Analysis and Management of Mining Risk

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ABSTRACT

Within the mining industry, project risk analysis has not yet found universal application because of misunderstanding of the types of risk analysis performed and confusion with the terminology. This is usually the fault of practitioners and has led to scepticism, especially in the validity of quantified results because they are not interpreted before submission to management who have little experience in their application. Because of the general lack of trust in the method there is often an unwillingness to accept risk analysis as a management tool and an erroneous belief, in some quarters, that risk analysis is of value only in safety. This paper attempts to correct some of these shortcomings describing the different application of risk analysis throughout a mining project and drawing on experience from other industries; and concludes that practitioners and managers should promote formal risk analysis out of the safety and environmental departments.

INTRODUCTION

Project risk analysis has not yet found universal application within the mining industry despite its adoption in other, related disciplines. For many in the mining industry their exposure to formal risk analysis is confined to safety and the environmental disciplines. The aim of this paper is to remove some of the mystique from project risk analysis and risk assessment and to show that different types of analysis exist and have their place; but that the place should be defined.

Misunderstandings have arisen because of the differing types and application of risk analysis coupled with the different aims and benefits of the process. Confusion is not always the fault of the mining engineer but often the fault of practitioners who fail to acknowledge that risk analysis is not a technique invented by them but is a methodology built up over a number of years from a range of different sources.

Risk is present in all projects, whatever their type, and understanding and controlling risk is an essential component of project management. The key to controlling risk lies in having a clear understanding of what risk is, the risks relevant to the project under design, and the risk acceptance thresholds set by the sponsors or owners of the project. Whilst these three requirements are easy to demand they are far more difficult to implement in a real project.

This paper will attempt to clarify some of the different applications in common use, describe the status quo within the mining industry, with comparisons to other industries; and highlight some limitations in risk analysis and suggest improvements. To achieve this the paper addresses the following issues in the context of a broader discussion of the application of risk analysis.

- definitions,
- risk perception and acceptance,
- risk analysis application, and
- risk management tools.

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CONTEXT AND DISCUSSION

Risk and its analysis is perceived and defined in many different ways, depending on the context in which it is applied. For example, the life insurance industry uses methods based on large amounts of historical data; actuarial risk analysis. This is the first conclusion that we reach when defining risk analysis in the mining industry; we very rarely have a full set of statistical data on which to base our probabilistic judgement. Two exceptions to this statement are the cases of the ore reserve, where there is usually a body of statistical data often enhanced by specific geostatistical techniques; and geotechnical data which is extracted from borehole logs and presented as probabilistic distributions. An example of risk analysis in ore reserve estimates is given by Ravenscroft (1992) in which he describes the technique of conditional simulation to incorporate reserve variability and sampling error into mine scheduling.

Perhaps the most appropriate source of inspiration for the mining industry comes from the civil engineering sphere, where risk analysis has been adopted in three main areas; operational safety, construction performance (from design to completion), and in the selection of successful tenderers. In the UK, the operational safety aspect has been driven, in part, by the Construction (Design and Management) Regulations (1995) which have made hazard identification and risk analysis an integral component of safety systems on sites; large and small. The mining regulations in the UK, South Africa, and Australia have followed this trend by introducing the requirement for hazard identification and safety risk analysis.

In construction performance, risk analysis has become a tool used by engineers and contractors to determine the most reliable construction options, for instance, in the prevention of damage to existing structures from ground movements. As an example, Powell and Beveridge (1998) provide a useful summary of the design of suitable NATM methods in civil tunnelling, where they emphasise the integration of risk analysis into design decisions. The recent report of the UK Health and Safety Executive investigation into the Heathrow Express Tunnel (2000) collapse in October 1994, has highlighted that: 'Risk assessment should be a fundamental step in the procedures adopted by all parties: it is inappropriate wholly to leave the control of risk to contractors'. The report criticises all parties in the project and describes a catalogue of errors and substandard construction over a period of three months prior to the collapse. The contractor was fined £1.2M, the designer £0.5M, and both had to pay costs of £100 000 each.

Risk analysis methods applied to the selection of contractor, examines the risks to the owner from the different options proposed by contractors, and attempts to balance the relative risk of each option against the price offered. Much is written about risk sharing and risk transfer in large civil engineering projects, but the owner is always left with the difficulty of having to determine how much money to pay in order to share risk with the contractor. Obviously, the contractor is not taking the risk without imposing a cost and the owner must decide whether the price demanded (Kampmann *et al*, 1998) is fair for the risk being shared. This is the second conclusion in risk analysis – risk must be assessed by the party or person who is going to bear the risk and, as we shall see later, risk perception is a key element in decisions.

Definitions

Definitions of some terms used in risk assessment are presented in Table 1. This is not a comprehensive glossary but defines terms used in this paper that have been modified from a number of different sources. Other terms will be defined as they are introduced.

TABLE 1

Definition of some risk analysis terms.

Term	Definition
Hazard:	A potential occurrence or condition that could lead to injury, damage to the environment, delay, or economic loss.
Risk Analysis:	A structured process that identifies both the likelihood and the consequences of hazards arising from a given activity or facility.
Risk Assessment:	Comparison of the results of a risk analysis with risk acceptance criteria or other decision parameters.
Risk Reduction Measure:	An action that could be adopted to control a risk by either reducing the likelihood of occurrence, or by mitigating the consequences of an occurrence.
Risk Management:	The process by which decisions are made to accept known risks, or the implementation of actions to reduce unacceptable risks to acceptable levels.

Perhaps the most important definitions to examine are those of 'risk analysis' and 'risk assessment' because they are often confused or used synonymously. There is an important difference between the two terms, which is more than a pedantic adoption of jargon. Risk analysis is the process by which risks are identified, examined, defined, and their magnitudes determined.

Risk assessment, on the other hand, is the process by which the outcome of a risk analysis is compared to the risk acceptance criteria established for the specific project. It follows, therefore, that a risk assessment requires a clearly defined set of risk acceptance criteria that are understood by all parties to the process.

Risk perception and risk acceptance are discussed later but, from the definition of risk assessment, it can be seen that two organisations could make different decisions relating to risk management simply because of differing risk acceptance thresholds. The concept of risk acceptance must always be considered when examining other people's responses to risk. It is not the role of risk analysts to make decisions relating to risk acceptance but it is their role to help elucidate risk acceptance criteria.

Uncertainty

Uncertainty is the source of risk and dominates almost all forms of human activity. Confining our consideration to mine design, uncertainties can be grouped as either: i) uncertainty as to the mechanism or working of a process, or ii) uncertainty in the actual value of a parameter or property of interest. These are referred to as conceptual uncertainty and parameter uncertainty, respectively.

Using examples from block caving, the ability of the rock mass to cave is governed by the prediction of a minimum required hydraulic radius of the undercut for a specific rock mass strength (Laubscher, 1994). The rock mass parameter MRMR is determined and plotted on the caveability relationship whereby the minimum hydraulic radius to induce caving, is predicted. For this relationship to be absolutely valid, the link between MRMR and hydraulic radius must be robust. However, the relationship is purely empirical, ie it does not follow some immutable law of physics but is based on human observations and assumptions; thus, there is a conceptual uncertainty – the relationship might not be valid for all circumstances of geology or geometry – and this constitutes conceptual risk.

The measured properties of rock are often quoted as indices (eg Rock Quality Designation) and cover a range of natural variability, yet we often derive unitary values for them, such as RMR and MRMR. Clearly, the single value cannot be universally applicable across the whole region, because there will be some situations where the property lies within a tail of the distribution used to determine the 'most likely' value. This is parameter uncertainty – we can never be entirely certain that the representative value chosen will be correct for a given location.

Risk analysis in design requires an examination of all areas of uncertainty and an assessment of the magnitude of the resulting risk. Without this, a sensible risk management process cannot be adopted. However, each mining design and mining operation is unique, and we operate in the area of 'sparse data' where most risk analyses are based on expert judgements, elicited from specialists and other 'experts', and this poses additional risk, as discussed later.

RISK PERCEPTION AND ACCEPTANCE

Risk perception and risk acceptance are, in some senses, the opposite sides of the same coin. People are often willing to accept a high risk that they feel able to control but will not willingly accept a lower risk that is imposed, especially through government organisations. The classic example of this must relate to smoking, where the risk of death is five times higher than for coal mining (see Table 3).

Risk acceptance can be difficult to determine, especially for economic risks, because of competing considerations. The literature often refers to the risks associated with a new or expanded mining project but very rarely, if ever, do we see the acceptable risk documented and used as a criterion to accept or reject a particular project. In the case of safety risk, however, the literature is well supplied with descriptions of risk to the individual, risk acceptance levels that have been determined by governments on behalf of their citizens, and risk to individuals from accident and disease, based on statistical data.

Acceptance of economic risks is a decision that is usually under the control of the board of directors who are often unwilling to divulge the reasons for decisions whether or not to proceed with a potential investment. In some instances this reluctance is because the decision relates to wider business strategy rather than the perception of risk inherent in the project itself. It is usually pointless to back analyse decisions to try and identify the risk acceptance threshold within any particular organisation as many decisions will be clouded by other considerations not related to the project itself.

Risk perception

There are clear indications that many people do not fully appreciate the risks that effect their daily lives. Hambly and Hambly (1994) has estimated (Table 2) the approximate risk to life from accidents during various daily activities, compared to the risk from disease for the individual's age group.

Few people would realise that the risk of death from cycling is about ten times that of car travel, only three times that of helicopter travel, and equal to that of dangerous work. From these published statistics, we can assume that the risk from being killed working underground is equal to that of cycling to work.

TABLE 2

Risk to life from accident and disease.

Death by accident or misadventure (per million)	*0.03*	*0.1*	*0.3*	*1*	*3*	*10*	*30*	*100*	*300*	*1000*
- At home being active	3 h	10 h								
- Travelling										
on foot beside road	6 min	20 min	1 h	3 h	10 h					
by bus	3 h	10 h								
by train	1 h	3 h	10 h							
by car	20 m	1 h	3 h	10 h						
by aeroplane			1 flight	3 flight						
by bicycle	2 min	6 min	20 min	1 h	3 h	10 h				
by motorcycle		2 min	6 min	20 min	1 h	3 h	10 h			
by helicopter		2 min	6 min	20 min	1 h	3 h	10 h			
- Working										
office work	3 h	10 h								
manual work	1 h	3 h	10 h							
dangerous	2 min	6 min	20 min	1 h	3 h	10 h				
- Leisure										
football	6 min	20 min	1 h	3 h	10 h					
skiing or boxing	2 min	6 min	20 min	1 h	3 h	10 h				
canoeing			2 min	6 min	20 min	1 h	3 h	10 h		
mountaineering			40 s	2 min	6 min	20 min	1 h	3 h	10 h	
smoking cigarettes			3 cigs	10 cigs	30 cigs					
Death by disease (per million)	*0.03*	*0.1*	*0.3*	*1*	*3*	*10*	*30*	*100*	*300*	*1000*
At age			0 - 24	25 - 34	35 - 44	45 - 54	55 - 64	65 - 74	75 - 84	85 +

Today, many mining companies are setting goals of zero accidents at work. Whilst this is a laudable position, demonstrating a good motivational approach to safety management, are such companies claiming that they will endeavour to reduce the risk of fatality to the individual below that incurred when driving to work?

Risk perception is a difficult issue to grapple with because human beings apply different criteria to determine the acceptability of risks. On a generalised level, risks to the individual can be classed as either; voluntary risk or imposed risk. The UK Health and Safety Executive (1992) has estimated that, in Britain, a 20 year old man has roughly a 1 in 1000 chance of dying within a year; for a man of 40 the chance is around 1 in 500. At 60 years old the chance of death within a year is 1 in 50 for a man and 1 in 100 for a woman. The important point to remember here is that this risk is the aggregate of all sources and in risk management we are often trying to reduce the risk from only one or two sources. Nevertheless, most people feel concern about accepting risks that are beyond their control and demand that these risks are very low compared to those that they choose to accept.

Risk acceptance

The fatal accident risk (FAR) is the measure usually used to indicate the probable number of fatalities from 1000 people working 100 000 hours (their approximate lifetime). Hambly has determined the relative FAR for various activities in the UK (Table 3), both voluntary and imposed. The tolerable risk levels shaded in Table 3 have been determined by the UK Health and Safety Executive and shows that many of the activities that we accept and take for granted, such as car travel, have a FAR almost twice that experienced in the UK coal mining industry.

Having gained some perspective about risk levels in general and the attitude of some regulators to the risk levels that they impose on society as a whole, we need to examine the process of

TABLE 3

Fatality accident risk (FAR) in the UK.

Activity	Risk of death $\times 10^8$ hours (FAR)
Rock climbing	4000
Helicopter travel	500
Motorcycle travel	300
High rise construction erection	70
Tolerable limit of 1/1000 per year at work (assume 2000 work hours pa)	50
Smoking	40
Walking beside a road	20
Air travel	15
Car travel	15
Coal mining (UK)	8
Train travel	5
Construction (average)	5
Metal manufacturing	4
Bus travel	1
Tolerable limit of 1/10 000 per year near a major hazard	1
Tolerable limit of 1/100 000 per year near a nuclear plant	0.1
Terrorist bomb in London street	0.1

Note: Shaded rows are tolerable risk levels defined by the UK HSE risk acceptance within the mining industry. It is apparent that the attitude of all responsible mining companies, in the developed world, is that serious injury and fatalities are quite unacceptable, and that every effort will be made to prevent such injuries.

Unacceptability is certainly the principle where operational safety risk is concerned, and when procedures and inspections can be adopted to help manage risk but, is this really the case when major re-design of a mine is required to control risk? Under such circumstances, directors and senior management may resort to other, less onerous, acceptance criteria such as the ALARP principle (as low as reasonably practicable) shown in Figure 1, on the basis that it would be too expensive to implement all the risk management strategies required to remove the risk.

ALARP may be used to justify existing levels of risk and could be considered to be an expediency applied in the absence of either a thorough investigation or a justifiable risk threshold. There is opportunity for interpretation as to what would be considered reasonably practical under the specifics of each risk, even though the ALARP principle states that all possible measures should be adopted unless the costs are grossly disproportionate to the benefits gained.

Having briefly set the scene, provided a few definitions and looked at some principles of risk analysis in other industries, we can move on to examine the specifics of risk in mining projects.

RISK IN A MINING PROJECT

Sources of risk in a mining project are many and varied and no project is without risk. Risk can be managed, minimised, shared, transferred, or accepted but it cannot be ignored.

The route by which a mining project develops, from the earliest scoping study to the final construction stage, reflects an ever increasing level of complexity with more and more detail added. Most mining projects go through three or four stages of analysis prior to construction: a scoping study, feasibility and investment studies, and a detailed design. The improvement in detail and understanding implicit in this progress is illustrated in Figure 2.

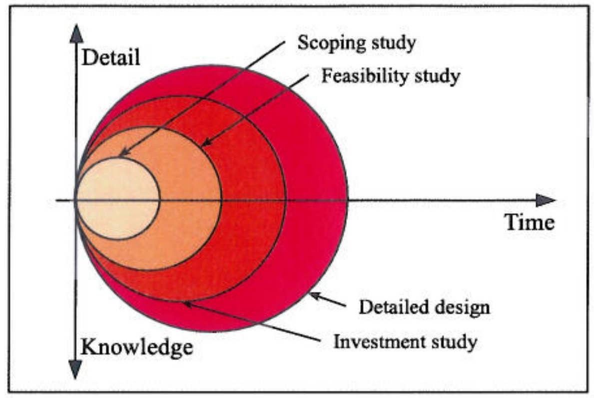

Fig 2 - Stages of a mining study.

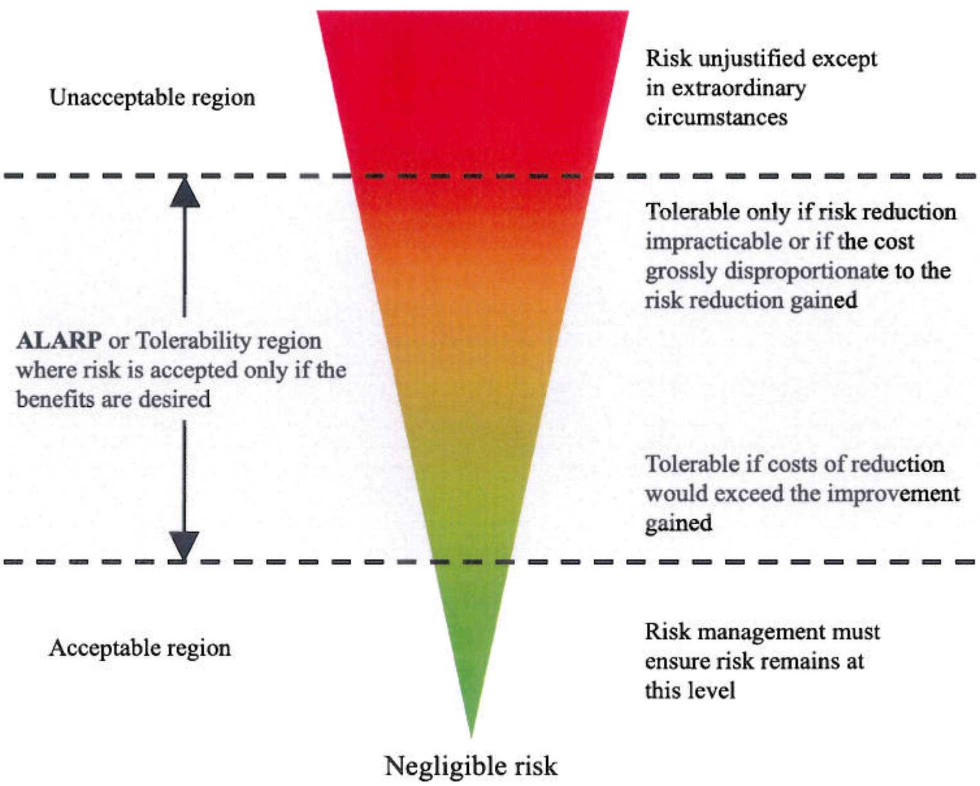

Fig 1 - The ALARP principle (after HSE).

As the project progresses through the various studies, the degree of financial risk is progressively reduced, as shown in Figure 4. However, risk is never totally eliminated and some risks manifest themselves only during the later stages of the design. To examine how risk sources can be identified throughout the design stages of a developing mine, we need to consider the life cycle of a typical mining project (Figure 3).

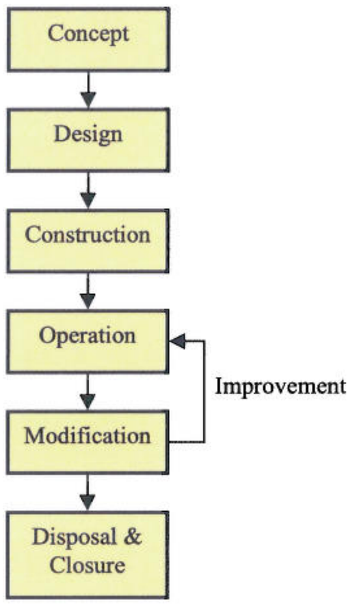

FIG 3 - Life cycle of a mining project.

Data gathering is generally conducted in parallel with analysis and design, and often driven by the requirements of analysis and computer modelling. Risk exists in data gathering, as in all aspects of engineering and, because of the timing of sequential activities, managers are generally compelled to address this risk within the analysis and design process. The risks associated with the execution, or implementation of the project depend upon the analysis and design process, but cannot be analysed until after the design is complete. Based on the life cycle stages defined above, some generalised risks to most mining and recovery processes are listed in Table 4.

The UK Association for Project Management (1997) states that, in general, implementing project risk analysis and management is better in the early stages of a project's life cycle where it is more effective and useful in guiding the development of the project. Introducing risk analysis late in the life cycle is difficult and with few compensating benefits, because: contracts have been placed, equipment purchased, commitments made, reputations are on the line, and resulting management of change is difficult and unrewarding.

To examine the various types of risk analysis commonly used in the mining industry, the typical life cycle of a project can be divided into five generalised groups, more or less corresponding to those in Table 4:

- design,
- project economics,
- construction,
- operation and safety, and
- environmental and closure.

These are examined in more detail later in this paper.

TABLE 4

Some sources of risk in mining projects.

Life cycle stage	Risk from changes or uncertainty in:	
• Concept	Resource uncertainty, Mining method, Political risk, Macro-economic risk,	Processability, J V partner(s), Collaborators, Project economics
• Design	Mine design, Process design, Infrastructure design, Licensing and permitting,	Scale of operation, Project finance, Early cashflow, Production build-up
• Construction	Schedule and milestone risk, Contractor's safety, Cost over-run,	Mineability, Processability, Rock mass performance.
• Operation and Improvement	Production schedule, Process recovery, Head grade,	Safety performance, Environmental issues
• Disposal and Closure	Waste management, Acid generation, Rehabilitation design, Rehabilitation costs,	Groundwater recovery, Post-closure maintenance, Community issues

Design risk analysis

The purpose of a mine design is to develop a mining, recovery, and infrastructure plan that maximises the exploitation of the resource and shareholder value, while minimising adverse impacts to the environment, the local community, and the work force. The aim of a design risk analysis is to examine the design in order to uncover and document sources of risk that could defeat the design purpose.

All forms of human activity, or inactivity, contain elements of risk. In a mine design, the sources of risk include some or all of the following:

1. optimistic or unsupported assumptions,
2. limited or poor quality data,
3. unjustified extrapolation of past experience,
4. use of inappropriate computer models,
5. models and parameters that have not been properly validated,
6. unsuitable or misdirected 'expert' advice,
7. unwillingness to acknowledge previous failures,
8. unexpected changes in conditions,
9. natural variability,
10. aggregation of risks, and
11. external hazards.

Two of the greatest sources of design risk are the use of inappropriate models or input parameters, and undue reliance on the untested opinion of specialists and experts. Figure 2 depicts the progress of a mine design over time, showing the increase in information and data. An additional source of risk is the inability to manage the transfer of knowledge between the different stages of the process. In other words, potential problems (or risks) identified in the feasibility study are not correctly captured or addressed in following design stages and the risk manifests itself later in the mine's life.

The analysis of design risks is usually conducted as a qualitative process, where hazards are identified, entered into a risk register, and a risk index or risk rank determined. This process is discussed below in greater detail.

Risk analysis of project economics

The earliest application of risk analysis in the mining industry was in the area of financial project risk evaluation, where boards of directors and their advisors sought methods by which they could evaluate the risks of investing in certain areas (both commodity areas and geographical areas), and gain an understanding of the reliability of the estimates presented to them by project sponsors.

There are a number of techniques in use to determine economic risk and contingency provision, a selection of which are discussed below. The reduction of cost uncertainty over the stages of a project can be illustrated by a torpedo model or diagram (Figure 4). The aim of economic risk analysis is to determine, and then reduce, the range of uncertainty at each stage of design.

Contingency estimating

Contingency estimating methods of risk analysis are used routinely in many mining companies to provide a justifiable estimate of the expected cost of a project (defined as the base cost estimate). These estimates are applied to both the capital cost and the operating cost estimates. The typical outcomes, or results, are illustrated in Figure 5 where there are three main elements to the final cost; the base cost, the contingency risk cost, and the risk event cost.

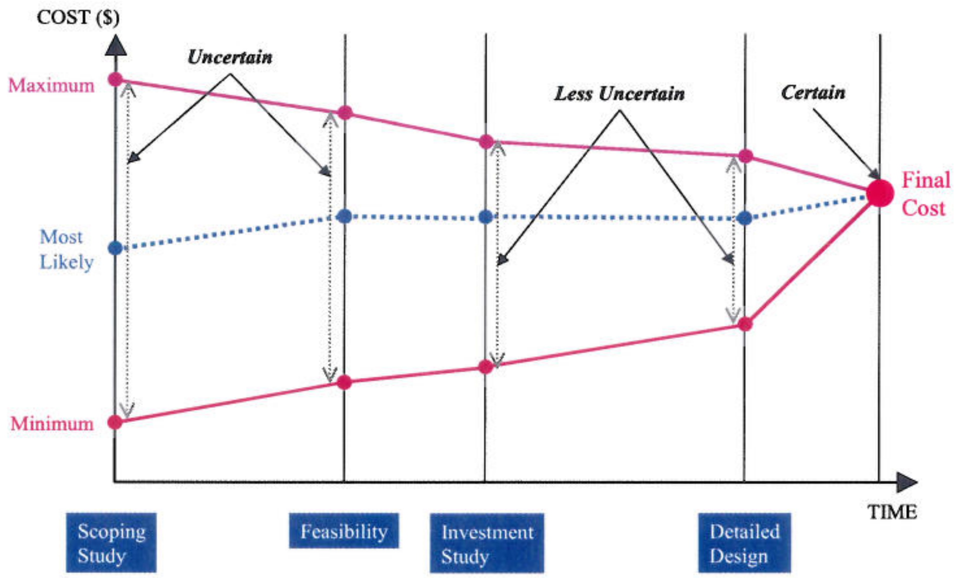

FIG 4 - Torpedo diagram of cost uncertainty.

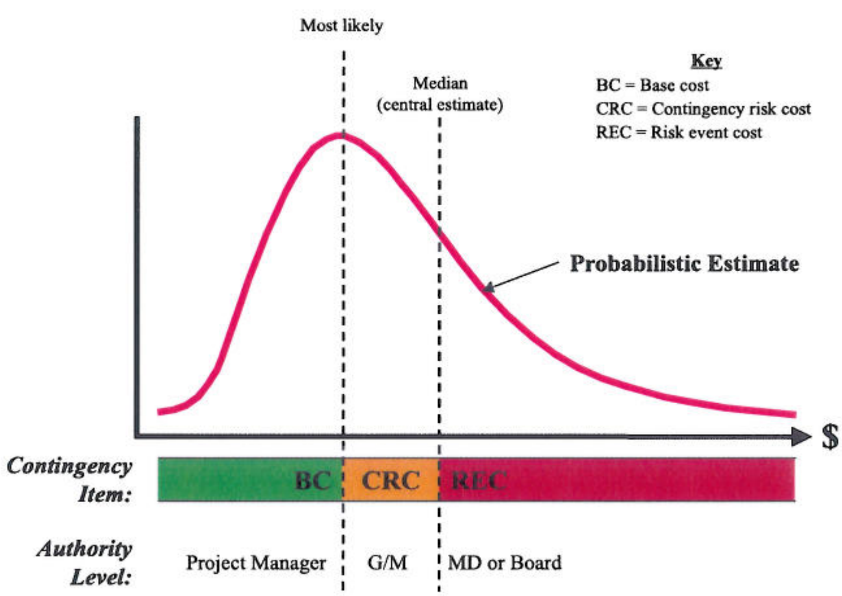

FIG 5 - Risk and contingency cost.

The base cost is derived by building up a spreadsheet model of single line items each of which is represented by a point cost determined from quantity and unit cost. This is the classic estimating technique. Often the individual point costs are judged to represent a range of uncertainty and so terms such as ±30 per cent estimate for pre-feasibility study levels and ±10 per cent for detailed design studies are often used. Contingency risk cost is estimated by a variety of techniques and added to the base cost. The resulting total is usually assumed to represent the median cost, where there is equal probability of the true cost being above or below.

The risk event cost is the sum of all costs associated with unexpected events such as inundation of a sinking shaft. In estimator's language, these represent changes in the project scope, ie the estimator had not expected (or been warned of) a flood in the shaft. Figure 5 also shows typical authority levels for contingency and risk expenditure.

The statement that an estimate is accurate to ±25 per cent indicates a symmetrical distribution of uncertainty – in other words, the chance that the true figure will be less than the estimate is equal to the chance that it will be greater. Experience suggests that there is a greater chance that the true cost will be higher than the estimate because costs tend to increase and problems rarely reduce the cost of a project. Coupled with the general desire of project teams to keep the estimates low enough that the project moves on to the next stage, it is probable that the uncertainty in such an estimate should be described as +25 per cent and –10 per cent.

Sensitivity analyses are conducted where individual components of a spreadsheet model are varied within defined ranges and the sensitivity of the model determined. The results are usually illustrated by a spider diagram (Figure 6) to show which of the components has the greatest effect on the overall outcome. While this information may be of use in the early stages of a project, the basic assumption in the analysis, that each component will vary independently of another, is potentially a severe limitation. Stochastic modelling (Monte Carlo simulation) can examine the numerous 'intermediate' cases, where individual components in the model vary at the same time, thus overcoming the idealised assumptions. This technique is described below.

Project valuation

Project valuations are determined using net present value (NPV) and the internal rate of return (IRR) of a project. Both are calculated from a cash flow model constructed to represent the expenditure and income stream for the life of the project. Such a prediction is subject to varying degrees of uncertainty depending upon the type and location of the project, and the commodity being mined. It is generally accepted that an expansion project has less uncertainty than a new project, where the location imposes political and macro-economic risks. Furthermore, the volatility of the price of the commodity also influences the perception of the risk, depending on who is judging the risk.

In the past, the usual method of assessing these uncertainties has been to increase the discount rate applied so that for projects with a perceived higher risk the discount rate is progressively raised for each adverse factor, which reduces the NPV making the project less attractive. With the arrival of tools capable of modelling uncertainty there has been a trend to explicit modelling using stochastic simulations (Monte Carlo modelling) of NPV calculations. Some modellers have argued that the 'explicit' modelling of risk in stochastic simulations, means that lower discount rates should be used. Davis (1995) has refuted this argument and shown that no amount of analysis can reduce the risk to an investor. The only way that investor risk can be reduced is by action, such as hedging the price of the commodity.

A quantified risk analysis of a project economics has a number of advantages, as expounded by Davis. Firstly, when the correct discount rate is applied, simulation gives a better estimate of the project NPV than does a deterministic analysis because the uncertainties in the model may be non-normal or correlated. Explicit modelling of these distributions gives a better understanding of the expected NPV.

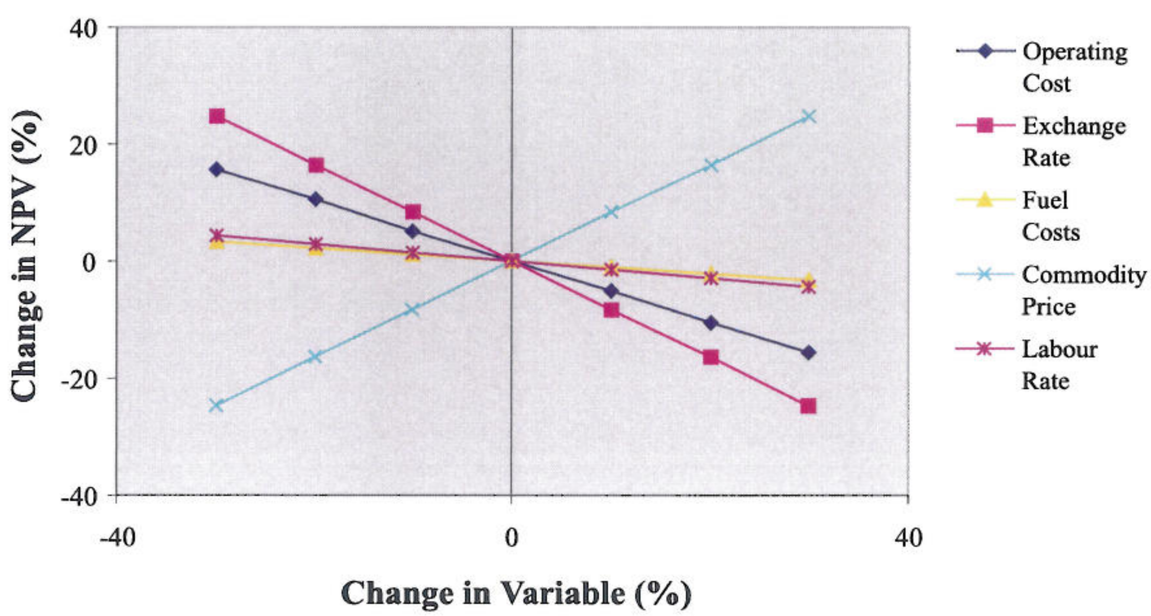

FIG 6 - Spider diagram.

Secondly, the variance in the modelling yields an uncertainty around the expected NPV value from which the probability of the true NPV being greater than a nominated value, can be determined. For example, the probability that the project will have a positive NPV can be calculated. Thirdly, uncertainties in a number of project NPVs can be compared and choosing the preferred option may be easier if the breadth of uncertainties are known for options with essentially identical NPVs.

Construction risk analysis

Construction risk analysis includes a number of related risk disciplines, such as safety and economic risk which are addressed elsewhere in this paper. The issue of concern here is that of schedule risk, our ability to predict the construction time and, more importantly, the point at which the cash flow becomes positive. Many of the techniques available to the mining industry have been borrowed from project management in general and civil construction in particular.

In evaluating the risk to estimated project construction time, two main sources of uncertainty become apparent; firstly, our ability to determine the duration for each of the tasks in the schedule model, and secondly, the degree of confidence that the resulting critical path is correct. The critical path risk is important because project managers appreciate that the construction duration can be controlled only if the critical path items are well managed, thus these items receive greater attention than non-critical path items. However, a minor hold-up in part of the project may change the critical path and brings other tasks, which may have received only minimal management attention, onto the critical path.

In large projects, the planning software often contains an uncertainty module which allows the duration (and resources) for each task to be specified as an uncertainty distribution. For smaller projects, third party tools are available, such as Risk+ (Risk and Program Management Solutions, Inc), an add-in for Microsoft Project, which provide the capability to specify uncertain ranges for each task. The output of these types of program are uncertain completion dates for the project and individual milestones, plus an estimate of the probability that a particular task may be on the true critical path. The latter output is, perhaps, the more important result from the point of view of the project manager.

Operational and safety risk analysis

This is, perhaps, the area of risk analysis that is the most familiar to mining engineers. The fundamental requirement for any risk analysis is the identification of a comprehensive and exhaustive set of hazards. Without such a list, it is unlikely that the risk analysis will be judged to be a success, especially if an unidentified risk occurs. The techniques used by safety analysts include hazard and operability studies (HAZOPs) hazard analyses (HAZANs) and job hazard analyses (JHAs). All of these are very similar in approach and rely on systematic techniques to identify specific hazards. Identification is usually conducted under the assumption that the task will be performed using established practices and methods.

It is usually assumed that an incident will result in an injury or a fatality and so the definition of consequences of an event is more limited than in other forms of risk analysis. In order to determine the level of risk the concept of 'exposure' is introduced and a mathematical relationship is determined, or assumed, to calculate the risk. The relationship may be non-linear (Eisenberg, 1975) of the form $c^m t^n$ where c is consequence and t is exposure time. In most applications, the mathematics is incorporated into a series of charts where the user selects the consequence level and exposure deemed appropriate and reads the risk index from a table.

Process and petro-chemical companies have developed these methods to a high level of sophistication which incorporate risk acceptance criteria. The user can see immediately if the risk level determined is above or below a response threshold and is often directed to the sort of response that is applicable. Such methods work well in the relatively constant environment of a process or petro-chemical plant but are not always well suited to the variable conditions in a mine.

Environmental and closure risk analysis

Closure risk and environmental risk analyses are very similar techniques; the difference being that closure analysis is directed to the longer term issues of mine closure and post closure maintenance.

Environmental risk in the mining industry can be classed as either; health risks (physical, chemical or biological) or ecological. Historically, the mining industry has dealt with health risks in conjunction with safety but more recently, with the advent of environmentalists on the staff of mining companies, health risks have become a bridge between safety and the ecological environment. In the future, as safety issues are examined in greater detail, it seems likely that health and ecology will become more closely linked.

Environmental risk assessment methodology is discussed by the European Environment Agency (1998) who summarise the steps as follows:

- problem formulation,
- hazard identification,
- release assessment,
- exposure assessment,
- consequence assessment, and
- risk estimation.

The problem must be clearly defined and include a specification of the source. For example, is it a single chemical, what transport mechanisms are involved or is it a disposal hazard? Additionally, the regulatory framework must be understood including the acceptable limits, any licensing limits specific to the site, and any special aspects of the end-point recipient (is it a children's hospital?).

Hazard identification follows, to determine the mechanisms and circumstances under which a release could occur and the receptors of concern, which could be flora, fauna, people, water courses, etc. The identification should also examine the methods by which the release could occur and the conditions necessary for it to happen.

A release assessment is the study of the potential for a risk source to release the hazard into the environment and this is often a probabilistic analysis. The exposure assessment involves the quantification of the intensity, duration and frequency of exposure of the receptors of interest to the hazard under examination.

A consequence assessment will quantify the effects of the release on the population of the receptors being examined. For human health, the consequences examined are usually death and illness. The data examined cover toxicity levels, epidemiology and modelling, such as dose-response predictions.

All these individual strands of the study are brought together to assess the overall risk from the defined hazard to the specified receptor group. This could be an estimate of the number of people likely to experience health effects over given time periods, from releases within the likely and the less likely magnitude ranges. In other words, the effects on people of 'routine' releases or licensed discharges and the effects of larger, accidental or uncontrolled releases.

This type of environmental risk analysis is equally relevant to operational conditions, such as routine cyanide discharges, and to post closure releases such as acid drainage from waste rock dumps.

RISK ANALYSIS METHODS

All risk analysis methods can be classed as either quantified, using probability distributions within numerical models; or subjective methods which usually use classification systems to derive a risk index or risk rank. Although quantified risk analysis is used extensively in certain industries, and has a place in mining, it is common to find that a subjective analysis is conducted as a pre-cursor to determine the major influences and issues to be examined. Often quantification of risk is a time consuming process and, unless sufficient justification for its use can be found from the outcome of a subjective analysis, considerable time and resources can be wasted.

Subjective and quantitative risk analysis employs a variety of tools, some of which have been developed specifically and others that have been adapted from other disciplines. The risk analysis literature contains numerous examples describing the tools that can be applied, especially to safety risk investigations. Computer based systems are also available but care must be taken in their application to guard against the analysis being driven by the capability of the technique used.

The stages of a typical risk analysis are shown in Figure 7, which illustrates the relationship between a subjective and a quantified analysis.

Subjective risk analysis

There are a range of techniques used by practitioners in the execution of a subjective risk analysis and, because a subjective analysis often precedes a quantified analysis, such techniques have indirect application to probabilistic analyses.

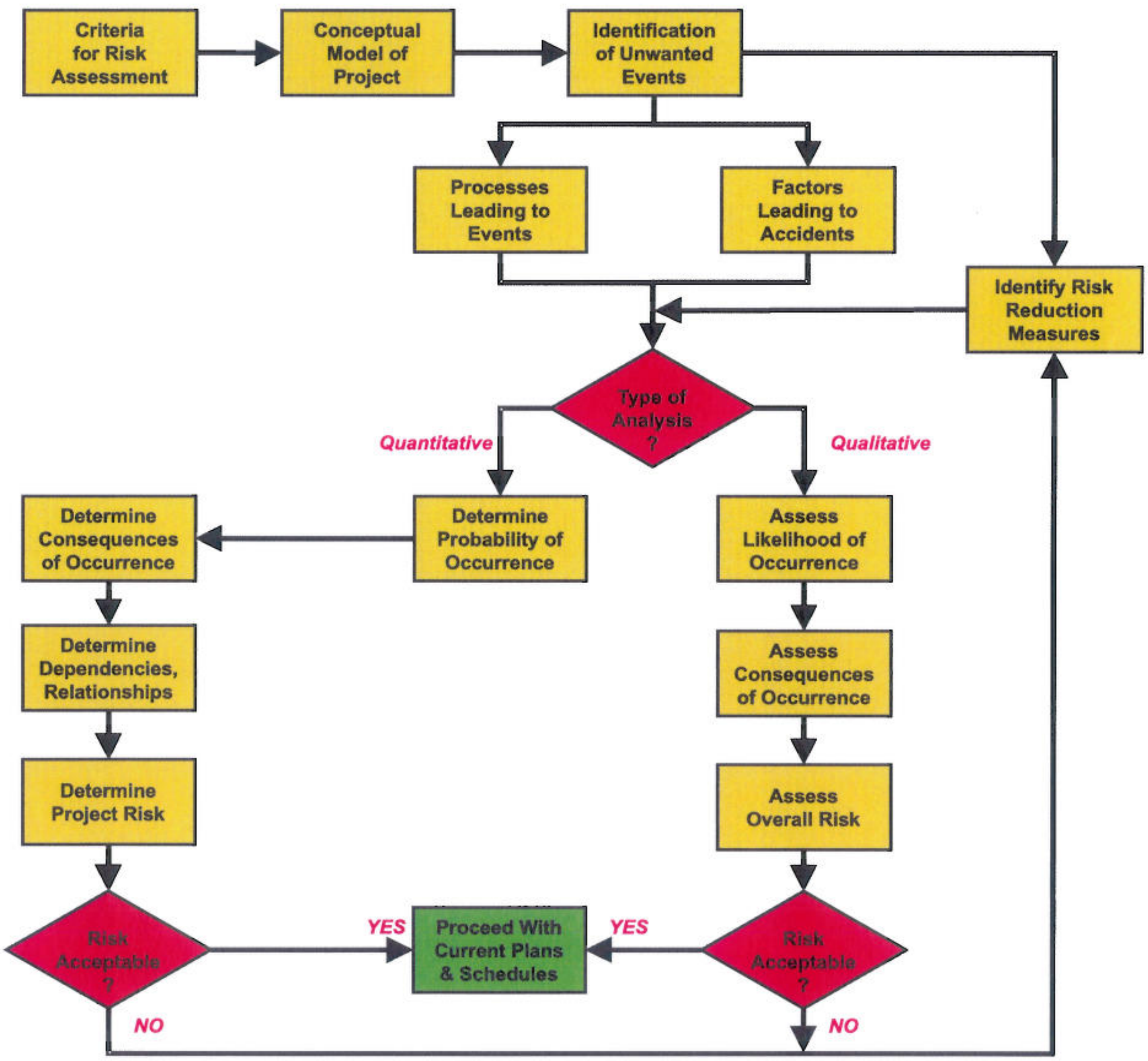

FIG 7 - Risk analysis flow diagram.

The main stages of a risk analysis can be summarised as follows:

- problem definition,
- identification,
- risk determination, and
- risk management.

Each of these is examined in a little more detail. The main output of a subjective risk analysis is a risk register that documents each hazard. The risk register is discussed later in more detail.

Problem definition

The definition of the scope of the analysis is a prerequisite to ensure that all parties understand the issues to be examined and have a clear definition of the expected outcome. Some of the tools available to gain an overall understanding of the components and structure of an underground mine design are:

1. Concept Map - a map of the main stages, phases or controls of the extraction cycle
2. Influence Diagram - an unstructured representation of links and dependencies between properties, processes and design controls
3. Logic Tree - a hierarchical presentation of the properties, processes and design controls in the extraction

Of these, the concept map and the logic tree are the two that tend to be used most extensively. Influence diagrams are mostly used to collect thoughts and ideas (brain-storming) which are transformed into the more structured representation of a concept map and a logic tree. Using the concept map and the logic tree, the problem can be divided into manageable sections.

Identification

Identification is the most important component of risk analysis; a risk that has not been identified cannot be ranked or adequately managed. Figure 7 shows the relationship between identification of the hazards and potential risk reducing measures. There are a number of techniques used to aid identification exercises, some of which are complimentary; as follows:

- HAZOP,
- brainstorming and what-if,
- HAZAN,
- Checklists,
- failure mode and effect analysis (FMEA),
- fault tree analysis (FTA),
- event tree analysis (ETA), and
- task analysis.

HAZOP (hazard and operability) is widely used in process applications and so has a place in mining process plants but can also be used as a routine 'toolbox' procedure to examine potential safety shortcomings, especially in unusual tasks such as maintenance interventions.

Brainstorming takes a variety of forms, and is essentially a structured forum where participants examine a system, or subsystem, to identify potential hazards. Brainstorming sessions work well only if guided by a facilitator, knowledgeable in the specifics of the system under examination.

HAZAN (hazard analysis) is similar to HAZOP except that it tends to be carried out by specialists external to the immediate organisation, using experience brought from outside and from relevant historical data, such as accident statistics.

Checklists specify known problems relevant to a type of plant and are designed to encourage designers to address known risks. The technique is similar to HAZAN in that it relies on industry wide information and experience from other locations.

Failure mode and effect analysis (FMEA) is a method of examining how a component or system can fail or be incorrectly operated or used. This technique is more suitable for process plants where the analysis can systematically examine every component of the system. It has application in mining where technology levels are high, such as hoisting.

Fault tree analysis (FTA) is used to examine the events and conditions necessary for a particular hazard to develop. The incident of interest (often called the top event) is de-convolved and the individual causes or conditions required are determined. Each cause or condition can be assigned a probability from which the total probability of the top event can be calculated. The system lends itself to computerised analysis and has become more popular in recent years because computers have made it easier to apply.

An event tree analysis (ETA) examines the potential string of consequences from a particular event, such as the failure of a pipeline. It is similar in concept to an FTA, except that it examines the likely outcome of the top event. Event tree analyses are used in environmental studies to examine the effects of a system failure that leads to a release. As with the FTA, it lends itself to probabilistic modelling and, thus, to computerisation.

Task analysis is used to examine the human contribution to a system or operation. Human error, or failure to perform as expected, is a major cause of accidents large and small, Chernobyl is a particularly well known example of the potential for humans to behave irrationally. Each task is examined to determine where breakdowns might occur and experience from related sites may be used to focus participant's attention.

Some or all of these techniques are used by the proficient facilitator to develop a comprehensive list of hazards and possible risk reducing measures that becomes the basis for the subjective risk analysis.

Risk determination

Risk is determined from the relationship between likelihood and consequences. Mathematically, this is expressed as *Risk = Likelihood × Consequences*, where likelihood is expressed as a probability. In a subjective analysis, likelihood and consequences are assessed according to suitable classifications such as those shown in Tables 5 and 6.

TABLE 5

Likelihood classification.

	Likelihood			
	Very Unlikely	**Unlikely**	**Probable**	**Highly Likely**
Descriptive	Almost Impossible	Possible Sometime	Isolated Incidents	Repeated Incidents
Frequency Interval (Multiple events)	Within 20 years	Within 5 years	Within 1 year	Within 6 months
Probability (Single events)	< 1/2000	1/2000 to 1/100	1/100 to 1/10	> 1/10

The level of risk is then determined either as a risk index, or from a matrix similar to that shown in Table 7.

TABLE 6

Consequence classification.

	Consequences			
	Very Low	**Low**	**Moderate**	**High**
Environmental Impact	Localised Degradation	Widespread Degradation	Severe Degradation	Catastrophic Degradation
Personnel Safety	No Injuries	Minor Injuries	Serious Injuries	Fatalities
Lost Time (shifts)	0	0 to 500	500 to 6000	> 6000
Operating Cost	< $A 0.5 M	$A 0.5 M to $A 2.5 M	$A 2.5 M to $A 10 M	> $A 10 M
Ore Milled (tonnes)	< 30 000	30 000 to 200 000	200 000 to 500 000	> 500 000
Total Mined (tonnes)	< 200 000	200 000 to 1 M	1 M to 2 M	> 2 M

TABLE 7

Risk determination matrix.

	Most serious consequence			
	Very Low	**Low**	**Moderate**	**High**
Very unlikely	Level 1	Level 2	Level 3	Level 4
Unlikely	Level 2	Level 3	Level 4	Level 5
Probable	Level 3	Level 4	Level 5	Level 6
Highly likely	Level 4	Level 5	Level 6	Level 7

Risk management

The risk analysis process in Figure 7, shows a loop around a decision point where the user determines if the risk is acceptable. Risk acceptance is discussed elsewhere in this paper and, assuming that a suitable set of risk acceptance criteria have been established, the risk manager is able to determine if risk reduction measures need to be implemented.

Risk management is the process by which conscious and informed decisions are made to accept known levels of risk or to implement a set of actions to reduce the unacceptable risks to acceptable levels. Once the risk is reduced to an acceptable level, possibly using the ALARP principle shown in Figure 1, the risk management process ensures that the risk remains beneath the acceptability threshold. This is often achieved by the use of inspections, audits, and the examination of formal risk indicators.

Quantified risk analysis

Quantified risk analysis (QRA) uses Monte Carlo simulation and is related to 'what-if' scenario modelling. However, QRA goes further than simple what-if because it examines all possibilities within the ranges specified; whereas what-if scenarios examine only a limited number of points and interpret between them. What-if scenarios give equal weight to each scenario and are unable to estimate how likely one scenario is compared to another. In addition, what-if models deal only with explicit, pre-determined combinations and cannot examine all the possible interactions between a number of uncertain variables. Monte Carlo based QRA examines all possible combinations of interactions between input variables, and faithfully reproduces the ranges of uncertainty specified in the input.

QRA allows the user to specify each uncertain variable as a range of values, defined by a probability distribution. Monte Carlo based QRA has gained a broader application in the past decade because of the availability of powerful computers and the universal adoption of the spreadsheet as a basic modelling tool. Any problem that can be established as a deterministic spreadsheet model can be examined as a QRA, however, considerable thought and skill is required to derive a justifiable and meaningful model. Simply to accept the software's default triangular distribution of ±10 per cent of the most likely value as the upper and lower limit for each variable; which results in a solution showing a ±10 per cent range, is an exercise in futility. The uncertain distribution used for each variable must be clearly thought out and the selected input justified.

Most modelling tools, available as add-ons to Microsoft Excel, offer a range of stochastic distributions to describe uncertain parameters some of which are well known to most mining engineers. One of the most important issues in any uncertain input is the shape of the distribution. Too often, inexperienced users assume a 'plus-minus' uncertainty assigning an equal probability that the true value will be greater than, or less than the most likely estimate. This is often not the case; capital projects do not under-run with the same likelihood as they over-run.

Vose (1996) provides an excellent description of QRA, and summarises the benefits of Monte Carlo simulation as follows:

- the distribution of the model's variables do not have to be approximated in any way;
- correlations and other inter-dependencies can be modelled;
- the level of mathematics required to perform a Monte Carlo simulation is quite basic;
- the computer does all of the work required to determine the outcome distribution(s);
- software is commercially available to automate the tasks involved in the simulation;
- greater levels of precision can be achieved simply by increasing the number of iterations performed;
- complex mathematics (power functions, logs, IF statements, etc) can be included with no added difficulty;
- Monte Carlo simulation is widely recognised as a valid technique and so the results are more likely to be accepted;
- the behaviour of the model can be examined with ease, and
- changes in the model can be made quickly and the results compared with previous models.

The results of a Monte Carlo simulation are illustrated in Figure 8a and 8b showing some of the main features of the output.

RISK MANAGEMENT TOOLS

Risk can be eliminated, transferred, shared, reduced, or retained; but it cannot be ignored. There are a number of different techniques for managing risk some of which overlap:

1. **Eliminated**. The cause of the risk can be removed completely by banning, such as the use of aluminium in coal mines; or in design by choosing to eliminate a method of working, such as hand raising in stopes. The mining industry has used both methods. One of the drawbacks of risk elimination is that other materials and methods must be available for substitution and they, in turn, carry their own risks.

2. **Transferred**. Two methods of risk transfer typical in mining are risk sharing arrangements with contractors, or the purchase of insurance. The limitations of both of these

methods is that the outcome of any incident can never be determined in advance as contract conditions are always liable to dispute and interpretation. With insurance policies, claims are only interpreted by the claim assessor in the light of the actual incident.

3. **Shared**. In mining, risk sharing occurs in; i) joint venture agreements covering the running of an operation, ii) with contractors in the execution of certain works, or iii) with the authorities in the establishment of formulae for royalty payments. In some instances the risk sharing is explicit, such as agreements with contractors; and in others it is implicit, such as where royalty payments are based on profit or revenue formulae.

4. **Reduced**. This is usually often the manner in which most mining risks are managed. The risk is analysed and feasible risk reducing measures identified. The risk management process involves selecting measures that are cost effective and able to reduce the risk below an acceptance or manageability threshold, or tolerable under the ALARP principle.

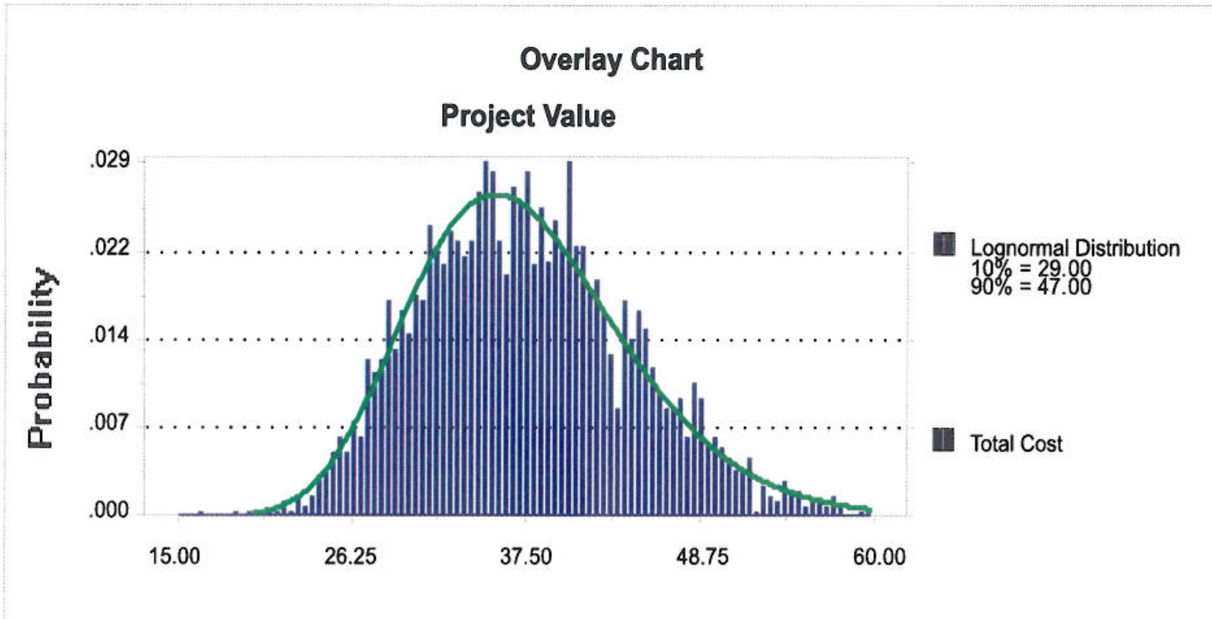

FIG 8a - QRA output showing overlain Lognormal distribution.

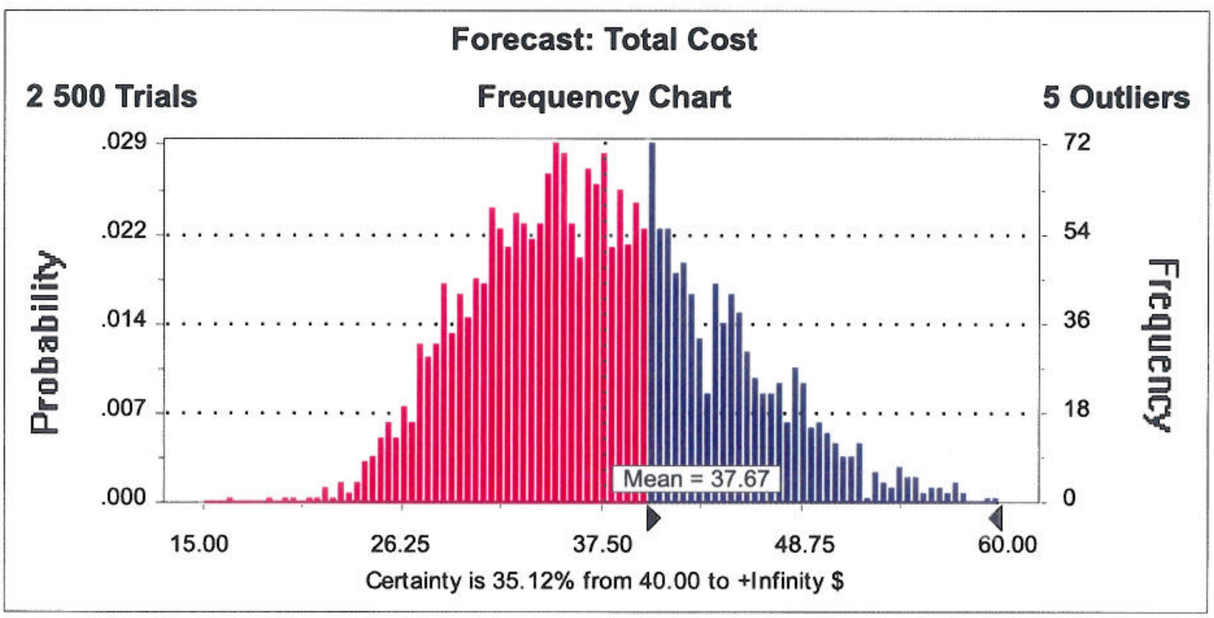

FIG 8b- QRA output showing probability that Total Cost will exceed $40.

5. **Retained**. Risk acceptance can occur knowingly or unknowingly. Known risks are usually accepted after a process of risk analysis and risk reduction so that the retained risk is assumed to be manageable with the resources available. Unknown risks are another matter entirely; these usually develop in the absence of a thorough or systematic risks analysis and, depending on the nature of the risk and the size of the incident, could be extremely damaging to company's reputation or financial security. Sometimes known risks are under estimated and erroneously accepted. Usually there is some aspect of the risk that was unknown and led to the incorrect decision to accept the risk.

Risk management has been described by the Royal Society (1992) according to what it does rather than what it is; using the three basic elements of organisational control: i) setting of goals, ii) gathering and interpretation of information, and iii) actions. This philosophy has been extended to form the basis of the operation of ISO14001 (1996) where the cycle is summarised according to the five basic actions shown in Figure 9; policy, planning, action, checking, and review. This cyclical approach to risk management embodies continuous improvement and depends on the updating of the risk analyses.

Discussion

In their publication on risk, The Royal Society presents a useful appraisal of the debate between practitioners, academics, and regulators governing the general identification and management of risk. Following the structure of the Royal Society's discussion, risk management approaches can be examined under seven headings:

1. anticipation,
2. liability and blame,
3. quantitative risk analysis,
4. corporate response,
5. cost of risk reduction,
6. levels of participation, and
7. regulatory targets.

Anticipation

Risk anticipation relies on systems of detection and warning. In the civil engineering industry this is termed the 'observational method' where complex instrumentation is used to signal a deterioration in some measured condition. In some circumstances there is a clear application for this method, for example in the case of cyanide discharges to tailings dams where routine monitoring of cyanide levels, coupled with a cyanide balance within the plant, are capable of detecting abnormalities in the process. Advocates of the observational approach use disaster investigations, where it is often shown that an accident was waiting to happen, to show that by measuring and monitoring the key factors, risks can be adequately managed.

The anticipatory approach relies on a number of parallel requirements. Firstly, it is necessary to monitor the right indicator. While this may be self-evident, in practice it does not always happen. For example, monitoring of cyanide in the tailings discharge line may be too late in the process to enable adequate and timely action to be taken to prevent a breach of discharge permits.

Secondly, it is necessary to set alert levels low enough that action can be taken in sufficient time before a dangerous condition develops. Thirdly, a pre-determined response plan is required. To be aware that the system has gone wrong but unable, through lack of procedures or lack of training, to respond immediately invalidates even the most sophisticated real-time monitoring system.

In summary, from a mining point of view, anticipation is potentially a useful approach, but it needs to be reinforced by a well designed monitoring and action response procedure.

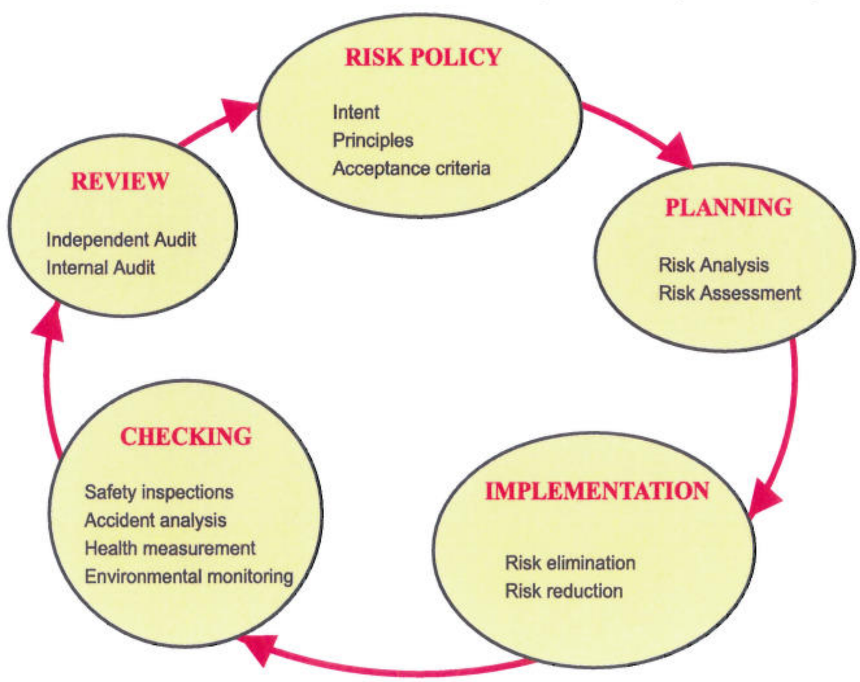

FIG 9 - Risk management cycle (after ISO14001).

Liability and blame

This approach advocates the use of incentives or punitive actions to 'encourage' compliance with rules. At a societal level, many of our laws are founded on this principle – that punishment will follow inappropriate actions. Within mining companies this is often the situation where individual employees are liable to instant dismissal for breaches of safety codes and standards.

Blame allocation has a number of limitations. Firstly, it tends to focus the investigation on the immediate actions leading up to the incident, especially in the event of an accident, and the so-called 'hunt for the guilty'. This often leads to underlying shortcomings in the overall system remaining undetected, or deliberately hidden, and blame apportioned to the immediate supervisor. Secondly, this approach is in direct conflict with the principle of a no-blame reporting system, where individuals are encouraged to report near-misses and to own-up to 'negligent' actions. Thirdly, at a corporate level, where regulations are framed to provide financial or other sanctions against the individual or the organisation; investigations after incidents are stifled because of the risk of self incrimination. There are arguments that a clear investigation as to the real cause of major incidents can be defeated by the requirements of individuals to protect themselves at all costs.

Quantitative risk analysis

There is considerable debate as to the extent to which risk management should rely on quantification of the risk as opposed to subject (qualitative) risk analysis methods. In the past, quantification of risk in the mining industry led to a reticence by managers to adopt the methodology partially because they were unable to interpret and apply the results of the analysis.

Quantification requires the ability to compare quantified risk against pre-determined acceptance thresholds. However, as discussed previously, in the mining industry we often work in a situation of sparse data which makes quantification of risk as a routine process difficult, if not impossible. This is not to say that quantification does not have its place – it does, especially in economic risk evaluation but it requires intelligent interpretation of the results so that management can make correct decisions having clearly understood the meaning of the results.

In summary, within the mining industry, quantitative risk analysis has a place in economic evaluation of projects, but the lack of applicable data and the inherent differences in operations between mine sites makes its universal application difficult. The need to understand the causes and sources of risks strongly suggests the need for a subjective analysis before a quantified analysis is contemplated.

Corporate response

Advocates of the corporate response argue that there is a knowledge base covering risk management within the confines of good practice in the corporate environment. This approach has led to initiatives borrowed from the petro-chemical and process industries, such as written commitments to safety and environmental behaviour made at the highest levels. The result is initiatives such as zero accident targets across organisations, with internal and external audits to enforce the action.

This 'safety culture' has been a focus of mine safety for a number of years and has worked its way downwards through the operating companies with total quality management (TQM) principles in middle management and tool box safety huddles at operator level.

While there have been clear benefits in some organisations, some international companies find great difficulty in applying the corporate directives to an equal standard irrespective of the country of operation. Thus, it is easier to apply these techniques in Australia or the USA, where the safety culture is already amenable to such methods, than it is in some developing countries, where the safety culture is not so well developed or where there is an attitude that accidents reflect God's will.

There is one area of corporate response where some mining companies are probably deficient; that of minimum design rules or standards for their operations. This approach is, in general, to be encouraged but only if the rules are well thought through, specify minimum performance requirements rather than prescriptive designs, and do not exonerate the designer from adequate consideration of the conditions and allow the unthinking application of a 'code'.

Cost of risk reduction

Perhaps the biggest issue in mining risk management is the cost of risk reducing measures. At its lowest level, this issue hinges on the risk acceptance criteria applied by the operating company or the main organisation. In some areas it is reasonably simple to apply, for example zero fatalities, but there is a financial cost above which no manager will incur expenditure.

For example, if the risk of fatality to each loader operator from falls of ground has been calculated as very low yet is deemed to be unacceptable; and if the only feasible risk reducing measure is to introduce remote loader operation at a total capital cost of A$10M, there will be considerable debate about the cost-benefit of such action. Despite the fact that there is a real probability of a fatality in the mine, management will probably be very reticent to commit itself to such a level of capital expenditure. If a fall of ground did occur and led to the fatality it would be hard to argue, in this example, that the fatality could not have been foreseen and that it could not have been prevented.

This leads to the principles of BATNEEC (best available technology not entailing excessive costs) and ALARP (as low as reasonably practicable) which allow risk managers to trade-off the apparent risk benefits against the costs involved, rather than forcing them to apply corporate accident targets directly. In many cases these risk acceptance principles are justifiable, especially in the absence of more formal acceptance criteria. However, they can be misused to minimise the costs of risk reducing strategies and to avoid applying more costly risk management rules set at a corporate level.

In summary, the application of sound risk management practices across an organisation usually indicates good business practice with links between expenditure on risk reduction and good training, management and operational practices.

Levels of participation

The size of the groups involved in risk management can be debated on a number of planes. At a societal level, it is argued that as broad a range of the 'peer community' will result in improved risk management. The example used is that amateur ornithologists first detected the decline in the populations of the peregrine falcon, resulting in the appreciation of the detrimental effects of DDT in the environment.

Within a mining operation, the issues are the involvement of the work force, especially safety risk management, and the involvement of the immediate community in decisions that have the potential to effect their lives. The involvement of the work force in safety risk assessment is now well established on both the formal and the informal levels, with the introduction of hazard analyses (HAZAN) as part of the general work procedure and the implementation of safe operating procedures (SOPs) governing activities that are considered to be hazardous.

The involvement of the wider community around the mine, as well as other stakeholders is not so well established. Some mining companies have suffered significant costs and delays due to the interference of these groups and, although their involvement may have been of overall benefit to the operation, community and environment, their contribution is not always acknowledged by management. In general, it is probable that wide participation and consultation leads to the best risk management because of a perception of involvement and ownership. Ownership of the solution is often as important as ownership of the risk.

Regulatory targets

At a higher level in society, discussion of regulation as a method of risk management is valid. For example, many countries now have rules governing the shelf life of perishable foods to minimise the risk of widespread food poisoning. These regulations are based on an analysis of the probability of food poisoning increasing as the storage time increases but, a number of simplifying assumptions need to be made including the method of storage and the state of the ingredients before they were packed. No amount of regulation governing the shelf life of food will compensate for the initial ingredients being tainted.

In the mining sphere, regulations have changed over the past decade moving away from a prescriptive set of minimum standards to a position of responsible action on the part of the appointed person, the manager, and the mining company. It is probable that this approach to regulation will continue into the foreseeable future with the possible exception of the introduction of regulatory targets within a probabilistic framework. In Australia, for example, there is considerable discussion regarding the definition of an acceptable probability of failure of pit slopes. The drawback of this approach is that the risk is a product of both the probability of failure and the consequences of that failure and so the regulations can only be defined within specific scenarios, such proximity to an active haul road.

Implementation

There are three main tools suitable for the implementation of risk management in mine design and operation, assuming that a risk analysis has been, or is about to be, conducted: i) risk register, ii) action management, and iii) risk updates.

Risk register

The risk register has been described briefly as a component of subjective risk analysis and was described as the main deliverable. To be of maximum value, the risk register should contain at least the topics defined in Table 8.

Without the acquisition of this level of information for each risk, a subjective risk analysis is incomplete and not capable of leading to effective risk management. The ability to complete entries for the topics in Table 8 for each hazard, indicates that the risk analysis has been thorough and that each risk is understood. Risk analysis is not a goal in itself, it is a tool and a pre-requisite to good risk management. Without the ability to demonstrate an understanding of the risks, the ability to succeed in risk management becomes much more difficult.

Action management

Once a risk register has been constructed, and the levels of the individual risk determined, the requirement is for action to reduce the unacceptable risks to acceptable levels. The risk register documents the potential risk reduction measures that can be adopted so that the manager has the option to implement one or more of these or to identify other actions. These actions require both tracking and management.

ISO 14001 (Figure 9) provides an outline of how such management fits into the overall scheme of risk management. Expanding on the principles in ISO 14001, the following sequence of tasks can be derived:

TABLE 8

Contents of a risk register.

Topic	Description
Hazard	Definition and description of the unwanted event, condition or threat.
Likelihood	Assessment of the probability of occurrence.
Consequences	Assessment of the most severe expected consequence of an occurrence.
Risk Level or Index	Determination of the risk based on likelihood and consequence.
Project Impact	Whether this is a risk of a deleterious effect or if there is upside potential which can be viewed as an opportunity.
Other Impacts	The objective or milestone effected by the risk or other areas impacted by the hazard, e.g. environment, mine closure, or underground extension.
Risk Manageability	The ability of the organisation to manage the risk. For example, earthquakes are an unmanageable risk.
Risk Indicator(s)	Physical or other measurements, or observations, that might signal that this hazard is about to develop.
Risk Reduction Measures	Possible measures that could be adopted to reduce the likelihood of occurrence or mitigate the consequences if the hazard occurred.
Risk Ownership	The individual or department who is responsible for managing the risk. In some cases, this might be a later stage of the project, e.g. feasibility design.
Secondary Risks	Additional risks that might arise from the risk reduction measures identified.

1. identify the unacceptable, or the highest priority, risks to be tackled first;
2. agree a set of actions to address the risk;
3. provide resources and a schedule to accomplish the remedial actions;
4. manage the implementation of the remedial actions; and
5. monitor the remedial actions to verify that the desired outcome has been achieved, ie that the risk has, in fact, been reduced.

The management of the remedial actions to ensure that the outcome of the risk analysis is implemented becomes the most important aspect of risk management after the risk analysis itself.

Risk updates

The last of the three main risk management tools most applicable to the mining industry is the risk update. Risk analysis and management is a continuous process by which risks are identified and reduced; and other risks are identified. Changes in operations – especially through continuous improvement – mean that all risk analyses need to be updated on a regular basis. The risk update serves two main purposes:

- to ensure that the risk register is updated considering the latest operational and management controls that are in place; and
- that new risks are identified and dealt with.

Both of these tasks can be viewed as an update of the risk register itself and the needs for an update becomes pressing when the risk register no longer contains the latest information.

Although it may seem self-evident that risks analyses should be updated, it is not always the case that such updates are conducted as a routine process. Despite the lack of a risk update, managers will often claim that they are using risk management techniques routinely across their operations.

BENEFITS AND LIMITATIONS OF RISK ANALYSIS

The Association of Project Management has defined the benefits of risk analysis as either:

- hard – contingencies, decisions, controls, statistics, indicators, etc; or
- soft – people related issues, attitudes, commitment, etc.

Not all projects will accrue all the benefits listed, but most will gain the advantage of at least half of those listed below. Hard benefits can be listed as follows:

1. enables better informed and defensible plans, budgets and schedules;
2. increases the likelihood that the project will follow the plan;
3. better type and structure to contracts;
4. provides a rigorous assessment of contingencies;
5. reduces the likelihood that economically flawed projects will be accepted;
6. contributes to an informal database of project experience useful corporately;
7. enables objective comparisons of alternatives; and
8. identifies and allocates responsibility to the best risk owner.

Soft benefits relate to improved communications, as follows:

1. formalises corporate experience and improves general communication;
2. improves understanding between disciplines and team spirit;
3. helps to distinguish between good luck and good management;
4. develops the ability of staff to assess risks in everyday tasks;
5. focuses management attention on the real issues;
6. demonstrates a responsible approach to staff, community and the environment;
7. allows justifiable economic risk taking form a position of understanding; and
8. encourages participation at all levels in the organisation.

Risk analysis is not the universal solution to all problems, and set against the benefits noted above are several limitations. The severity of the limitations can often be reduced, or even eliminated, by a well designed and properly managed risk analysis project.

Limitations can be grouped under five headings.

Garbage in and Gospel out

The results of a risk analysis are only as good as the quality of the information provided. Poor quality models or an inexperienced modeller will result in misleading results. The risk analysis is only as good as the analyst. All risk analyses require evaluation and interpretation; simply presenting the results to management is not good enough.

Transfer of risk ownership

There is an ever present danger that responsibility for managing risk will be transferred to either the risk analysis process or to the risk analyst leading the project. After the risk analysis itself, risk ownership is one of the basic requirements for effective risk management.

Validity fades with time

A risk analysis is not a one-off project. Risk profiles change over the life of a project and, in rapidly developing projects, frequent updates of the risk analysis are required. The risk register should be viewed as an active tool for risk management that requires routine updates.

Effectiveness of the process difficult to prove

Where uncertainty in intrinsic, it is impossible to demonstrate the effectiveness of risk analysis. If the risk failed to develop was the risk analysis deficient or was the risk management process effective? Risk analysis cannot predict where, when and if a particular risk will occur – it can only assess the likelihood and consequences; management must decide whether or not to accept the risk. There is often a general reticence to acknowledge low probability high consequence events and to act accordingly. When such an event occurs it is viewed as an indictment of risk analysis not of management practice, despite the fact that no risk reducing actions were taken.

The process can antagonise or threaten staff

Overselling risk analysis by management or the risk analyst leads to disillusionment. A lack of credibility in those on the risk team, especially the risk analyst, leads to scepticism of the benefits. There can be a lack of co-operation, especially from middle management who feel threatened by the process and intimidate their staff who are asked to participate.

CONCLUSIONS

Within the mining industry risk analysis is slowly gaining ground but still has many hurdles to jump. This paper opened by suggesting that:

- there is misunderstanding of the types of risk analysis and confusion with the terminology;
- scepticism of the results because they are not interpreted before submission to management;
- a general lack of trust in the method because it is not understood;
- unwillingness to accept risk analysis as a management tool; and
- an erroneous belief, in some quarters, that risk analysis is being used correctly.

This paper has attempted to correct some of these issues by describing the types of analysis typical in mining projects, using examples from other industries; and has reached a number of conclusions to be considered when applying risk analysis and management in mining projects:

1. risk analysis is not a goal, it's a process which can assist management if properly conducted, interpreted and reported;
2. risk analysis has a place at all levels in a mining operation and its benefits are not confined to safety and environmental management;

3. risk analysis in mining is based on sparse data, requires expert participants, pools the collective opinions of all specialists, and does not replace the need for retained experts;
4. quantified risk analysis is usually less useful that subjective analysis;
5. risk definition and risk ownership are the keys to effective management of risk;
6. risk analysis is a specialist task requiring experienced practitioners who should be 'external' to overcome project 'group thinking';
7. a risk register is the management tool emanating from a risk analysis; and
8. risk analyses need frequent updating to maintain their value.

Risk analysis practitioners and managers who have used the methods must do their utmost to ensure that this useful technique receives wider application across the industry and is not left as a tool for the safety department and the environmental section.

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