is overcome within the Bateman approach by using @Risk software plus applying a Monte Carlo simulation to calculate the value of the mean deviation. The end result is an output range and associated distribution curve for the cost estimates. Unfortunately, as a result of time limitations such investigations for the junior and small-scale sectors are not often undertaken.

The need for the formulation of an accurate DCF model is shown in how bank involvement increases during the life of a project (Figure 8). It is possible to move a project down the curve using the correct financial structuring (Benning, 2002). The basis for any analysis in any of the categories shown in Figure 8 remains the discounted cash flow model.

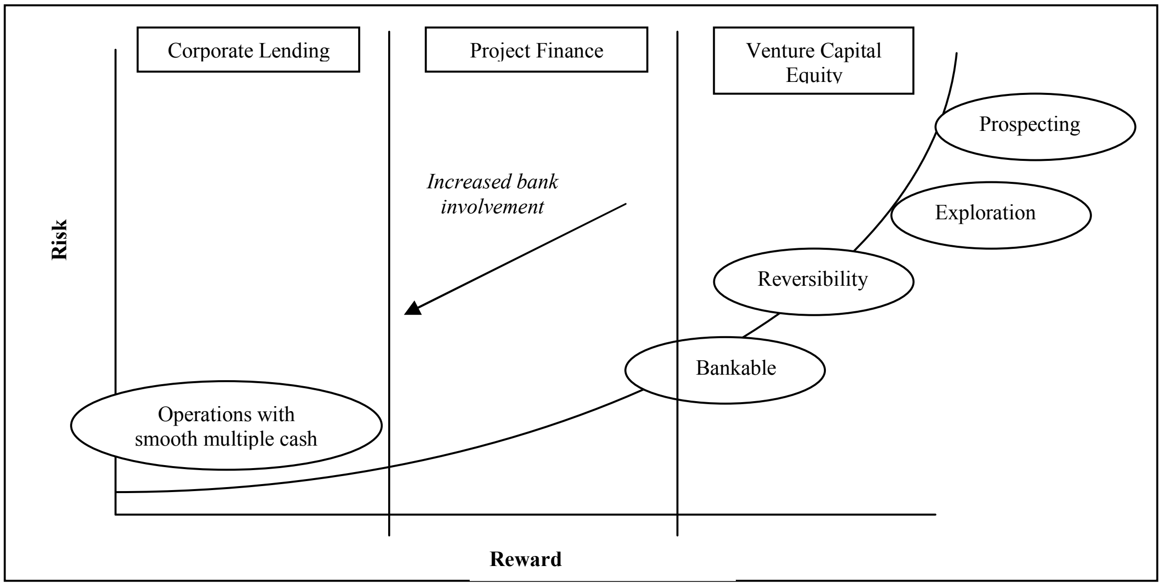

Figure 8: How bank financing of projects changes according to the overall stage of a project as well as the relationship between risk and reward (Benning, 2002)

Often banks assess financial risk in the form of guideline ratios, where grade and tonnages of reserves play a key role (Cole-Barker and Bower, 1998). One of the key ratios is the Debt Service Cover Ratio (DSCR), which is the ratio between cash available (usually annually) for debt repayment and the loan repayments plus interest (Figure 9).

$$\text{DSCR} = \frac{\text{Net Cash flow before debt servicing}}{\text{Loan repayment + interest}}$$

$$= 1.5 \text{ minimum}$$

Figure 9: Calculation of DSCR

As junior and small-scale operators require the same pre-feasibility, feasibility documentation *etc.* as larger operations, the financial requirements also hold true for this scale of operations too. Unfortunately the reality currently, in terms of the authors personal experience, is that potential role-players often find the requirements both onerous to fulfil and difficult to finance. This results in a “chicken and egg” phenomenon where the lack of funding means no feasibility documents can be prepared. The lack of feasibility documentation means that banks are not prepared to carry the risk of securing funding or guaranteeing loans.

Additional constraints result from certain industry rules. For example, the "Bankers Rule" (Smith, 1997, p 48) states that "from a financier's point of view mineable reserves (cash flow) should be twice as large as the reserves (capital cost) to be mined during the loan repayment period". Other related economic "rules of thumb" state that "the cash flow should pay the capital back in two years" and that a "minimum seven-year life of mine" should exist (Smith, 1997, p 48). It is immediately obvious that the ability of the majority of deposits, that junior and small-scale operators are considering investing in, will not pass these "rules of thumb". Junior miners may be in the position to consider a portfolio of deposits that collectively contribute to a more sustainable approach to extraction. It may be prudent for small-scale operations to consider mineral terrains, e.g. the alluvial diamond sector, in the same regional manner. Within the current dispensation, to support emerging role-players, certain legislative and/or financial aspects may be deemed non-inhibitory so as to allow the required development of the sector within South Africa. Once again, the overriding proviso is that definite reserves exist.

5.2.4 Country risk

Country risk includes the following elements: political, geographic, economic, and social. An expansion of each of these is given in Table 10. Many companies generate their own risk assessment profiles of countries and/or companies in certain countries (Simonsen and Perry, 1999). A risk profile can, however, not be better than a pre-defined envelope. For example, South Africa has a moderate risk profile (A-; according to Standard and Poor's, (2005)), so a specific project within South Africa should not have a better risk rating. As will be demonstrated later, country risk is normally included in the discount rate applied in a discount cash flow.

Table 10: Elements of country risk (Smith, 2003)

Political	Government stability Foreign policy Taxation Environmental policies and legislation (EIA,EMP) Land claims
Geographic	Transportation Climate
Economic	Currency stability Foreign exchange policies
Social	Ethnic influences Literacy rate Corruption HIV/Aids

Risk profiles can be generated by companies too, as companies tend to take much higher risks than independent bodies. The negotiating of the "fairest" contract between host government and the investing company is suggested as a means of minimising risks. Most banking institutes issue credit ratings on the basis of short and long-term outlooks. Such tables are available e.g. Standard and Poor's. Where financial institutions decide they cannot absorb political risk then the only recourse is to access government-sponsored export-credit agencies, or the World Bank or funds like the IMF.

5.2.5 Operational risk

A variety of potential risks exists in any mining operation. These diverse risks include (but are not limited to): the application of a suitable mining method to enhance optimal recovery; process performance from extraction through to final product production; the application of an optimal schedule duration; staff and management experience and expertise (related to the particular deposit and mining method); the application of new or proven technology to enhance productivity; and, finally risks associated with the incorrect scaling regarding exploitation and markets. Operational risks are particularly relevant to the junior and small-scale mines. A relatively low level of technical competence exists. The need for capacity building and skills transfer to improve this is important. Many junior-scale mines often enter into technical operating agreements with partner companies. An example would be where the new owner of a dolerite quarry engages with a contract mining company to perform the technical function but is at the same time, contracted to provide much required skills development.

5.2.6 Technical risk

Mining is very technical industry. Technical risk can relate to any of the technical requirements within mining. Technical risk will be prevalent in all decisions relating to mining, rock engineering, engineering, metallurgy *etc*. In an attempt to identify a unit of measurement for technical risk, acceptability criteria such as "time it takes for failure" or "number of fatalities" may be considered. Most often, risk is also calibrated in financial terms (Raftery, 1994).

Financial institutions rely on experts for assessing the technical aspects of all pre-feasibility and feasibility-level studies. Technical aspects of MRM risk will be dealt with in far more detail in subsequent sections of this treatise. However, in such assessments the project initiator's capability and experience are noted, especially in relation to projects of a similar nature (Chicken, 1994). This accountability is particularly important in relation to the CPR requirement within the SAMREC Code (MRM and the business model). Often, where there is no hard quantitative data on which to base decisions, recourse has to be taken to the qualitative opinions of experts.

5.2.7 Resource risk

One specific area of technical risk is resource-related risk. Worth and Haystead, in Glacken (2002, p 25) provide a particularly accurate assessment of the importance of understanding resource-related risk:

> "The assessment of ore reserves is the most important point of any technical evaluation. Errors in the project reserve estimate derived from optimistic characterisation of grade continuity or the incorrect application of calculation methodology are usually fatal. Money and time can generally fix errors made in the estimation of certain operating parameters. Money cannot create ore that was not put in place by providence."

There are a number of ways that resource risk can be assessed, both subjectively and quantitatively. Resource modelling depends on subjective interpretation of measured data. It is, therefore, very difficult to quantify the risk associated with this technique. Resource estimation, however, is based on a series of best estimates from geological, engineering and economic data. Therefore the ability exists to conduct a quantitative resource risk assessment on this information.

Resource estimation inherently contains uncertainty, but the measurement of the probabilities (expressed as a range) associated with certain outcomes will help to manage risk (both upside and downside). Various verification procedures exist to eliminate resource risk during the entire resource and reserve definition process. Simonsen and Perry (1999) provide a summary of these typical tools, which are presented in Table 11.

Table 11: Typical MRM activities with the corresponding technique and associated data type.

Activity	Process	Data
Sampling	Diamond Drilling RC Drilling Channel chip sampling Sample preparation	Core logs Sections and plans Existing mapping and photographic records
Assaying	Various technique available depending on commodity	Assay certificates Density report
Drill hole logs	Diamond core drilling	
Scan lines	RC drilling	
Geotechnical Data	Rock mass classification	Rock density RQD values

Activity	Process	Data
Metallurgical Data	Ore testing	Recovery index Milling behaviour
Data base	Data storage, retrieval and compositing	Metal grades Rock mass classifications Survey data Lithological data
Geological model	Interpretation of data	Mineral controls on orebody Metal continuity - zonation and trends Electronic mineralisation model, maps and sections
Geological units	Frequency curves Variography	
Estimation	Block model construction Geostatistics	3D co-ordinates Semi-variogram determination lithological units and rock densities grade interpolation
Declaration	Resource classification	Validation Kriging variance Sampling distance Drilling density

In each of these activities there is clear evidence for specific risk-quantification techniques within resource estimation. This process and overriding technical responsibility for the outcome rests with the MRM department.

The extent of resource risk inherent in alluvial diamond deposits is, in fact, often considered to be so great that certain funding institutions will not finance such initiatives at all (Jurd, *pers comm*). The key financing downfalls within the alluvial diamond sector include the fact that a proven reserve statement cannot by submitted (refer to Section 4.1), as the confidence levels in preparing the mineral resource are mainly inferred, which also implies that a bankable feasibility document cannot be prepared (Coetzee, 2004). Grade is typically a function of carats and continuity, two parameters that are difficult to predict with high confidence. Mining activities are typically nothing more than bulk sampling exercises, where discrete trenches are often excavated individually (Coetzee, 2004). As there is generally limited technical and financial ability to recover from negative planning, fluctuations and unplanned cash flows, the alluvial diamond sector is precariously balanced. The 1. 5 ha mining permit (MPRDA, 2002) is too small an entity for potential operators to produce sufficient supporting evidence for funding opportunities, while the requirements of a mining licence (preparation of a mine works programme (inclusive of a resource and reserve statement) and social plan) are often far too onerous on the concession owners as a result of the migratory nature of many of the activities and the low levels of financial capacity. The alluvial mining sector requires some careful attention by stakeholders, for ensuring the livelihoods of many communities in the Northern Cape and North West Province are not adversely affected.

The challenge, therefore, is for junior and small-scale mining sectors to combine applicable methods or tools of risk analysis and management to potentially lower levels of resource risk. However, it must be realised that the inherent nature of a deposit (high nugget effect for diamonds) cannot be altered.

5.3 Risk quantification/analysis techniques

5.3.1 Introduction

Menell, in his APCOM address in Cape Town in 2003, observed that "tools without purpose are toys", while Rozman and West (2001, p 501) state that "no single tool exists, which combines the many and varied uncertainties in a mining operation" (or project). This evidence is support for the fact that risk analysis and quantification are exceptionally difficult within a mining framework. Various methodologies have been applied over time and continue to evolve as understanding of the overriding uncertainties increases. By way of introduction to this section of the treatise, various quantitative resource risk assessments that exist are (Mullins *et al.,* 2003):

- Sensitivity analysis of key variables, which provides good information on the sensitivity of an outcome (e.g. NPV) to changes in the input parameters;
- Reporting confidence levels for resource classes, this is rarely used, however, in public reporting forums. (See section on SAMREC); and
- Reporting the range of possible outcomes for variables such as tonnage and grade.

In addition, other risk assessment techniques applicable to resource risk assessments include (Smith, 1995):

- Most likely case (base case);
- Best case/worst case;
- Decision tree;
- Monte Carlo simulation; and
- Root sum of squares procedure.

The objective of this section is to introduce some of the more widely applied risk assessment techniques in the MRM arena. Each will be outlined and relevant examples of application will be explained, where appropriate. The overall size of the operation and/or deposit need not be a reason not to adopt certain of these methodologies. In fact because of the greater element of risk in smaller mines the need to begin applying such techniques is critical to ensure success. Risk analysis quantifies exposure and losses to prescribed circumstances so that probabilities of future losses or opportunities can be projected (Terblanche, 2002). In addition, one should not lose sight of the overriding business objectives, which makes the most important aim of risk analysis predicting the likelihood of a planned profit to be achieved over a given period of time (Simonsen and Perry, 1999). Essentially, this process provides answers to the following fundamental queries:

- What can happen?
- How likely is it that it can happen?
- What are the consequences if it does happen?

5.3.2 Risk classification

The first technique or approach of risk assessment is called risk classification. A basic approach has been to categorise risk as either known, known unknown or unknown unknown (Toll, 1994). Risks can be categorised in tabular format, according to these headings, where known risks are those circumstances where variability is common and understood (resource risk). Known unknown applies to risks that have a low probability (but are foreseeable) and will have severe consequences if they occur. Unknown unknowns are very rare and therefore cannot be predicted. Typical examples relevant to the junior and small-scale sectors are given in the table below.

Table 12: Example of MRM risks relevant to the junior and small-scale mining sectors

Risk classification	
Known	Generally poorly defined mineralisation models, hence impact on overall recovered grade.
Known unknown	Risk exposure due to sudden loss of key MRM staff.
Unknown unknown	Events of natural disaster that could destroy the entire deposit e.g. landslides (clay deposits), 50-year floods (alluvial gold and diamond deposits).

Another widely used application for classifying risk is according to a probability/impact risk matrix where risk is defined as the product of probability of event (frequency) and magnitude of loss/gain (severity). By combining probability and impact scales an overall risk rating can be assigned. To be able to accurately rank the above risks the two variables (probability and impact of the risk occurring) need to be used in conjunction with each other. Risks with high probabilities and high overall impacts will need attention and aggressive risk management strategies. Various authors have illustrated an application of this (Pitzer, 1989; Terblanche 2002). The two variables considered in the application of this methodology are:

- Frequency of loss = actual number of times the same, or similar, loss occurs; and
- Severity of loss = size or cost of the loss to the organisation or mine.

It is the relationship between these two variables that is then represented in the form of a matrix calibrated to specific circumstances. A risk exposure that has both a high frequency and a high severity of occurrence should be given the greatest consideration for elimination or control. The total amount (or value) of risk is a product of the probability of the risk occurring (a percentage) and the overall cost, if the risk were to materialise.

$$\text{Total risk} = \text{Probability} * \text{Amount}$$

Examples of possible probability and impact scales are as follows:

- Probability Scale

  0 No probability of risk becoming a reality

  1 Certain probability of risk occurring

- Impact Scale

  Essentially, this answers the question "What would the impact on the original objective be if the risk were to occur? The use of ranked values (very low – low – moderate – high – very high) as the answer provides the impact scale.

The effect of the impact would be felt in three ways by the company and/or operation. The impact could affect either the overall project cost, or time (duration to completion), or quality (sometimes a delay may be avoided but quality may be sacrificed; for example, quicker drilling rates but poorer core recover and quality).

From this process essentially four main categories of risk exist. These are:

- High probability - high impact;
- Low probability - high impact;
- High probability - low impact; and
- Low probability - low impact.

A practical application of the risk matrix process was undertaken in the selection of a suitable or appropriate small-scale mining method for a travertine deposit in the Eastern Cape (McGill, 2003). Travertine comprises deposits of fresh water limestone formed by precipitation of calcium carbonate from hot or cold mineral springs. It is very soft and often quite porous. The two critical criteria assessed in the evaluation of potential mining methods were the overall cost and the applicabiliy to small-scale mining. The mining methods were ranked accordingly (Table 13). The criteria for each method were rated from 1 to 5, i.e. low to high ranking.

An alternative method to the probability/impact matrix described in the literature is the use of a project success matrix (Oosthuizen *et al.,* 1998). A weighting to various success factors is given for a specific project and then these are individually scored. Essentially, this is the inverse to a probability matrix but this approach has the ability to pinpoint areas not meeting certain success criteria and that, therefore, could be potential obstacles to the success of a project.

Table 13: Matrix for determination of a mining method for a potential travertine deposit (McGill, 2003)

	Cost	Applicability	Comments
Channelling	4	5	Suitable for travertine mining, but high capital cost.
Chain saw	5	2	Not suitable for SSM due to size and capital costs.
Stitch drilling	2	5	Suitable for SSM, but need suppliers and affordable expanding clay/cement.
Wire saw	3	4	Suitable for SSM but expensive if diamond tipped equipment is used.
High pressure water jet	2	3	Suitable for travertine mining since the quarry is next to the river, but method needs to prove its applicability and reliability. Environmental constraints.

In summary, various methods of risk classification exist. Those described in this section include the categorisation of risk, the use of a probability/impact matrix, as well the application of a project success matrix. Each of these methods can be applied adequately to the junior and small-scale sectors, as each of the matrices is designed specifically for the particular operation. It would prove beneficial to many smaller mines to apply these easy techniques. To further illustrate the use of a probability/impact matrix a case study is provided in Appendix A.

5.3.3 Hazard and operability studies (HAZOP studies)

HAZOP studies are techniques adopted from the safety and health aspects of processing plant design and chemical-related sectors. These techniques have been extended into the mining sector with much success. It was discovered that traditional approaches to plant design often missed critical weak points. HAZOP studies were developed during the 1960s to systematically identify potential hazards and operation problems in new designs (RSC, 2001). The results of the HAZOP process are recommendations for design changes.

5.3.4 Fault-tree/decision tree analysis

Fault-tree analysis typically considers a key effect together with a certain number of underlying causes. This key effect is the “top fault”, with certain interrelated and underlying causes making up the branches of the “cause tree”. Fault-trees enable the probability of a hazard to be determined while the probable consequences of the threat, the cause tree, are identified. The causes in a fault-tree may be considered to be either dependent or independent of each other. Decision trees contain decision points, usually represented graphically, where the decision maker must select from several available alternatives (Kerzner, 2001). Chance points are then included, which represent the probability of an expected outcome occurring. The application of fault-tree analysis is a valuable method to compare alternatives.

Fault-tree analysis has been used by Cockram *et al.,* (2004) to examine the impact of specifications and procedures relating in particular to remnant mining scenarios. The study revealed that mining without consideration for procedures exceeded the study threshold, while the appropriate specifications satisfied the applicable criteria. Ultimately the mine (Harmony Number 2 shaft, Orkney) was able to determine using fault-tree analysis whether mining remnants according to the specified procedures was economically viable or not.

An example of the application of fault-tree analysis to the small-scale mining sector considers the following problem. In small-scale gold recovery the current technique most commonly applied to concentrate gold is through the use of a sluice box and a Chinese blanket. The feed material is passed over the blanket in the sluice box trapping the heavier gold particles in the dense weave of the material. All other material reports to the tailings (usually into a river or pool of standing water). An alternative approach to the sluice box is a stepping pump concentrator, recently developed by the CSIR and tested in South Africa, Ghana and Mali. The mechanical device is a density separator, where feed material is passed into a conical basin that is agitated with water through a nozzle, resulting in a basic cyclone effect. All the oversize is removed manually, leaving the heavier concentrate in the bottom of the bowl. The hypothetical problem concerns the choice of implementing one of these two methodologies on an alluvial gold recovery site (Figure 11). The associated probabilities of success are given in the form of a decision tree in Figure 10.

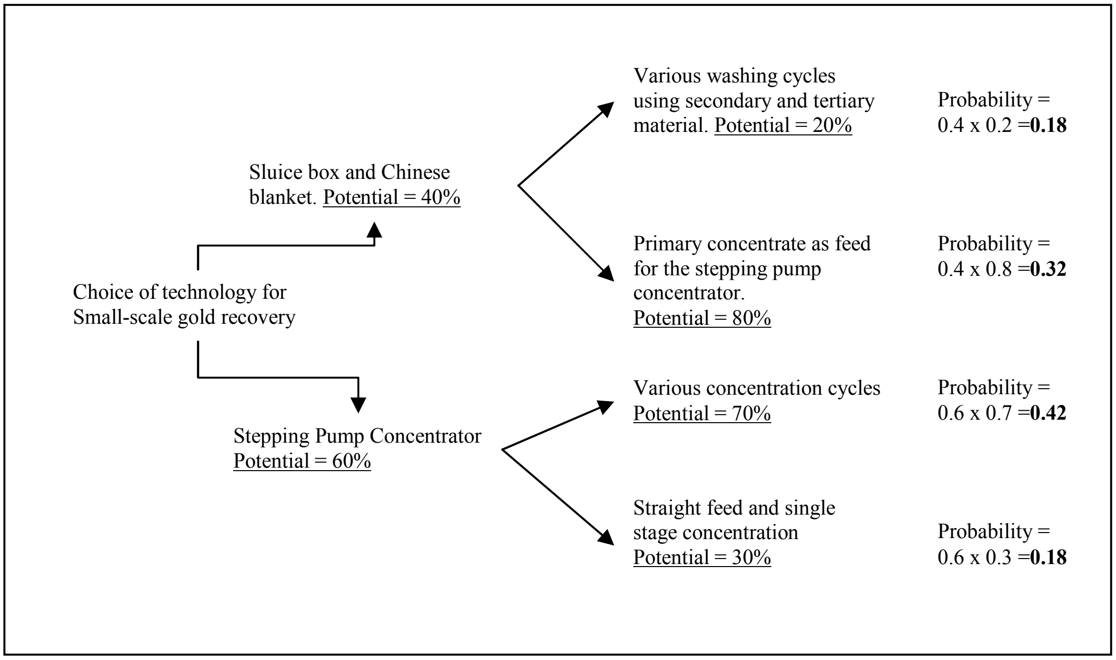

Figure 10: Example of an application of a decision tree (figures are illustrative)

This example illustrates that by graphically depicting the various choices available and allocating numerical values (numbers used for the purpose of example only) for associated potential the associated probabilities for each method are expressed. From the above example the method with the greatest potential considers various concentration cycles of the stepping pump, while the lowest potential is the use of the sluice box and Chinese blanket for the entire process.

Figure 11: Comparison of the stepping pump concentrator (foreground) and sluice boxes (background) for small-scale gold recovery.

5.3.5 Sensitivity analysis

A sensitivity analysis comprises the changing of a value of (a) key parameter(s) within a specified range from the initially estimated value. Factors usually considered are those that have the greatest influence over the value of the project. Possible variables include tonnage, grade, metal price, metal recovery, capex and opex costs. However, usually no attempt is made to estimate the probability that the parameters will take these values (Rendu, 1999). Sensitivity scenarios could be opex, capex, commodity pricing or even project delays (plus or minus 10% and 20%). Sensitivities may be simplistic, as changes may have a knock-on effect into other areas. This conservative method will, however, provide a best/worst case result.

Other useful parameters include how much the NPV or IRR will change in response to a given change in input variable, other things being constant (Hartley *et al.,* 2000). One begins with the "base case" (which is a set of economic conditions and operating plans felt to be the most probable case - for example, calculation of the expected

NPV), and then, in turn, adjusts the input variables by a fixed percentage and then recalculates the NPV. These changes are then graphed. An example of this resultant graph is provided in Figure 12.

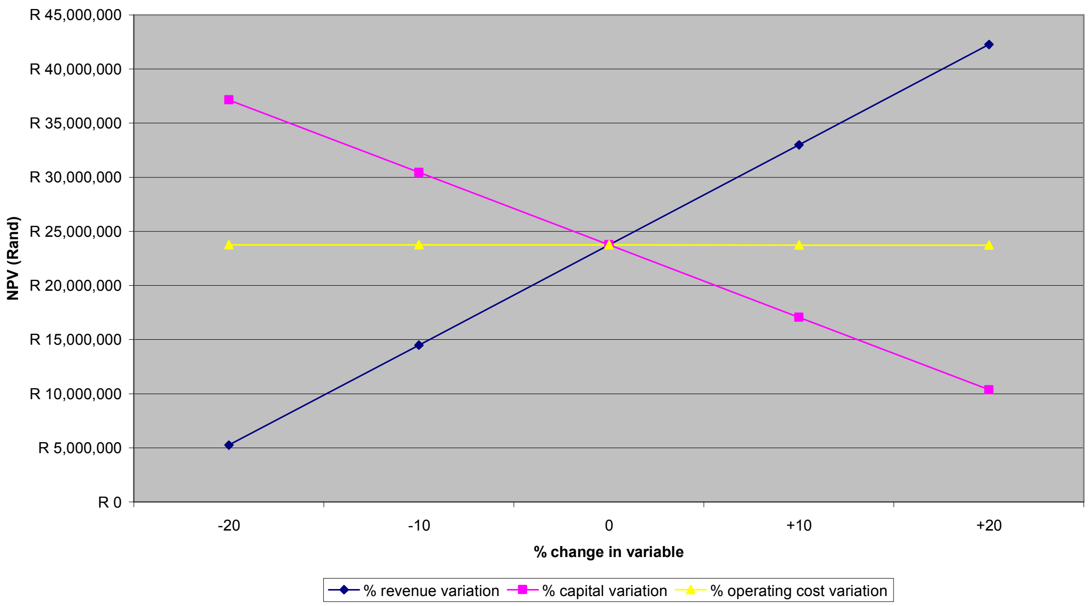

Figure 12: Example of a sensitivity analysis undertaken on a potential junior-scale operation in Limpopo

The sensitivity analysis (Figure 12) was completed using the variables revenue, capex and opex. From the figure it can be assessed that variations in total revenue will have the greatest impact on the NPV of the project, due to the slope of the line. The inputs to the revenue calculation were tonnage, grade, mine call factor, recovery, and gold price. All these factors are affected by the production rate. The determination of a viable production rate is critical for preparing a DCF model, which will be used as the basis for a sensitivity analysis. Various tools are provided by O'hara (1980) to estimate operating costs. In this scenario, operating costs have the least impact on the NPV, when compared to opex and capex.

The impact of each of these parameters is even more noticeable on junior and small-scale mines. The usefulness of sensitivity analysis is in providing information to the emerging operator with regards quantifying and prioritising risks and where best to mitigate them. Institutions evaluating deposits for small-scale operation should share the outcome of this technique (if prepared during the evaluation process) with the successful recipients of funds.

5.3.6 Subjective or "expert" judgement

A typical expert judgement technique is the *Delphi method,* named after the Greek oracle. It is a group-decision process about the likelihood that certain events will occur. They represent the opinion of the group rather than a statistically significant sample set (Gordon, 1994). An anonymous panel, chosen as a group of experts, makes predictions on potential risk factors and outcomes to a scenario, and then the results are collectively pooled. This method is particularly useful, as the experts are not required to be in the same place. New predictions are then made based on this individual feedback. Various reiterations of the process are possible; however, they add to the duration of the entire process. Gordon (1994, p 10) states that "no better way exists to collect and synthesise opinions than (the) Delphi (method)".

This technique would potentially be very useful on a strategic level for analysing the diverse opinions of the various role-players and stakeholders within the junior and small-scale mining sectors. These sectors have been the focal point of numerous conferences and workshops but remain fraught with challenges. This subjective judgment technique could be applied to establish strategic outcomes of and resolutions to the numerous challenges within the sector.

5.3.7 Classic statistical techniques

Classical statistical techniques form the platform for a variety of techniques and tools applied to understanding mineral resources and reserves. The discipline of geostatistics deals with statistical tools and measures applied to the geological and mining environments. The aim of these techniques is essentially to describe existing sample data as well as to infer and predict potential grade values at locations not sampled (Clark and Harper, 2000).

Such techniques are particularly relevant to junior and small-scale operations where any sampling and/or grade data can easily be assimilated statistically. The best starting point is to take known data and understand it by producing descriptive statistics. The measures include the mode, median, mean, range, variance, skewness, kurtosis and coefficient of variation (Clarke and Harper, 2000). Once the characteristics of the actual data are known it is possible to begin inferring or predicting potential grade values for unsampled areas or localities. It is this data that is used in procedures such as kriging and for constructing semi-variograms.

Certain geostatistical applications can be undertaken by individual operations but the potential also exists to outsource such competencies to qualified specialists. This would be particularly necessary for the delineation of resource and reserves to comply with SAMREC requirements (refer to Section 4.1). The advantage of having a good statistical knowledge of the orebody will go a long way to reducing a variety of risk types. The underlying importance of sound geostatistical data is to be able to accurately predict where suitable revenues can be achieved to ensure the long-term sustainable development of the mine.

5.3.8 Monte Carlo simulation

Monte Carlo simulation utilises random values or percentage variations of various assumptions, which are then used to provide a probability description of a project's viability (Rozman and West, 2001). In this way the Monte Carlo simulation process attempts to create a series of probability distributions for potential risk items, randomly sample these distributions, and then transform these numbers into useful information that reflects a real-world situation (Kerzner, 2001).

Heuberger (2005, p 76) explains that "the term 'Monte Carlo' originated at Los Alamos during the Manhattan project when scientists used a roulette wheel to generate random numbers". For Monte Carlo simulation to be truly representative, certain conditions need to be in place. These are (Heuberger, 2005):

- The model must be an accurate representation of the operation under investigation;
- The estimate must be realistic and based on actual exposure to the relevant sector; and
- The objective of the analysis must be clearly defined.

Owing to the high level of technical input required in this technique it would probably not be widely applied on junior and small-scale operations. However, the value of such a technique could reside with suitable technical consultants who could apply the technique independently on a variety of mining licence and/or permit holders' sites within a single mineralised area, e.g. gold mining areas of the Barberton district, Mpumalanga. The results of such a holistic Monte Carlo simulation, based on a variety of data from available mines, could then be assimilated and distributed in a way that individual operations could benefit accordingly.

5.3.9 Conditional simulation (range analysis)

Simulation techniques attempt to address potential shortcomings of other estimation techniques by providing a range of realistic potential values within models (Thomas *et al.,* 1998). Conditional simulation is a tool for assessing the risk of predicted tons and grade of any resource model. Conditional (sequential) simulation, therefore, produces different possibilities of how the deposit might look in terms of geology and grade. Essentially, numerical modelling at all levels of uncertainty occurs.

This method comprises 3D-simulated models of reality. Information/data used in the process includes geological interpretation, data integrity, grade ranges, and variograms (Glacken, 2002). In well-understood areas simulation models will be similar (low risk) while in areas of reduced information the simulations will be very different. These are, therefore, high-risk areas. However, through the process of conditional simulation worst, best and in-between cases can be predicted. Usually between 25 and 100 similar models are generated during the process of conditional simulation (Figure 13). This technique is obviously better than other techniques that produce a single estimate. The simulation's results can be analysed to quantify the uncertainty associated with the overall resource (Dohm, 2003).

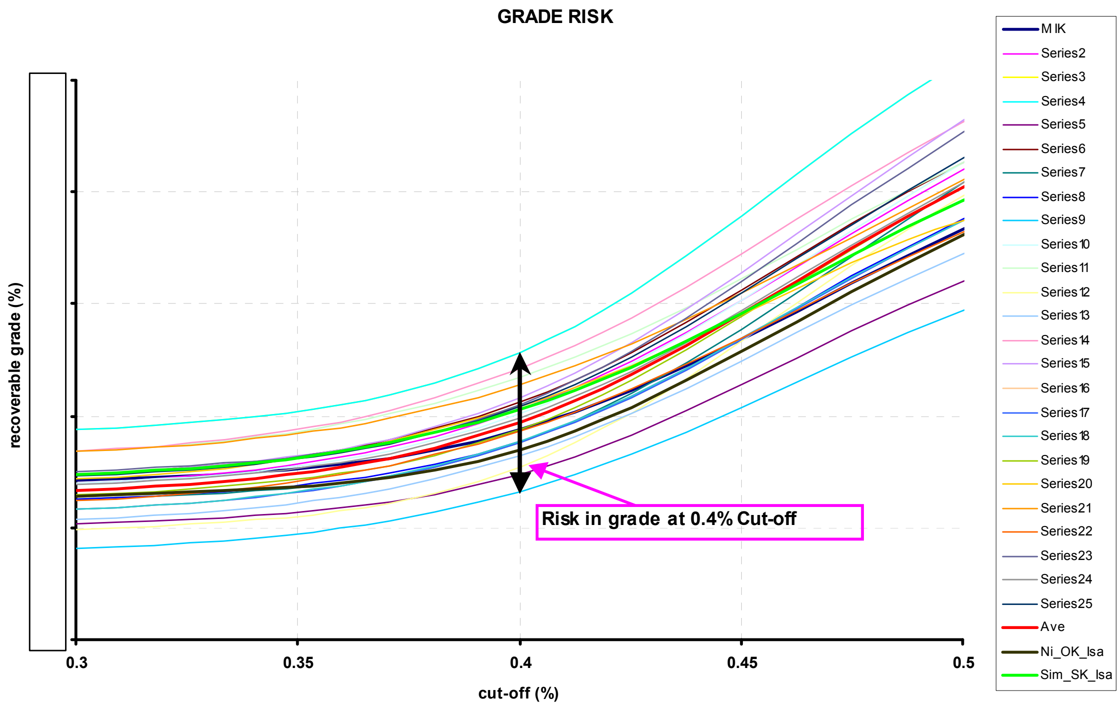

Figure 13: Graphical representation of the result of a conditional simulation process, for 25 series. The range of possible grades is clearly shown (Carey, 2002)

Conditional simulation allows the mine planning staff to assess the effects of short-term variability in the deposit, including variables such as coal-seam thickness and to quantify the risks associated with such issues as ore/waste classification, mine design parameters, stockpile designs *etc*. It is obviously important to consider the integrity of the simulation exercise where the number of simulations is observed and the reproducibility of the variogram model and histogram are reviewed and verified. An example of verification would be to generate variograms for the simulated data. This should represent the same as the input variogram used in the initial phases of conditional simulation.

Various forms of simulation methods exist and the most widely applied are sequential simulation methods. These are either sequential Gaussian (which uses ordinary kriging) or sequential indicator (which uses indicator kriging) (Glacken, 2002). It is important to choose a technique that suits the style of mineralisation and its associated continuity. As all deposits are different, one technique should not be used in all circumstances. Various examples as to applications of conditional simulation are provided in the next paragraph. In summary, conditional simulation provides a tool for detailed risk analysis, risk conscious mine planning, as well as decision making.

Table 14: Steps involved in the conditional simulation process (Snowden, 2002)

Diagnose risk requirements and define the risk profile
Understand the geological controls on mineralisation
Define the relevant mining and metallurgical issues affecting simulation outcomes
Validate the database and develop a geological model
Investigate the statistical behaviour of the mineralisation
Investigate the spatial continuity of the mineralisation
Determine the appropriate block size and point simulation grid dimensions
Choose the appropriate simulation method and parameters
Validate the simulation models against the input data and the continuity model
Composite point simulations to block simulations
Post process the simulations to address the risk outcomes
Produce a risk-qualified or optimised outcome

The following paragraphs provide certain industry applications for conditional simulation. BHP Billiton adopts a process of conditional simulation to provide quantified information on upside or downside potential (Mullins *et al.,* 2003). There are a number of conditional simulation techniques and the choice of technique depends largely on the style of the mineralisation and its continuity, as well as on the inherent statistical behaviour. One method typically applied by BHP Billiton is the sequential Gaussian simulation. Here, the algorithm defines a random path through a grid of nodes. Kriging of the nodes in the path generates a local distribution. A new value is then given from this local distribution. This grade and associated position is added to the nodes in the random path and the next node is simulated (and so on). The generation of up to 200 simulations provides a distribution of grade estimates for each block. It is these distributions that are use to calculate various probabilities of occurrence. BHP Billiton has demonstrated this approach to quantify global or reserve risk, pit optimisation risk, phase pit risk, and mine scheduling risk (Mullins *et al.*, 2003).

Dimitrakopoulos and Fonseca (2003) demonstrate how conditional simulation was used successfully to predict the variability of recoverable copper (including metallurgical factors) and the associated risk within a Brazilian complex multi-element copper deposit.

Another workable application has been provided by Sullivan (2003) in whose study conditional simulation was applied to determine the underlying value of additional drilling at a mainly copper deposit in northern Chile. Initially, the project was set at a 10% discount rate based on a certain level of drilling. Simulation exercises revealed that the risk premium for not completing proposed additional drilling was 3.6%, which meant the discount rate was raised to 13.6%. In other words, if the additional drilling were not to be completed the project should be discounted at 13.6% which the author stated equated to a reduction in the project NPV of USD 150 million (Figure 14). The additional funds spent on drilling would therefore be well spent. There is, of course, a maximum amount of drilling too, reflected in the overall NPV distribution curve below.

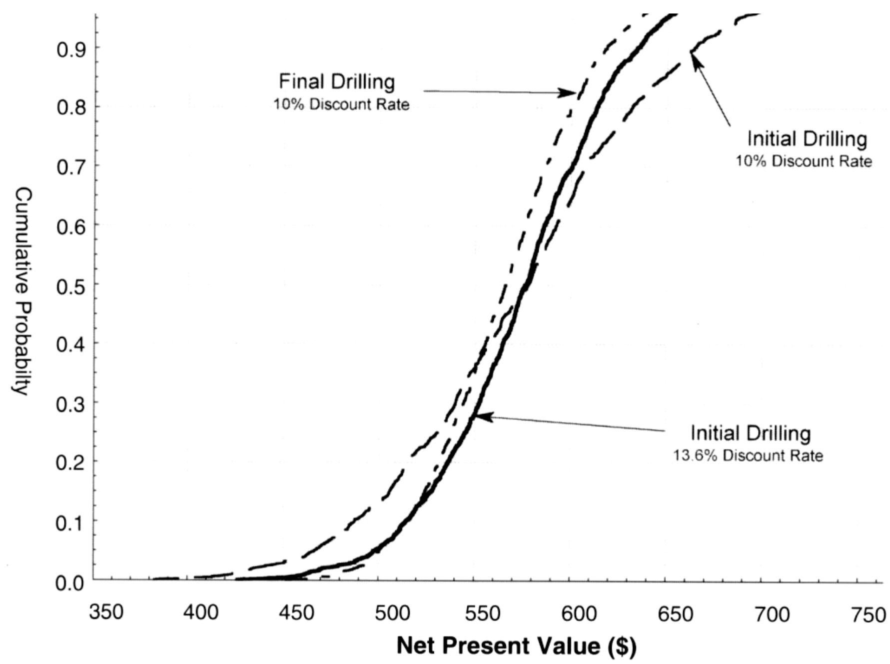

Figure 14: Impact of increased drilling on the distribution of project NPV (Sullivan, 2003)

The potential applicability to the junior and small-scale mining sectors is similar to the statement applied for the section describing the Monte Carlo simulation (Section 5.3.8.) where it is the opinion of the author that because of the high level of technical input required (which equates to financial expenditure) this technique would probably not be widely applied on individual junior and small-scale operations. Potential application could be undertaken on a regional scale, however. There are definite advantages to applying such techniques. The increased understanding of the orebody will provide data to decrease associated MRM risk and, in turn, make funding initiatives more likely.

5.4 Tools for managing MRM risk

The aim of this section is to describe techniques for managing risk that have particular relevance to the mineral resource sector. In addition is it crucial to note the applicability of such techniques to in the junior and small-scale mining sectors. Often, techniques may not be considered appropriate because of the high overall cost of implementation, but this should not deter operators from perceiving the inherent relevance of the technique and how techniques could possibly be "tweaked" for use by role-players in the sector. Other reasons for not applying such techniques include the overall integrity of the data. Date generation, capture and storage on smaller operations is often not considered as high a priority as it is by larger operations. Through capacity building, the underlying importance of such data to be used in risk management tools - which would ultimately translate to greater funding opportunities will be realised.

It is important to realise that one's attitude to risk will dictate the potential strategic options available (Pearce and Robinson, 2000). In situations where risk is favoured, the range of possible strategic choice expands and high-risk strategies are more acceptable. In a risk-averse environment certain strategic choices are eliminated from the decision-making process before it even begins. Outcomes from past strategies also have a profound influence on risk-averse managers. This is particularly evident within the high-risk mining sector. Owing to the higher risk within the mining operating environment profile managers are more prone to considering broader and more diverse risk related strategies.

5.4.1 Bayesian approach

The Bayesian method uses objective data and subjective judgement to provide probable outcomes (Glacken, 2002). This method is especially applicable within an exploration environment where data is generally sparse, and data from similar prospects in the same area tends to be used as conditioning data. This approach was applied in exploration drilling phase at Target Mine, Free State, where the conditioning data was a borehole (ERO1) that intersected a stacked reef scenario. A matching distribution was then applied from the known Loraine Gold Mine's reef distribution model. This approach allowed for further targeted drilling, which reduced the risk associated with exploring in the wrong place. The obvious shortcoming, however, with this approach is that comparisons are only possible in identical situations, which seldom occur. For this reason, the method should be applied with caution, particularly in the junior and small-scale mining sectors, where very site-specific issues exist.

5.4.2 The discount rate in DCF models

The discount rate is a fundamental means of reflecting risk in discounted cash flow evaluations (Smith, 1995). It is therefore imperative to estimate realistic project-specific discount rates. The discount rate applied should be appropriate for an individual case but also take into account the industry expectations for such a project, risk factors associated with mineral projects in general, and risks related to the specific project. When a discount rate is applied to junior and small-scale mines, in particular, the discount rate will be higher than that applied to bigger mines. The discount rate consists of three distinct aspects, where project specific risk will equal the sum of these three values (Smith, 2003):

- Risk-free interest rate – the value of long-term risk-free or "real" interest (bank) rate;
- Mineral-project risk – representative of the numerous risks as outlined in this research; and
- Country-specific risk – as supplied by various agencies in the form of bank ratings, where it is important to consider both a current assessment plus historical data. (Refer to Section 5.2.4.)

It could be argued that a certain amount of country risk is also incorporated in the risk-free interest portion. Each country's inherent economic situation will be reflected by the independent bank interest rates. In addition, a variety of additional factors is used to establish country risk rates as provided by, for example, Standard and Poor's.

(Refer to Section 5.2.4.) A more representative project-specific risk value will therefore comprise the sum of these three values, rather than just that of the first two. However this point is not without debate (Holmes *pers comm;* Smith, *pers comm;* Jurd *pers comm*).

From a survey generated by the MES in 1996, Smith was able to obtain data on discount rates applied by industry to various stages of mining project life-cycles (Table 15) and compare this with conceptual values. All 33 sample points were from Canadian operations, which meant that any overriding country-risk elements were neutralised (Smith, *pers comm*). (This study is currently being updated to include cross-continental data.) It was shown that the discount rates applied on gold projects/operations were 2 - 3% lower than those used for base metals. This conclusion has been attributed to the capital asset pricing model used in the valuations. This conclusion could further be explained by the fact that it is easier for gold mines/prospects to obtain bank loans, as a result of the sophisticated hedging methods and other financing tools available to the gold sector. This scenario is particularly relevant to the junior sector where gold is traditionally viewed as "money in the ground" therefore easier to fund and enabling the lowering of the applicable risk rate as opposed to other commodities.

Table 15: Summary of discount rates (%) in concept and practice (Smith, 2003)

Level of Study	**Conceptual study values**	**"Real world" values**			
	Mean	Mean	Range +/- SD	Mean	Range +/- SD
	Smith (1995)	MES Survey - 1996			
	Gold	Gold		Base Metal	
Exploration	20				
Order of Magnitude	15-20	17.4	11.6 – 23.1	17.7	11.1 – 24.2
Pre-feasibility	15	11.3	6.9 – 15.7	13.3	10.1 – 16.5
Feasibility	10	8.8	4.8 – 12.8	11.3	8.5 -14.2
Operation	5-8	5.3	1.6 – 9.1	8.6	6 – 11.3

In the context of South African junior and small-scale operations ABSA Corporate Bank currently applies a discount rate of 16% to all mining ventures considered by the resource division, independent of size (Jurd, *pers comm*). The reworking of dumps and the processing of aggregate from borrow-pits is not deemed as mining *per se* and such investments are accorded lower discount rates. Not all commodity groups are supported by banks, like ABSA, for various reasons. For example; alluvial diamonds are very difficult to evaluate as a reserve status, and cobalt suffers from potential oversupply, as well as associated country risks (Jurd, *pers comm*).

5.4.3 Grade/tonnage curve

The most important tool within the MRM toolbox is the grade/tonnage curve or the VAC, as applied by AngloGold Ashanti because it allows for the derivation of cut-off grade and the average mining grade above a certain grade cut-off, as well as the resultant tons available above the cut-off (Figure 15). Each deposit would have its own unique curve because of the grade distribution in the deposit, but certain deposit types display internal similarity.

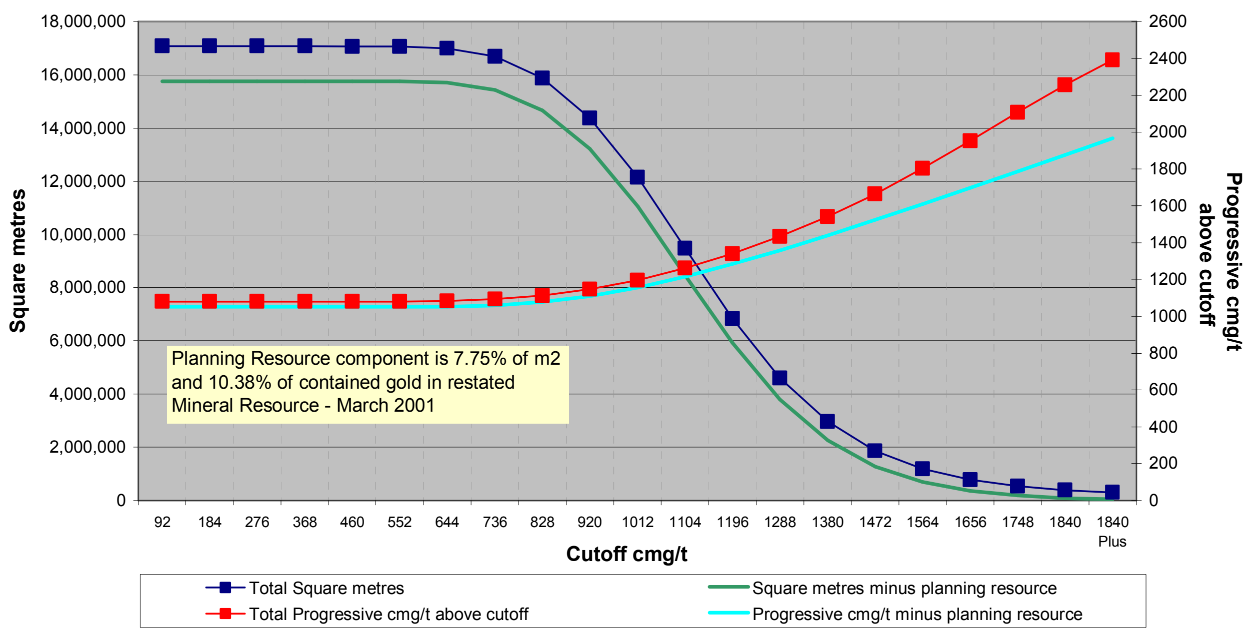

Figure 15: A typical value-area curve (VAC)

The grade/tonnage relationship is also dependent on the block size used in the calculation. Using too large a block size will underestimate the potential to mine selectively, while using too small a block size will result in an optimistic view of the degree of selectivity that can be achieved (Dewar, 2001). The grade tonnage or VAC curve is the overall result of the geostatistical evaluation process and, therefore, represents the overall quality of the orebody. Other important derivatives include the estimation and comparison of grade/cost as well as grade/volume relationships. DCF analysis and risk analysis techniques related to this will allow constant re-optimisation of the orebody, according to fluctuating financial circumstances. Certain shortcomings do exist with this technique. These shortcomings include the fact that the actual grade distribution or the continuity of grade between ore blocks is not described.

As already stated, the generation of a grade tonnage curve is one of the critical outcomes from geostatistical evaluation. This technique is more suited to deposits of high-value commodities like gold, platinum, and iron-ore for example. The methodology requires a good level of basic geostatistical data (refer to Section 5.3.7) and would probably be the most beneficial to junior-scale operations. A geostatistical consultant can ensure SAMREC compliance (Section 4.1) if this is required.

5.4.4 Geological modelling

Parameters fundamental to obtaining the knowledge required for geomodelling relate to geochemistry, geophysics, sampling for grade, mineralogy and geological structure. Such information forms the basis for meaningful geological modelling. Examples that have been referred to by Viljoen (2000) include facies modelling, ore shoot modelling, stratigraphic and structural modelling, and the use of geophysics. In addition, the relevance of 3D rock mechanical models of stress patterns, based on information available prior to mining, should not be underestimated. The 3D computer modelling process produces various virtual models of the orebody (sometimes using wireframes) as outputs, based on this data.

Irrespective of the modelling methodology applied, the final mineral resource is the result of an estimation process. Interpretive errors will exist, as well as variability in the assay data and/or sampling results (Rozman and West, 2001). The correct order of accuracy must, therefore, be assigned to the overall reserves and resources. It is paramount that high levels of accuracy exist in the sampling design phase.

AngloGold Ashanti identified that risk is associated with the estimation of gold grades and grade distribution due to inadequate knowledge (Dewar, 2001). Certain internal AngloGold Ashanti processes existed on individual operations but these were highly dependent on available data, techniques applied, knowledge of the controls on the mineralisation, and the judgement of those making the estimations. The greatest risk areas in a geological model are summarised as (Dewar, 2001):

- The accurate delineation of limits or boundaries to the orebody, especially where data is scarce or missing, to prevent an over- or under-estimation of volume and tonnes;
- The estimation of block grades from samples, which involves kriging, to obtain a relationship between known and unknown data points;
- Sampling and assaying errors through systematic biases during the process; and
- Accuracy and geological interpretation applied when developing mineralisation models as a foundation to the geomodelling process.

Dohm (2003) states that an effective estimation process is dependent on both a geological model based on a thorough understanding of the mineralisation, and an appropriate estimation technique, such as kriging. Deraisme and Farrow (2003) describe how, through geological modelling, a relationship between the number of planned boreholes within a diamond kimberlitic environment and the confidence in the estimates of annual production, roughly corresponding to a mining level, can be obtained.

Ashanti operations introduced various methodologies to geomodelling (McGill, 2000) certain commonalities in approach were proposed for the reduction of associated risks. (Refer to Appendix B.) Within AngloGold Ashanti the geological model was defined according to various developmental stages (McGill, 2001a).

Initially, reef polygons were created in 3D space using Cadsmine software, revealing fault cut-offs. A second stage involved the extrapolation of these surfaces, which gave a holistic view of faults and intrusives. Finally, it was possible to combine various geological parameters and grade data to provide a holistic tool for accurate geological predictions beyond the existing mapping sheet. This holistic model was then used for geostatistical evaluation.

Of concern is the misconception that a 3D geological model is merely a static graphic or "pretty picture". The true value-add of a geological modelling system lies in how the information derived from the model can be incorporated into the holistic MRM system. The benefits of such a modelling system are both soft and hard:

Soft Benefits:

- Improved communication of information between various people or departments on mines;
- The distinction between luck and good management practices;
- Potential to encourage participation at all levels in the operation; and
- The interrogation of the model and its potential for improving communication at all levels.

Hard Benefits:

- Allows optimal mine design and scheduling;
- Reduces the likelihood of accepting flawed interpretations;
- Provides for accurate geological reconciliation year on year;
- Plans generated will be defensible and will expedite drafting of accurate drilling budgets and scheduling of the resource;
- Increases the likelihood that the project will follow the plan, which reduces the panels to be stopped and started in any given month; and
- Highlights structurally complex (risky) areas from a distance.

Such models will also be of use to rock engineers, mining engineers and any other interested party, as they facilitate proactive management of the mineral resource. However, often a mental shift is required to adapt to the understanding of such 3D systems. Identification of key risk areas is the main area where geological modelling can help reduce risks associated with mining. Computerised geological modelling is a key advancement for effective MRM. The challenge is to ensure that the geomodelling process is integrated into the existing MRM systems and ensures maximum value-add to operations in this way.

The AngloGold Ashanti example provided in Appendix B is indicative of how geological modelling is incorporated into the MRM system on larger operations. It is prudent to question the effectiveness of such methodologies for smaller operations. The acquisition of geological modelling software and the associated capital outlay in terms of computer hardware and training of personnel is crucial, in the opinion of the author, if the junior operations want to compete effectively and continue to operate in an efficient manner. An example of the application of 3D geomodelling by a junior mine encountered by the author involved the (then) Bosveld Gold Mine in Pongola. Here, the mine had never considered computer modelling of the shear-hosted mineralisation. When the Bosveld Mine management acquired the operation, one of the first management decisions involved carefully updating all the mapping sheets, which were ultimately captured in a computer geological model. The process was time consuming and expensive, but the gains and ability to locate additional development-drilling platforms to expose the richer reef types added two very much needed years to the LOM. Owing to the nature of the deposits exploited by the junior and small-scale sectors, the value addition through the application of geological modelling is limited and can be considered unnecessary. 3D modelling expertise could also be applied on a contract basis to update mine models and need not be used on a continuous basis, as it is in larger operations.

5.4.5 3D seismics

3D seismics has been used as a technique of mineral resource risk reduction with much success in a variety of geological environments. Extensive 3D seismic surveys have been undertaken within the AngloGold Ashanti mining house as well as the Target Mine of the gold sector. 3D seismic techniques have also been proven successful on the platinum mines.

3D seismics is a geophysical tool to provide the gross structure and depth of prospective stratiform ore horizons (Figure 16). In addition, through careful analysis of 3D seismic attributes, validated borehole control, and direct geological observations, seismics can provide important information on small-scale faulting and variations within the ore zone conglomerates. Stuart *et al.,* (1999) commented that modern 3D seismic evaluation techniques, applied prior to mine planning and development, can provide detailed geological information that reduces risk and increases mining efficiency and safety

The application of 3D seismics at Tshepong Mine, Free State, enabled structural interpretation that was used to plan access to a 1 000 000m^2 block of ground, as well as to a decline system. In addition, geological confidences and associated mining risk factors could be adjusted accordingly (McGill, 2001b). The potential economic impact of geophysical mineral resource risk-reduction techniques was further demonstrated at Impala Platinum, where 3D seismic surveys were undertaken by the mine on the Western Bushveld during 1998 and 1999, covering 25km^2 and 45km^2 (Mellowship, 2000). The associated total project costs were ZAR 720 000/km^2 for the 25km^2 survey and ZAR 600 000/km^2 for the 45km^2 survey. When compared to a conventional drilling programme, the survey costs equated to 2.4 boreholes per km^2. The capital costs for a major shaft system to access the same size block of ground were estimated (1999) to be ZAR 1.6 billion. Therefore, the cost to undertake such a survey is <1% of the capital investment.

Borehole radar as another 3D geophysical technique has successfully been applied on mines to determine reef geometry before mining begins. Having this knowledge before mining occurs allows for optimal ore extraction to occur and reduces the related mineral-resource related risk considerably. Borehole radar has been successfully applied on the Ventersdorp Contact Reef (VCR) at AngloGold Ashanti's Mponeng Mine to site-stabilising pillars in low-grade areas, as a replacement for the traditional standard grid layouts (du Pisani and Vogt, 2004). The gold value locked in one underground support pillar was estimated to be in the order of USD 2.6 million. Positioning such support pillars in low-grade areas, as delineated by the borehole radar analysis technique, allows significant economic potential to be unlocked.

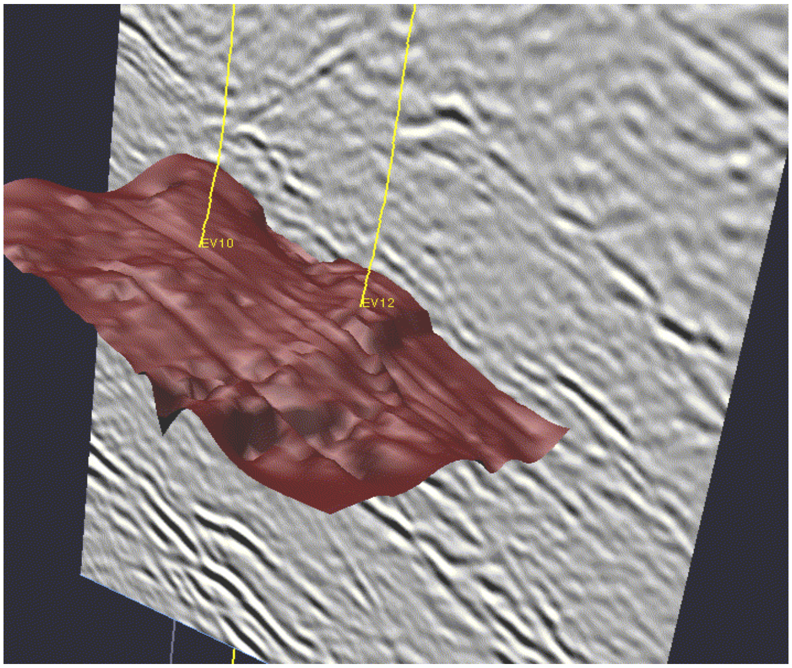

Figure 16: Representation of the basal reef horizon pick in a 3D cube – Tshepong Mine

3D seismic techniques, used either on the surface or by means of underground borehole radar, can provide extremely useful geological data that goes a long way to reducing mineral resource risk. However, accessibility to these techniques is restricted to mining operations or companies that have significant capital expenditure budgets and resources to implement or contract geophysical services. The applicability of such techniques for the junior and small-scale sectors is questionable. However, in the current dispensation and conversion of mining rights, certain operators may obtain the marginal "discards" of larger established operations. The case might be that such techniques were applied over such areas and the information and data-sets can be acquired by the junior mines. Therefore 3D data, as a tool to reduce mineral resource risk, should not be overlooked.

5.4.6 Mining due-diligence studies

Traditionally due-diligences were carried out on functional areas such as legal and financial (Anderson and Tingley, 1988). Mining technical risk appraisal has the ability to assess all factors impacting on the operation and/or sale condition in a structured way. To appraise the impact of future risk requires the application of business due-diligence. Mining due-diligence studies constitute the backbone to most sound investment decisions within the minerals sector. The completion of a due-diligence study is generally a phased approach, which considers the following in order: resource/reserve calculation and verification; identification of key technical risks; assessment of production volumes and costs – based on a production plan and utilising the given infrastructure and proven reserves; and market analysis and financial analysis (Anderson and Tingley, 1988). During each phase, until the completion of feasibility, gathering and analysing data on the orebody and markets reduce the degree of various risks. It is apparent, therefore, that within the due-diligence report various techniques are used to adequately analyse and evaluate all aspects of the operation or project.

Mineral investment evaluation, of which technical due-diligence is key, is further complicated through each mineral investment possibility having its own singular combination of risks and opportunities (Tingley, 1990). This unique combination considers all aspects, including that of the mine/operation, available infrastructure, political environment, and environmental aspects *etc*. Even proven reserves (refer to SAMREC, Section 4.1) can differ materially in both type and degree of risk.

Through timely involvement of an independent technical auditor, responsible for the formation of a feasibility and/or independent technical audit, risks associated with seeking outside finance can be addressed. Technical questions can expose issues that can potentially delay or jeopardise raising finance (Cole-Baker and Bower, 1998). In a best practice situation, due-diligence audits should be repeated at different stages of a project's development, as more information becomes available and conditions are better understood (Rozman and West, 2001). In other words, risk assessment through due-diligence should become an iterative process.

Mining due-diligence reports are critical tools for the assessment of prospects under consideration for the junior and small-scale mining sectors. All funding institutions require such documentation and often may duplicate or re-do the entire feasibility process in-house for clarification. Without such documentation most ventures would not be undertaken. Unfortunately, the cost of acquiring such documentation is often in itself prohibitive for the potential entrepreneur. Vehicles such as the NSC are in place for technical service providers to the DME to complete such studies on behalf of successful applicants.

5.4.7 Reconciliation

Reconciliation plays a very important role in the evaluation process. It is one of the most crucial tools for any evaluator and is used to check the confidence of the evaluation. It is through reconciliation that the geology model, variograms, local area means used, and other assumptions are put to the test (AngloGold Limited, 2001b). Through an effective reconciliation process effective learning about the orebody occurs and this information is integral to future forecasting for the deposit.

Reconciliation entails the comparison between 'planned' grade estimates (kriged predictions) and the 'actual' estimates (kriged together with additional/new sampling points) of kriged blocks (Figure 17) to kriged values for the same blocks once mining and sampling have taken place. Through reconciliation, the evaluation process can be refined and optimised so that the best possible estimation of values for the particular orebody can be produced.

Reconciliation, therefore, serves as a value check. Factors such as geology and mining changes (in the case where a mining plan is reconciled) need to be excluded from the exercise. The planned mining and actual mining may differ and, therefore, differences in the value estimates can be expected. The mining plan should then be reconciled so that the errors associated with mining can be eliminated. For standard reconciliation the effect of mining is removed by reconciling kriged grid blocks only.

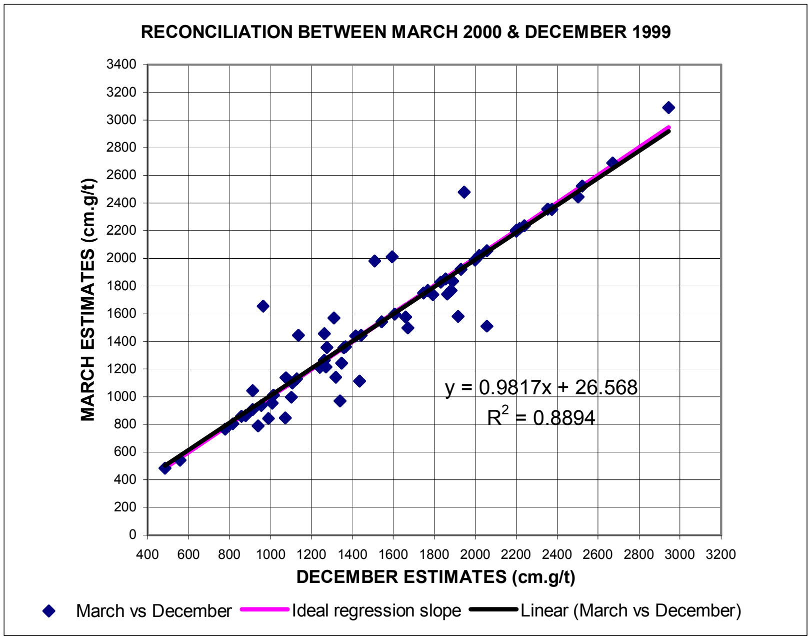

Figure 17: Regression plot as a comparison of kriged block estimates for December 1999 and March 2000 on a mine. The original estimated values (December 1999) are compared to re-estimated samples on the basis of stope sampling. As the scatter plot reveals a good correlation (slope approaching 1) the estimation process is deemed accurate (AngloGold Limited, 2001b)

The advantage of a properly conducted reconciliation exercise is that it allows the MRM practitioner to accurately predict the grade coming out of a mine, which, in turn, equates to a better prediction of expected revenues. Reconciliation is a crucial tool in assessing the effectiveness of planning, which is essential in management. The required data needs to be collected during the mining process. Such a requirement necessitates effective planning, which is, unfortunately, often lacking in junior-scale operations. The overriding desire to mine for "now" rather than consider the forward plan is one of the greatest impediments to successful MRM implementation on junior and small-scale operations.

5.5 Risk control techniques

5.5.1 Introduction

In the risk management cycle (refer to Section 5.1) the first two activities are identification and quantification. Once these activities have been applied to the junior or small-scale operation, an appropriate method of eliminating or controlling the particular risk must be identified. Various options exist (Terblanche, 2002) and will be the main focus of this section. The key options for dealing with or alleviating risk are the following:

- Risk avoidance: ignoring or not participating in the risky activity or action;
- Risk prevention: reducing the frequency of losses;
- Risk reduction: based on the assumption that it is impossible to entirely eliminate the risk, so reduction techniques are imposed to reduce the severity of the loss;
- Segregation of exposures: a mixture of both risk prevention and reduction techniques according to which risky activities are isolated from other company business;
- Risk transfer: often applicable in a legal or financial environment, where identified risks can be moved to outside parties who are contractually obligated to deal with them.

Each of these options has advantages and disadvantages depending on what level of risk mine management is prepared to be exposed to.

Risk transfer can be alternatively addressed in the marketing of commodities by long-term contracts, forward sales and other hedging tools. Risk sharing is well represented in the aluminium industry as a method for sharing the risk associated with the troughs related to the commodity life-cycle. As seen below there are no risk-sharing options that include the mineral resource management aspect of the business. Most options cover financial aspects only, but have been included in these sections as an illustration. The various finance-related risk-sharing options available include the following:

- Commodity sales at a straight percentage of the selling price;
- Sales swapped for other metal according to an exchange ratio;
- The commodity is sold at fixed prices; and
- The commodity is sold by long-term call and put options (hedging).

Within the junior and small-scale sectors various options that can be considered as methods of risk-sharing include:

- The introductions of shareholders in the company;
- The formation of joint venture agreements with technical partners;
- The outsourcing of certain technical competencies to consultants; and
- The purchase of varying levels and types of personal and corporate insurance.

Implementing any of the risk-control techniques mentioned above, has the ability to provide the following opportunities for mining companies (Alexander Forbes, 2003):

- Improving unfavourable financial ratios;
- Guaranteeing and smoothing cash flows;
- Obtaining discounted services;
- Insuring conventionally uninsurable risks;
- Releasing capital tied up in other portfolios; and
- Smoothing commodity price cycles.

MRM-specific risk management techniques are varied. The purpose of the case study provided (Appendix D) is to reveal certain of the risk-control techniques that have been tested on some larger operations. The development and application of geological risk domains at Tshepong mine provided an excellent framework for mine planning. Undoubtedly, the challenge for the junior and small-scale sectors is to adequately address risk issues and design applicable risk-control techniques for a particular size of operations in different commodity environments. Similar techniques could easily be adapted for the junior gold operations in Mpumalanga and Pongola. Most surface deposits are not as structurally complex as some gold orogenies, but other criteria, such as slope stability, could be substituted.

Table 16: Summary table setting out the applicability of risk management techniques to the South African junior and small-scale mining sectors

Stage of Risk Management Cycle[2]	Technique available[3]	Applicability to junior and small-scale mining[4]
Risk Identification (Types of risk)	• Management risk • Financial risk • Country risk • Operational risk • Technical risk • Resource risk	• All these risk types will interact with each other and have individual influences on the overall success of operations or projects within the junior and small-scale mining sectors. Of greatest importance to the particular sectors is the impact of technical and resource risk. High levels of resource risk severely affect the alluvial diamond sector.
Risk Quantification/Analysis	• Risk classification (matrices) • Hazop studies • Fault-tree/decision tree analysis • Sensitivity analysis • Expert judgement • Classical statistical techniques • Monte Carlo simulation • Conditional simulation	• Very applicable and easy to implement – recommended. • Owing to limited process complexity, most operations may not obtain any value from applying this method. • A useful tool to substantially quantify risk and probability in various scenarios – recommended. • Where the detail in a DCF allows the use – recommended • Potential strategic method for obtaining input from stakeholders. • High level of application possible – recommended • Requires large quantities of data and computation • Requires large quantities of data and computation but potential exists for junior operations.

[2] Refer to section 5.1
[3] All techniques described in Section 5
[4] Is the technique available suitable for application in the South African Junior and small-scale mining sectors and what opportunities exist for implementation?

Stage of Risk Management Cycle[2]	Technique available[3]	Applicability to junior and small-scale mining[4]
Tools for managing MRM risk	• Bayasian approach • Discount rate in a DCF • Grade tonnage curve • Geological modelling • 3D seismics • Mining due-diligence studies • Reconciliation	• Technique loosely applied currently to infer potential by operations adjacent to larger established operations. • Evidence reveals that not much variation exists in discount rate applied but the DCF remains a critical tool for evaluation purposes – recommended. • Potential exists for the "larger" junior operators within the gold, platinum and iron-ore sectors, for example • Very useful method to graphically obtain an understanding of various mineral resource aspects, recommended especially for more structurally complex deposits. Use of relevant consultants encouraged. • Expensive technique but allows high levels of confidence for geological understanding and mine planning. Acquisitions of old-order rights from majors could involve the purchase of such data. • Integral to the holistic understanding of the operation, most commonly completed on behalf a operation by technical consultants – recommended, especially if funding is required • A good measure for the level of confidence in grade estimates but requires high levels of data, role for a relevant consultant, but remains a highly recommended approach.
Risk control techniques	Risk avoidance Risk reduction Risk prevention Risk transfer/sharing	• The application of a variety of these methods is recommended. The application of the planning domain example can provide useful quantified information.

6 CONCLUSION AND RECOMMENDATIONS

The junior and small-scale mining sectors in South Africa undoubtedly make a significant contribution to the livelihoods of a large proportion of communities, particularly rural communities. Junior and small-scale operations are the central node to numerous other add-on opportunities and developments. It is in the interest of the development of South Africa to continue supporting and nurturing this sector.

The practice of risk management has been applied to most areas of general business operation e.g. production and human resource management. The application of risk management to technical areas is far more complex. Because geology is not an exact science, accurate grade predictions are more difficult to make. Uncertainty is inherent in each stage of resource and reserve estimation. One of the areas commonly exposed by errors is the impact of over- and under-estimation of commodity grades (Glacken, 2002). Low levels of sound geological and evaluation data on many junior and smaller operations equate to very high levels of resource risk.

One of the aims of MRM is, therefore, the minimisation of overall resource risk. Methods to quantify technical risk are varied, as is the level of potential application in the junior and small-scale sectors (Table 16). For some aspects of risk it may be acceptable to rank variables by relating the probability and the consequence of failure and representing the relationship on a probability-impact matrix. The relationship between cause and risk is also important. By the removal of obvious causes, the likelihood of the risk occurring will be reduced. As Pitzer (1998, p 58) states, "unknown causes of unknown risks usually constitute the unexpected". For the average junior and small-scale operator avoiding the 'unexpected' equates to being aware of the mineral resource and reserve being exploited and through capacity building, where required, being able to quantify the risk accordingly.

The level of risk acceptability is generally determined by a risk-benefit analysis (Dowd, 1997). This approach compares the cost of a project or operation with the value of benefits generated. The greatest benefit to junior operators will result in lower levels of resource risk and, consequently, a greater ability to obtain funding. Other approaches to risk management available to the junior and small-scale mining sectors include: decision tree analysis; assessing the impact of uncertainty on finances via a discounted cash flow model; and sensitivity analysis. Certain methods described in the treatise may be best undertaken by technical consultants on behalf of mine management. These methods include 3D seismics, geological modelling and conditional simulation.

Obviously, the greatest hurdle for many junior and small-scale operations is the cost associated with obtaining these technical services. The NSC is an avenue that exists for junior and small-scale operators to apply and request that technical feasibility and mine works programmes are completed on their behalf by relevant science councils. In effect, however, this service equates to a consultancy service where the technical fee is paid by the government on behalf of the successful applicant. The result is that limited capacity building and skills transfer in related areas and disciplines occurs. The operators remain dependent on outside individuals for financing outcomes and decisions relating to their own permitted or licensed areas. A recommendation is that the science councils (CGS, CSIR Mining Technology, and Mintek) play a greater role in the provision of capacity building, as well as in the research and development of technical techniques on a platform to enhance this sector's position. Two examples of current capacity-building initiatives include: the MQA-funded ASSM training school at Mintek that provides entry level skills training on commodity-specific areas (Mutemeri, *pers comm*); and the development of a board simulation by CSIR Mining Technology, which demonstrates in a practical manner the range of decision making required throughout the mine value chain as well as the actual impact of these decisions on the underlying orebody and cash flow. Technical research and development solutions that have been developed by the science councils to reduce risk in portions of the mine value chain include the stepping pump concentrator developed at CSIR Mining Technology (described in Section 5.3.4) and the I-goli mercury-free gold-refining technique at Mintek (Mutemeri, *pers comm*). In addition, universities should be encouraged to promote the mining-related disciplines of geology, geophysics, geostatistics, mining engineering and metallurgy, for example, as viable career options.

Finally, there are many voices in the junior and small-scale mining sectors in South Africa. Many independent interest groups, organisations and stakeholders are practitioners and advisors to this sector. Confusion still exists over clear definitions of the concepts of artisanal, small-scale and junior mining; legislative constraints exist; and limited technology and skills transfer occurs. Within the working environment small-scale activities often develop in response to poverty situations, operations are often migratory and overall skills level and understanding low, while junior operations struggle to obtain leverage to bridge critical financing hurdles.

Certain critical challenges undoubtedly exist for the South African government, related ministries, as well as the servicing organisations and science councils. With the increased need for assistance, mostly financial and capacity building in nature, the key will be to deliver these services so as to enhance and uplift the development of the community. Junior and small-scale mining has the ability to reduce poverty and augment technology transfer, but only through formal and focused channels. This treatise creates a platform by describing the characteristics of the sector and dealing with minerals resource management issues in particular. The overall aim was to highlight techniques to reduce mineral resource-related risk such, which, in turn could make these prospects or operations viable for financing and/or investment opportunities. No process can create additional value in the ground but these mechanisms can go a long way to quantifying the inherent risk that exists and, hopefully, to allowing the entrepreneur access to the intrinsic opportunities of the emerging mining sector in South Africa.

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Appendix A: Application of matrix-based risk classification

To illustrate the application of the matrix risk-assessment technique a case study of a "Long Inclined Borehole" (LIB) drilling programme is described. Such a drilling exercise is often costly and time consuming. Therefore, a reliable classification of risks will assist in achieving success. It must be noted that such drilling programmes are not normally undertaken by smaller operators but the types of risks described in this case study could be applied to most drilling and or trenching programmes. The objective of this case study is to illustrate one potential application of the matrix technique in the MRM environment.

This particular LIB drilling programme was planned on a mineshaft such as to provide the following key deliverables:

- Accurate elevations for reef intersections on various mineable levels; and
- Sampling of reef intersections allowing for overall reef quality (grade) determination.

Geological features of recovered drill-core assist to define geological model boundaries. These are boundaries where the geological model is believed to be of higher or lower grade as a result of geological constraints. A drilling programme has very tight time and cost constraints. Time is of an essence, as information must be obtained and assimilated as soon as possible to facilitate future decision making. On a shorter time-scale the underground drilling platform is also required for production purposes. Drilling must therefore be completed timeously. Below are the three main different categories of risks that could affect the outcome of the LIB drilling programme (Table 17). A risk is an uncertain event or condition that, if it occurs, will have either a positive or negative impact on the project objective. Certain of these risks would, however, not be applicable to smaller operations with smaller staff complements.

Table 17: Three main areas of risk to the LIB drilling programme

1	**Potential external risks**
1.1	Cost escalation of drilling programme as a result of currency exchange circumstances
1.2	Drill machine availability
1.3	Material-machine spares availability
1.4	Labour issues
1.5	Intersection of methane gas during drilling
1.6	Underground conditions e.g. temperature of working environment
1.7	Project-based sources of risk
1.8	Technical complexity of achieving reef intersections by wedging
1.9	Physical working environment
2	**Risk potential within the geology section of the MRM department**
2.1	Allocation of clear authority for the drilling programme
2.2	Impact of other routine issues resulting in a increased workload
2.3	Top-down corporate assistance or interference
2.4	Geological expertise associated with rock-type recognition due to virgin area drilling
2.5	No grade being intersected by the core
2.6	Continuity of expertise due to any personnel changes
2.7	Effective management of drilling contractors
3	**Risk associated with the drilling contractors**
3.1	Technical constraints of LM 75 (machine–type) drilling
3.2	Technical expertise of the drilling crew
3.3	Technical constraints of successfully achieving wedging
3.4	Proper core recovery of reef intersections
3.5	Contractor-company communication between management and shaft team
3.6	Communication with geology section
3.7	Time of completion
3.8	Quality of service provided
3.9	Supply of machine parts in event of break-downs or machine failure

Below is the probability/impact matrix that was designed to assess all the risks (from Table 17 above) of the LIB drilling programme.

Table 18: Probability/impact matrix used to assess risks of a LIB drilling programme

Impact versus Probability

	0	0.5	1
Very low			
Low			
Moderate			
High			
Very high			

The overall result is indicated graphically by the given colours; where blue is low risk, green moderate risk, and red high risk (i.e. very high impact and probability of occurrence). Each of the risks applicable to the drilling programme is again listed below with the colour indicating the overall level of risk, as determined from using the above probability/impact matrix. The issues perceived to be of the greatest risk (red areas) will be addressed in more detail.

Table 19: The three main areas of risk to the LIB drilling programme and the corresponding assessment result, where red is high risk, green is moderate risk and blue is low risk

1	**Potential external risks**
1.1	Cost escalation of drilling programme as a result of currency exchange circumstances
1.2	Drill machine availability
1.3	Material–machine spares availability
1.4	Labour issues
1.5	Intersection of methane gas during drilling
1.6	Underground conditions e.g. temperature of working environment
1.7	Project-based sources of risk
1.8	Technical complexity of achieving reef intersections by wedging
1.9	Physical working environment
2	**Risk potential within the geology section of the MRM department**
2.1	Allocation of clear top-down authority for the drilling programme
2.2	Impact of other routine issues such as to possibly increase geologist workload
2.3	Top-down corporate assistance and/or interference

2.4	Geological expertise for rock-type recognition in virgin area drilling
2.5	No grade being intersected by the core
2.6	Continuity of expertise due to personnel changes
2.7	Effective management and compliance of drilling contractors
3	**Risk potential of drilling contractors**
3.1	Technical constraints of LM 75 (machine–type) drilling
3.2	Technical expertise of drilling crew
3.3	Technical constraints of successfully achieving wedging
3.4	Proper core recovery of reef intersections
3.5	Contractor company communication between management and shaft team
3.6	Communication with geology section
3.7	Time of completion
3.8	Quality of service provided
3.9	Supply of machine parts in event of break-downs or machine failure

From the probability/impact risk matrix (Table 18), applied as described, the range of potential severity for the individual risks is evident (Table 19). Due to the large amount of risks provided only the high (red) risks will be considered in more detail. The green and blue risks are those deemed to have a low probability of occurring and if the risk were to materialise then the impact would also be low. Green ranked risks have to be carefully monitored as left untouched while a moderate risk has the potential to become a larger one. Red risks are those which, if arose, would have the greatest impact on the project outcome. Due to the highly technical nature of this particular example, most of the responsibility for the high-risk areas lies with the drilling contractor.

Table 20: Risks ranked as high

1	**Potential external risks**
1.2	Drill machine availability
1.3	Material–machine spares availability

1.5	Intersection of methane gas during drilling
2	**Risk potential within the geology section of the MRM department**
2.5	No grade being intersected by the core
3	**Risk potential of drilling contractors**
3.3	Technical constraints of successfully achieving wedging
3.4	Proper core recovery of reef intersections
3.7	Time of completion
3.9	Supply of machine parts in event of break-downs or machine failure

The proposed response for alleviating these ‘red’ risks, in each category, is set out below.

1. The drill machine is a problem for management until it is delivered on site. However, once onsite machine availability longer poses a risk. Risk associated to machine availability needs to be totally accountable to the drilling contractor and is penalised with standing time claims. A possible dangerous intersection of methane gas is always a risk by the mere nature of the service. Drilling contractors by law have to take the necessary precautions in the event of a methane intersection.

2. The risk associated with no grade being intersected is one that which is always carried by any geology department. The reason for any diamond drilling programme is to help eliminate risk for further developments underground.

3. The contractor is responsible for all the identified drilling related risks. If a risk becomes an actual event then no core would be drilled. Non-payment or reduced payment for services would result. It is in the best interest of professional organisations to limit these risks by implementing their own internal risk management programs.

To minimise the risks to be retained by drilling contractors, such contractors need to fully inspect their own risk management strategies. Even though the contractor may carry the cost of the risks the drill-core will not be produced. The objective of the programme is to provide a project with good quality drill-core. It is then in the best interest of company's to have close ties with the drilling contractor and ensure that common goals are always achieved. The ultimate goal is to ensure that the contractor-client relationship works well.

Appendix B: Geological modelling as a method of risk reduction

In 2001 the importance of realistic 3D geological modelling at AngloGold Ashanti, as opposed to mere computerised reproduction of underground plans, was demonstrated by McGill and Mokoatle (2001). Effective geological modelling was used to identify and quantify geological risk on both the Tau Lekoa and Tshepong shafts of the then AngloGold. Tshepong Mine is now owned by Harmony.

The development of a robust, accurate and efficiently maintained geological model is the most important deliverable required from any geology department. A distinction needs to be made between the computerised reproduction of underground geological plans and the creation of a holistic 3D model that is able to be viewed from various perspectives. In addition, the value-adding role of a dedicated "geomodeller" on an operation needs to be highlighted.

This appendix focuses on the modelling of reef and structural surfaces. In addition it looks at simple techniques that can be utilised to quantify inherent uncertainties that reside within 3D reef interruption models. The 3D reef interruption model developed at Tau Lekoa and Tshepong highlights existing synergies on the operations, and stresses the applicability of the organisational structure currently in place to varied geological settings.

Compiling a reef interruption model is just one step in the formation of a holistic geological model, but probably the most important for optimal macro mine design and optimal extraction of the orebody. A holistic model will include data points in relation to the main economic horizon in 3D space. Such data includes fault and dyke planes, depth in the footwall, facies, mineralisation, and key isopach information.

There are few projects in deep level mining that rely on 3D modelling techniques to ensure the high-quality geological input required to accurately estimate resources and reserves. Of those sites that have digital models, very few link these to confidence matrices. Likewise, little work has been completed with regards to uncertainty analysis techniques required to display due-diligence and quantify overall confidence in the model or parts of the model.

Uncertainties and shortcomings, where present within traditional models, can be hidden by short-term profits and go unnoticed on a large scale. These shortcomings can potentially affect mine development, development costs, life of mine cash flows, and may result in delays in the build-up to full production. This will result in a project delivering lower revenues than were originally anticipated.

On a stope (small) scale, these shortcomings can affect the panels that need to be stopped and those that need to be mined in any given month. This uncertainty impacts on planned and unplanned crew moves, face advances, face length, ventilation circulation, planned volume, planned gold, and hence the profit margins (cash flow) of the business.

Although these shortcomings will not cause significant damage to the business in the short term, it is the cumulative effect of these over time and across a number of business units that is of concern and will affect credibility of MRM and mine management. Consistent unreliability can potentially impact on the long-term value of any operation. It was mainly this uncertainty, coupled with designer unfriendliness and the hidden risk inherent in traditional plans that led Tau Lekoa to formulate a four-phased approach to the creation of a 3D geological model and to a method that would identify and highlight structural uncertainties hidden in traditional reef interruption models.

Tau Lekoa's 3D Reef Interruption Model

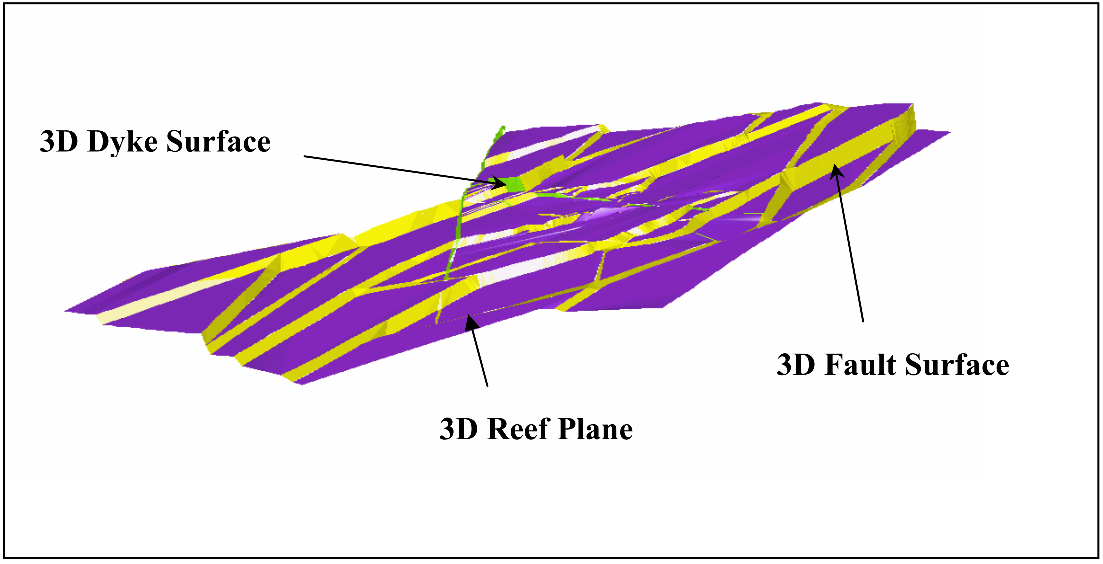

Figure 18: Illustration of the Tau Lekoa 3D model showing fault, dyke and reef surfaces

The production of a 3D reef interruption model at Tau Lekoa Mine (Figure 18) is a four-phased process. At Tau Lekoa, the creation of the 3D reef interruption model was governed by the factors set out under headings below.

Transparency – The model generated must provide clear and unambiguous information for users to understand the risks and impacts associated with mining various reef blocks, as well as mining through adjacent reef blocks separated by structural or other geological features.

Auditability – The model and its associated risk must be auditable. The data used for compiling and fine-tuning the model must be stored in standard files and levels within the software. Any interested party must be able to reference any information used in generating the model and be convinced that the risk to the business as determined by the model has been adequately quantified.

Materiality – The model must contain all of the information that could be required to make reasoned, informed, and professional decisions regarding mine design and mining. This will ensure that the mineral resource is optimally extracted given the constraints identified by the model.

Competency – The geological model must be generated by a suitably qualified and experienced person with extensive knowledge of geology, as well as the various software packages required to generate the model. All assumptions must be validated through teamwork with the production geologists in order to ensure that the margin of error is reduced as far as possible.

Tshepong's 3D Reef Interruption Model

Through development of a mineralisation model at Tshepong Mine, and the generation of a dedicated "geomodelling" and "data management" position, it was possible to develop a holistic 3D geological model. The 3D model at Tshepong Mine was initiated through the detailed modelling of a structurally complex portion of the mine. Work was subsequently expanded to include other portions of the shaft, ultimately to cover the entire Tshepong lease. Through GMSI software it was possible to quantify the impact of these changes on the business plans for planning purposes. This was aided by colour coding the reef blocks according to infrastructure accessibility by level. Applicable data sources incorporated in the modelling process included raise line pegs, surface and underground borehole intersections, and seismic horizon picks.

The basis of the modelling process adopted at Tshepong Mine provided a framework and testing ground for the company wide "geomodelling process" that identifies specific audit points during the process (McGill, 2001a). This ensures that actual data elements are utilised to generate the model.

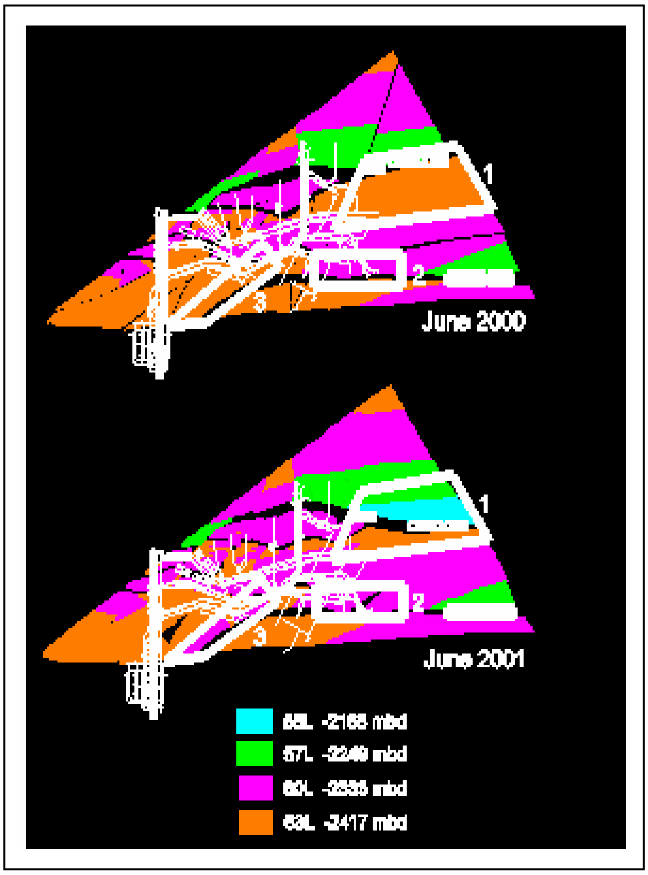

Figure 19: Basal reef structural changes due to geological modelling on Tshepong Mine. The top diagram represents the structure model in June 2000, while the diagram below represents the structure in June 2001. Dramatic changes in geological structure are revealed by colour coding mining levels

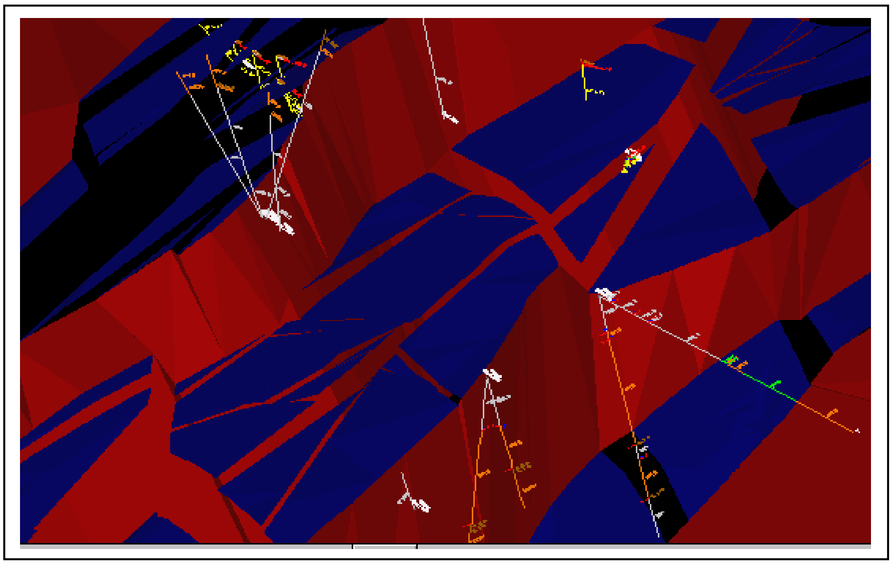

Figure 20: Example of the modelled reef (blue) and fault surfaces (red) of Tshepong Mine, with borehole information included

Appendix C: Application of the Turnbull Process

The London Stock Exchange commissioned a working group to address technical risk management, and the process it generated is referred to as the "Turnbull Process". It is this process that AngloGold Ashanti, among other companies, adopted to ensure sound management and corporate governance (Dewar, 2001). Through implementation of the Turnbull Process AngloGold Ashanti identified certain "headline risk areas" as a corporate initiative in 2001 (see Table 21). One of the key risk areas was given as the "company's mineral resource base". This outcome resulted in a process to understand and eliminate these key mineral resource related risks (Dewar, 2001).

The main headline risk areas for AngloGold (and for most players within the mining industry) are as follows:

Table 21: Key headline risk concerns as identified by AngloGold Ashanti in 2001

Commodity price
Currency – exchange rate
Interest rate
Counter party
Dealing
Capital efficiency
Safety
Environment
Shareholder/stakeholder relationship
Employee relationships and performance
HIV/Aids levels
Legal and regulatory framework
Mineral resource Base
Political environment
Fraud

Stemming from this process and through risk analysis and assessment the following factors were tabled as having the greatest impact on AngloGold's South African operations:

Table 22: Factors with greatest risk for AngloGold's South African operations in 2001

Risk factors	***Impact***	***Probability***
Grade Estimation	4 - 5	5
Structure	4 - 5	5
Staff Levels/Skills	9	4

Note: 1 has the lowest significance and 9 will threaten the survival of the Group.
A probability of 1 will never happen and a 9 will definitely occur within the financial period. Geological structure refers to continuity, accessibility, and dimensions of mineralisation.

It is therefore the goal of every mine to independently ensure that the above risk factors are limited by way of transparent mineral resource management techniques. Each mine's business plan needs to be evaluated in terms of varying confidences. These levels of confidence are categorised below.

Level l: Assured plan – part of the business plan based on reserves and approved capex

Level 2: Reasonably assured plan – areas where resources may be converted into reserves, as well as unapproved scoping exercises, which have a reasonable chance of being approved in the current economic scenario.

Level 3: Blue sky – the least confidant part of any business plan but contains projects with upside price potential

Individual mines and operations have then developed certain methodologies to assess the impact of mineral resource-related risk.

Appendix D: Application of a risk control technique

Fault population or fractal analysis has been utilised at Tshepong Mine in order to delineate areas of contrasting faulting intensity and, therefore, structural complexity. A high degree of structural complexity often results in highly risky mining conditions.

Owing to the geological complexity of the mine a detailed geological analysis was completed to quantify the actual amount of faulting and fracturing that would impact production adversely. This information was used to sub-divide the mine into nine "planning domains" – areas where the actual geological complexity is applied to the production rate required. For each domain a faulting probability factor was calculated as a product of macro and micro structural discounts. Each of these domains can be plotted graphically, relating the amount of small-scale faulting to large-scale faulting (Figure 21).

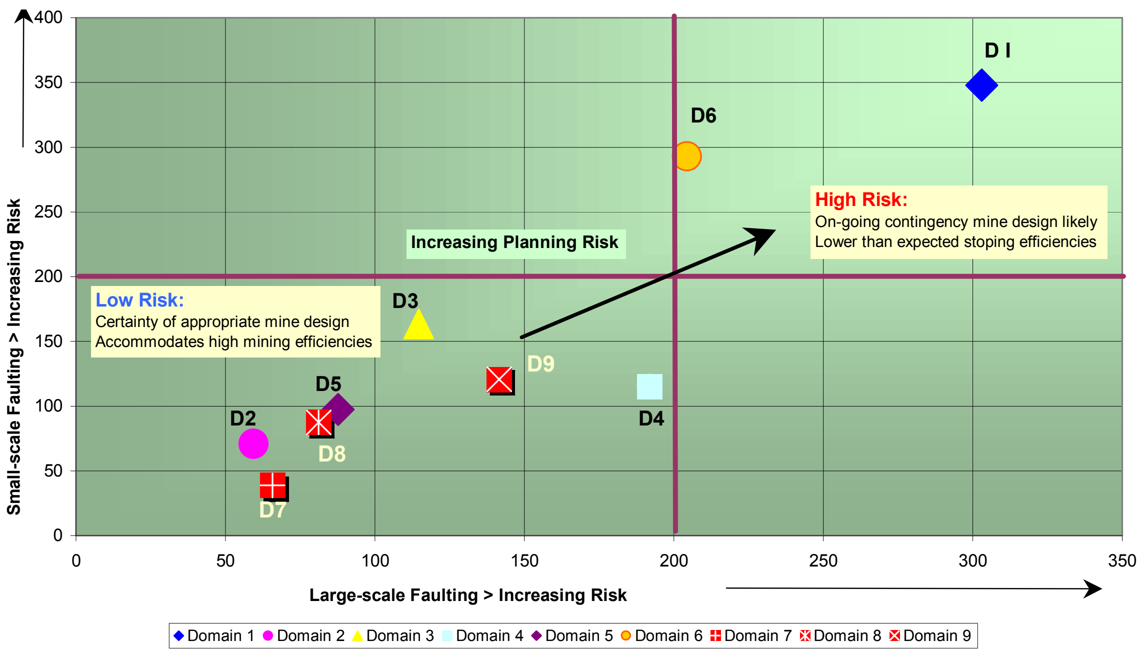

Figure 21: Planning domain risk profiles for Tshepong Mine

Through this method, the overall geological risk per planning domain is quantified and the potential risk is reduced by knowing which areas to avoid, or which require more detailed geological information. Geological planning domains have been utilised to profile the probability of geological structure hindering development and stoping operations in different areas, and the potential impact of these on the business outputs.

The percentage of gold contribution from each planning domain is plotted on the x-axis (Figure 22) and used to quantify the potential impact on the business plan. The result is a risk matrix chart that ranks the various domains as low, moderate or high geological risk for specific planning time-frames. The knowledge of high-risk zones coupled with the areas of potential high grade as indicated by the mineralisation model in place on Tshepong Mine, allows for a targeted approach to the modelling work required and reduces the risk for the overall mine plan. A domain with high levels of uncertainty would be flagged as low risk if only a small gold contribution is planned for.

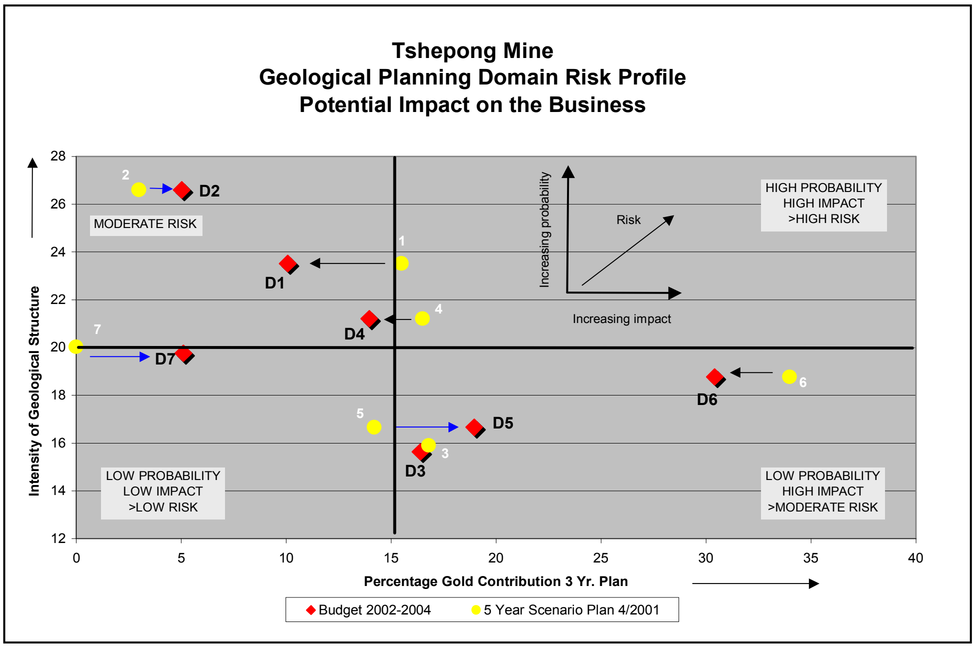

Figure 22: Risk reduction through implementation of a geological domain/risk profile, Tshepong Mine

In the mine planning process, dependency on areas that are considered high risk can be reduced until such time as more geological information is obtained. This approach is also useful when capital funding for new projects is being applied for. If the planning domain of a new area is shown to be lower risk than areas within the current Life of Mine plan then the MRM department is seen as actively striving to minimise the overall geological risk profile of the operation.