



Australian Government



RISK MANAGEMENT

*Leading Practice Sustainable Development
Program for the Mining Industry*

September 2016



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Leading Practice Sustainable Development Program for the Mining Industry.

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FOREWORD

The *Leading Practice Sustainable Development Program for the Mining Industry* series of handbooks has been produced to share Australia's world-leading experience and expertise in mine management and planning. The handbooks provide practical guidance on environmental, economic and social aspects through all phases of mineral extraction, from exploration to mine construction, operation and closure.

Australia is a world leader in mining, and our national expertise has been used to ensure that these handbooks provide contemporary and useful guidance on leading practice.

Australia's Department of Industry, Innovation and Science has provided technical management and coordination for the handbooks in cooperation with private industry and state government partners. Australia's overseas aid program, managed by the Department of Foreign Affairs and Trade, has co-funded the updating of the handbooks in recognition of the central role of the mining sector in driving economic growth and reducing poverty.

Mining is a global industry, and Australian companies are active investors and explorers in nearly all mining provinces around the world. The Australian Government recognises that a better mining industry means more growth, jobs, investment and trade, and that these benefits should flow through to higher living standards for all.

A strong commitment to leading practice in sustainable development is critical for mining excellence. Applying leading practice enables companies to deliver enduring value, maintain their reputation for quality in a competitive investment climate, and ensure the strong support of host communities and governments. Understanding leading practice is also essential to manage risks and ensure that the mining industry delivers its full potential.

These handbooks are designed to provide mine operators, communities and regulators with essential information. They contain case studies to assist all sectors of the mining industry, within and beyond the requirements set by legislation.

We recommend these *leading practice* handbooks to you and hope that you will find them of practical use.



Senator the Hon Matt Canavan

Minister for Resources and Northern
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1. INTRODUCTION

1.1 The Leading Practice Sustainable Development Program

The Leading Practice Sustainable Development Program targets the key issues affecting sustainable development in the mining industry. The leading practice handbooks published through the program provide information and case studies to illustrate how sustainability can be achieved. The handbooks are relevant to all stages of a mine's life, from exploration and construction through to operation, closure and rehabilitation.

1.2 Audience

The primary audience for this handbook is those who manage mining and related processing operations, including those involved in design and construction. It is the responsibility of the mine manager to identify and assess risks and take action to control them.

The handbooks also target mining sector stakeholders such as regulators, contractors, consultants, non-government organisations (NGOs), mine communities and students. The aim is to provide all stakeholders with a common view of good practice and to provide site management teams with information on how such practice can be applied.

1.3 The risk management handbook

This handbook provides leading practice guidance on risk assessment and risk management. Mining operations are often inherently hazardous and the sector is also capital intensive, meaning that project and operational failures can be very costly. Failures can also cause substantial loss of life or permanent and significant impacts on the environment and near-mine communities.

Given this context, risk management should be a core process and skill in the mining sector. The industry's historical performance, however, suggests that work is needed to ensure that mining projects and operations use risk management to best effect.

Leading risk management practitioners have recently shifted their focus from risk assessment to control management. This has significantly improved outcomes from the risk management process and reduced the potential for unplanned or unwanted events and outcomes.

This handbook highlights this shift in focus and provides guidance on how benefits can be achieved by companies following a similar approach.

1.4 Development of the handbook

The first edition was published in 2008 as the output of a working group comprising industry, government and academic advisers. This second edition is the result of an overall review and refresh of the Leading Practice Sustainable Development series.

1.5 Scope

This handbook is one of series addressing sustainable practice and establishes how risk management is positioned within sustainable businesses.

1.5.1 Approach to ‘sustainability’

The United Nations defines ‘sustainable development’ as ‘meeting the needs of the present without compromising the ability of future generations to meet their own needs’ (Drexhage & Murphy 2010). In the business sense, sustainability is more about the management and coordination of environmental, social and financial demands and concerns to ensure responsible, ethical and ongoing success. Sustainability is considered to have three core requirements or ‘pillars’ that address social, environmental and economic aspects¹, and those goals have an extended timeline for return on effort.

Each of three pillars—social, environmental and economic—has a number of components that vary depending on whether they are being considered in a global, national or local context and whether that consideration is by government, business or other interest groups. A useful description of the components of the three pillars for organisations is that published by the US Environment Protection Agency.² While the *Risk management* handbook has a broad application, in terms of that description of the three pillars of sustainability the focus is:

- **social:** the safety and health of workers and communities, participation, resource security
- **environmental:** ecosystem services, green engineering, air and water quality, environmental stressors, resource integrity.

While **economic** sustainability uses different tools for risk management that are not addressed in this handbook, there is an overlap and inter-reliance on the three pillars of social, environmental and economic.

The environmental and economic risks of mining are generally well identified and managed, but social risks remain a more challenging area for the minerals industry. Social risk can manifest in a variety of ways—through Indigenous issues, community development, workforce issues and so on. The relationships between social, environmental and economic risks are often not clearly defined or easy to clarify—yet they must be incorporated into risk management to ensure that the minerals industry contributes strongly to sustainable development.

1.5.2 Business context

While the business case for effective risk management should be recognised, mining industry projects and operations continue to suffer unplanned and unwanted incidents and outcomes that substantially affect their profitability, reputation and licence to operate. This occurs through poor understanding or poor application of the risk management process or because risk management is applied to an unnecessarily limited range of business aspects and activities.

1 See UN, <http://www.un.org/en/ga/president/65/issues/sustdev.shtml>.

2 See http://epa.gov/ncer/rfa/forms/sustainability_primer_v7.pdf.

Good risk management is achieved through the sustained application of a systematic process. It also requires skilled application and deep functional input for risk identification and assessment. Risk management also needs to be applied holistically across a site, not just to areas of interest to the current management team, and at all stages of a mine life cycle, specifically:

- exploration and discovery
- concept, order of magnitude, pre-feasibility, feasibility, design and project approval
- construction and commissioning of mine and mineral processing facilities
- operation, maintenance and production
- closure, decommissioning and rehabilitation
- post-closure monitoring.

Each stage presents significant challenges from a risk management perspective. For example, exploration in new areas may raise geological, environmental, social, sovereign and economic risks; operating phases will include community, health, safety, environment, regulatory and reputation risks; closure will involve community, regulatory and reputational risks. Even where risk groups are similar, the specific nature of the risks will vary and need separate analysis and control.

Effective risk management can minimise the potential for a project or operation to suffer unplanned and unwanted events and outcomes. When applied well and transparently, it can:

- protect financial performance
- maintain the health, safety and wellbeing of employees, communities and the environment
- build confidence with internal and external stakeholders
- secure the legal and social licence to operate.

1.5.3 Risk management

Risk management across the mining industry should be applied to all aspects of the mine life cycle, including mining, processing and downstream stewardship of minerals and metals products. The standard AS/NZS ISO 31000: *Risk management—principles and guidelines* provides a generic framework for establishing the context and identifying, analysing, evaluating, treating, monitoring and communicating risk. This handbook builds on the standard by providing practical risk management guidance for mining industry managers and outlining the most common risks affecting the industry that are substantially within the control of site management. It also presents examples of key risk management frameworks and tools that may be used to assess and manage the risks.

The key chapters of the handbook outline the analysis, identification and evaluation of risk and discuss how they can be controlled through proper planning and decision-making. Finally, the handbook emphasises the importance of communication, both internally and externally, throughout the risk assessment and management process.

2.0 RISK MANAGEMENT OVERVIEW

Key messages

- Mining and mineral processing operations face many types of risks, including workplace health and safety, environmental, public health and safety, regulatory, production, reputation, conflict minerals and bribery.
- The impact of the range of risks and their controls should be evaluated for the potential impact on the company's financial position, reputation and licence to operate.
- Risks that may be normalised over time need special consideration.
- Cumulative risks may also need special consideration.
- Stakeholders are a diverse group who vary in their perceptions of risk. Communicating and engaging with those potentially affected by mining industry risks is an essential element of good risk management and adds credibility to both the process and the organisation.
- Risk management processes must encompass the life cycle of a mine.
- Materials stewardship provides a useful framework for integrating risk management activities, especially in the context of newly developed environmental and quality management standards, which require the consideration of the life cycle of activities, products and services.

2.1 Principles of effective risk management

The Minerals Council of Australia has developed a program to provide a formal and consistent framework for sustainable practice in the Australian mining industry titled *Enduring value* (MCA 2005). *Enduring value* outlines 10 principles that encourage council members to consider how the decisions they make and the practices they implement align with their interests and with broader sustainable development goals. The principles include the fundamentals of ethical governance, sound risk management and transparent engagement, as well as individual principles relating to health and safety, employee rights, community development and environmental management. In essence, the framework is intended to help mining companies to go beyond statutory compliance and contribute positively to sustainable development. Enduring value Principle 4 requires companies to implement risk management strategies based on valid data and sound science and to consult with interested and affected parties in the identification, assessment and management of social, health, safety, environmental and economic impacts associated with mining and mineral processing activities. This is to ensure that risks are comprehensively reviewed and stakeholders are kept informed. ISO 31000 goes further and lists principles for effective risk management that should be reflected in organisational risk management frameworks.

2.2 Types of risk

2.2.1 Workplace health and safety

Health and safety risks may be considered under the two headings of 'safety' and 'health', as they present different challenges in management.

Safety risks are characterised by acute consequences, ranging from a minor injury requiring first aid treatment or a more serious lost-time injury through to a permanent disability or a fatality. They range from relatively low-consequence events that may occur quite frequently to rare but potentially catastrophic events.

Health risks may be the result of single or multiple exposures leading to acute or chronic illness or disability. Often those outcomes only materialise over long timeframes and can easily be overlooked in the urgency to manage more immediate concerns.

2.2.2 Environmental risk

Mining activities can pose significant risks to the environment. They may be direct mining impacts, including open-cut and underground mining activities, waste disposal and infrastructure development. They may also include resource use, such as the use of surface and underground water, quarry materials, port development and operation, plus waste and emissions that may include dredging and disposal of dredge spoil and air pollution caused by mining and smelting. Mining companies are reported to employ the most environmental professionals of any industry in Australia, which demonstrates the importance of environmental risk management to mining.

2.2.3 Natural environment risk

The natural environment may interact with mining and minerals processing activities in two ways. First, environmental risk can be defined in terms of the impact of exploration, mining or mineral processing activities on the environment, which is typically the primary focus of environmental risk assessment. It is also important to remember that the environment can pose risks to the sustainability of mining operations, such as flooding a mine or causing overtopping of process water following heavy rainfall, or the converse, when a long dry period means water supply cannot meet demand.

Second, impacts on flora, fauna and ecosystems may have a range of indirect impacts on the business, such as public outrage leading to reputation damage, start-up delays or bans, costs of closure and rehabilitation, and ongoing legacy risks after closure.

2.2.4 Community risk

Community risk addresses both the direct impact on local populations and the potential to affect community health and safety. Direct impacts range from pressure on resources such as water and power to the potential displacement of populations requiring resettlement and the provision of essential economic and social services. Health and safety impacts can be immediate but are often longer term. Emissions to air, water or land, health problems associated with the growth of an operation or project and the migration of communities to the area with resultant cultural, social or infrastructure pressures all need consideration. For example, communicable diseases may spread from rapid expansion and the migration of itinerant

workers and communities. Where such community health issues are prevalent, mining companies may choose to fund health programs or provide community infrastructure in remote areas. Such an approach benefits both the community and the company, as the health and wellbeing of the community and the company's employees are interlinked.

Three useful references on environmental health risk assessment are as follows:

Environmental health risk assessment guidelines for assessing human health risks from environmental hazards (Enhealth 2012)

This Australian publication presents a framework combining risk assessment, risk management and risk communication. It details steps specific to environmental health risk assessment—in particular the inclusion of toxicology, epidemiology, exposure assessment and dose–response assessment in the determination of risk to the general population, subgroups or individuals.

Investigating human exposure to contaminants in the environment

This consists of two handbooks: a community handbook that provides information on descriptive exposure assessment and developing a health profile for a community (Health Canada 1995a) and a handbook for exposure calculations that describes a step-by-step process for calculating human exposure to environmental contaminants, including chemicals and radionuclides (Health Canada 1995b). The methods presented may be of use to health professionals performing exposure assessments and may help the public to understand the process and methods usually followed for such assessments.

IFC performance standards on environmental and social sustainability (IFC 2012),

This publication, produced by the International Finance Corporation (part of the World Bank) provides valuable guidance for mining companies.

2.2.5 Regulatory risk

Safety, health, environmental and community health and safety are subject to regulation. Failure to address regulatory requirements creates risks for the company that can have serious consequences, including protracted permitting timeframes, prosecution, enforced shutdown, and production and reputation consequences. Both current and future risks associated with regulatory compliance at an operation need to be addressed, as failure to recognise new and emerging regulatory requirements can limit the operation's business agility and ability to address change.

To a large extent, government regulation reflects public expectation. The expectation for regulatory change may be initiated locally, can be driven nationally by legislative frameworks or can be influenced by international trends. Regulation in other countries may also directly affect the Australian minerals industry through market restrictions.

Regulatory processes seek to ensure that workforce, community and environmental health are protected and that the public's 'right to know' about relevant risks is maintained. To date, regulations have been primarily framed around operational activities or the 'licence to operate'. In more recent times, regulations are also being developed for the 'licence to market', whereby risks related to downstream product use are also evaluated.

Regulatory policies and practices change regularly as political priorities and views on best practice change. Engagement with policymakers and other bureaucrats can provide an early warning of potential issues, and opportunities exist for businesses to pre-empt future legislation and gain a competitive advantage.

The mining industry is also subject to sovereign risk, which relates to arbitrary regulatory or other changes imposed by a government that fundamentally affect an operation's ability to operate. Examples include changes to royalties and taxes or the expropriation of an asset.

2.2.6 Production risk

Production risk must be managed to control and sustain operational activities or to benefit from an identified opportunity. Production risks are identified in areas of the process that affect production volume or product quality and, ultimately, the costs and revenue streams of the business. These risks are largely economic but may be closely associated with non-economic risks. For example, social and environmental compliance issues may be triggered by a change in production. Similarly, environmental and social concerns may affect production; for example, mining or processing may need to cease if the wind is blowing emissions towards a population centre.

Examples of production risk include pit failure or underground collapse causing ore flow to stop or be restricted; major plant or equipment failure causing prolonged plant shutdown; and resources and reserves re-estimation due to fall in metal prices. Process safety is a major area of potential risk for mining, for example in uranium mining where process incidents can be extremely damaging to reputation and attract significant regulatory attention; in iron ore mining where the orebody contains asbestos that must be removed before export licences are issued and the waste then permanently stored; and in goldmining, where cyanide is a significant issue.

2.2.7 Reputational risk

Risk to reputation is in some respects a flow-on consequence from many of the other risk categories. Effective risk management is likely to have a positive impact on an operation's reputation, offering new opportunities for growth, sustained activity and access to new markets.

Poor risk management—or a lack of identification and analysis of the potential consequences— may have a negative impact on reputation and can lead to the premature cessation of mining and mineral processing if reputation is damaged to the extent that the local community, government, other stakeholders or any combination of them take action against the company. The Ok Tedi case study (see box) contains many of the messages and possible consequences where reputation can be damaged.

CASE STUDY: Risk management of the Ok Tedi project, Papua New Guinea

Key messages

- When risk management is not undertaken thoroughly, it can lead to major flow-on impacts on an individual mine, company and the mining industry.
- Sustainability requires that the complex relationships between various risks be well understood, especially the potential for links between environmental, social, political, economic and reputation risks.

Background

The Ok Tedi copper-gold project is a memorable name in the mining industry. The deposit was discovered in the 1960s and subsequently developed by an international consortium led by BHP Ltd in the mid-1980s. The project is located in the Star Mountains of western Papua New Guinea (PNG). The remote region has intense rainfall and steep and rugged mountains, is prone to landslides and is also within a seismically active area. The engineering challenges for mine waste and environmental management in this context are significant.

Risks

Significant risk was at the forefront of the debate about Ok Tedi from its inception—major environmental risks, social risks (especially with respect to the indigenous communities in the region) and economic risks that are commonly associated with a developing country, including government and governance risks (for example, Pintz 1984).

Risk and consequence

Construction of a tailings dam was started but abandoned in 1984 due to a major landslide which effectively destroyed the dam. Subsequently, Ok Tedi was given approval for the tailings from the mine to be discharged into the neighbouring Fly River.

In 1994, the villagers downstream from the Ok Tedi mine took legal action against BHP Ltd, claiming extensive environmental and social impacts as a result of the tailings discharge into the river. This court case was settled in 1996, with the company making compensation payments and commitments to study future mine waste management options. The case caused major damage not only to BHP's corporate reputation, but also to the reputation of the mining industry globally.

In 2002 BHP ceased its involvement in the project, transferring majority control of Ok Tedi to the new PNG Sustainable Development Program Ltd.



The Ok Tedi mine. Source: Ok Tedi Mine CMCA Review.

Risk management

There are many risks which need to be considered with a project such as Ok Tedi. The extent and nature of environmental impacts present numerous and varied risks—during operation as well as during closure, and following rehabilitation. The social risks are difficult to assess—who receives benefits versus negative impacts—and are further complicated by the varying perceptions of the nature of social risks (within PNG and externally in the developed world). Initially the economic impacts and risks of the project may appear to be easy to ascertain and assess but the costs and externalities derived from environmental and social impacts can be very significant and impact on project economics.

Operating major mining projects presents an array of governance and government risks. For example, when governments are minority investors in projects (the receivers of royalties and taxes) as well as regulators, the perceived conflict of interest and need for transparency presents major challenges.

The Ok Tedi project and the dilemmas it raises are not unique in the world—the multi-faceted and interconnected nature of risk is at the heart of the sustainability debate. The mining industry can contribute to sustainable development by striving to understand the complex relationships between social, environmental, economic and governance risks.

The Ok Tedi case has helped to lift the awareness of these issues in the mining industry as well as the public realm along with the need to implement sound risk management for such large and complex projects and improve the global mining industry's approach to risks and sustainability.

References

Pintz, WS (1984), *Ok Tedi: 'Evolution of a Third World Mining Project*, Mining Journal Books, London, UK, p. 206.

In the context of product marketing, responsible producers also value the mantle of ‘supplier of choice’, which reflects positively on the whole company and not just on a specific mining operation.

Positive reputation can be built and enhanced by performing well in the eyes of stakeholders, but that can only be achieved through effective risk communication and an understanding of the factors affecting people’s perception of risk.

2.2.8 Closure and post-closure (legacy) risk

Risks associated with the closure and post-closure phases in the mine life cycle cover both economic and non-economic consequences. These risks are long term, and the expectations of the local community, government, landowners, neighbouring property owners and non-government organisations (NGOs) need to be taken into account. A well-planned and managed closure process will protect the community from unintended consequences well after the mining company has left the district and will protect the reputation of the company.

Closure strategies for some mine operations may include initiatives to create enduring legacies that enhance social and/or environmental values in the vicinity of the mine and surrounding communities. In this way, the reputation of the mining company will be enhanced. Closure can also be a very expensive exercise: the Martha Gold mine case study (see box) shows how a good risk assessment and well-structured control program reduced a company’s potential closure liabilities dramatically.

CASE STUDY: Using quantitative risk assessment to set post-closure financial assurances, Martha Gold mine, Waihi, New Zealand

Waihi Gold Company (WGC) has operated its open cut Martha mine in New Zealand since 1988. WGC applied for consents in 1997 to extend the Martha mine for a further seven years past the planned and consented end of mine life. Under the approvals process the regulator required a post-closure bond (financial assurance) that would last beyond the closure period.

The objective of the post-closure bond was to indemnify the people of New Zealand against the costs for site management and for prevention or remediation of environmental risk events that could occur in the future. The post-closure securities were to exist in perpetuity.

The anti-mining and environmental lobby groups stated that a bond in excess of \$100 million would be required. WGC wanted to post a bond that was proportionate to the level of post-closure risk.

WGC proposed that at closure, the land currently in and around the mine pit and the area occupied by the tailings and waste rock disposal facilities would be transferred to a specially capitalised charitable trust that would then assume responsibility for ongoing management and maintenance of the assets, and for remediation of any unplanned risk events.

Capitalisation bond structure

The potential future costs to manage and maintain the site were divided into four categories:

Base costs: The costs of activities that were known and required—administration, maintenance, monitoring.

Public liability insurance: The cost of annual premiums for public liability (third party) insurance.

Industrial and special risk (ISR) insurance: The cost of annual premiums for the potential occurrence of insurable sudden risk events that were uncertain and were not expected to occur, but which could occur (for example tailings release or failure of pit lake outlet structure).

Gradual risk issue costs: The potential cost of uninsurable gradual risk events that were uncertain and were not expected to occur, but which could occur (for example, pit lake water quality deterioration, acid rock drainage seepage, dust emissions) and were either not insurable or not cost-effectively insurable.

Estimation of the base costs of the known activities to manage and maintain the site, and estimation of the public liability insurance costs was relatively straightforward and the costs were estimated in the usual way using discounted cash flow to generate this component of the capitalisation fund.

The challenge for the project was to estimate a reasonable, yet conservative dollar value to reserve for ISR insurance and for the potential occurrence of uninsurable gradual risk events.

Risk assessment

A formal risk identification process was performed using an expert panel comprised of WGC section managers and external specialist expertise. The disciplines represented were geochemistry, hydro-geochemistry, hydrogeology, law, and engineering (mining, tailings dam, environmental, milling, water treatment and geotechnical).

The panel identified around 95 credible risk events that included, for example, pit wall stability, settlement, blasting impacts, damage to heritage assets, noise, pipeline bursts, chemical spills, regulatory change, soil contamination, dust, hazardous materials, wildlife impacts, traffic, visual impact and property values.

Many of the identified risk events were excluded from consideration for the post-closure bond on the basis that they only existed during mine operation and closure activities, and/or were improbable or inconsequential following closure.

The 10 post-closure risks that were included in the post-closure bond analysis were: pit wall instability, pit lake outlet structure failure, pit lake water quality, collection pond water quality, tailings bypass seepage, waste rock bypass seepage, perimeter bund acid rock drainage, catastrophic release of tailings, seepage release, and tailings pond water quality.

The risk events were subdivided into the two groups: ISR and gradual. Sudden, catastrophic events were identified as being insurable and were included in the ISR grouping, the catastrophic release of tailings being the primary risk event in this group.

For the gradual risk events, a quantitative approach to risk modelling was used for the risk assessment. Risk is calculated as the product of likelihood and occurrence cost for each risk event. A risk cost, which formed the gradual risk component of the capitalisation fund, was calculated as the sum of the occurrence cost of the highest ranked risk issues that contributed to 95 per cent of the total risk for that group.

Capitalisation bond amounts

Post-closure base cost

The estimated base cost of the known activities to manage and maintain the site was \$550,000 (net present value, NPV).

Public liability insurance cost

The cost to provide \$5 million cover was estimated to be \$130,000 (NPV).

ISR insurance cost

The ISR group risk cost (\$12 million) was used to explain and negotiate the ISR cover requirement to the insurance broker. The broker indicated that the required annual premium of \$45,000 to cover \$12 million, would cover up to \$50 million. This premium was then used to calculate the ISR component of the capitalisation bond. The NPV of an annual ISR premium of \$45,000 per year, discounted over the 50 years that the potential for a tailings release event was assumed to exist, was \$960,000.



Martha mine, Waihi, New Zealand.

source: Newmont

Gradual risk issues cost

For the gradual component, the risk cost (\$4 million) represented the cost that should be reserved to cover the occurrence of gradual risk events post closure.

Conclusion

Using the above process, it was estimated that a total sum of around \$5.6 million would allow the trust to undertake its land management and maintenance responsibilities in perpetuity.

When the bond proposal was put to the regulators, the bond structure and quantum were accepted without challenge. In the subsequent Environment Court hearing, the judge chose to round the amount up to \$6 million, and WGC posted a capitalisation bond of that amount.

The process is subject to annual review and WGC will have the opportunity to re-evaluate and modify its post-closure risk profile. There is an expectation that, over time, this focus will enable the capitalisation bond to be further reduced.

2.2.9 Conflict minerals

In 2012, the US Securities and Exchange Commission adopted a rule to require companies to publicly disclose their use of 'conflict minerals' that originated in the Democratic Republic of the Congo or an adjoining country. The rule addresses the role of US companies in the illegal exploitation of workers and the trade in resources and holds US firms accountable. Australia has not adopted similar regulations, but the US ruling may affect Australian companies because it requires US companies to investigate and disclose whether their products contain conflict minerals.

Some Australian resource companies have extensive operations in Africa, and this is expected to increase. Conflict minerals include tin, tantalum, tungsten and gold that originate from African regions ravaged by civil war. Trade in those minerals funds armed rebel groups operating in conflict zones, and companies risk being associated in potential human rights abuses and corporate social responsibility and ethical issues. Australian companies operating in conflict regions should determine whether their products include conflict minerals and track the destination of those minerals. Failure to do this could make organisations legally liable under the US rule if such minerals are traced to American products, especially electronics. Defending company positions needs careful consideration, as there can be difficulty in tracing these low-volume, high-value minerals.

Leading practice suggests that Australian companies operating in conflict areas should include conflict minerals in their risk assessments and document that they do not deal in such minerals, including purchasing from artisanal miners or traders who buy minerals from them. There is great interest in this subject from activists and NGOs as well as government agencies worldwide. Failure to demonstrate due diligence regarding conflict minerals could have an adverse effect on the company's reputation and share price, as well as restricting sources of finance.

2.2.10 Bribery

According to Marsh (2014), section 70.2 of the Australian Criminal Code Act, which deals with the bribery of foreign officials, makes it an offence to bribe a foreign public official, even if the bribe is perceived to be 'customary, necessary or required in the situation', and even if there is 'official tolerance of the bribe'. A bribe is made when the benefit is not legitimately due to the other person and it is made for the purposes of influencing an outcome required of an official. Under Australian law, benefits extend far beyond money and can include items such as scholarships, training and many other benefits. Minor 'facilitation payments' might not be considered to be a bribe, provided the payment is minor and made to influence the timing rather than the outcome of a minor, routine function. The Australian Government recommends that individuals and companies make every effort to resist making facilitation payments.

The situation is challenging, as in some countries where Australian mining companies operate bribery may be an expected and common practice despite domestic laws against it, and the laws may not be enforced as strongly as they are in other jurisdictions.

The Australian Criminal Code places the responsibility on organisations to ensure that their employees do not engage in conduct that constitutes an act of bribery. The onus is on organisations to be familiar with the laws and to be aware of the types of activities that are legal and illegal when interacting with foreign officials. In addition, the offence will apply 'regardless of the outcome of the bribe or the alleged necessity of the payment'. Penalties for bribery under Australian law are severe. An individual can be imprisoned for up to 10 years or fined up to a maximum of \$1.7 million. For a business entity, the fine could be three times the value of the benefits obtained (if those can be ascertained), 10% of the company's annual turnover (in cases where the value of the benefit cannot be ascertained) or \$17 million, whichever is highest. The liability of a company extends to actions of its employees and others working on its behalf.

Australian mining companies should follow leading practice by putting in place effective risk management frameworks covering bribery and corruption and create a culture of compliance, starting with senior management. Australian and foreign employees and associates must also be fully informed and trained in the company's requirements. Appropriate auditing of payments made in foreign countries is an important risk management and due diligence technique.

2.3 Risk and uncertainty

'Risk' is not an easy term to define, so there are various definitions (Cross 2012). While risk is often considered in terms of the likelihood of something happening and the severity of the outcome, risk as a concept is more complex, and that complexity needs to be understood.

AS/NZS ISO 31000 defines risk as the 'effect of uncertainty on objectives', where uncertainty may relate to a deficiency of information, understanding or knowledge of an event, its consequences or its likelihood. When making decisions as part of managing risk, it is important to remember that this is not an absolute science; it is about managing uncertainty to achieve objectives that may include social, environmental and economic objectives. Risk is also circumstance-specific and has to be dynamic, iterative and responsive to change.

Risk is usually considered in terms of both threats and opportunities. However, for the purpose of this handbook, whose primary audience is site operational management, risk is considered only as the identification, analysis and management of threats.

The sustainability challenge in the mining industry is to coordinate activities to manage numerous risks that will change throughout the mine life cycle and with changing circumstances, with the objective of balancing the social, environmental and economic pillars. It is important to remember that the assessment of risk is based on assumptions that an event will or will not happen or that it will be at an assumed intensity. If the assumptions are incorrect, the assessment may be flawed. For example, failure to properly assess extreme weather can lead to flooding of mines or closure because of lack of water. Failure to accurately assess community reaction to mining operations can lead to closure of operations and even changes in legislation to accommodate those reactions.

The nature of mining presents a range of uncertainties, which may come from global, national or local factors. Such uncertainties may relate to technical and human factors; environmental impacts; social benefits; economic factors, such as the cost of energy, commodity prices and exchange rates; geological and climate conditions; and political risks. To manage risk effectively, uncertainty and unpredictability must be recognised and information gaps filled to reduce uncertainty. In addition to comprehensive technical work, this requires engagement with relevant stakeholders who will have different perceptions of uncertainty and the various aspects of mining.

2.4 Risk and human error

The uncertainty in risk also derives from the actions of people at all levels and from the knowledge that rules and procedures will not always be followed. Studies in many industries have found high levels of noncompliance, and that managers usually overestimate compliance levels. The reasons for noncompliance vary, but include lack of awareness, unworkable procedures, procedures that are too restrictive or time consuming, and better methods being available (Hale et al. 2012). This is not to suggest that rules and procedures are not required or important, but the assessment of risk should not be based on an assumption of full compliance with procedures. The impact of such assumptions has been demonstrated in many disasters, such as the Macondo Gulf oil well explosion.

A popular model of accident causation is the 'Swiss cheese' model (Reason 1997), which considered the variation in behaviour of those in the field and led to three taxonomies of error: 'slip or lapse', 'mistake' and 'violation' (Reason 1990). It is important to understand these different taxonomies, as different error types are mitigated in different ways, particularly when compared with the most common response of addressing errors through training. Task design, equipment design, environmental factors, fatigue and poor procedures can all contribute to the likelihood of errors and will require different and often more complex interventions.

Another perspective on the reason for errors comes from the efficiency–thoroughness trade-off principle (ETTO), which states that 'in their daily activities people routinely make a choice between being efficient and being thorough, since it rarely is possible to be both at the same time. If demands for productivity or performance are high, thoroughness is reduced until the productivity goals are met. If demand for safety is high, efficiency is reduced until the safety productivity goals are met' (Hollnagel 2009:15). Hollnagel takes the view that people have a preference for efficiency and will modify their behaviour to that end. This adaptation for efficiency can be positive and innovative if the potential negative aspects are identified and managed.

Adaptation can be deeper than compliance failures, risk understanding or efficiency. Gradually, we are becoming more aware that during normal work people continuously adapt to their environment and changes in it. The challenge is to create open conversations to identify such scenarios and either sanction the adaptation or plan and design out the need.

2.5 Cumulative risk

Risk management processes in the minerals industry often focus on the risks associated with the operation of a single facility. Where a single mine operation is remotely located, that approach may be reasonable. However, where mining and mineral processing activities occur in clusters, in conjunction with other industries or in proximity to sensitive community or environmental receptors cumulative impacts may need to be considered.

Cumulative risk can be due to the aggregate effects of multiple mining operations in a region or the combination of different impacts from a single mine (such as noise, air, water and visual amenity issues). Cumulative risk is likely to be less obvious, as it is often subtle and spread over time. For health and environmental risks, science continues to provide improved monitoring and evaluation methods. Communities take the cumulative impact of all mining activities in their local area very seriously, and it is critical to realise in the modern information age that if cumulative risks are not well acknowledged and managed that can significantly impact on a company's social licence to operate.

2.6 Stakeholders

Stakeholders are people and organisations who may affect, be affected by or perceive themselves to be affected by a decision, activity or risk. Stakeholders can include managers, workers, customers, suppliers, the local community, landholders, company owners or shareholders and, in the case of cumulative risk, other operators in the area.

Stakeholders understand and perceive risks in various ways and react accordingly. A critical component of all risk management processes is risk communication. This must be a two-way process, proactive at all the life cycle stages of a mine, and consistent and responsive to feedback. Early application of risk management principles lays the foundation for good relationships throughout the whole mine life cycle. There are many examples of relationships being damaged at the exploration or discovery stage or during mine feasibility studies, creating difficulties for stakeholder relationships that can carry through to the construction, operational and closure phases of a mine. These issues may require significant additional management effort, delay project start-up or adversely affect the life of the mine. As technical solutions to risks are planned and implemented, the effectiveness of those solutions should be canvassed among stakeholders in order to maintain and build confidence in the risk management process.

Section 5.5 of this handbook includes a discussion on risk communication and stakeholder engagement.

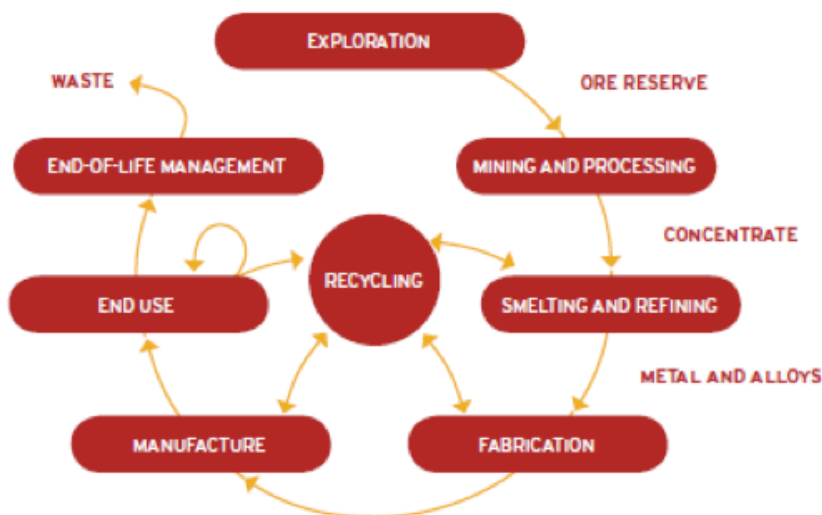
2.7 Time line for risk management

Mining project risks need to be considered over long timeframes which will be based on assumptions made about the long-term risk profile of the mining operation. For example, mine closure and rehabilitation objectives need to be defined during project development phases (feasibility and design). This predictive process requires input from regulatory authorities and local community stakeholders. Regulators normally require assurance mechanisms to ensure that funds are available to deal with situations in which closure and mine site rehabilitation objectives are not met. While these planning processes might not be the responsibility of the site manager, all managers should be aware of the scope of the planning and risk management processes plus the implications for current operations (see the leading practice handbooks *Mine closure* and *Mine rehabilitation* for more information).

2.8 Applying risk processes to the materials value chain

Stewardship is the management of materials, resources and products throughout their life cycle to maximise value and better manage the environmental and social impacts arising from their production and use. The materials stewardship approach focuses on creating integrated systems for managing materials throughout their life cycles, particularly wastes, hazardous substances and products. Thus it has the potential to provide a central framework into which other critical functions, such as risk management, can be linked. Figure 1 illustrates a generic example of the materials value chain.

Figure 1: Generic materials stewardship value chain for the minerals industry



Source: Rio Tinto.

With increasing awareness of the potential hazards arising from the use or inappropriate disposal of some materials, there is a need for proactive industry action on materials stewardship. This challenge is already being addressed by some companies in their conduct of comprehensive life cycle assessments for key products. Failure of the industry to properly respond is likely to lead to materials management principles being imposed through regulation; for example, the REACH legislation (registration, evaluation and authorisation of chemicals) in the European Union and the NSW Extended Producer Responsibility Regulations in Australia.

The materials stewardship value chain assists in the identification of chemical substances that are present in the ore supplied; used in mineral processing; emitted in primary mineral processing or downstream refining, smelting, and manufacturing; or emitted during disposal or recycling at the end of product life. The following questions can help to identify chemical substances that could affect human health or the environment:

- What are the chemical and mineralogical characteristics of the ore at extraction, including valued substances and naturally occurring impurities?
- What chemicals are supplied and used in the mineral processing operation?
- How are the processing chemicals manufactured, transported and stored before use?
- What emissions of interest occur in the mineral or metal extraction process and subsequent processing?
- How are emissions controlled?

- How are hazardous waste streams managed?
- What impurities of interest are contained in product that is sold and transported to customers?
- Are there residual processing chemicals of concern to stakeholders (such as cyanide)?
- What is the fate of chemical substances in the product?

Once this information has been collected, minerals supply chain (upstream and downstream) stakeholders who are interested in chemical substances can be identified. Those stakeholders (communities, regulators, suppliers, customers, manufacturers, transporters, plant operators) need to be provided with information on the chemical substances of interest, such as:

- the properties of chemical substances present, whether naturally occurring in the product or added
- possible exposure pathways and necessary controls to protect employees and the community
- available options for reducing, recycling, denaturing and disposing of priority substances
- emergency preparedness and response procedures
- information on appropriate transport, storage, handling and use.

Materials stewardship concepts provide a basis for defining the flow of materials and chemical substances related to mining and mineral production. That helps to identify stakeholders along the materials supply chain who may need to be involved in risk management activities.

While the initial steps of a materials stewardship approach provide useful data for risk management, the broader focus on managing material flows throughout the value chain in partnership with other users provides a basis for managing overall risks to community and environmental health.

2.9 Financial impact (direct and indirect)

Financial impacts or economic consequences as they relate to capital expenditure, schedules, operating costs, production and revenue should be evaluated for all risk types identified for an operation's activities. The consequences may be negative or positive and have the potential to affect the profitability and net present value (NPV) of the operation. The assessment should be relative to the operation or project size or in line with the company's definition of materiality.

While the financial impact of proposed sustainable development risk controls should be considered as part of risk management, financial risk events are not considered in this handbook. However, there may be significant financial risks arising from environmental issues such as the remediation of contaminated sites (mine sites are often automatically designated as contaminated sites under legislation); financial loss relating to prosecutions (environmental and workplace health and safety); risks from extreme environmental events causing temporary shutdown or closure of mines with consequent financial implications; sovereign risk that prevents planned projects from proceeding; and many more.

3. RISK ANALYSIS AND CONTROL

Key messages

- The benefit achieved by risk management is measured by the effectiveness of the controls implemented (that is, whether the controls are designed properly to control the risk), whether controls are implemented as intended and whether controls are in place and working effectively.
- Risk analysis tools should be used carefully by people trained and skilled in their use and purpose.
- A wide range of risk assessment approaches is available to the mining industry. It is important that decision-makers choose risk assessment techniques suited to their application and information needs.
- More complex techniques generally deliver more accurate results but with the cost of increased time, involvement and need for greater specialist expertise to run the analyses. A combination of techniques may prove most efficient.
- Risk assessment is not a one-off process. Regular review of risk assessment outcomes is required.

3.1 Introduction

The business importance of risk identification, analysis and management to the mining industry has increased significantly over recent years. Consequently, the range of risk management methods has also expanded.

Organisations should select the combination of risk assessment and management options most appropriate to achieving their specific objectives within available budgets and time lines. This section is designed to aid that selection process. Events or issues identified as 'higher risk' should be selected for higher priority mitigation actions to lower the likelihood of the event happening, reduce the consequences if the event were to occur, or both.

3.2 The generic risk management processes

Most managers and technical professionals associated with the Australian minerals industry will be familiar with risk assessment processes and a broader risk management framework encompassing the identification, analysis, evaluation and treatment of risks. Historically, risk management approaches have focused on the technical aspects of risk management. Contemporary risk approaches as described in ISO 31000:2009 *Risk management—principles and guidelines* now place more emphasis on communication at each stage of risk management. It is important for risk practitioners and managers to fully appreciate the relationship between effective risk management, risk communication and the technical risk assessment process. The key elements of ISO 31000 are:

- 1) Communicate and consult
- 2) Establish the context
- 3) Identify the sources of hazard or threat (this additional step is not in ISO 31000, and is intended to avoid pitfalls encountered by jumping directly to risk identification—see Section 3.5)

- 4) Identify risks
- 5) Analyse risks
- 6) Evaluate risks
- 7) Treat risks
- 8) Monitor and review.

3.3 Communicate and consult

Communication and consultation with internal and external stakeholders as appropriate at each stage of the risk management process and about the process as a whole is vital for obtaining quality information for the risk assessment and for developing effective controls. See Section 5.5 for a detailed discussion on risk communication.

3.4 Establish the context

Establishing the external and internal context in which the rest of the process will take place establishes the background to the risk management process, the nature of the activities and the range of potential impacts. This leads to the identification of key stakeholders, the formulation of the risk management aims and structure, and the criteria against which the risk will be evaluated. The scope of the risk management process is then defined.

The first step is to understand the activity being analysed and describe its significance to the business, from which the aims of the assessment can be developed. Risk analysis is intended to assess the risk posed by a number of activities and situations within the minerals industry, such as:

- project work within the organisation
- risk posed by an activity to the wider environment (environmental impact statement applications)
- estimation of the financial cost of risk events
- public safety risk
- worker safety risk
- selection of least-risk options
- determination of financial assurances (bonds or trusts)
- estimation of risk transfer through acquisitions and divestments.

Project evaluation requires a comprehensive description that clearly articulates the aims, benefits and costs of the project, including the schedule of activities, new infrastructure or changes to existing infrastructure, interfaces with existing operations, and potential impacts of the project.

The context of a risk assessment determines the types of output required, the approach taken and the detail needed. A range of methodologies is available, including qualitative, semi-quantitative and quantitative approaches. Risk assessments can be used for corporate overviews to prioritise risks and screen options through to defining management focus or specific events and planned tasks. The context description helps determine what structure is required for the assessment and the nature and levels of expertise needed to identify and describe key risk events (subject matter specialists, names, experience, reputation, conceptual capacity).

3.5 Identify the sources of hazard or threat

There is a tendency to move directly to risk identification after establishing the context. It needs to be tempered to ensure that those involved look more broadly at potential risk events than their personal or collective knowledge and experience might otherwise lead them to. Before beginning to identify risk events, it is helpful to draft a hazard or threat inventory that can be used in conjunction with the mining process being examined to develop a set of risk events for analysis.

In safety areas, a very effective way to do this is to focus on potential sources of energy and then think through the unwanted outcomes that may result from the loss of control of potentially damaging properties of those energies (Viner 2015). Energy must be released to cause physical damage, so energy sources should be identified before risk events are described. Energies in mining are either naturally inherent in the work or a required part of the work process, and many are present in large quantities, so an unwanted release can cause major physical damage.

For environmental areas, it is common to think in terms of pathways and receptors and the role that each of them plays in framing clear risk statements (DEFRA 2011). This is more intuitive than the energy models in safety or the even clearer monetary indicators in finance, but used carefully will enable a good identification of hazards sources.

In communities, this potentially becomes even fuzzier when factors such as vulnerable sectors and community elements need to be considered (CDMP 2005). Again, provided that those are used carefully to clearly identify threats, the intention will be achieved. A major community risk factor is perceptions of the proposed or operating mining project and how it affects the health, safety and environment of the affected communities. Often, this perception is adversely influenced by the media or a small but vocal opposition group, for which the emotions expressed cannot be adequately answered with facts.

The focus can extend beyond safety, environment and community to cover government relations or commodity price changes. In all cases, the threats must be identified and understood so that the risk can be managed effectively, which includes gathering knowledge on the magnitude and nature of the threat. The purpose is to ensure that the risk assessment team is clear and unified on the sources of hazards or threats before moving to the second step of identifying the risks for analysis.

3.6 Identify risks

Once hazards are understood, identify where, when, why and how events could prevent, degrade, delay or enhance the achievement of the objectives. A clear understanding of risk and its contributing factors is needed to identify and describe risk and analyse its potential impact on the environment, organisation or activity. The aim of the risk identification process is to understand all the key risk events that are relevant to a project, activity or other situational context; define their cause-and-effect relationships; identify the nature and extent of all potential consequences (for example, financial, environmental, social, economic, safety); and understand their likelihood of occurring. All information obtained during the risk identification is used in the subsequent risk analysis and assessment.

Most risk information is obtained from experienced operators and subject matter specialists who jointly understand the activities that will be carried out and their potential impacts on the business and the assets in the wider environment. External stakeholders are consulted when risk situations can have broader community consequences and a range of stakeholder viewpoints are needed to better define risk. Information from experts is most often obtained during specifically convened workshops and subsequent ongoing follow-up and consultation with experienced operators, specialists and their teams.

Risk identification workshops are usually designed and facilitated by a specialist risk analyst. Benefits of a workshop approach for the identification of risks include the following:

- Information obtained is directly relevant to the risk assessment.
- Appropriate processes are followed.
- Time and the available expertise are used effectively.

Before a workshop, the risk analyst, in consultation with the project manager or risk owner, develops a good understanding of the project. They review available data, identify the relevant hazards or threats, develop a preliminary list of risk events, develop preliminary cause-effect relationships, and develop the structure of the risk assessment to the point where a preliminary risk assessment model (qualitative or quantitative) can be produced. Workshops can vary in length from a few hours to a few days (depending on context and scope).

The agenda normally begins with introductions, a safety briefing, a summary of the context, an introduction to the risk assessment approach to be used, the role of participants, required outputs from the workshop, and a briefing on how the available information will be used in the risk assessment process. The workshop initially focuses on the identification of risk events. The preliminary list of risk events is usually presented at the meeting and the participants are then asked to engage in a brief brainstorming session to add to the list, without much discussion.

For the remainder of the workshop (most of the allocated time), a facilitator systematically leads the participants through the complete list of risk events. During that process, the participants describe the cause-and-effect pathways, also referred to as risk scenarios, and describe their range of potential consequences and likelihoods.

To define consequences, the operators and subject matter specialists are asked to describe the nature and magnitude of consequences if a given risk event occurs in the given timeframe. Their judgements are often based on:

- previous events on site or at other organisation sites
- events in the industry locally, regionally and globally
- previous events in other business contexts and environmental settings
- judgement from their own and industry experience
- media reports and communications from interested parties.

A key requirement is to understand and describe the uncertainty related to the magnitude of all types of consequences. For qualitative risk assessments, participants may be asked to justify their decisions on consequences based on what is most reasonable.

The workshop concludes when all risk events have been discussed and have either been included in the risk assessment or excluded on the grounds that they are not relevant, not possible or not of material consequence.

3.7 Analyse risks

The objective of risk analysis is to produce outputs that can be used to evaluate the nature and distribution of risk and to develop appropriate strategies to manage the risk.

Before commencing risk analysis it is important to not waste time analysing known and understood risks that already have specific, mandated controls in place. In such cases, proceed directly to risk treatment to evaluate the effectiveness of controls (Safe Work Australia 2012).

Qualitative methods use descriptive terms to identify and record the consequences and likelihoods of events and resultant risk. Quantitative methods identify likelihoods as frequencies or probabilities. They identify consequences in terms of relative scale (orders of magnitude) or in terms of specific values (for example, estimates of cost, number of fatalities or number of individuals lost from a rare species). Monte Carlo simulation methods may be used to refine uncertainty into quantitative estimates.

It is important to understand that all risk analyses are based on assumptions; that is, it is assumed that a certain event will (or will not) happen at a certain place and time and under assumed circumstances. If those assumptions are incorrect, then the risk assessment must be flawed. It is therefore imperative that the assumptions used are validated as much as possible and that the widest range of risk scenarios is canvassed. Until all of the circumstances are investigated, it is dangerous to assume that something cannot happen.

For critical risks, such as those that may result in fatalities or business collapse, assessing probability may be detrimental to the risk management process. Estimates of likelihood for rare events are notoriously inaccurate, and the ethics of applying likelihood estimates to such events can be dubious.

3.7.1 Qualitative approaches to risk assessment

Qualitative methods are the most commonly applied, as they are quick and relatively easy to use. Broad consequences and likelihoods can be identified and can provide a general understanding of the comparative risk of events, using a risk matrix separate events into risk classes (ratings).

A logical, systematic process is followed to identify the key risk events and to assess the likelihood of their occurrence and the consequences. Outputs are usually evaluated using a risk matrix incorporating predetermined thresholds for which risks require treatment and the priorities that should be applied. This process is described in Appendix 1.

For qualitative methods, it is important to invest time in developing appropriate rating scales for likelihood, consequence and the resultant risk. The full range of risk situations likely to be encountered within the scope of the exercise should be considered when developing rating scales. The concept of materiality should also be used to define the significance of consequences to the organisation as a whole and its management units. Clear descriptors need to be drafted for each level of likelihood and consequence to enable comparative judgements to be made. Different sets of descriptors can be developed for different types of consequence, and the equivalence of the different descriptors for each consequence level should be considered (see Appendix 1 for an example of a consequence table).

While qualitative risk assessments are useful because they can be used by the workforce (with supervision or facilitation) and they help to give ownership for the risk assessment process, they have significant limitations that affect their validity and application (Bofinger et al. 2015). A great strength of qualitative processes is in bringing together a diverse range of experienced individuals with technical and practical insights in a social process to 'bounce off' one another and tease out what might happen and how likely it is. However, qualitative assessments also bring to these processes inherent biases that can easily prevail. So, while the social process of risk workshops is very powerful, distilling great insights into a simple risk matrix can damage the impact and lose important detail. Appendix 1 has a detailed discussion on the limitations of qualitative risk assessment.

In practice, people can reverse engineer qualitative analyses in their heads without really trying. When someone gets used to the simple matrix scales, they understand the impact that choosing values will have on whether work can proceed, require a pause for further analysis, require higher authority review, or require more robust controls. Through this understanding, users can consciously or unconsciously influence outcomes.

3.7.2 Semi-quantitative methods

When moving from qualitative matrix to quantitative methods, the basic risk formula can be expressed in non-mathematical terms, which may aid understanding of the quantitative concepts:

Risk equals the sum of all credible consequences divided by likelihood pairings for a given event.

Semi-quantitative approaches are widely used in an effort to overcome some of the shortcomings associated with qualitative approaches. They are intended to provide a more detailed prioritisation of risks than qualitative risk assessments and take the qualitative approach a step further by attributing values or multipliers to the likelihood and consequence groupings.

One of the biggest problems with semi-quantitative assessment comes from the fact that it has not been defined. For example, ISO 31000 notes that semi-quantitative assessment exists but does not define what it is, simply identifying that it is neither quantitative nor qualitative. The accompanying ISO 31010 standard on risk assessment techniques only states that semi-quantified risk is measured in numbers based on a 'formula', which may vary.

Where semi-quantitative methods are to be used across a range of outcome types (such as safety, environment and financial), the development of consistent consequence tables is critical to the risk assessment. Effective consequence tables have been developed by experts and for each type of asset or impact under consideration (for example, infrastructure, species, habitat, tourism, heritage and amenity), clearly describing the nature and extent of impact for each consequence level. Most importantly, the expert team needs to put considerable effort into aligning consequence levels across the table. See, for example, the consequence table shown in Appendix 1 developed for a major Victorian environmental effects statement.

Consequence tables can be very useful for assessments of environmental impact where risks to diverse environmental and social assets need to be communicated to community stakeholders. Stakeholders often understand that consequence tables will never be perfect, or agreed on by everyone, but acknowledge that if well-constructed they allow useful comparisons between diverse types of events. Consequently, semi-quantitative approaches have been supported by many stakeholder groups.

Consequence–likelihood matrices

Appendix 1 shows an example of a semi-quantitative risk matrix in which the likelihoods and consequences have been assigned numbered levels that have been multiplied to generate a numerical description of risk ratings. The values assigned to the likelihoods and consequences are not related to their real magnitudes, which have not been calculated, but provide numerical values derived to allow the grouping of risks to generate indicative risk ratings.

An advantage of this approach is that it allows risk ratings to be set based on the derived numerical risk values. A major drawback is that those values might not reasonably reflect the relative risk of events due to possible order-of-magnitude differences within the likelihoods and consequences classes. To overcome this, likelihood and consequence values that more closely reflect their relative magnitude can be applied, as described in Appendix 1.

Risk ratings can be weighted to place more emphasis on higher consequence events by manipulating the risk descriptors. This is sometimes done to reflect an organisation's lower tolerance of higher consequence events but can be difficult to justify and can be misleading in overemphasising some risk events (if the full range of consequences can be expressed in the same terms, such as dollars, for example).

In summary, matrix-based semi-quantitative risk assessment methods are quick and relatively easy to use, but they offer no significant improvement in the ability to define more accurate assessments or provide a cost–benefit basis for treatment options, including demonstrating that risk is as low as reasonably practicable.

Consequence–likelihood nomograms

There are various ways of trying to approximate the theoretical risk formula. Generally, the faster the assessment, the cruder the value generated. While qualitative risk assessment is fast, it can give a distorted concept of risk proportionality. It also does little to help the user handle the difficulty of assessing likelihood for events rarely experienced in their workplace and allows only one likelihood–consequence pairing for prioritisation purposes. Simple nomograms are intended to deliver assessments that take a little longer than the matrix but offer advantages in risk prioritisation and even action justification to a modest degree.

The risk nomogram has been around for at least 40 years but fell out of favour as the popularity of the matrix exploded in the 1990s. Perhaps the nomogram looked more technical, lacked colour, or simply never had the good fortune to be favoured in the early risk standards. The most basic version is simply the same formula as the matrix but with much greater variation on the risk value estimated. However, it is inherently expandable to include some of the more valued parts of risk management, including risk appetite definition and cost–benefit analysis of treatment options, which is covered later in this section.

Appendix 1 looks closely at nomograms with the same 5 x 5 spread of risk values as matrices and describes the greater level of understanding and accuracy that can be expected. Unlike the matrix approach, the nomogram does not allow accidental formula tampering other than to choose the type of scale for the 'risk value' tie line. Appendix 1 shows nomograms using both a linear and a logarithmic scale. The latter can be used to better reflect likelihood values that are 10 times bigger in each step (such as once in 10 years or once in 100 years) when reviewing several very different risk values. Nomograms also have the advantage that a cost–benefit capability can be included. Also, with modern computers, spreadsheets and graphics a company's specific values can be embedded in the nomogram and do much more than just assess one of a limited number of risk values; specifically, it can provide a case for going ahead with or declining a proposed risk treatment plan. While the overall process can look more daunting than the matrix, this can be overcome with freeware and bespoke software programs. Essentially, nomograms are far more resistant to unintended distortion than the matrix.

Spreadsheet-based semi-quantification

Using a slightly more advanced risk formula together with spreadsheets can lead to a more accurate expression of risk, and the formula can be easily modified for use as the basis for more accurate approaches to risk estimation (see Appendix 1). The risk formula asks the assessor to determine all the consequences of interest and then to define the frequency of each one. Once each consequence has been multiplied by its frequency, the sum of all answers is the total risk. The assessor has to make the call on which consequences are of concern. Commonly, this approach considers only the more severe consequences (such as fatal scenarios in safety), but could look at a set of matrix consequence ratings of minor, moderate, major and catastrophic, ignoring only the 'insignificant' category. There are three reasons for this:

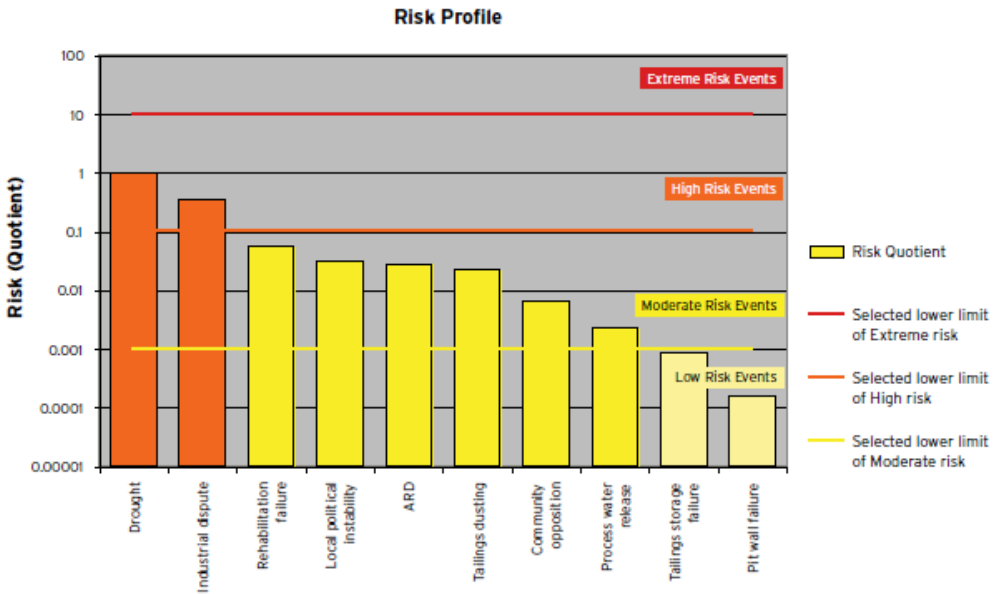
- This approach takes a little more time than methods using the simple likelihood x consequence formula and so might be focused on the more serious events.
- To some degree, it can be assumed that effective management of the more serious consequences will also lead to fewer less serious losses. This would not be the case where less severe but nonetheless concerning events have no potential to create major or catastrophic events (such as manual handling in safety or social pollutants such as plant noise and odours).
- It is difficult to add the total risk of different consequences if their relationships are not clear; for example, is a fatality twice as bad as a disabling injury or 10 times as bad?

This spreadsheet approach takes a little longer than the matrix and simplest nomograms but offers advantages in risk prioritisation and risk reduction estimation, and even a level of treatment justification. The calculation takes into consideration the chronology of a loss event and allows the separate consideration of prevention and mitigation aspects of the event for the application of the risk hierarchy. The risk units are usually in loss per year, such as \$millions/year or fatalities/year. As with quantitative risk assessment, the most serious events tend to occur once over decades or centuries rather than annually. Appendix 1 has examples of the practical application of the spreadsheet semi-quantification approach.

Improved reporting options with semi-quantified methods

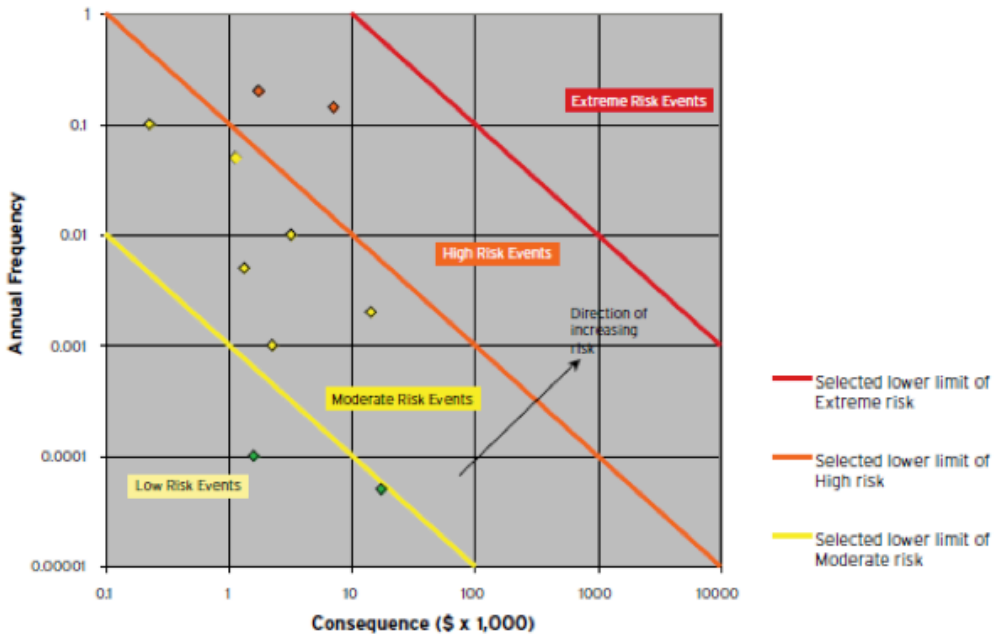
All but the first matrix and first nomogram discussed in this section allow the expression of risk profiles in bar chart format that shows genuine relativity between risks and allows the introduction of specific risk values for expressing risk appetite. Figure 2 is an example of risk profiles in a bar chart.

Figure 2: Examples of risk reporting using a bar chart



Spreadsheet tools and nomograms allow greater granularity in the profile than the matrix option because of the spreadsheet’s three-part calculation and the limited number of risk values on the matrix—just nine on some matrices, compared to the nomogram’s relatively unrestricted choice, as shown in Figure 3.

Figure 3: Examples of risk reporting using nomograms



3.7.3 Quantitative methods

Quantitative risk assessment is increasingly applied in the mining and minerals industry to:

- support financial decisions
- evenly compare financial risks with environmental and social risks
- demonstrate the transparency, consistency and logic of the assessment.

However, quantitative risk approaches often are not intuitive and require some up-front investment in learning by decision-makers. Just as the gap between qualitative and semi-quantitative assessment is poorly defined, so is the one between semi-quantitative and 'full' quantitative assessment. For the purposes of this handbook, full quantification of risk involves a methodology that:

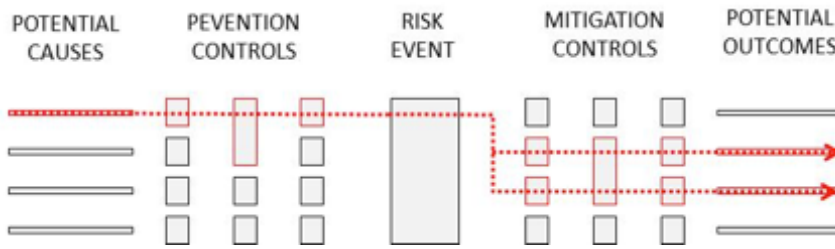
- uses a formula-based process, recognising that multiple potential outcomes are possible from a single event and that all significant outcomes must be considered in the risk value generated
- captures and shows in diagrammatic form all significant causes for and outcomes from a risk event
- uses the diagram(s) and calculation to indicate the most serious failure concerns
- assists in the identification of the critical controls for the management of the risk event
- assists in the assessment of the risk benefit likely to be achieved by proposed treatment measures for use in cost-benefit deliberations.

There are two dominant forms of quantified risk assessment under this definition. The one with the longest pedigree and most technically pure is commonly labelled QRA (quantitative risk assessment). This approach was developed to address process safety and environmental disasters that occurred before 1990 in the nuclear, oil and gas, and chemical industries. It is mathematically intensive, but where the conditions are right for its application it is the most valuable for estimating the frequency of events and identifying the weak points in controls, even in situations in which the event has never occurred. The method is commonly used in processes in which highly hazardous fluids are contained in pressurised equipment.

The second methodology does not have a widely recognised label, largely because when it was introduced at the end of the 1990s it was given the name 'semi-quantitative risk assessment' and the acronym 'SQRA' by its designers, but the semi-quantitative term has proven to be too broad since the introduction of national and global risk standards. Perhaps a better description is 'experience-based quantification' (EBQ) of risk to differentiate it from the maths and failure data based methodology of QRA. For more than a decade, EBQ has been a common part of risk management in many global mining corporations and in some oil and gas companies. This section describes the basics of both and then compares their advantages and shortcomings.

Both QRA and EBQ recognise a general chronology of a disastrous event that allows the event to occur: first, one or more potential causes of a loss of control occurs; second, the preventive controls intended to manage the situation fail. At this stage, the outcome is largely dependent on the performance of mitigation controls to prevent or lessen harm and, if those controls fail, one or more losses will occur. Both methods determine the incident (or initiating event) and then look at potential causes, prevention controls, mitigation controls and the range of potential outcomes. The incident is the risk event being analysed, such as the release of harmful energy. It is also called the 'top event' in some bow-tie software. Figure 4 is a schematic showing causes and outcomes from the risk event and, most importantly, the prevention and mitigation controls.

Figure 4: General schematic of a risk event



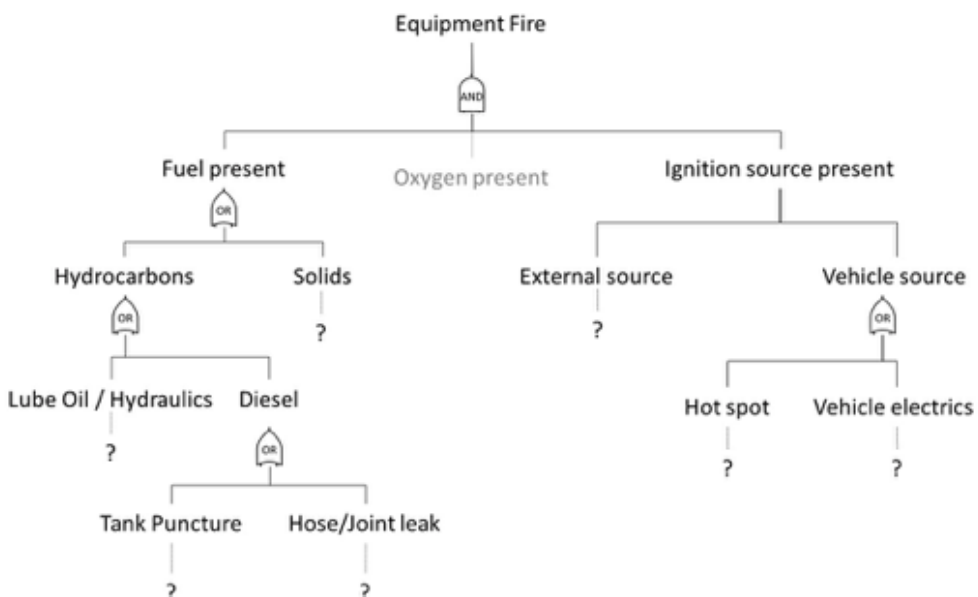
Quantitative risk assessment

QRA is founded on two primary risk tools, the fault tree and the event tree, which are discussed in detail in Appendix 1. The fault tree starts with the risk event, which is traditionally called the ‘initiating’ event in QRA and the top event when specifically referring to fault trees. The analysis works backwards in time to define what might occur to cause such an event.

The simple example in Figure 5 shows how to take the first few steps towards building a fault tree for a heavy vehicle fire underground. The fault tree modeller needs to keep an open mind because the requirement is for a diagram that considers all credible failures, not just the ones already experienced. The modeller knows that there are three essentials for a fire to develop but in this case can omit the oxygen factor because air is pumped throughout the underground mine.

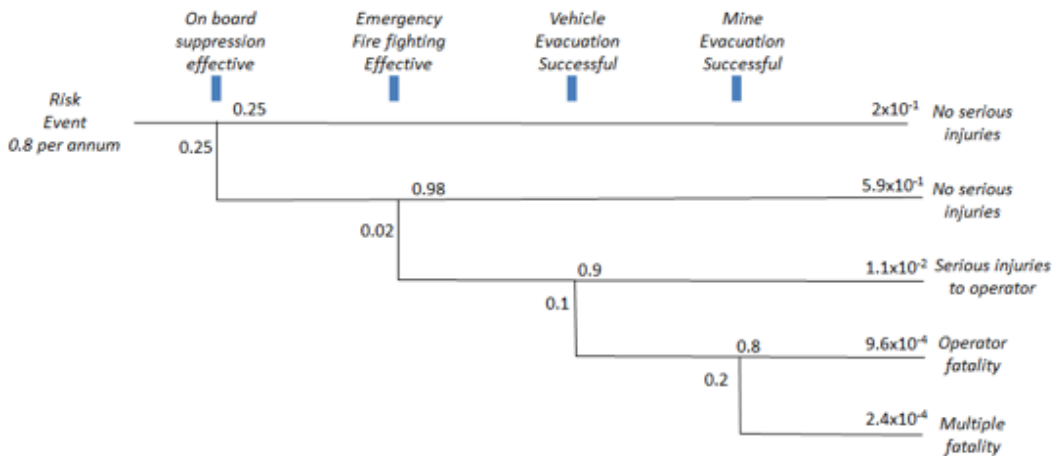
Where two events are required for the scenario to progress to the next step, those two events go through what is called an ‘AND’ gate, meaning that if either one is not present the event cannot occur. Fuel and ignition therefore constitute an ‘AND’ gate. This is a very different situation from ‘OR’ gates, where the scenario will progress if either failure is present. The fault tree mathematically calculates the probability of the event occurring.

Figure 5: Typical fault tree



The second half of the storyline, from risk event to predicted outcomes, is covered by the event tree, which is a representation of the many courses that the event might take, depending on the effectiveness of the mitigation controls. The event tree in Figure 6 carries over the result from the fault tree by analysing the probability that the event results in harm and calculates the probability of each level of harm that may result. At each junction point, a probability for successful performance of the control is estimated or calculated with the help of ‘consequence modelling’, as described in Appendix 1.

Figure 6: Typical event tree



QRA is seldom applied in fields other than health and safety, performance reliability and environmental impacts (radiation, dam wall failure etc.). Perhaps its nearest cousin in business risk is Monte Carlo modelling, in which a mathematical model of a project or the potential ramifications of a business decision can be constructed and run many thousands of times using random selection within the rules established for the specific model. In the simplest of terms, it is equivalent to throwing two dice many times and counting how many times 12 is rolled compared to 11, 10 and so on. Based on the law of large numbers theorem, the more throws that are made, the closer the results will be to real life. Monte Carlo modelling can be a great asset in the quantification of risk but cannot be used across all risk events and therefore cannot be used as a broad (enterprise) methodology. However, Monte Carlo results can effectively inform values generated by QRA and EBQ.

At the beginning of this century, two comprehensive QRA assessments of all credible fatal risk scenarios were undertaken in response to separate multiple fatality events in Australian mines, but later analysis revealed that the QRAs failed to meet expectations. The reasons were complex and largely specific to mining:

- Humans play a direct role in mining (drilling, blasting, scaling, driving etc.) compared with the automated oversight and maintenance role typically involved in nuclear, oil and gas and chemical plants. As a result, mathematically accurate fault trees were difficult to generate.
- No significant international failure database exists for mining, whereas it does for process facilities and aviation.
- The workforce did not ‘buy in’ to a computer-centric methodology (black box syndrome) and did not trust the results.

However, it is not true to say that QRA has no place in the resources sector. For example, some products are refined in automated systems, and the remote operation of automated mine production is being trialled for future use. Nevertheless, several global miners use EBQ as a standard tool across all sites due to its transparent nature and workforce acceptance.

Experience-based quantification

In response to the identified shortcomings of QRA in mining, one company did further work to refine an EBQ approach that was not dependent on the collection of failure data. Building on a process developed for operators of low-technology hazardous plant, such as chemicals warehousing and water treatment plants, the company used a team of miners to estimate the frequency of reasonably common incidents and then estimate the probabilities of those incidents progressing through various stages to a fatal event.

Where QRA uses a fault tree and event tree connected by the risk event, EBQ uses the bow-tie concept first developed by Shell and the American Bureau of Shipping. While fault trees are based on mathematical modelling, event trees can be understood by more of the workforce but have no inherent mathematical value. EBQ therefore partners the bow-tie generator to a bespoke spreadsheet that calculates the risk. By developing the bow-tie in a strict format, the combined tools help to identify the most critical controls. Software tools are available for EBQ, including a fully integrated spreadsheet and bow-tie generator.

The process is described in detail in Appendix 2 and essentially involves building a bow-tie model with the incident as the knot in the middle. Then the causal categories (or causal pathways or groups) are defined to help the assessment team thoroughly identify all credible causes and to assist in distributing the risk burden. Finally, controls are identified and their levels of criticality are rated. The most critical undergo further analysis for dependability, workforce acceptance and how performance will be monitored and maintained.

3.7.4 Comparison of strengths and limitations

All risk analysis techniques have strengths and weaknesses, which are discussed Appendix 1. Generally, the more complex techniques deliver more accurate results but at the cost of increased time and the need for greater specialist expertise to run the analyses. Often, there is a cost in decreased understanding and therefore acceptance of the results by stakeholders. Figures 7 and 8 may be helpful when selecting risk analysis tools.

Figure 7: Risk tool selection based on business phase

	TOTAL RISK PROCESSES			MAJOR SUPPORTING PROCESSES		
Phase	Informal (Step-back, Take 5 etc., JSA/JSEA etc.)	Formal qualitative (matrix, etc.)	Formal quantitative (QRA, EBQ, etc.)	Hazard identification (e.g. HAZOP)	Consequence (e.g. Monte Carlo, gas dispersion)	Control integrity (e.g. LOPA, SIL)
Concept	Red	Green	Green	Red	Red	Red
Feasibility	Red	Green	Green	Red	Red	Red
Design	Red	Green	Green	Green	Green	Green
Construct	Green	Green	Green	Red	Red	Red
Commission	Green	Green	Green	Green	Red	Red
Operate	Green	Green	Green	Green	Green	Green
Closure	Green	Green	Green	Red	Red	Red

Figure 8: Risk tool selection based on risk consequence

	TOTAL RISK PROCESSES			MAJOR SUPPORTING PROCESSES		
Consequence	Informal (Step-back, Take 5 etc., JSA/JSEA etc.)	Formal (matrix, etc.)	Formal (QRA, EBQ, etc.)	Hazard identification (e.g. HAZOP)	Consequence (e.g. Monte Carlo, gas dispersion)	Control integrity (e.g. LOPA, SIL)
Minor	Red	Green	Green	Red	Red	Red
Significant	Red	Green	Green	Red	Red	Red
Catastrophic	Red	Green	Green	Green	Green	Green

Green - preferred risk tool, Red - non-preferred or unsuitable risk tool

When choosing a risk analysis technique, note the following points:

- Qualitative techniques are simple and easy to use and are very useful for sorting risks and establishing to what level in an organisation a risk needs to be elevated.
- Qualitative techniques are unlikely to withstand scrutiny; as the complexity of the scenario increases, this becomes more evident.
- Semi-quantitative techniques can be almost as easy to use as qualitative ones and generally provide more insight into the nature of the risk and what controls are needed. They also tend to provide more uniformity in the risk analysis.
- Quantitative risk assessments need to be carefully designed and implemented but when done well will address many of the drawbacks associated with more qualitative approaches.
- Quantitative risk assessment is very useful for the development and justification of comprehensive risk treatment strategies and for internal business decisions that involve complex business risk events and a wide range of environmental and social issues. In such cases, the results can be readily expressed in equivalent financial terms and incorporated into business planning.
- Quantitative risk assessment is not very useful for environmental impact risk assessments where many diverse environmental and social issues need to be evaluated and their risk communicated to the community and other stakeholders. People often do not accept the concept of placing a dollar value on 'intangible' and often emotive events.

- While the development of the fault tree looks a simple task (especially with special software doing all the maths), the modeller has a very difficult task because not all failures act independently of each other. Some failures are more likely to occur if another control fails, because they may be caused by common factors including age, corrosion, design faults, fire and so on, and the mathematical modelling of such situations is complex. A fault tree with all branches completed and with interactions between controls taken into account can be both very large and very complex.
- The successful application of quantitative risk assessment depends on the availability of necessary data, the capacity and commitment of the organisation to manage the process and the availability of the required expertise.

When considering the availability of data, the impacts on Macquarie Harbour from the Mount Lyell copper mine (see box) make a good case study of the need to base assessments of risk on accurate data and to validate or reject assumptions that are made.

CASE STUDY: Mount Lyell Copper mine impacts in Macquarie Harbour, Tasmania

The 100-year operation of the Mount Lyell Mining and Railway Company Ltd copper mine in Queenstown, Tasmania, resulted in more than 100 million cubic metres of mine tailings, smelter slag and topsoil being deposited into the King River and Macquarie Harbour.

Despite the cessation of tailings dumping, exposed tailings on the river banks and in the delta continually leach iron, manganese, aluminium and copper, which have contributed substantially to the metal loads in Macquarie Harbour waters and sediments.

In the mid-1990s, the Mount Lyell Remediation Research and Demonstration Program, undertaken jointly by the Supervising Scientist and the then Tasmanian Department of Environment and Land Management, aimed to assess the environmental risk of metal release from the mining operation and to develop a remediation strategy.



Mt Lyell Copper mine geographical location.

Source: Google Maps.

A preliminary risk assessment of copper in Macquarie Harbour waters compared monitoring data for copper in mid-salinity waters with literature data on copper toxicity for a wide range of estuarine species. This showed that there was a probability greater than 0.98 that dissolved copper concentrations in the harbour would exceed the copper concentration (with 50 per cent confidence) harmful to at least five per cent of species. Dissolved copper concentrations as high as 500 µg/L had been reported in harbour surface waters near the mouth of the King River, although typical concentrations ranged from 10µg/L to 100 µg/L of copper. Electrochemical techniques showed that a significant proportion of the dissolved copper was in a chemical form that was potentially available for uptake into aquatic organisms. Fish, benthic invertebrate communities and phytoplankton were found to have lower abundance and/or species diversity than in other south-eastern Australian estuaries.

A comprehensive study was then undertaken to assess the environmental impact of metal release from the mine and smelter as part of the development of a remediation strategy. The chemical forms (speciation of copper) and their potential availability to estuarine organisms in Macquarie Harbour waters were investigated using the approach now outlined in the ANZECC–ARMCANZ (2000) water quality guidelines. This included studies on the chemical speciation of copper and direct toxicity assessment (DTA) using microalgae, crustaceans and juvenile flounder.

Using electrochemical and resin techniques, DTA revealed that there were no significant effects on algal growth, crustacean and flounder survival, or osmo-regulation or copper accumulation in flounder. This result was in contrast with results from chemical speciation techniques which showed that copper in the harbour waters was potentially bioavailable. Further tests showed that these waters were not toxic to the microalga *Nitzschia closterium*, despite the fact that they contained copper concentrations greater than that known to cause inhibitory effects on this alga (Stauber et al. 2000).

Amelioration of copper toxicity was probably due to binding of dissolved organic matter at the algal cell surface, preventing copper binding and uptake into the algae. This case study demonstrates the inadequacy of relying on one single line of evidence in risk assessment. Screening level assessments based on chemical analyses and literature data alone may overestimate or underestimate risk. To better evaluate risk and develop appropriate remediation options, site-specific investigations—including chemical speciation analyses, direct toxicity assessment and biological monitoring as outlined in the current ANZECC–ARMCANZ (2000) guidelines—are often required, together with an understanding of mechanisms of toxicity.



The King River.

Source: Jenny Stauber, CSIRO.

References

ANZECC-ARMCANZ (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council and Agricultural & Resource Management Council of Australia and New Zealand, Canberra.

Stauber, JL, Benning, RJ, Hales, LT, Eriksen, RS Novak, B (2000). 'Copper bioavailability and amelioration of toxicity in Macquarie Harbour, Tasmania, Australia', *Marine and Freshwater Research*, 51:1-10.

3.8 Evaluate risks

Evaluating risk is a complex area in which, in the purist sense, the risk level is compared to predetermined acceptance criteria to facilitate decisions on treatment. There are some industries in which this is applicable and the assessment results are more absolute, allowing an understanding of risk levels with acceptable/unacceptable criteria and clarity on decisions about the extent and nature of treatment and priorities.

In mining, however, this is rarely the case. Due to the fluid and changing nature of the mining process, risk analysis tends to provide a comparison of risks as the output rather than an absolute assessment. The tools most commonly used to evaluate risks are consequence tables, such as those shown in Appendix A1.3. More detailed evaluations build on the increasing popularity of bow-tie methodology and consider multiple consequences as inputs to the evaluation. Appendix A2.4 discusses this in some detail. Also relevant to the evaluation and discussed in Appendix 2 is the assurance of controls. While this is not exactly a risk evaluation, done well it can affect the evaluation process by highlighting those opportunities that are most likely to be successful.

3.9 Treat risks

Risk treatment involves developing and implementing specific cost-effective strategies and action plans to increase benefits and reduce costs. The strategies and plans usually involve the improvement of existing controls or the introduction of new controls to reduce the risk.

3.9.1 Design of risk controls

Risk control design is aimed at ensuring that the effectiveness of a risk control is appropriate, given the potential consequences associated with the risk. As the consequences increase, there is a need to have a greater degree of confidence that the risk control will be effective. The treatment of risk should generally follow the accepted hierarchy of controls, which in order of preference is:

1. Eliminate the hazard or threat
2. Minimise or replace the hazard or threat
3. Control the risk using engineered devices that do not require human actuation
4. Control the risk using devices that require human actuation
5. Control the risk with procedures
6. Control the risk with personal protective equipment (PPE)
7. Control the risk through administrative means (such as job rotation to limit exposures)
8. Control the risk with warnings and by raising awareness.

(Adapted from NSW Department of Primary Industries 2007.)

In existing operations, the elimination or modification of hazards may be impractical, so the focus would be on control Types 3 to 8. Risk controls are generally described as being engineering, system, procedural or people-based. There are two important notes when considering the hierarchy:

- The hierarchy is based on impact, without reference to prevention being preferred over mitigation. While there are occasions when mitigation has the greatest impact, the user should be aware that risk prevention is the goal.
- Controls may link together, and the lowest on the hierarchy should be considered as the level achieved. For example, pre-heating materials to avoid moisture explosions when charging a molten metal furnace could be considered a Type 4 control, but because the process relies on a set procedure it is a Type 5 control.

Type 3 engineering controls are usually inherent in the physical design of plant or equipment. Engineering controls are 'automatic' and do not require human intervention to be effective. Control reliability is achieved by having an adequate margin between the critical engineering characteristic of the control device and the system's potential range of variability.

Type 4 system-based controls are executed by people within the bounds of a defined management system. Execution is based on a prescribed approach governed by set rules and protocols. Examples include physical barriers on plant that must be removed and replaced for maintenance, or hazard monitoring systems that require an operator to initiate action in response to a condition such as an elevated gas level or an offsite water release. Control reliability is achieved through the system surrounding the control, including management review and follow-up.

Type 5 procedure-based controls rely on people acting in accordance with written rules or guidelines. Control reliability is achieved through the effective design of the procedure, through the training and competency of people required to execute the procedure, and through monitoring of performance.

Type 6 PPE controls are generally for safety and are mitigative, relying on the cultural mindset of the organisation for effectiveness, such as wearing goggles as protection. Where they are used to control critical risks, they need to be supported by a strong process for checking and sign-off, such as for PPE use in a confined space.

Type 7 administrative controls are typically used in health risk management, where people are rotated to minimise exposures to prescribed levels. Such controls should be considered temporary while more reliable controls in levels 1 to 6 of the hierarchy are sought.

Type 8 controls are people-based controls relying on the skills, knowledge and experience of individuals to identify a hazardous situation, assess the potential consequences and react accordingly. Control reliability is very low and is achieved by the inherent experience and capability of the people and their capacity to adapt that knowledge to situations that are often changing.

There can be overlap between these characteristics and existing controls. For example, a specific control may have some characteristics of a procedural control and some elements of a system-based control. In general, the following principles apply:

- Engineering or system-based controls are more reliable than procedural or people-based controls but are generally more expensive or difficult to implement, particularly if they are not included in the original design.
- Increasing confidence in risk management is achieved by applying highly effective controls to risks with high-potential consequences.
- Risk tolerability can be established to some degree by setting the minimum type of control for a given severity of potential consequences.
- Controls for material risks should have documented control objectives and related performance requirements, whether they are engineering, system, procedural or people-based. The control objective is a statement of the design intent of the control. The reliability target for engineering controls usually specifies the required level of repeatability of the control or, conversely, the maximum allowable 'failure on demand' for the control.

These elements provide the basis by which the ongoing effectiveness of the control can be assessed.

3.9.2 Effectiveness of risk controls

Establishing the effectiveness of controls is very important (previous sections discuss methods of examining risk that require the consideration of control effectiveness). Some risk analysis methods help to consider the degree to which controls reduce risk, but in mining the consideration of control effectiveness is often a separate analysis for the consideration of risk event likelihood and consequence. There are various methods for identifying and critically reviewing current and potential controls, some of which look at individual control effectiveness. Innovations are also being developed for consideration of control sets (that is, the effectiveness of a set of controls for preventing or mitigating a priority risk event).

For this handbook, two types of control analysis methods are suggested: first the bow-tie analysis method to identify controls related to a priority risk event; second, a method to discuss and establish control effectiveness. The assumption is that an inherently high risk or consequence will be tolerable only if the controls are adequately effective. Therefore, the question must be answered: do I have the right controls and, if so, are they effective?

Bow-tie analysis is often chosen because it helps to visually represent controls and their effectiveness. The output of the bow-tie method includes:

- a description of an unwanted event, as well as its threats and consequences
- the identification of the controls that prevent an unwanted event
- the identification of the controls that mitigate the consequences of an unwanted event
- the identification of the factors that can cause controls to fail or can undermine the effectiveness of controls
- an analysis of the reliability of controls
- descriptions of the activities, actions, procedures, policies and standards that are needed to monitor, maintain and improve control effectiveness.

The bow-tie is discussed in Section 3.7.3 and in Appendix 1; a more detailed description and application guidance are in Appendix 2.

Four steps are recommended for selecting and optimising critical risk controls (ACARP 2015):

Step 1) Identify relevant unwanted event(s)

Step 2) Select the best risk treatment options for the unwanted event

Where the risk is to be treated (rather than eliminated or substituted):

Step 3) Identify optimal controls to achieve the required risk reduction by using bow-tie analysis in the sequence below (which is discussed in detail in Appendix 2):

1. Describe the unwanted event
2. Determine the scope of analysis
3. Identify the range of threats
4. Identify possible consequences
5. Identify prevention and mitigation controls
6. Identify failure modes for important controls
7. Determine assurance required

Step 4) Select methods for measuring the operational effectiveness of controls.

Each step is discussed in more detail below. It is important to remember that this process should be iterative, and the bow-tie analysis output should be a set of live documents that are regularly reviewed and updated.

Step 1: Identify relevant unwanted event(s)

Unwanted events are scenarios that have potential adverse effects on important objectives, such as operations, safety, health, the environment, communities, and legal and financial performance. Unwanted events can emerge from threats, variability, incomplete knowledge and drifts in performance.

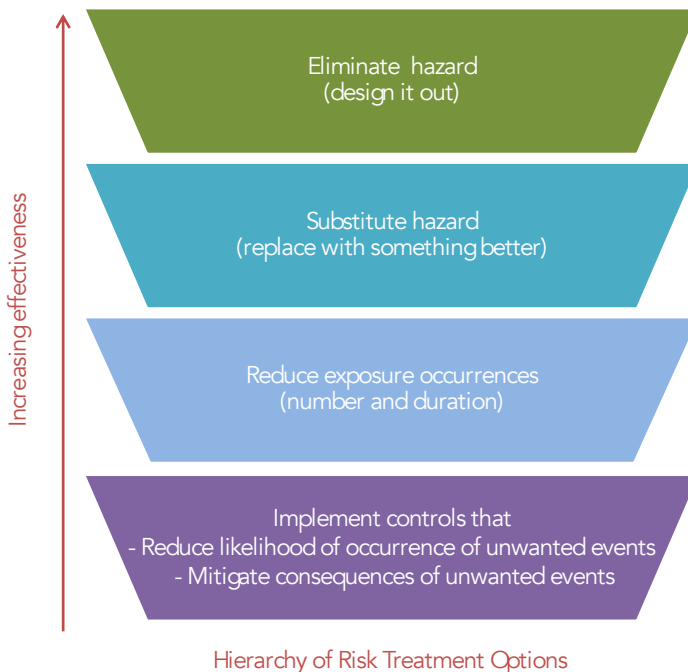
Once unwanted events are identified, it may be appropriate to prioritise them for further analysis.

Step 2: Select best risk treatment options for the unwanted event

The most effective way to manage an unwanted event is to eliminate the hazard that can cause it. If elimination is not an option, consider substituting the hazard with something that has less risk and

minimises exposures. If elimination, substitution and reducing exposure levels do not reduce the risks to an acceptable level, identify the unwanted events that can emerge from the hazard and select and optimise controls that help ensure the effective protection of people, assets and the environment. The risk treatment options are summarised in Figure 9.

Figure 9: Risk treatment options for treating unwanted events



Step 3: Identify optimal controls to achieve the required risk reduction using bow-tie analysis

As a minimum, a bow-tie analysis should have the following characteristics:

- It should be developed by a team of people, including people who understand the bow-tie process; those who understand the unwanted event; and those responsible for actioning, monitoring and maintaining the controls.
- It should be based on clear definitions for describing the unwanted event and for determining what constitutes a threat, consequence and control.
- It should consider 'control failure modes' for important controls. Control failure modes should include factors that can cause the control to fail or undermine its effectiveness. Consideration of failure modes should also identify failure prevention elements needed to protect the control against performance failures. Those elements might be additional controls or they might directly link to the control assurance management system.
- It should identify the control management system elements needed to monitor, maintain and improve the controls so they work as required when required.
- It should present the information in a format that helps those enacting and managing controls make informed decisions about the importance and adequacy of controls.

Step 4: Select methods for measuring the operational effectiveness of controls

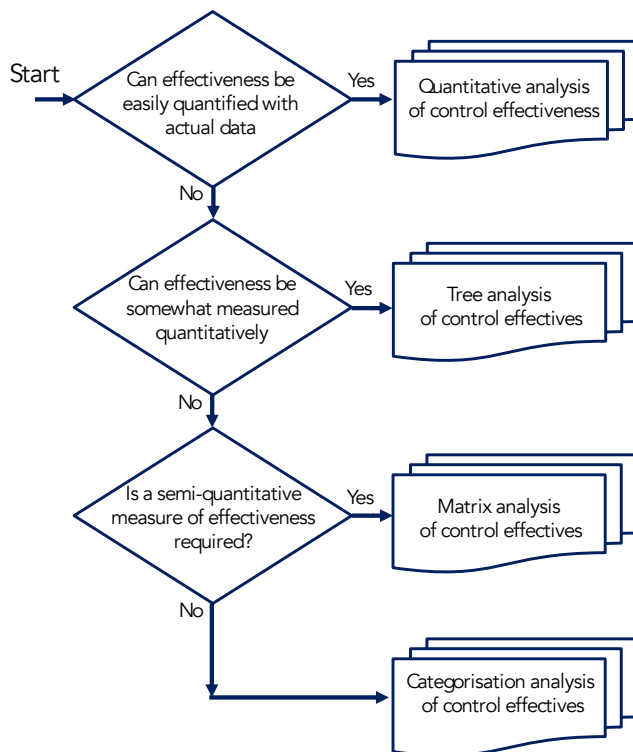
The management and optimisation of controls should focus on maximising control operational effectiveness. This can be done by measuring control effectiveness performance and using the results to track control performance over time and to identify controls that need to be improved, supplemented or replaced. If the measurement of control effectiveness is done well, this provides an opportunity to benchmark control performance across entities. As the measurement of control effectiveness matures within an organisation, it should be used to help assess control adequacy.

Control effectiveness has three components:

- the availability and use of the control when required
- the ability of the control to function as required
- the extent to which the control eliminates or minimises exposure to a threat or mitigates the severity of the consequence.

Controls need to be specific, measurable and auditable, and quantitative measures of effectiveness are preferred, especially for critical controls. However, where quantitative measures are not possible a range of methods, from semi-quantitative to subjective, can be used to determine control effectiveness (summarised in Figure 10). Note that control effectiveness may be measured differently depending on the control and that the decision tree provides a guide for this.

Figure 10: Decision tree guidance for analysing control effectiveness



Source: ACARP (2015).

3.9.3 Critical control management

Performance monitoring and reporting of a key control ensure that it remains effective and that performance shortfalls are identified promptly. Such monitoring should be planned and the frequency of monitoring and reporting should be documented. Effective execution generally requires the designation of a control owner responsible for monitoring and reporting on the performance of the control. There should also be a system to ensure improvement when measured performance falls below minimum requirements.

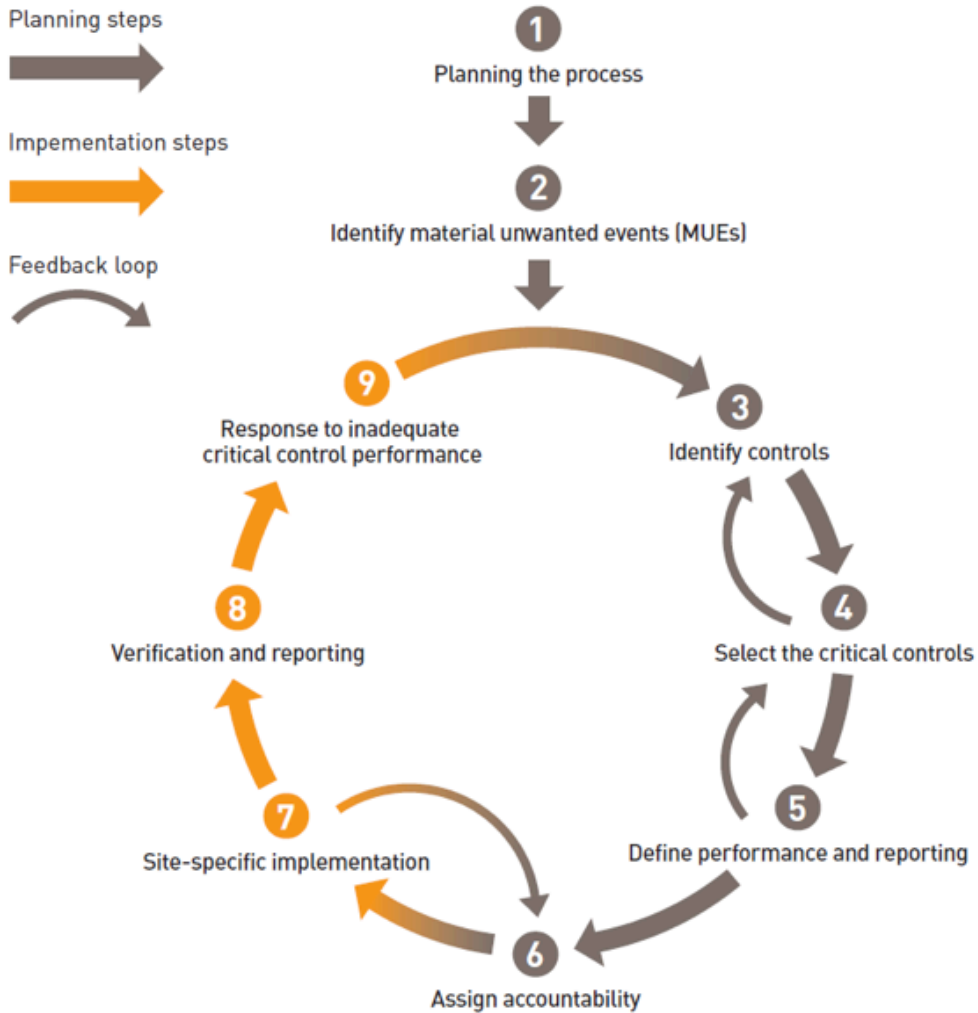
The responsibilities of control owners should be documented either in their position description or in the procedure or system design document from which the control is derived. For critical controls, the performance could be included as an element in the control owner's personal performance scorecard. The International Council on Mining and Metals (ICMM) has developed a resource for guiding this process in its 2015 publication on Critical control management. The ICMM recognises that critical control management is a step-change in the evolution of minerals industry operational risk management; its aim is to have businesses develop critical control management plans to focus them on the effective management of controls for the highest priority events.

Critical control management involves a greatly improved alignment of risk management with good management practice. Currently, risk management can be undertaken with limited connection to business management processes, such as by using risk registers that include long lists of potential events and controls but provide limited management focus and therefore limited value. Critical control management should include the management of risks at several key decision points, including overall site and process risk reviews; progression to different phases of the business; significant change to the operation or business; and the development of safe practices or systems of work.

Critical control management is part of examining the overall priority site risks, is part of the overall risk management approach for the life cycle of the business, and needs to be applied at all phases of the cycle.

Figure 11 outlines the nine steps of the critical control management process, six of which are needed to plan the critical control management plan program before the final three implementation steps (ICMM 2015).

Figure 11: Critical control management



Source: ICMM (2015).

There are many iterative loops in Figure 11, in which a step may require a revisiting of the previous step to achieve the desired output. For example, the loop from step 7 to step 6 indicates the potential need to revisit information from the planning steps when site implementation is defined. This might occur because a control's performance on site varies from assumptions made in the planning steps.

Businesses should recognise that this may be a major change in the way risk is treated and that it may be necessary to take steps to prepare for critical control management before embarking on planning and implementation. Once the nature of the process is understood, including the essential leadership involvement, it is recommended that the company review its readiness to adopt critical control management. The ICMM provides a tool for undertaking that assessment.

3.9.4 Critical equipment management

A defined critical equipment management program is an effective way to manage risks associated with equipment failure. An effective critical equipment management program includes:

- a clear definition of 'critical equipment' based on the potential impacts of equipment failure and a systematic process for identifying critical equipment, including technical experts and stakeholders to develop a 'critical equipment register' specifying:
 - the make and model of the equipment
 - the equipment's purpose and performance requirements
 - details of the potential consequences associated with equipment failure
 - the required testing, inspection and preventive maintenance program
 - testing, inspection and maintenance records
- a maintenance work order process that differentiates work planning and completion reporting; management reporting on completion of critical equipment testing and maintenance; a critical equipment disablement or bypass approval procedure; process safety; and workforce training.

3.10 Monitor and review

Assurance of risk control effectiveness is an essential element of the system; assurance is the explicit, systematic and objective examination of evidence for the purpose of providing an independent assessment of the efficacy of risk management processes and controls against established performance criteria. The scope should include the design and performance of the processes and controls to minimise process risk.

Risks need to be monitored to ensure that the controls have been properly designed, have been implemented as intended and are working effectively. Assurance reviews of risk controls should be led by a person with no direct responsibility for either the design or the execution of the control, but should include the control owner and other key stakeholders. Assurance reports for critical controls should be reviewed and endorsed by the asset management team. Accountability for completing agreed control improvement plans should be assigned to an individual, and progress on the plan should be tracked by management through to completion.

The Northparkes case study (see box) is a good example of the need for risk identification, analysis and review at all stages of an operation.

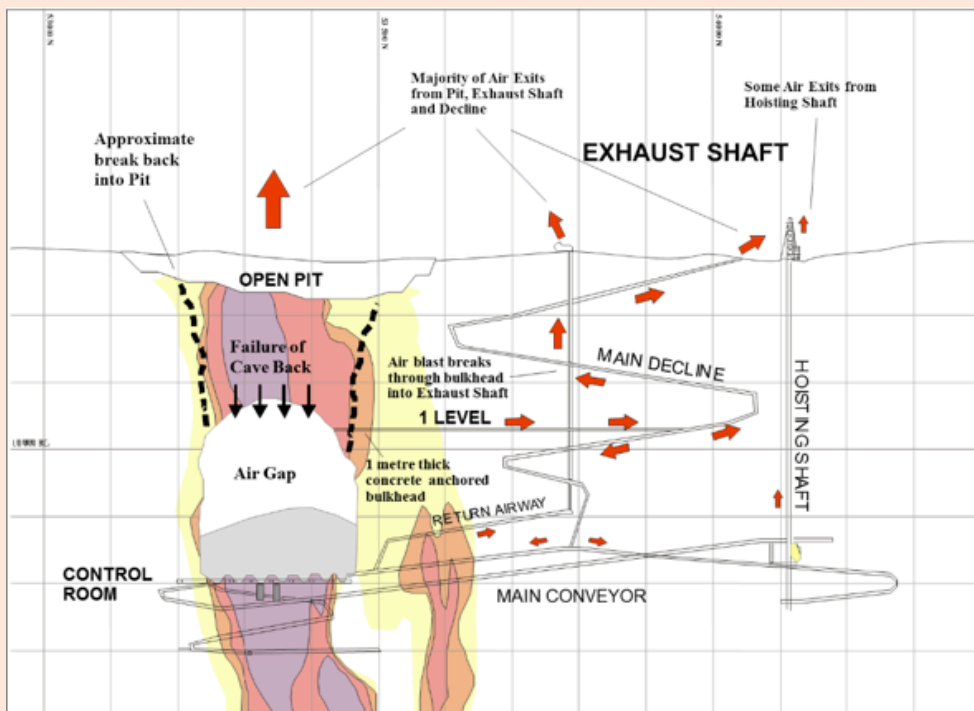
CASE STUDY: The Northparkes block cave collapse, November 1999

Key messages

- Risk identification must be undertaken at all stages from feasibility through to closure.
- Risk analysis techniques must be chosen to ensure that they are suited to the specific assessment.
- Critical risk controls must be chosen and monitored for effectiveness over time and adapted to changing conditions.

Background

On 24 November 1999, a large underground cave created by a block cave mining method suddenly collapsed at Northparkes Mines in New South Wales. The cave was very large—approximately 160 metres in diameter and 180 metres high (about the size of three Sydney opera houses). Within seconds, a huge plug of collapsing rock compressed about 4 million cubic metres of air in the cave. The rapidly and highly compressed air was forced from the cave through several routes, as shown in the diagram, including an old exploration drive that was high above the production level and at the time of the collapse opened directly into the cave air gap. Compressed air entered the workings from the exploration drive with entrained rock, debris and other material as an airblast, which had a velocity estimated by subsequent modelling to be over 1,000 kilometres per hour. The airblast caused massive damage throughout the workings and fatally injured four people.



The mine had become fully operational in 1997 and was designed to draw ore from 130 'drawpoints' on a horizontal plane more than 200 metres below the surface. The rock was expected to fracture under its own weight and, through controlled extraction of ore at the drawpoints, to self-propagate.

The risk of airblast was known and was initially controlled by maintaining a pile of broken rock (a muckpile) over the drawpoints, plus an air gap of 10 metres or less between the muckpile and the cave itself. This 10-metre air gap limited the amount of air that could be compressed in a major collapse of rock. The mining team later conducted a qualitative risk assessment to identify major hazards and, for airblast protection, chose a 60-metre muckpile to protect the workings. This control replaced the 10-metre air gap control, and the air gap was no longer part of the control strategy. At that point, there were no other openings into the cave.

The cave did not propagate as expected and eventually the air gap grew to 180 metres at the time of collapse in 1999. During that time, the cave air gap also grew past an existing exploration drive high up in the ore body and created an opening into the cave. Further qualitative risk assessments recognised the airblast hazard, and a concrete bulkhead was installed in the exploration drive along with other alarms to warn of changes to ground conditions. Because the cave had undercut the bulkhead, the bulkhead provided no protection when the cave eventually collapsed. Quantitative or semi-quantitative assessments were not carried out.

Implications for risk analysis and critical control monitoring

The coronial inquest after the incident found that the mining industry should incorporate into all relevant codes of practice or industry guidelines for safe mine design the identification of core risks inherent in the proposed operations and methods; independent audits of controls at the feasibility and design stages; and repeated milestone audits to ensure that critical safety-related design issues and strategies remain appropriate and adequate throughout operations. The coroner went on to say that underground mine operators need to adequately assess all risks and develop and maintain hazard management procedures to cover all hazards associated with the mining method.

References

Bailey, J (Coroner) (2003). Findings and recommendations from the 'Inquest into the deaths of R. Bodkin; M. House; S. Osman; C. Lloyd-Jones; on the 24th November, 1999 at the E26 Lift 1 Mine North Parkes Mines, Parkes, New South Wales'.

Minerals Industry Safety and Health Centre and Rio Tinto (2005). *Managing major hazards in the mining industry*, video presentation.

3.10.1 Documenting the results

The outputs from the risk identification process need to be documented in order to:

- communicate all risk events considered
- be used as a reference when developing strategies to identify key intervention points and develop appropriate actions
- be used as reference when reviewing risks after some time has elapsed to consider changed circumstances due to strategy implementation or changed business, environment, regulatory, social conditions
- keep a record for due diligence purposes.

In most cases, risk assessments require full documentation of the process, the judgement values (likelihoods, costs and impacts), the rationale behind judgements, and the parties responsible for providing each judgement.

Risk registers are commonly used to present risk information, to document the outputs from the risk identification process and to present the results of risk analysis and strategy development. Typical contents of risk registers include:

- a tabulation of the risk events considered
- events excluded, the reasons for excluding them, and their likelihoods and consequences
- the results of risk analysis and evaluation (risk ranking or grading; environmental risks are commonly assessed as 'inherent' without controls in place and 'residual', assuming the controls are effective)
- existing control measures, planned management actions, allocations of responsibility, and timings of actions.

3.10.2 Outline of a risk register

The following information needs to be provided for each identified risk:

- a unique reference number
- the date of last risk update
- a brief title of the risk
- a description of the risk
- the materiality of the risk
- an assessment of all types of consequences
- the likelihood of occurrence
- a risk rating
- risk responses, together with their current status
- the risk owner.

To provide an audit trail and to assist in learning for future risk analyses, the risk register must retain information on all closed risks. In addition to routine performance monitoring, key risks with potentially material consequences should also undergo periodic independent assurance assessment and reporting.

4.0 RISK MANAGEMENT IN MINING

Key messages

- Risk management is an important part of business efficiency and effectiveness and should be a primary input to annual budgets and work programs.
- Responsibility for risk treatment programs should be linked to performance and advancement.
- The effectiveness of risk control programs and updates of registers following serious incidents in the company or industry should be tested by internal audit.

This section describes generic risk management processes and considers some of the risk tools that may be employed for enterprise risk management, operational risk management and task/activity risk management.

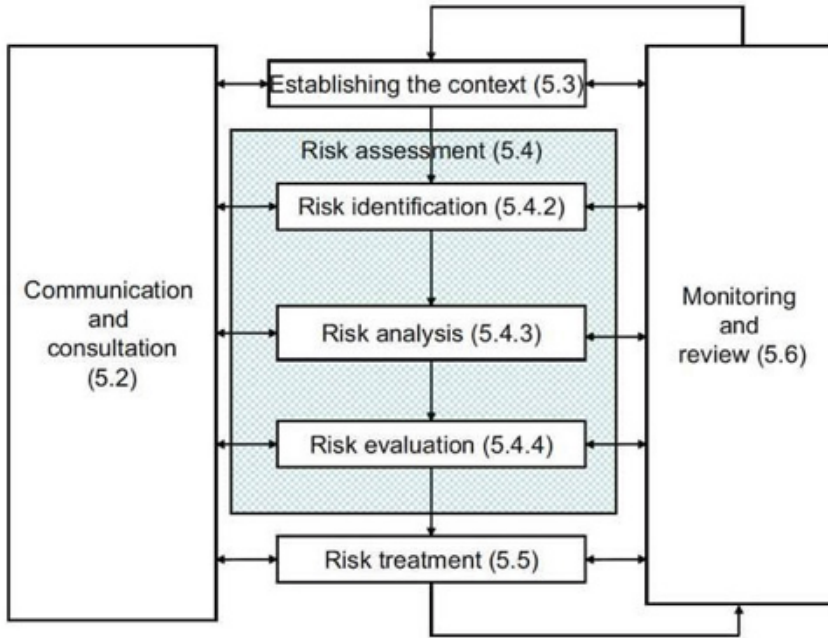
4.1 Enterprise risk management

Throughout exploration, development, production and closure, hazards need to be contained and controlled. A wider social layer of complex political and cultural issues needs to be dealt with carefully to achieve corporate social responsibility, and a successful company needs to manage all of them by applying a single risk management framework built with the mission and structure of the business as its base. This is very unlikely to succeed if systems are developed separately for finance, IT, health and safety, environment and community and so on. Competing elements need to be compacted to a single framework that is an integrated system. This framework is called enterprise risk management.

4.1.1 The enterprise risk management process

The process of risk management is not new and is inherent in our thinking. However, for successful use in an organisation it needs to be formalised so that everyone works in the same way to the same end. It needs to be transparent, so that the effects can be continually improved even when the original assessors are no longer with the organisation. Figure 12 shows this formalisation as it is shown in international standard ISO 31000.

Figure 12: The risk management process



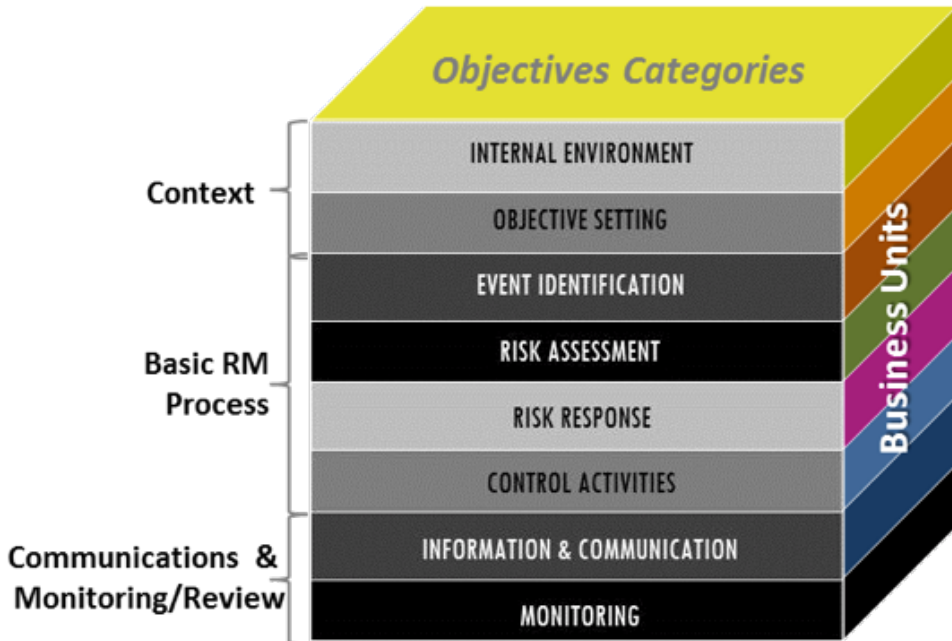
Source: ISO 31000 (2009).

The Committee of Sponsoring Organizations of the Treadway Commission (COSO) provides principles-based guidance to help organisations design and implement effective enterprise-wide approaches to risk management through its *Enterprise risk management—integrated framework* (COSO 2004), which states:

This Enterprise Risk Management—Integrated Framework expands on internal control, providing a more robust and extensive focus on the broader subject of enterprise risk management. While it is not intended to and does not replace the internal control framework, but rather incorporates the internal control framework within it, companies may decide to look to this enterprise risk management framework both to satisfy their internal control needs and to move toward a fuller risk management process.

The framework is widely accepted and used by management to enhance the organisation's ability to manage uncertainty, consider how much risk to accept, and improve understanding of opportunities as it strives to increase and preserve stakeholder value. Figure 13 is COSO's graphical representation of the framework; the front face of the COSO risk cube has almost identical steps to ISO 31000 (shown in Figure 12).

Figure 13: The COSO risk management model



The risk process seems very obvious once understood. However, even the adoption of common process steps does not mean the adoption of any specific risk tools; nor does it ensure that risk management will work for all businesses. These issues have to be resolved by each organisation for the specific objectives and needs of that organisation.

4.1.2 Choosing risk management tools

As discussed in Section 3.7.4, risk assessment tools range from informal processes of thinking through risk steps for simple activities, usually involving a single person, through to processes capable of estimating the frequency of events and calculating the most effective treatment plan based on mathematical modelling of potential failures from formally recorded and published historical data. Picking the wrong tool could reduce confidence in the risk management process.

Two common errors in choosing risk tools are:

- selecting a tool that is not capable of effectively analysing, evaluating and defining treatment for the risk event
- selecting a tool that is more complex or time consuming than is necessary, given the simplicity of the analysis, the clarity of the appropriate treatment, or both.

Essentially, a mix of risk assessment tools is needed to suit the complexity of the risks being analysed. Qualitative tools can be useful for quick analyses and fully quantitative tools for critical risks. A good framework will incorporate a fit-for-purpose combination of tools for the organisation and for the time of the assessment. As organisations mature, there is likely to be a trend towards reduced qualitative assessments and a corresponding increase in quantitative assessments. There is therefore no 'winning methodology' for risk management because there is no simple measurement of performance (for example, it is very difficult to demonstrate that a disaster was averted). Every organisation differs in the risks it has

to manage, the integrity of its incident reporting and its movement on the risk maturity scale (novice, stagnant, improving, declining and so on).

4.1.3 Senior management involvement

Many risk management frameworks have been built without pre-planning on a company-wide basis and then patched together. Health, safety, environmental and business risk systems have historically been built in isolation from each other in most organisations.

Even where organisations have a combined consequence table that includes all risk sources, it is often evident that there has been no overall consistency in the completed product. For example, Table 1 below belonged to a global mining company.

The purpose of the consequence table is to guide risk assessment teams in ranking risks to drive consistent analysis. Table 1 is similar to many in use but shows significant inconsistencies that would prevent that objective being achieved:

- Property damage, which is likely to be covered by insurance, has a critical ranking that is five times lower than earnings before interest and tax EBIT loss (uninsured, actual loss) and 30 times lower than NPV loss.
- Similarly, the factors by which financial losses change are inconsistent with each other. In the rest of the table, NPV is a consistent 10 times reduction for each lower classification, whereas EBIT and property losses are not consistent and vary significantly.
- The environmental guidance uses 'disastrous', 'serious' and 'moderate' to describe impact and 'long', 'medium' and 'short' term to describe the recovery period. These are open to interpretation and are unlikely to be applied consistently.
- The community / reputation guidance has only 2 of 11 guidance notes that relate to real community harm and uses confused wording ('Impact on local economy' at level 4 and 'Negative impact on local economy' at level 3).

There are many other inconsistencies, but the consequence table has many characteristics of those commonly used. Organisations should review their processes to ensure that they are logical and withstand scrutiny.

Table 1: Typical consequence table

Rating	Financial impact US\$ EBIT	Property Damage US\$	Investment Return US\$ NPV	Health and Safety	Environment	Community / Reputation	Legal and Compliance
5	\$100m+ loss or gain	\$20m+	\$600m + loss or gain	<ul style="list-style-type: none"> Multiple fatalities and/or Significant Irreversible effects to 10's of people 	<ul style="list-style-type: none"> Category 5 - an incident that has caused disastrous environmental impact with long term effect requiring major remediation 	<ul style="list-style-type: none"> Prominent negative International media coverage over several days. Significant negative impact on share price for months. 	<ul style="list-style-type: none"> Major litigation or prosecution with damages of \$50m Custodial sentence for company Executive Prolonged closure of operations by authorities
4	\$20m-\$99.9m loss or gain	\$2m-\$19.9m	\$60m-\$599.9m loss or gain	<ul style="list-style-type: none"> Single fatality and/or Severe irreversible disability (Permanent Disabling Injury) or illness to one or more persons 	<ul style="list-style-type: none"> Category 4 - an incident that has caused serious environmental impact with medium term effect requiring significant remediation 	<ul style="list-style-type: none"> National media coverage over several days Significant negative impact on share price for weeks Community / NGO legal actions Impact on local economy 	<ul style="list-style-type: none"> Major litigation costing \$10m+ and Investigation by regulatory body resulting in long term interruption to operations Possibility of custodial sentence
3	\$2m-\$19.9m loss or gain	\$200k-\$2m	\$6m-\$59.9m loss or gain	<ul style="list-style-type: none"> Serious bodily injury or illness (eg fractures) and/or Lost Time injury > 2 weeks 	<ul style="list-style-type: none"> Category 3 - an incident that has caused moderate reversible environmental impact with short term effect requiring moderate remediation 	<ul style="list-style-type: none"> Local media coverage over several days Negative impact on local economy Persistent community complaints 	<ul style="list-style-type: none"> Major breach of legislation with punitive fine Significant litigation involving many weeks of senior management time
2	\$200k-\$1.9m loss or gain	\$10k-\$199.9k	\$600k-\$5.9m loss or gain	<ul style="list-style-type: none"> Medium term largely reversible injury or illness to one or more persons Restricted work injury Lost Time Injury < 2 weeks 	<ul style="list-style-type: none"> Category 2 - an incident that has caused minor reversible environmental impact requiring minor remediation 	<ul style="list-style-type: none"> Local media coverage Complaint to site and/or regulator 	<ul style="list-style-type: none"> Breach of legislation with investigation or report to authority with prosecution and/or moderate fine possible
1	<\$200k loss or gain	<\$10k	<\$59.9k loss or gain	<ul style="list-style-type: none"> First aid treatment or medical treatment 	<ul style="list-style-type: none"> Category 1 - an incident that has caused negligible reversible environmental impact requiring very minor remediation 	<ul style="list-style-type: none"> No media coverage No community complaints 	<ul style="list-style-type: none"> Minor legal issues, non-compliances and breaches of legislation

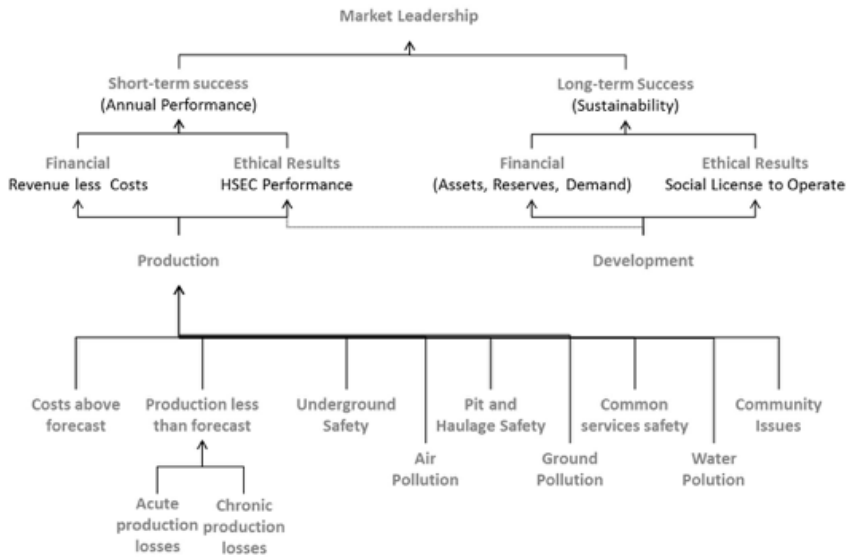
Conversely, a well-considered consequence table indicates risk understanding and leadership from the top. Two other indicators are a picture of how all the risk activities across the business are brought together to allow proper risk oversight from the executive and board, and direct and substantial linkages between risk management and other business systems, including budgeting, planning, training, individual performance management and internal audit. The example below highlights the critical need for the board and executive team to thoroughly review the risk framework before releasing it for use.

One large organisation in Australia had a risk framework that had its likelihood scale graduations described in terms of 'probability of occurrence'. While this is not uncommon, it is usually accompanied by some guidance on what period this probability applies to. This additional information is critical because, if the probability is 50% (or 0.5) and the period under consideration is 'per annum', we would expect a loss every two years, but if the probability period is the life of the facility (say, 20 years), we would have an even chance of not experiencing the loss before the plant is closed. This error was recognised in 2014, but not before people across the organisation had been putting their own interpretation on the applicable period and merging the results in a common risk register over a period of several years. In effect, all risk management work that had been done during this period was undermined and much rework was needed to identify where risk exposures had been underestimated.

4.1.4 Effective risk oversight

Risk registers can vary dramatically between different sites and projects even where the risk scenarios are similar. Although sites may have a common risk process, preferred methodology and requirements to record decisions, guidance on how to achieve this in a systematic and consistent manner is crucial. One way to do this is to identify risks in predetermined categories. At the executive or board level a 'picture' of success can be outlined along with potential setback scenarios. Market leadership will require both annual and long-term success. Figure 14 shows what this 'picture' could look like.

Figure 14: A risk management 'picture' for success



The risk picture provides a tool for executives and risk and audit committees to view risk in broad areas of impact and dig deeper to areas of concern. Comparisons between sites can also be made and substantial differences can be questioned.

The key message is that risk management is an important part of business efficiency and effectiveness and should be a primary input to annual budgets and work programs. Further, responsibility for risk treatment programs should be linked to performance and advancement. Internal auditors can test the effectiveness of risk control programs and the assessment in the risk registers can be reviewed and updated if an incident with serious potential occurs in the company or in the industry. Some companies have hardwired such linkages into their organisation, but many see risk management as a stand-alone activity.

The content of a risk register and its use indicate the health of risk management in an organisation. Although mining companies tend to spend significant time on risk assessments and the risk register, a few questions will help to gauge the effectiveness of the register and its benefits:

- Would the response of a general manager asked to name the top five risks in the company and the top three risks in their area of responsibility tally with the risk register? If the answer is yes, that is a sign that the officer trusts the register, or at least knows that the company leadership expects the register to be taken seriously.

- Is there a clear, logical division of risks in the register, rather than an ad hoc list with no predetermined structure?
- Do clear criteria exist for identifying and assessing a risk scenario?
- Are all risk scenarios actual risks? There is a tendency to use generic statements, such as 'poor health, safety and environmental (HSE) performance', 'reputation impact' and 'challenges in resuming an operation' and causes such as 'fatigue', 'corrosion' and 'loss of a key person'. Although causes and controls are an important part of good performance, that does not mean that they should be the subject of individual risk assessments. Risks should be stated as outcomes, such as 'failure to achieve start-up and production targets', 'difficulty accessing capital due to poor reputation' or 'increased regulatory pressure or suspension of operations due to health, safety or environmental performance'.
- Is the register put to effective use to benefit the organisation? For example:
 - Do senior managers use the risk register in quarterly reviews of project teams or during site visits?
 - Is there an expectation that monthly or quarterly project reviews will include an 'over the horizon' look at upcoming critical risks to explain the changing risk landscape?

A good risk register is concise and either covers the whole business or dovetails neatly with others to cover the whole business.

4.1.5 Enterprise risk assessment summary

The characteristics of leading practice in enterprise risk management include:

- support and genuine participation from the executive and board
- a framework designed specifically for the company's needs
- a small number of considered tools that come together to provide a picture of the organisation's exposure to major risks
- recognition that risk is not the opposite of opportunity, but that risk often has both upsides and downsides and that an appropriately considered risk may be a good investment.

Two Australian organisations that have taken the step of using quantified risk assessment across the business for all material business exposures (both monetary and moral) are Newcrest Mining and Orica. As a result, they can:

- look at the risk profile using bar and pie charts for analyses of focus areas
- compare similar parts of the business and question or improve them based on disparities
- aggregate risks across the business by value-chain component and by risk type
- review financial and social responsibility risks together or separately on demand
- demonstrate how they have identified critical controls
- provide cost-benefit comparisons between different risk improvement options.

The many factors that can undermine enterprise risk management need to be understood and actively managed. They include:

- a non-collaborative approach in which different risk owners insist that they require a special approach. Financial, project, safety, health and environment activity centres have all been known to claim that they have special needs, but that is rarely true. Even if special needs do exist (for example, for Monte Carlo modelling of projects, toxicology maximum safe exposure levels and environmental consequence complications), all can be included in a single business reporting framework.
- underestimating what the business can cope with—Risk assessment is occasionally ‘dumbed down’ because the workforce will not be able to understand it, when what the risk owners need to do is to make complex analyses understandable. In addition, people generally have little difficulty grasping the outcomes of risk analyses when given the chance, regardless of their education or qualifications.
- failure to make the risk system ‘talk’ to other systems in the business.
- the belief that one risk tool can do everything—The most basic tools are often used because of their simplicity, but this should be avoided.
- leaders who say that risk management is very important but do not engage with the analyses and do not ‘own’ the system.

Organisations should ask whether senior, site and department managers refer to the risk registers to remind themselves of gradually developing issues. They should also ask whether the events in the register are reactive (events that have happened) or proactive, and whether assumptions that a certain risk may occur under assumed circumstances are valid and justifiable.

4.2 Operational risk management

Operational risk management can be a simple but extremely important process for use by individuals and small teams that are about to undertake an activity for a relatively short duration, and where the person or people involved can realistically identify the main hazards that they face and identify simple but effective controls to manage those hazards. The risk tools are used in all phases of work in the field, including projects, development and production.

This section covers the very wide ground that remains for work in the field; that is, relatively complex and/or recurring hazardous situations in the production and processing of minerals. Typically, there are many potential causes of an incident and some existing controls in place to manage it, such as procedures, systems (for example, change management) and hard controls (guards, shutdown systems, bunding and so on). Nevertheless, no control is perfect and there is a need to assess the ongoing danger in these situations and test to see whether reasonable control improvements could reduce the risk further. There is no official name for this group of risk tools, but we refer to them here as ‘formal risk assessments’. In this context, ‘formal’ does not simply mean written down or approved by a senior person, because task safety assessments also require documentation and sign-off.

Table 2 provides some clarity on what constitutes a formal risk assessment.

Table 2: Formal versus activity assessment

FORMAL SAFETY ASSESSMENT	JOB HAZARD ANALYSIS OR ACTIVITY ASSESSMENTS
Pit wall collapse	Removal of a dewatering pump from the pit
Fall from elevated structures	Repairing a handrail on an overhead walkway
Toxic chemical release	Relocating toxic chemical drums
Unplanned explosives detonation	Repair work on the explosives store

Note that a fatality or serious environmental event can occur in every one of these examples. However, the number of people involved, the number of times the exposure occurs and the complexity of considering all of the potential causes mean that formal safety assessments require more detailed review and expertise, in addition to good maintenance and operating representatives, to do the appropriate analysis.

Organisations generally recognise the need for good minerals industry practice. This means that many typical industry controls will already be in place in production and processing operations. However, leading risk management philosophy is based on continuous improvement, and that means there is a need to constantly assess whether:

- the organisation is now in a better position to improve controls
- controls have deteriorated with time
- there is a better way of doing things than when key controls were first selected.

To deliver this, objective formal risk assessments need to be undertaken, recorded in a register and revisited every time an incident occurs in the business or the wider industry, when a critical incident becomes apparent in the organisation, or after a pre-determined period of time has lapsed (such as every two years).

4.2.1 The operational risk management process

The ISO 31000 process does not change for operational risk management. However, compared to task and activity assessments, formal risk assessments require a more rigorous identification of risk scenarios, a listing of causes and controls and an assessment of risk within a tightly defined company framework. Even at the more formalised level of qualitative, semi-quantitative and quantitative risk assessment, there is a great deal of variance in the thoroughness of the tools.

The workplace risk assessment and control process is a good example of base-level risk assessment because it involves the identification of risks, and identifies the most evident causes and the controls that are most relied on in order to establish an action plan (where practicable) for improving and keeping a watchful eye on the controls. The assessment of risk is a simple likelihood and consequence pairing, and a risk matrix is commonly, but not necessarily, used to show the various levels of risk ranking. Usually, workplace risk assessment and control is entered and maintained in a spreadsheet, of which Figure 15 is typical.

Figure 15: Typical risk spreadsheet

Project No:			Project Title:				Page: of		
Operation Description:				Documents:			Date:		
Team Leader:			Team Members:			Minutes By:		SOPs	
	A	B	C	D	E	F	G		
No	Step in Operation	Potential Incident/Accident	Probability	Consequence	Risk Rank	Current Controls	Recommended Controls	Agreed Action	Accountability

For most businesses, something similar to workplace risk assessment and control or a simple risk nomogram will form a significant part of the suite of risk assessment tools. However, and as previously described, risk leadership cannot be attained if such basic tools dominate the risk suite. For example, compare the base level of formal risk assessment with the first step in the processing of ore, in which various levels of separation are used to overcome increasingly stubborn by-products. It would make no commercial or technical sense to subject all recovered ore to sophisticated separation, yet the commodity available for sale would be of extremely low quality if it had been subjected only to crude separation. Similarly, the greater the sensitivity of the assessment, or the more extreme the price of failure, the more sophisticated the risk tool should become.

There should be clear guidance in the risk framework on the level of formal risk assessment required based on the level of risk, the possibility of a catastrophe, and the sensitivity and complexity of the subject under review. In addition, evidence that the guidelines are understood and adhered to across the organisation should exist. At a more detailed level, the occasions when formal risk assessment tools are needed will rarely be confused with occasions when a task hazard analysis, such as a job safety analysis or a job safety and environment analysis, is appropriate (see figures 7 and 8 for a description of when the various risk assessment tools should be used).

4.2.2 Operational risk management summary

Good businesses have clear guidelines (which consider the full spectrum of risk assessment tools) on the tools to be used and when to use them. Leading practice focuses on the highest consequence risk scenarios, no matter how low their probability. For mines, this almost certainly includes ground stability events; mine flooding and other potential multiple fatality events, including heavy/light vehicle interfaces and ore pile / ROM collapse; and serious environmental incidents, such as tailings dam collapses and releases of toxic or hazardous substances such as cyanide through the collapse of a tank, the rupture of a pipeline or an accident with a transport vehicle. Some risks may be away from the mine site but still be the responsibility of the mine operator, such as an accident to a transport vehicle carrying cyanide to or product from the mine, the contamination of groundwater or the pollution of a river or stream on which a local community relies for its water supply.

Leading risk practitioners define the most reliable tool to assess such events and determine whether their management is within the capacity of the site or organisation or whether external assistance is needed. In making this call, the organisation must consider what the team can understand and manage and what is practical for them to master. Whatever the decision, leading practice involves using tools that consume more resources than the most basic qualitative tools. Note that stipulating the in-depth risk tools for the highest consequence risk events is crucial, as is stipulating what constitutes an appropriate event for in-depth assessment.

Organisations need to then consider the subsequent levels in event complexity and consequence and define the risk tools to use. This is important to balance the consumption of resources with the extra insight and decision-making assistance that the tools provide. Care must be taken to avoid favouring one risk tool and using it exclusively or excessively—be it a simple matrix or an exquisite mathematical model. The use of risk tools should be analysed by users to ensure a balanced approach, noting the following:

- There is a real danger that the base formal risk assessment is undermined by over-simplistic assumptions.
- Likelihood and consequence guidelines need thorough review before issue.
- Qualitative assessment risk values can be deliberately or accidentally depressed by undertaking assessments in small bites. For example, 'Spill from chemical A drum' is low risk, 'Spill from chemical Z drum' is medium risk and so on, but the more general 'Chemical spill in hazardous storage' may be a much higher risk.
- The likelihood x consequence model can only assess the risk of a single outcome of an incident.
- There is a danger of becoming dependent on external consultants when using quantified risk tools if the consultants do not use methodologies that the organisation can manage effectively. Some companies have engaged senior risk personnel who are fully trained in quantitative risk management, while others have senior risk managers who understand the principles very well and can manage consultants as a result.
- There is potential to throw too many options into the risk framework. Many tools and methodologies have a degree of overlap. For example, there are overlaps between example workplace risk assessment and control and preliminary hazard analysis (PHA); layers of protection analysis (LOPA) and safety integrity level (SIL); hazard and operability study (HAZOP) and failure mode effects and criticality analysis (FMECA); and so on. It is important to make selections based on the needs of the organisation; for example, HAZOPs will be essential for a metal refining process using acid or other pressurised fluid systems but of little use for mine sites using only basic thickening and separation processes.

Organisations should ask:

- Is a one-tool-fits-all approach to formal risk assessments in use?
- Are the social and financial consequence ratings equivalent (that is, would they cause equal trauma to the business if they were to occur)?
- Are the same likelihood scales used for HSE and enterprise risks, and do they distinguish between a likelihood of one in 1,000 years and one in 1 million years (for example)?
- If quantified risk assessment is used,
 - is control of the process internal or outsourced?
 - is expenditure for large improvements justified without a cost-benefit analysis and business case?

Direct linkages need to be made between the outputs of risk assessments and standard company systems, including:

- having risk treatment programs inform the annual budget and planning processes
- having performance against risk treatment programs a significant part of personal performance reviews and bonus programs
- having mandatory reviews of relevant risk assessments when internal and external industry incidents occur
- tracking risk treatment completion percentages and at executive level.

4.3 Task and activity risk management

Task and activity risk management is generally aimed at protecting the health and safety of individuals. Work can be classified as either routine or non-routine. Routine work is that which is done periodically by an individual or work team. The purpose or objectives of routine work do not change but there is potential change in the work environment. A task is routine if the frequency of the activity allows the individual or work team to retain an understanding of the task and the work requirements from one execution to the next. Non-routine tasks are generally one-off activities. They can also include periodic but very infrequent activities, where understanding of the task might not be retained between task executions.

Work can also be classified as being either potentially hazardous or not potentially hazardous. A potentially hazardous task is one in which a person can be seriously injured if the task is not performed correctly or there could be serious long-term health consequences or possibly the risk of serious environmental harm.

Leading practice organisations manage potentially hazardous, routine work through procedures or work instructions that specifically identify the hazards, consequences and controls. Those doing the work are trained in the associated procedure or work instruction and their competency is confirmed. The competency assessment includes a demonstration of their understanding of the hazards, consequences and controls. Workforce consultation is also included (this is a regulatory requirement in some jurisdictions).

Supervisors in leading practice organisations ensure that people doing potentially hazardous, routine work understand the hazards and the controls. Critically, supervisors visit the workplace periodically during the work to ensure that the required controls are in place and are effective.

Procedures and work instructions in leading practice organisations are simple, easy to understand and difficult to misinterpret. They have been developed by people with a deep technical understanding of the hazards associated with the work, in consultation with those who carry out the work. Hazards associated with each step in the procedure or work instruction are listed and the controls are specified.

Potentially hazardous, non-routine work in a leading practice organisation is done using a task-specific analysis, commonly referred to as a job safety analysis (JSA), a job safety and environment analysis (JSEA) or a task hazard analysis (THA). The analysis has been developed by the work team performing the task and has been approved by the work team's supervisor. Most importantly, the work team has used the analysis process to develop a method of work that is free of significant hazards. Where hazards cannot be eliminated, the analysis specifies the controls. As with work under a procedure or work instruction, in a leading practice organisation the supervisor ensures that everyone doing work under a task analysis has an understanding of the hazards associated with the work and their required controls. The supervisor visits the workplace regularly to ensure that the controls are in place and effective. Leading practice organisations require that the task analysis be done by the work team that will be doing the work. They also mandate that the JSA, JSEA or THA cannot be transferred to another work group. They recognise that the discussion and analysis undertaken by the work group, and the consensus on controls, are the most important attributes.

Those planning and writing a JSA, JSEA or THA need to assume that unforeseen developments may occur. The JSEA needs to provide clarity on the process to be followed in such circumstances: specifically, under what circumstances does work stop to review the JSEA and who needs to then be involved?

There may be a need to include 'hold-points' in the management of high-risk work. This can ensure that local management or supervisors have agreed ahead of time how they will be assured that everything is ready to go at specific points along the work sequence.

Even within the controls listed in a procedure or job analysis, people can still be injured by minor hazards not included in the assessment. They can fall, can be hit by tools or can work in a way that causes minor sprains or strains. Minor hazard events can release hazardous substances into the environment or create issues with neighbours or the community. Leading practice organisations may manage the potential for these minor injuries and impacts by having their people apply a simple, personal process such as 'Take 5', which is designed to be used by individuals as they plan and execute tasks. At every stage of the task, the individual should be thinking about the task, the tools being used and the work environment to identify how they could be injured. Such methods encourage people to stop before they do anything; think about what they are about to do; assess the hazards; and respond by taking particular care in what they do. Take 5 is not a substitute for a more formal assessment as discussed above; rather, it is a continuous mental process applied by an individual as work is done.

Over recent times, Take 5s have shifted from being a personal, mental exercise to being a paper-based checklist. Organisations now sometimes retain and analyse paper-based Take 5s to verify that risks are continually assessed. However, controls are needed to ensure that the process is not compromised by Take 5s becoming superficial or completed ahead of time to provide an illusion of control by merely counting Take 5 forms. Borys (2006) casts doubt on the effectiveness of such informal tools if they become a 'paperwork' exercise describing work as viewed by management rather than work as it is done. In place of such counting, it is normally preferable to review Take 5s through interactions between supervisors and operators and discuss whether all hazards have been identified, whether the best controls have been considered and, most importantly, whether the controls have been implemented. These three questions provide far superior leading indicators than simply counting the number of forms completed.

Issues that negatively affect task risk assessment include the following:

- Loss of simplicity, which is difficult to achieve but an important driver. Driving simplicity is an important leadership role.
- Too many and/or too complex procedures:
 - a) Procedures and work instructions should only be developed, maintained and used for potentially hazardous, routine work or for work where failure to meet quality requirements can have a material impact on the business. Disciplined organisations limit the number of procedures, but strictly enforce their use.
 - b) Disciplined organisations also keep procedures short and focused. Procedures are designed to be used in the field by people doing work. They should be self-contained and provide the user with only the information needed to complete the related work safely and to the required quality while protecting the environment and avoiding community issues. Procedures and work instructions do not need to reference other documents and they do not need to reference standards or regulations. They simply need to provide instruction on how to complete a task properly and to achieve quality. They are best prepared by or in consultation with the person who does the work, modified where necessary by management.
- Misguided use of multi-dimensional risk matrices in assessing hazards. At times, these methodologies are used to find ways to undertake a task without controlling the inherent hazards, rather than to find an alternative method or effective controls. Multi-dimensional risk matrices are those with three or more levels of consequence and three or more levels of likelihood. While work groups are usually capable of assessing consequence (potential impacts from a hazard) at different levels, they are rarely able to competently assess the likelihood of the consequence being incurred—especially if the options are daily, weekly, once a year, or once every 10 years. Generally, the relative likelihood is irrelevant; if the potential consequence is credible and unacceptable, the work group should be seeking a work method that is free from the inherent hazard.

A useful example is the assessment of a task that involves safety and the field cutting of a steel pipe with an angle grinder. The use of a hand-held angle grinder is inherently hazardous. Even with protective guards, the kickback from the tool can hurt the operator severely. A workgroup may identify the potential hazard, but the likelihood chosen, if very infrequent, may make the activity acceptable according to the risk matrix. This is an inherent failure in using risk matrices. However, if this is recognised by those assessing the risk and there is a mechanism for escalating a risk with a low frequency, then risk matrices still have an important role to play. The hazard assessment process should encourage the work team to seek a means of cutting the pipe that does not involve the use of the angle grinder in the field (such as using a gas cutter, cutting the pipe in a workshop or using a pipe cutter).

5. IMPLEMENT AND COMMUNICATE

Key messages

- An effective risk management program requires commitment and adequate resourcing.
- The program must be led from the top, with executives engaged in the process and the outcomes.
- The organisation must seek opportunities to continually improve.
- An effective program hinges on good risk facilitation.
- Effective communication to all stakeholders is essential.

5.1 Introduction

Previous sections describe a range of risk management programs and solutions, but even the best analyses may be undermined by those who are affected by them if there is not an effective implementation and communication process. Leading organisations employ professionals both as risk experts and as discipline specialists to identify risks, advise on control options and monitor the implementation of those controls. However, the direct engagement of management, together with processes and structures to assess, monitor and communicate on the risks and their controls, is equally important and is discussed in this section.

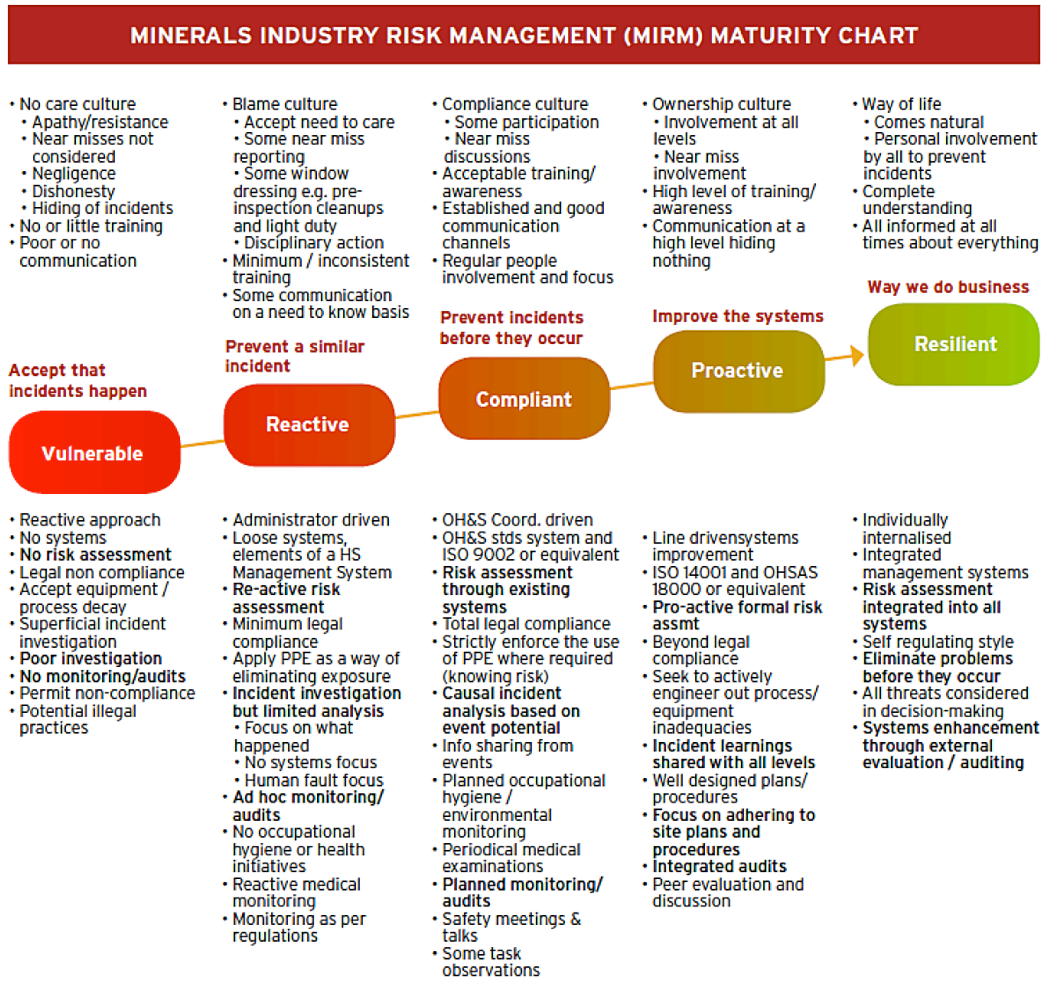
5.2 The board and senior management

Management has a pivotal role in controlling risk by establishing the organisation's risk appetite and risk tolerance. This is accomplished by specifying expectations on the content of the risk register and reporting processes for material risks. Failure to do this results in management focusing on important detail in some areas but very likely at the expense of good oversight of risk across the business (that is, not seeing the forest for the trees).

5.3 Maturity and decision-making criteria

The role of site leadership is to direct attention to aspects of the business that are most important. This especially applies to risk management, in which the ultimate definition of success is a lack of incidents. Without management paying overt attention to the state of risk controls, it is easy for everyday focus to slide to more urgent issues. A useful way of thinking about how organisations develop their ability to manage risk is the minerals industry risk management (MIRM) maturity chart (NSW Department of Primary Industries 2007), a version of the Hudson Ladder (Hudson 2001) shown in Figure 16. The model demonstrates how organisational attitudes to risk and management actions to deal with risk range from simply reacting to problems via an attitude of compliance as the key risk management strategy through to a building a resilient organisation in which excellent risk management practices are internalised. The MIRM maturity chart also provides a clear link between improvement in the culture of the organisation and the development of a systems approach.

Figure 16: MIRM maturity chart



Risk assessment results are very useful for decision-making, but they are only an input. No risk model can dictate a specific course of action, because all risk assessment is based on assumptions and simplifications. Risk indices and model results are a way of representing reality, but some organisations fall into the trap of managing the model rather than the risks. When presented with risk results, managers should ask probing questions, such as:

- What assumptions have been made about the events that may initiate the risk?
- How confident are we in the results?
- How have the results been benchmarked against performance (ours and others)?
- What are the limits of this analysis?
- What assumptions have been made about the effectiveness of controls and how have they been verified?

5.4 Making decisions on risk

Risk management is part of organisational decision-making. Such decisions will be informed by the knowledge and processes described in this handbook. However, poor risk decision-making has been a factor in a number of disasters as well as in workplace fatalities, major environmental incidents and community outrage. A model describing the factors affecting decisions about risk developed by Bofinger et al. (2015) groups the influencing factors into three categories:

- Factors associated with the risk.
- Factors associated with the external and organisational environments that overtly or subtly influence the decision-maker(s), such as the economic environment, business financial pressures, organisational culture and resource allocation.
- Factors related to the people making the decisions. This includes the way they think about a particular risk or situation (their mental model) and is developed from the person's knowledge, experience, beliefs, social and peer pressures, and physiological state (for example, fatigue and stress are known influencers on decision-making).

Effective risk management requires skilled application of the principles and tools outlined in this handbook and also requires an understanding of how both strategic and operational decisions are made in organisations. Bofinger provides a useful summary of decision-making theory and the factors affecting decisions about risk.

5.5 Risk communication

Risk communication can be interpreted differently, depending on the context in which the phrase is used. First, in relation to stakeholder engagement and the communication process it focuses on getting the best input to a good assessment and the best possible understanding and ownership by stakeholders. Second, risk communication is a field of research into why people question the logical engineering and scientific interpretations of risk. This is sometimes called risk communication theory. Both these interpretations are outlined below and discussed in detail in Appendix 3.

The ISO 31000 standard requires communication and consultation with internal and external stakeholders, as appropriate, at each stage of the risk management process and the risk process as a whole. A companion to ISO 31000 on communicating and consulting about risk is Guide HB 327 (Standards Australia 2010) *Communicating and consulting about risk*, which discusses communication and consultation as important considerations at each step of the risk management process and emphasises the value of:

- establishing a dialogue with stakeholders, focusing on consultation rather than a one-way flow of information
- developing a communication plan for both internal and external stakeholders at the earliest stage in the process
- ensuring that stakeholder perceptions of risk are identified, recorded and integrated into the decision-making process
- establishing a consultative team approach to define the context, ensure that all risks are identified and ensure that different views are considered
- facilitating engagement in the risk process.

These go hand-in-hand with the outcomes of technical and overall risk evaluations to provide a comprehensive risk management process. The primary reasons for seeking both internal and external stakeholder engagement are to ensure the best results from the assessment and to enable the results to be accepted.

When communicating on risk, especially with external and community groups, it is important to recognise that people commonly worry about some risks more than is necessary, to the point of phobias, while other risks are underestimated, such as the health risks of smoking. This has much to do with individual and group risk perception and whether or not the risk is voluntary. Appendix 3 is a detailed discussion on these aspects. For the purpose of implementing an effective risk management program at a mining business, it is important to recognise that an engineering or scientific evaluation of risk may be insufficient to allay the concerns of stakeholders. Fully engaging stakeholders and genuinely understanding their concerns are crucial to an effective risk management program. Community perceptions are often based on emotional reactions rather than rational assessments, and the management of community risks by mining companies is often a difficult to almost impossible task requiring a careful and professional approach.

5.6 The organisational structure

The importance of the risk management process should be reflected in the organisation's structure:

- The leadership chain (CEO, managing directors, regional directors and so on) need to be constantly aware of their top five risks and the status of controls for each.
- The senior risk professional should be part of or report to the executive committee.
- Executive meetings should include an overview of each area's critical risks and the status of controls.
- The senior risk professional should have oversight of risk in all aspects of the business.

5.7 Risk assessment facilitators

The risk assessment processes described in sections 3 and 4 are designed to identify and make appropriate decisions about risk controls. Those processes rely on having the right people and information and effectively following the right process. Risk assessments are also guided by a facilitator who is responsible for the quality of the outcome, making the skill and capability of that person pivotal to a good outcome. The risk facilitator must be involved in workshop planning in order to ensure that the workshop has the right people, sufficient time, the right data, the right process (followed effectively) and accurate minutes.

Every effort should be made to collect the right people in a single location for a specific (and sufficient) period of time. Sometimes compromises are necessary. For example, some participants may need to participate from remote locations, but remote participation should be restricted to those who have a very specific input; core participants should engage face to face. The right people will sometimes include external agency representatives, especially if an extreme event, such as the collapse of a major dam wall, is being assessed, and may include police, emergency services, local government, ambulance, health department, community and other representatives. Such an assessment would be a major exercise requiring careful planning and expert facilitation and reporting.

The key to effective facilitation is to stay primarily focused on the process that is being followed to ensure everyone's contribution in accordance with their knowledge and expertise. The facilitator needs to have skills in the risk assessment process and also good listening and communication skills and an ability to manage group dynamics. They need to have enough knowledge of the content of the discussion to effectively guide the group, but the best facilitator is usually not the technical expert on the system being studied. In fact, high content knowledge can distract from the facilitation role.

Without an effective facilitator, the group may experience a drifting focus, misunderstandings, uneven participation, difficulty in reaching consensus and ultimately conflict. It is often useful (if not essential) to have a second person acting as the recorder or scribe for the workshop, rather than expecting the facilitator to do that role in addition to facilitation. A good scribe will work with the facilitator to allow the discussion and recording to flow well.

Some processes require an independent facilitator to ensure that the views of the group are challenged and to reduce the chance of falling into 'groupthink', in which everyone agrees rather than putting forward a contrary view. An independent facilitator can sometimes ask the 'naïve' questions that others are uncomfortable voicing.

5.8 Continuous improvement

There is a need to continually improve an organisation's measurement, monitoring and review of risks, particularly those risks critical to the business and its people. This requires a review cycle, system and process. The ISO 31000 standard (2009:22) summarises this assessment as integral to the organisation's performance measurement system:

This can be indicated by the existence of explicit performance goals against which the organization's and individual manager's performance is measured. The organization's performance can be published and communicated. Normally, there will be at least an annual review of performance and then a revision of processes, and the setting of revised performance objectives for the following period.

When considering risk maturity and continuous improvement, it is worth noting that claims of compliance to ISO 31000 are often incorrectly made, as it is not a compliance standard and certification is not available. Like ISO 31000, risk management in a mining business is not static—it is a process of continual improvement.

6. CONCLUSION

This handbook has presented key risk concepts, processes and practices that are commonly applied or needed across the Australian minerals industry. Mining and mineral processing operations face many types of risks, including workplace health and safety, environmental, public health and safety, regulatory, production, reputation, conflict minerals, bribery and sovereign risk. The inherent uncertainty of risk combines with the adaptive behaviour of people and the nature of the mining industry to contribute to this uncertainty, which also has impacts on risk assessments. The impact of risks and their controls should be evaluated for the potential impact on the company's financial position.

Key messages when trying to understand risks in a mining business include the following:

- Cumulative risks and risks that may be normalised over time need special consideration.
- Stakeholders are a diverse group who vary in their perceptions of risk. Communicating and engaging with those potentially affected by mining industry risks is an essential element of good risk management and adds credibility to both the process and the organisation.
- Risk management processes must encompass the life cycle of a mine.
- Materials stewardship provides a useful framework for integrating risk management activities.
- The benefit achieved by risk management is measured by the effectiveness of the risk controls implemented; that is, whether controls are designed properly to control the risk, whether they are implemented as intended, and whether they are in place and working effectively.

When assessing risks, it is essential that the right analysis tools are chosen and are matched to the assessment complexity. Further, the assessment must be undertaken by people trained and skilled in the process. There is no one tool that will satisfy all requirements. Generally, the more complex techniques deliver more accurate results but at the cost of increased time and the need for greater specialist expertise to run the analyses. For this reason, a combination of techniques is usually the most efficient.

Risk management is not a one-off process—it is an important part of business efficiency and effectiveness and should be a primary input to annual budgets and work programs. Both the individual risks and the risk treatment program should be reviewed and challenged regularly to ensure that purposes are being met. Ideally, the responsibility for risk treatment programs should be linked to performance and advancement.

The effectiveness of risk control programs and the updating of registers following serious incidents in the company or the industry should be undertaken and tested by internal audit.

Finally, to be successful an effective risk management program requires commitment and adequate resourcing. It must be led from the top, with executives engaged in the process and outcomes, and the organisation must seek opportunities to continually improve.

Two of the key messages in all risk assessment are:

- An effective program hinges on good facilitation of risk workshops.
- Effective communication to all stakeholders is essential.

A case study from the Argyle Diamond mine (see box) is a good example of what can be achieved when these factors are implemented well.

CASE STUDY: Argyle diamond mine, Western Australia

In December 2005, Rio Tinto approved a major investment to extend the Argyle Diamond mine into an underground block cave operation. The existing open pit was scheduled to close in 2010, while the extension would allow the operation to continue until 2025. As would be expected for an investment of this size, the feasibility study included a comprehensive risk assessment covering all aspects of the proposal. These included not only the financial and technical risks associated with the change to a new mining method, but also the environmental and social implications.



Argyle diamond mine.

Source: Rio Tinto.

The team charged with assessing these sustainable development implications focused, in particular, on the impacts of the decision on two communities. The first was the mainly Indigenous regional population of the East Kimberley area where the mine is located. In recent years Argyle had adopted a strong localisation focus, moving away from a fly-in, fly-out model and increasing its Indigenous employment target to 40 per cent. The second focus was on the large number of people involved in processing Argyle's diamonds downstream in India—an estimated 220,000 workers. In this decision there was no 'do nothing' option, but each alternative involved its own particular set of risks and opportunities.

Team-based workshops were used to address the social risks and opportunities for the two community areas. The workshops were preceded by detailed commissioned research into the social and economic context of the two communities in question, and the potential impacts of the two scenarios. The workshops involved both internal and external participants and, wherever possible, used the same risk assessment protocols as the more technical areas. This allowed the outcomes to be readily integrated into the overall risk register for the project. New controls were developed for key areas and the residual risks recalculated. The social risks were among the highest rating group for the whole project. The workshops served to identify areas where proactive management could increase positive outcomes associated with the decision scenarios.

As the industry integrates sustainable development considerations into its decision making processes, the treatment of external socioeconomic risks and opportunities will become increasingly important. The 'mainstreaming' of these issues into risk management processes reflects their significance and importance to most large mining and processing operations.

APPENDIX 1: RISK ANALYSIS

Section 3.7 discusses options for risk analysis and overviews common methods used in the mining industry for qualitative, semi-quantitative and quantitative assessments. This appendix looks at these techniques in more depth and explains the application of each process.

Before delving into this information, a few words of caution: some of the simpler techniques described have become ‘seductively attractive’, as they can provide a quick or reasonably quick process that often provides an illusion of risk quantification and a perceived, associated understanding of risk foreseeability. Although this handbook has already recommended caution to maintain focus on prevention and control, the seductive nature of a numerical ‘answer’ can negate this rationality. Risk audiences should be somewhat distrusting of the products generated by the simpler analytical processes. Questioning the outcomes is helpful, but most importantly the target audiences should question whether the preventions or controls are well founded and appropriate. As discussed in Section 3.7.1, the insights that come from the social interaction of applying the techniques may be the greatest benefit. Many research papers and books have recognised these issues, such as Daniel Kahneman’s *Thinking fast and slow* (2011), in which he shows how the fast-thinking part of the brain trumps the slow, deliberate, analysis part of the brain most times, even though most times we do not realise it, demonstrating that the judgements made in risk management processes are heavily influenced by the orders in which choices are presented and creating bias that may be predictable but hard to control. Hubbard (2009), Pickering & Cowley (1990), and even the HSE (2009) behavioural economics Review recognise risk analysis shortcomings.

In short, this means be very wary of qualitative or semi-quantitative methods. As stated in Section 3.7.1:

In practice, people can reverse engineer qualitative analyses in their heads without really trying. When someone gets used to the simple matrix scales, they understand the impact that choosing values will have on whether work can proceed, require a pause for further analysis, require higher authority review or require more robust controls. Through this understanding, users can consciously or unconsciously influence outcomes.

A1.1 Qualitative approaches most commonly applied

Qualitative risk assessment methods are quick and relatively easy to use, broad consequences and likelihoods can be identified, they can provide a general understanding of comparative risk between risk events, and the risk matrix can be used to separate risk events into risk classes (ratings). The importance of this approach is that it can be used by the workforce on a mine (with supervision or facilitation) and it helps to give ownership for the risk assessment process.

A logical, systematic process is usually followed during a qualitative risk assessment to identify the key risk events and to assess the consequences of the events occurring and the likelihood of their occurrence.

Qualitative risk assessment techniques use descriptive terms to define the likelihoods and consequences of risk events. An example from ISO 31000 describes the magnitude of all consequences (or subsets of consequences, such as economic, financial, environmental or social) as insignificant—level 1, minor—level 2, moderate—level 3, major—level 4 or catastrophic—level 5. Similarly, likelihoods can be determined as almost certain—level A, likely—level B, possible—level C, unlikely—level D or rare—level E. The meaning of these descriptions, in terms of the various consequence types and likelihood levels, then needs to be developed.

Outputs from qualitative risk analyses are usually evaluated using a risk matrix format, such as the example in Table 2 in the 2008 edition of the *Risk assessment and management* handbook. The risk matrix incorporates the predetermined acceptance thresholds to determine which risks require treatment and the priorities that should be applied. Using the matrix, a risk rating for a given risk event can be selected by reading across and down the matrix using the assigned likelihood and consequence descriptors.

In the example matrix, there are 25 potential risk combinations and the risk outcomes have been divided into four risk levels (ratings). This type of matrix is typically used to compare risk levels for different events and to set priorities for risk treatment actions.

Qualitative approaches are best used as a quick, first-pass exercise where there are many complex risk issues and low-risk issues need to be screened out for practical purposes. Many organisations use qualitative methods for more comprehensive risk assessments, but this needs to be done with extreme care because qualitative approaches have serious shortcomings compared with more quantitative approaches. Key criticisms are that qualitative methods are imprecise, it is difficult to compare events on a common basis, there is rarely clear justification for weightings placed on severity of consequences, and the use of emotive labels makes it difficult for risk communicators to openly present risk assessment findings to stakeholders. Furthermore, the outputs from qualitative approaches are difficult to incorporate into financial business considerations.

A1.2 Semi-quantitative methods

Before discussing quantitative and semi-quantitative risk methods, it is worth looking at a non-mathematical expression of the basic risk formula. This expression is intended to help current matrix users understand quantitative concepts and therefore uses only consequence and likelihood terms:

Risk equals the sum of all credible consequence divided by likelihood pairings for a given event.

Semi-quantitative approaches to risk assessment are currently widely used in an effort to overcome some of the shortcomings associated with qualitative approaches. However, there are many traps for the unwary or those simply copying and pasting another organisation's product. Semi-quantitative risk assessments are intended to provide a more detailed prioritisation of risks than the outcome of qualitative risk assessments (a colour or seriousness label). Semi-quantitative risk assessment takes the qualitative approach a step further by attributing values or multipliers to the likelihood and consequence groupings.

Perhaps the biggest problem with semi-quantitative assessment comes from the fact that there is no definition of it. For example, ISO 31000 notes that it exists but does not define what it is, simply noting that it is neither quantitative or qualitative (Section 3.7.2). Sister standard ISO 31010 on risk assessment techniques states only that semi-quantified risk is measured in numbers based on a 'formula', which may vary.

A1.3 Quantification of consequence/likelihood matrices

Figure 17 shows an example of a semi-quantitative risk matrix where the likelihoods and consequences have been assigned numbered levels that have been multiplied to generate a numerical description of risk ratings. The values that have been assigned to the likelihoods and consequences are not related to their actual magnitudes, but the numerical values that are derived for risk can be grouped to generate the indicated risk ratings. In this example, extreme risk events have risk ratings greater than 15, high risks are between 10 and 15, and so on.

Figure 17: A basic semi-quantitative risk rating matrix

		Consequence level					
		1	2	3	4	5	
Likelihood level	Descriptor	Insignificant	Minor	Moderate	Major	Catastrophic	Risk rating
5	Almost certain	5	10	15	20	25	Extreme
4	Likely	4	8	12	16	20	High
3	Possible	3	6	9	12	15	Moderate
2	Unlikely	2	4	6	8	10	Low
1	Rare	1	2	3	4	5	

An advantage of this approach is that it allows risk ratings to be set based on the derived numerical risk values. A major drawback is that the numerical risk values may not reasonably reflect the relative risk of events, due to possible order-of-magnitude differences within the likelihoods and consequences classes.

In many cases, the approach used to overcome the above drawbacks has been to apply likelihood and consequence values that more closely reflect their relative magnitude, but which are not absolute measures. The semi-quantitative risk matrix in Figure 18 shows the relative risk values that would be derived by replacing the qualitative descriptions of likelihoods and consequences with values that better reflect their relative order of magnitude and provide more realistic relativity within each class.

Figure 18: A basic semi-quantitative risk rating matrix with logarithmic scale

		Consequence level					
		1	10	100	1000	10 000	
Likelihood level	Descriptor	Insignificant	Minor	Moderate	Major	Catastrophic	Risk rating
1	Almost certain	1	10	100	1000	10 000	Extreme
0.1	Likely	0.1	1	10	100	1000	High
0.01	Possible	0.01	0.1	1	10	100	Moderate
0.001	Unlikely	0.001	0.01	0.1	1	10	Low
0.0001	Rare	0.0001	0.001	0.01	0.1	1	

In this example, the risk assessment clearly indicates that there is an order-of-magnitude difference between likelihood classes and also between consequence classes. Using this approach, it is possible to derive numbered risk levels by multiplying likelihood and consequence levels for each cell of the matrix.

For example, a risk event that is possible (likelihood level = 0.01) and would have a major consequence (consequence level = 1000) would show a risk level of 10. If the issues were comparable, then this event would pose the same risk as another event that was, for example, likely (0.1) but with lower, moderate (100), consequences.

The matrix of Figure 18 also shows that, in this particular case, the risk ratings have been weighted to place more emphasis on higher consequence events (note that this is done by manoeuvring the risk descriptors but not the risk values, which remain accurate to formula). This is sometimes done to reflect an organisation's lower tolerance of higher consequence events but can be difficult to justify and can be misleading in overemphasising some risk events (if the full range of consequences can be expressed in the same terms, such as dollars, for example).

Where the method is intended to be used across a range of outcome types (such as safety, environment and financial), the development of consistent consequence tables is critical to the risk assessment. Effective consequences tables have been developed by relevant experts and for each type of asset or impact under consideration (for example, infrastructure, species, habitat, tourism, heritage and amenity) clearly describe the nature and extent of impact for each consequence level. Most importantly, the expert team needs to put considerable effort into the alignment of consequence levels across the table. Table 3 is a public domain example of a consequences table that was developed for a major Victorian environmental effects statement.

Table 3: Example of a consequence table

CONSEQUENCE LEVEL		NEGLIGIBLE	MINOR	MODERATE	MAJOR	HIGH
		Minimal, if any impact for some communities. Potentially some impact for a small number of (<10 individuals.	Low level impact for some communities, or high impact for a small number (<10) of individuals.	High level impact for some communities, or moderate impact for communities bay-wide.	High level of impact for communities bay-wide.	High level of impact State-wide.
		0.1	1	10	100	1000
Property/ infrastructure	Cost to repair/ replace (and lost revenues)	Approximate range from \$0 to \$0.1 million.	Approximate range from \$0.1 to \$1 million.	Approximate range from \$1 to \$10 million.	Approximate range from \$10 million to \$100 million.	Approximate range from \$100 million to \$1 billion.
Environmental	Ecosystem Function (need to consider resilience and resistance)	Alteration or disturbance to ecosystem within natural variability. Ecosystem interactions may have changed but it is unlikely that there would be any detectable change outside natural variation or occurrence.	Measurable changes to the ecosystem components without a major change in function (no loss of components or introduction of new species that affects ecosystem function). Recovery in less than 1 year.	Measurable changes to the ecosystem components without a major change in function (no loss of components or introduction of new species that affects ecosystem function). Recovery in 1 to 2 years following completion of Project construction.	Measurable changes to the ecosystem components with a major change in function. Recovery (ie within historic natural variability) in 3 to 10 years following completion of Project Construction.	Long term and possibly irreversible damage to one or more ecosystem functions. Recovery, if at all, greater than 10 years following completion of Project Construction.
	Habitat, communities and/or assemblages	Alteration or disturbance to habitat within natural variability. Less than 1% of the area of habitat affected or removed.	1 to 5% of the area of habitat affected in a major way or removed. Reestablishment in less than 1 year (relative to component seasonality) following completion of Project construction.	5 to 30% of the area of habitat affected in a major way or removed. Reestablishment in 1 to 2 years following completion of Project construction.	3 to 90% of the area of habitat affected in a major way or removed. Reestablishment in 3 to 10 years following completion of Project construction.	Greater than 90% of the area of habitat affected in a major way or removed. Reestablishment, if at all, greater than 10 years following completion of Project construction.
	Species and/or groups of species (including protected species)	Population size or behaviour may have changed but it is unlikely that there would be any detectable change outside natural variation/occurrence.	Detectable change to population size and/or behaviour, with no detectable impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery in less than 1 year (relative to species lifecycle) following completion of Project Construction.	Detectable change to population size and/or behaviour, with no detectable impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery in 1 to 2 years following completion of Project Construction.	Detectable change to population size and/or behaviour, with no detectable impact on population viability, or dynamics. Recovery (ie within historic natural variability) in 3 to 10 years following completion of Project Construction.	Local extinctions are imminent/ immediate or population no longer viable. Recovery, if at all, greater than 10 years following completion of Project Construction.
Social	Amenity - Recreation (water sports, fishing, beach going)	Short term interruptions in recreational use say 1 to 2 days.	Activities restricted in a localised area for short term periods (months).	Restriction on whole or parts of communities to pursue personal recreational pursuits when visiting the Bay during capital dredging period. No impact post construction period.	Long term inability for whole communities to pursue personal recreational pursuits when visiting the Bay post construction period (i.e. >2 years).	Long term inability for the general community to pursue personal recreational pursuits when visiting the Bay post-construction period for more than 10 years.
	Amenity - Sensory/ Perception (visual, noise, odour)	Short term impacts on Bay that alter perception as a high amenity place to live/visit. Region still seen as attractive place to live.	Short term (months) localised impacts on Bay that alter perception as a high amenity place to live/visit. Region not locally seen as attractive place to live.	Medium term (1-2 years) regional impacts on Bay that alter perception as a high amenity place to live/visit. Region not widely seen as attractive place to live.	Community perception that the Bay is significantly damaged. Bayside area loses appeal as residential area. Recover > 2 years.	Community perception that the Bay has experienced major damage as a residential location and a recreational area and is a place to be avoided. Recovery, if at all, is greater than 10 years.

	Non-Aboriginal Heritage	No measurable alterations to existing natural and human processes already impacting on heritage sites.	Detectable impact to State or Commonwealth significant site with heritage values remaining largely intact. OR Partial reduction in heritage value intrinsic to non-State/Commonwealth significant site.	Partial reduction in heritage value intrinsic to non-State/Commonwealth significant site. OR Substantial reduction in heritage value intrinsic to non-State/Commonwealth significant site.	Substantial reduction in heritage value intrinsic to non-State/Commonwealth significant site. OR Complete loss of heritage value intrinsic to non-State/Commonwealth significant site.	Complete loss of heritage value intrinsic to State or Commonwealth significant site.
	Aboriginal Heritage*	No measurable change in existing natural or human processes impacting on Indigenous Heritage Sites in any CDP Project Area.	Partial removal of one or more Indigenous archaeological sites on a specific landform within a single CDP Project Area.	Complete removal of one or more Indigenous archaeological sites on a specific landform within a single CDP Project Area.	Complete or partial removal of multiple Indigenous archaeological sites on different landforms within more than one CDP Project Area.	Complete or partial removal of multiple Indigenous archaeological sites on all landforms across Port Phillip Bay.
Economic	Commercial fishing and aquaculture	Limited or short term reduction in activity. Limited impacts localised and not Bay wide. No significant impact on regional businesses.	Short term reduction in activity in less than one year.	Significant reduction (5-30%) in fishery capacity. Recovery in 2 to 10 years.	Permanent significant reduction (30-90%) in sustainable yield of the fishery and/or aquaculture industry. Impact Bay wide.	Commercial fishing and aquaculture completely and permanently prohibited or destroyed across the whole bay.
	Tourism	Limited and short term reduction in tourist visitation. Limited impacts localised and not Bay wide. No significant impact on tourism businesses. Region still seen as attractive place to visit.	Short term reduction in tourism use. Recovery in less than 1 year.	Substantial reduction in tourism use. Recovery in 2-10 years.	Permanent reduction in visitation with changes in character of visitors. Impact Bay wide. Business viability compromised across wide range of sectors with substantial business failure in both direct and flow on sectors. Impact noticed on Melbourne region and State tourism numbers.	Permanent loss of icon tourism assets of national significance. Significant flow on affects to supporting businesses.
	Shipping	Shipping disruption of negligible consequence. Shipping disrupted for 1-2 hours.	Port closed for 24 hours.	Port closed for 1 week, or significant ongoing unexpected interruptions to Port business.	Port closed for 1-4 weeks.	Closure of shipping channel to all vessels. Infrastructure loss has extreme consequences. Shipping channel is not able to be opened for more than 1 month.
	Delayed project benefits			Project delayed around 1 year.	Project delayed by 1-3 years	Project delayed by more than 3 years.
Public health and safety	Minor injury/illness	Minor injury or illness to less than 10 individuals.	Minor injury or illness to between 10 and 100 individuals.	Minor injury or illness to between 100 and 1000 individuals.		
	Major injury/illness	Major injury or illness to 1 individual.	Major injury or illness to between 1 and 10 individuals.	Major injury or illness to between 10 and 100 individuals.	Major injury or illness to between 100 and 1000 individuals.	
	Fatality/serious injury, disability			1 fatality or serious injury	Between 1 and 10 fatalities or serious injuries.	Greater than 10 fatalities or serious injuries.

Consequence tables can be very useful for environmental impact statement risk assessments where the risks to diverse environmental and social assets need to be communicated to community stakeholders. Stakeholders often understand that consequence tables will never be perfect, or agreed on by everyone, but acknowledge that if well-constructed they allow useful comparisons between diverse types of events. Consequently, such semi-quantitative approaches have been supported by many stakeholder groups.

In summary, matrix-based semi-quantitative risk assessment methods are quick and relatively easy to use, and in the case of the Figure 18 option offer far more accurate relativity assessment between risk events than the Figure 17 semi-quantified option and the qualitative matrix. However, they offer no significant improvement in the ability to define more accurate assessments or provide a cost-benefit basis for treatment options (including a demonstration that risk is as low as can reasonably be argued if that is part of the company methodology).

A1.4 Consequence/likelihood nomograms

There are various ways of trying to stay in proximity to the theoretical risk formula. Generally, the faster the assessment, the cruder the value generated. While qualitative risk assessment is fast, it can give a distorted concept of risk proportionality, does little to help the user to handle the difficulty of assessing likelihoods for events rarely experienced in their workplace and allows only one likelihood/consequence pairing to be used for prioritisation purposes. Simple nomograms are intended to deliver assessments that take little longer than the matrix to undertake but do offer advantages in risk prioritisation and even action justification to a modest degree.

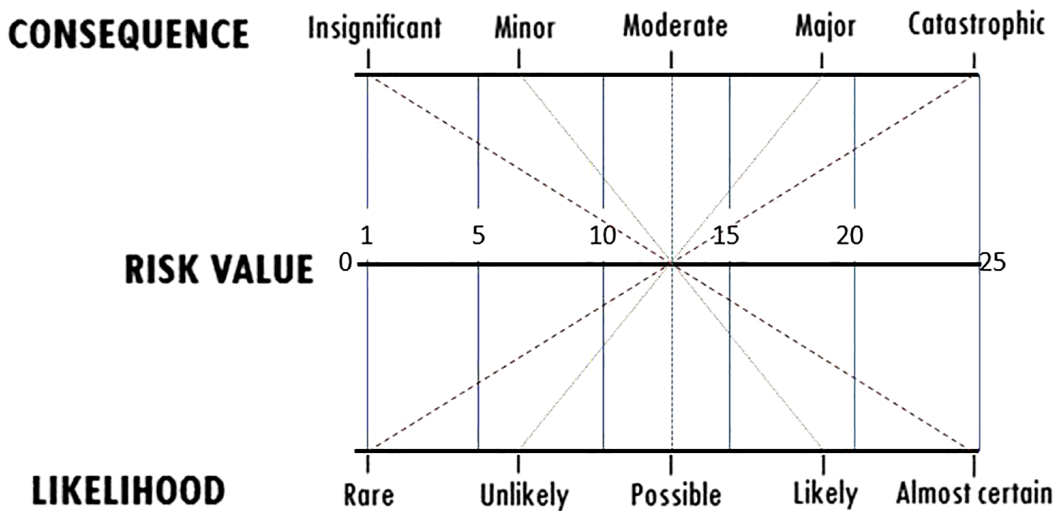
The risk nomogram has been around for at least 40 years but fell out of favour as the popularity of the matrix exploded in the 1990s. Perhaps the nomogram looked more technical, lacked colour, or simply never had the good fortune to be favoured in the early risk standards, but the most basic version is simply the same formula as the matrix but with much greater variation on the risk value estimated. However, it is inherently expandable to include some of the more valued parts of risk management, including risk appetite definition and cost-benefit analysis of treatment options, which are covered later in this section.

Nomograms and matrices are not simply different representations of the same risk values. The nomogram is a pure mathematical approach offering near-infinite values whereas the matrix offers a limited number of preselected risk value choices. Consider the relative risk values of the following five consequence/likelihood pairings:

- Insignificant and almost certain
- Minor and likely
- Moderate and possible
- Major and unlikely
- Catastrophic and rare

Figure 19 shows a nomogram with the same 1 to 25 (5 x 5) spread of risk values as the matrix in Figure 17. The five selected pairings go through the same score of 13, because they all intersect the mid-point between the scores 1 and 25 (that is, 12 plus the 1 unit representing zero risk that is ignored in the matrix but exists in any mathematical formula).

Figure 19: Simple risk nomogram with linear scale'



Comparing the values for these pairings to those on the matrix in Figure 17 gives values from 5 to 9 for these pairings. In other words, there are four units of difference in the matrix version for a single value in the nomogram version. This variation constitutes a major discrepancy in a method that only has 25 steps on the scale (that is, 80% variation between 5 and 9 for what is really the same risk).

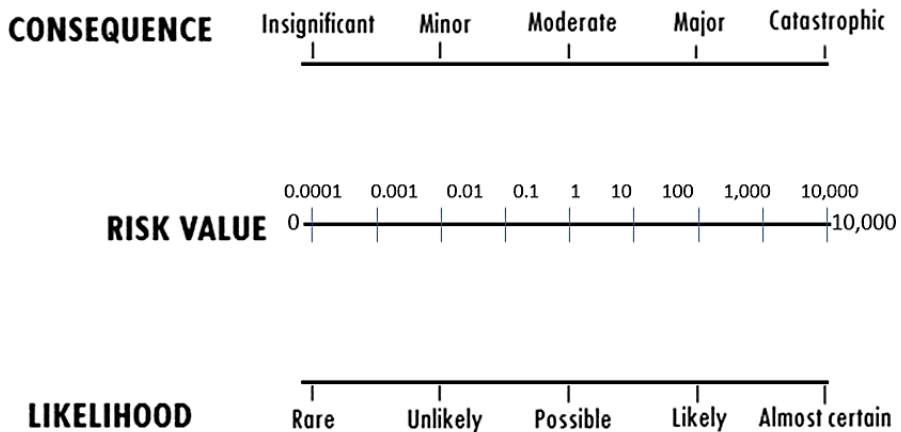
Table 4: Simple risk nomogram with linear scale

Consequence	Likelihood	Fig. 17 rating	Fig. 18 rating	Fig. 19 nomogram
Insignificant	Almost certain	5	1	13
Minor	Likely	8		
Moderate	Possible	9		
Major	Unlikely	8		
Catastrophic	Rare	5		

In simple terms, the nomogram does not allow accidental formula tampering other than to choose the type of scale to be used for the 'risk value' tie line, whereas the matrix allows the user to manipulate the values.

The above example is linear with each step the same increment as the last. As in Figure 18, a logarithmic scale could be used to better reflect likelihood values that are 10 times bigger each step (for example, once in 10 years, once in a 100 years, and so on) when reviewing several very different risk values. An example is shown in Figure 20.

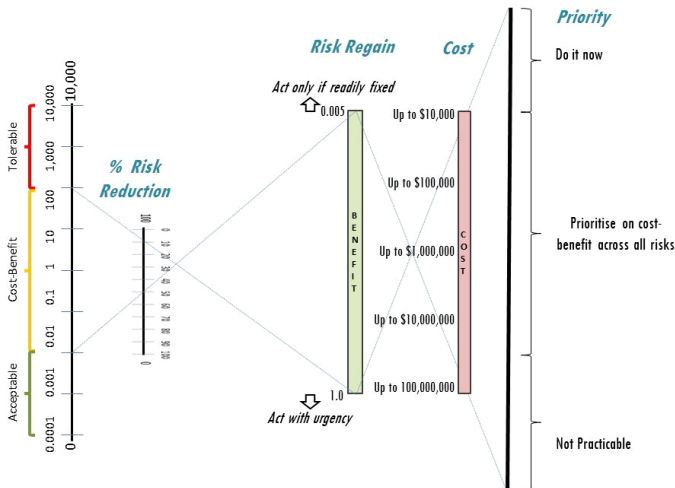
Figure 20: Simple risk nomogram with logarithmic scale



Figures 18, 19 and 20 all represent a genuine if simplified mathematical risk formula based on likelihood and consequence, with restricted values in the matrix in Figure 18. This is evident when comparing the Table 4 ratings for the five pairings previously described. All three reflect a common risk value for the five pairings. Note the much bigger spread of 0.0001 to 10,000 in figures 18 and 20.

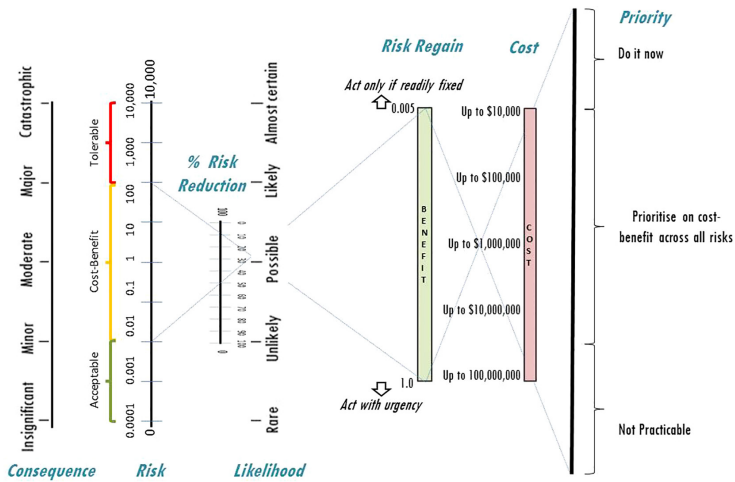
The above nomograms have a further and important enhancement to the matrix because it is possible to add a simple cost-benefit capability to the tool. Figure 21 shows the additional inputs that the assessors would make, specifically, an estimate of the percentage change in risk that the proposed treatment would make and a broad (perhaps qualitative) estimate of the cost of that treatment.

Figure 21: Basic cost-benefit analysis option for nomogram



Perhaps an early factor in the decline of nomograms was the fact that it was a paper-based concept using a ruler and pencil—antique tools compared to an LCD projected image of the matrix on a large screen. However, embedding the company’s specific values in the nomogram means it can do much more than just assess one of a limited number of risk values—in most cases it can provide a case for going ahead or declining a proposed risk treatment plan. Nevertheless, Figure 22 shows that the overall process can certainly look more daunting than the matrix.

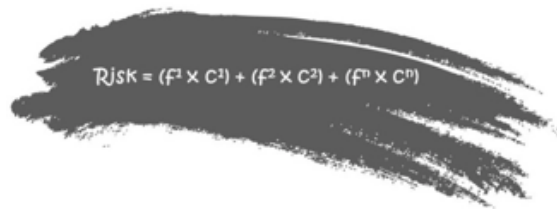
Figure 22: Integrated risk calculation and cost-benefit analysis nomogram



Today, however, it is possible to get both freeware and bespoke software programs for nomograms with relative ease, and the nomogram is far more resistant to unintended distortion than the matrix alternative.

A1.5 Spreadsheet-based semi-quantification

By using a slightly more advanced formula together with the power of spreadsheets, a significant improvement in risk management can be realised. The following formula is a more accurate expression of risk and can be easily applied to risk estimation using spreadsheets such as Excel.


$$\text{Risk} = (f^1 \times c^1) + (f^2 \times c^2) + (f^n \times c^n)$$

Source: Hogarth & Pooley (2015).

Where:

- c^1 = the lowest loss outcome under consideration and f^1 is the frequency with which that outcome is expected to occur
- c^2 = the next, more severe, outcome and f^2 is its associated frequency
- the value c^n is merely a way of saying 'et cetera', meaning that c^3 , c^4 and so on are increasingly severe levels of outcome
- the value f^n represents f^3 , f^4 and so on, the frequency of the occurrences associated with c^3 , c^4 and so on.

This risk formula asks the assessor to determine all the consequences of interest and then define the frequency of each one. Once each consequence has been multiplied by its frequency, the sum of all of the answers is the total risk. The assessor has to decide which consequences are of concern. Commonly, this approach considers only the more severe consequences (such as fatal scenarios in safety), but could if required look at a set of matrix consequence ratings of minor, moderate, major and catastrophic, ignoring only the 'insignificant' category. There are three reasons why only more severe consequences are considered:

- This approach takes a little more time than methods using the simple likelihood x consequence formula and so might be focused on the more serious events.
- To some degree, it can be assumed that the effective management of the more serious consequences will also lead to fewer less serious losses. Note that this would not be the case where less severe but nonetheless concerning events have no potential to create major or catastrophic events (for example, manual handling in safety or social pollutants like plant noise and odours).
- It is difficult to add the total risk of different consequences if their relationships are not clear. For example, is a fatality twice as bad as a disabling injury or 10 times as bad?

In practice, this risk formula has been modified by many major mining organisations, most commonly in regard to safety, to reflect the following: $\text{Risk} = f \times p \times c_{ave}$

Where:

the risk event is the initial loss of positive control of the situation (also known as the initiating event)

f = the frequency of the risk event in occurrences per annum

p = the probability that the event results in the minimum consequence under consideration (between 0 and 1)

c_{ave} = the overall average consequence (in dollars, fatalities, etc.).

This formula will deliver assessments that take longer than the matrix and simplest nomograms but does offer advantages in risk prioritisation, risk reduction estimation, and even a level of treatment justification. The calculation takes into consideration the chronology of a loss event and allows the separate consideration of prevention and mitigation aspects of the event for the application of the risk hierarchy. Note that the risk units are usually in loss per annum, such as \$millions/year or fatalities/year, but, as with quantitative risk assessment, the most serious events tend to occur once over decades or centuries rather than annually, and this leads to very small numbers.

The example in Figure 23 shows subjective drop-down lists that automatically apply semi-quantification as each selection is made. The assessment team has selected 'once in 100 years' for an inrush to occur, irrespective of whether anyone gets hurt. They have then selected the option that approximately 20% of the times an inrush occurs at least one person will die (0.2 probability), but that the average number of deaths when a fatality does occur will be 3.

Figure 23: Three-part spreadsheet risk assessment

Risk Event Equipment Fire on an underground vehicle	Type Safety
DELIBERATIONS	
Incidents per annum (f) Occurs most years	1
Probability of material outcome (p) Rare	0.001
Average outcome (risk distribution) (c_{ave}) Most outcomes at the low end	1.5
Risk = A x B x C	Risk Units
0.0015	Fatalities p.a.
or	
Material events	
1 material event every 666.67 years	

The result given above is in the same units that a quantified risk assessment would provide and therefore allows integrated reporting of both risk methods in a single risk framework. However, while it must be recognised that all quantification is subject to error (as is an annual budget estimate or a project schedule), it should also be noted that not all levels of risk quantification are equal in their accuracy, and this method is at the lower end of the accuracy scale for the more advanced formula set of tools. A useful option in all quantification tools is to express the risk in terms of how many years pass between predicted events, in addition to loss per annum (in this case, 166 years between events rather than just 0.006 or 6×10^{-3} per annum). The comprehensive nature of spreadsheets allows people to enable overwriting of the subjective values if desired. For example, where the team selected a frequency of 1 in 100 years for the risk event in preference to 1 in 10, or 1 in 1,000, such an amended spreadsheet would allow the team to insert, say, 1 in 300 years if they wanted to. This raises the accuracy of the toll significantly, but not to the level of full quantification options.

Estimating the risk reduction from a treatment plan can be done in two ways:

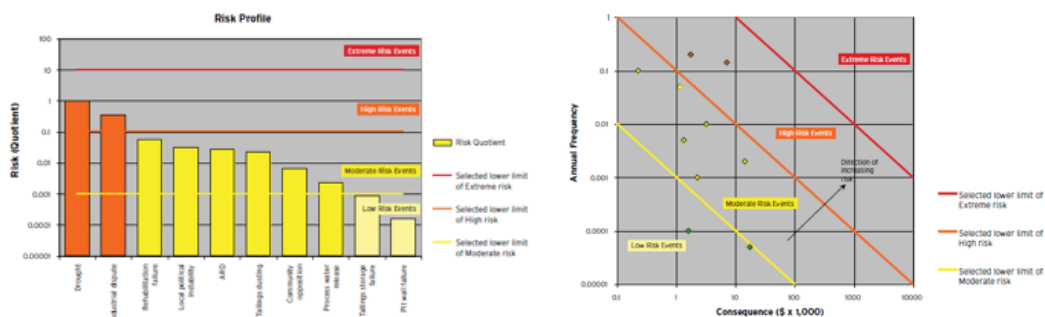
- estimate new values for each step in the calculation (f, p and c), or
- estimate the percentage reduction in each of the three steps.

Option 1 is less appealing without the ‘overwrite’ option because it limits the assessors to very large reduction increments. For example, even a reduction of approximately 50% in a frequency of 1 in 100 years is unlikely to result in a reduction to 1 in 1,000 years.

A1.6 Improved reporting options with semi-quantified methods

All but the first matrix and first nomogram shown in this section allow the expression of risk profiles in a bar chart format that shows genuine relativity between risks and allows the introduction of specific risk values for expressing risk appetite.

Figure 24: Some examples of quantitative risk reporting



Spreadsheet tools and nomograms will allow even greater granularity in the profile than the matrix option above because of the spreadsheet’s three-part calculation (compare combination locks with two and three wheels) and the limited number of risk values on the matrix (just nine on the matrix in Figure 18 compared to the nomogram’s relatively unrestricted choice).

A1.7 Quantitative methods

Quantitative risk assessment is increasingly applied in the mining and minerals industry due to business requirements to support financial decisions, to evenly compare financial risks with environmental and social risks, and to demonstrate transparency, consistency and logic of approach. However, quantitative risk approaches are often not intuitive and require some up-front learning investment by decision-makers.

As noted in Section A1.2, there is little official definition of the gap between qualitative and semi-quantitative assessment. However, the same can be said for the gap between semi-quantitative and ‘full’ quantitative assessment. For this reason, and for the purposes of this handbook only, we are going to make the following distinctions between semi-quantification and ‘full’ quantification.

Full quantification of risk involves a methodology that:

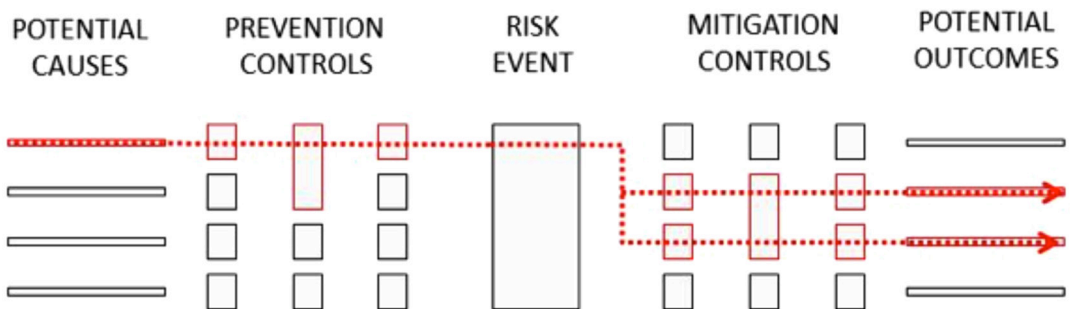
- uses a formula-based process that recognises there are multiple potential outcomes possible from a single event and that all significant outcomes must be considered in the risk estimate
- captures and shows in diagrammatic form all significant causes to, and outcomes from, a risk event
- uses the diagram(s) and calculation to provide an indication of the most serious failure concerns
- assists in the identification of the critical controls for the management of the risk event
- assists in the assessment of the improvement likely to be achieved by proposed treatment measures for use in cost-benefit deliberations.

There are two dominant forms of quantified risk assessment under the above definition. The one with the longest pedigree and the most technically pure is commonly labelled QRA, which is short for quantitative risk assessment. This approach to risk assessment was developed to address process safety and environmental disasters that occurred before 1990 in the nuclear, oil and gas, and chemical industries. It is mathematically intensive, but where the conditions are right for its application it is the most valuable for estimating the frequency of events and identifying the weak points in controls, even in situations in which the event has never occurred previously. The method remains the most commonly used in contained process industries, where highly hazardous fluids are contained and conditioned in pressure-containing equipment.

The second methodology does not have a widely recognised label, largely because when it was introduced at the end of the 1990s it was given the name ‘semi-quantified risk assessment’ and the acronym SQRA by its designers, but the semi-quantitative term has proven to be too broad since the introduction of national and global risk standards. Perhaps a better description of it is ‘experience-based quantification’ (EBQ) of risk to differentiate it from the maths and failure data based methodology of QRA. Over more than a decade, EBQ has become a common part of risk management in many global mining corporations and even in some oil and gas companies. This section describes the basics of both and then talks about their comparative advantages and shortcomings.

Both methods recognise the following general chronology of a disastrous event. One or more potential causes of a loss of control occurs and the preventive controls intended to manage the situation fail to do so, resulting in a risk event occurring (Figure 25). At this stage, the outcome is largely dependent on the performance of mitigation controls to prevent or lessen harm, and if those controls fail one or more loss outcomes will occur.

Figure 25: General schematic of a risk event

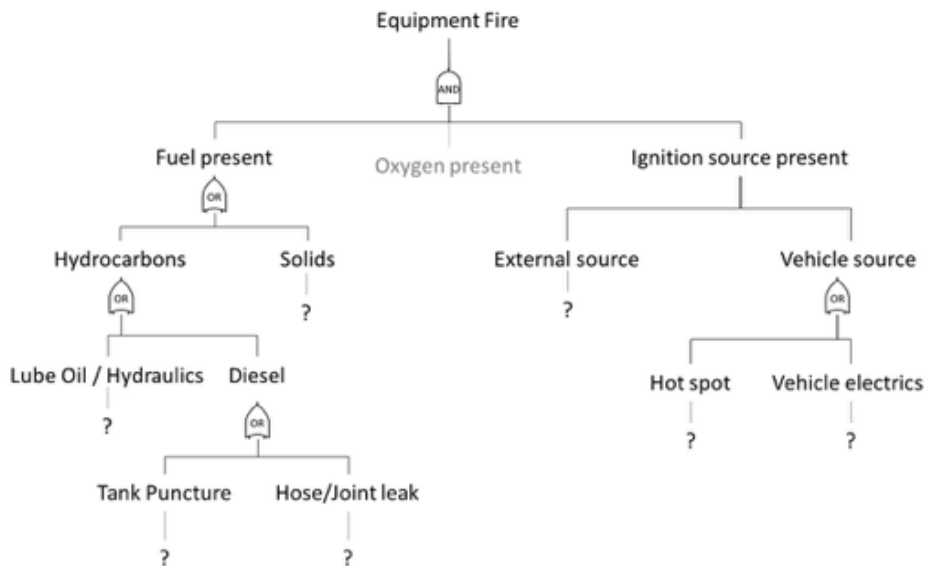


Both methods determine the risk event first and then look at potential causes, prevention controls, mitigation controls and the range of potential outcomes.

A1.8 Quantitative risk assessment

QRA is founded on two primary risk tools: the fault tree and the event tree. The fault tree (Figure 26) starts with the risk event, which is traditionally called the ‘initiating event’ in QRA and the ‘top event’ when specifically referring to fault trees. The analysis then works backwards in time to define what might occur to cause such an event. The following simple example shows how to take the first few steps towards building a fault tree for a heavy vehicle fire underground.

Figure 26: Fault tree example



The fault tree modeller needs to keep an open mind because the requirement is for a diagram that considers all credible failures, not just the ones that have already been experienced. The modeller knows that there are three essentials for a fire to develop but in this case can omit the oxygen factor because air is pumped throughout the underground mine.

Where two events are required for the scenario to progress to the next step, those two events are considered to go through what is called an ‘AND’ gate, meaning if either one is not present the event cannot occur. Fuel and ignition therefore constitute an ‘AND’ gate. This is a very different situation from an ‘OR’ gate, where the scenario will progress if either failure is present. Mathematically, ‘AND’ gates require the probability of the two failures to be multiplied; for example, if fuel is 80% likely to be present each year and ignition is likely to occur when fuel is present once in two years, a fire is expected to occur every 2.5 years ($0.8 \times 0.5 = 0.4$), whereas ‘OR’ gates result in the probabilities being added. For example, if hydrocarbons are likely to be present 1 in 5 years and solid fuel 6 in 10 years, there would be fuel present every 1.25 years ($0.2 + 0.6 = 0.8$). Note that the calculation process does not start at the top of the tree (where the selected examples have come from) but at the very bottom. The lowest layer of failures, where no further branches can be defined, are called ‘basic events’ and the calculation is started with the frequency of these events and continues with the probability that subsequent stages occur.

The second half of the storyline from risk event to predicted outcomes is covered by the event tree (Figure 27), which is a simple representation of the many courses that the event might take, depending on the effectiveness of the mitigation controls.

Figure 27: Event tree example

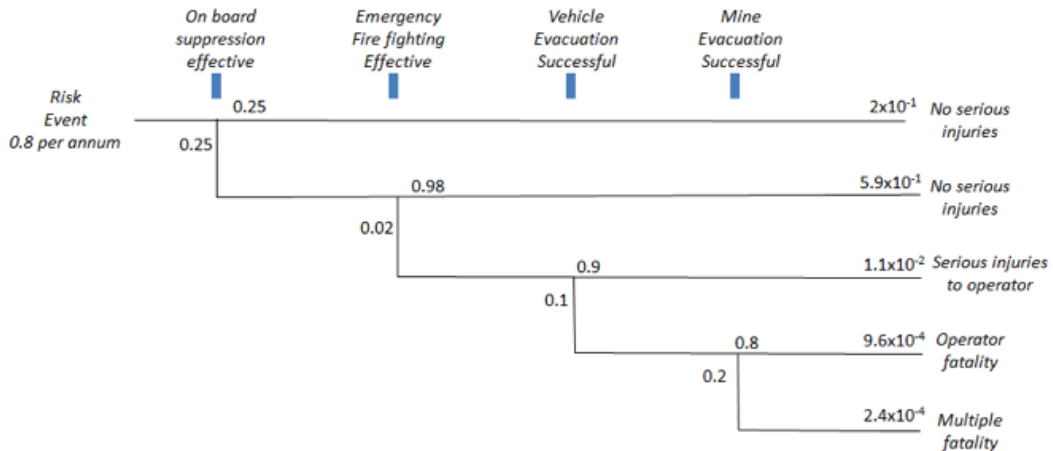


Figure 27 carries over the result from the fault tree and then looks at the probability that the event results in actual harm. The diagram shows four layers of mitigation control, from on-board fire systems on the vehicle to total evacuation of the mine. At each junction point, a probability for successful performance of the control is estimated or calculated with the help of 'consequence modelling'. In this case, a fatal event is forecast once in 833 years ($1/[9.6+2.4] \times 10^{-4}$), although further work must be done to estimate the number of fatalities, taking into account that some outcomes will result in more than one fatality and that the number of fatalities may vary with multiple events.

Consequence modelling usually involves sophisticated computer programs designed for specific tasks, most of which are intended for safety or environmental purposes (for example, fire, explosion overpressure, smoke and gas dispersion modelling). Such models can predict range, intensity, and mortality and morbidity rates.

QRA is seldom applied other than in the fields of health and safety, performance reliability and environmental impacts (for example, radiation and dam wall failure). Perhaps its nearest cousin in business risk is Monte Carlo modelling, in which a mathematical model of a project or the potential ramifications of a business decision can be constructed and run many thousands of times using random selection within the rules established for the specific model. In the simplest of terms, it is equivalent to the throwing of two dice many times and counting how many times 12 was rolled compared to 11, 10 and so on. Based on the law of large numbers theorem, the more throws that are made, the closer the results will be to real life. Monte Carlo modelling can be a great asset in the quantification of risk but cannot be used for all risk events and therefore cannot be used as a broad (enterprise) methodology.

In 1999 and 2000, there were multiple fatalities in two Australian goldmines: Northparkes in New South Wales and Bronzewing in Western Australia. The separate owners of those mines were so determined that such events would never occur again that they commissioned QRA consultants to undertake a QRA of all credible fatal risk scenarios. The assessments were done by two well-respected risk consultancies, but the QRA failed to meet expectations. The reasons were complex and largely specific to mining, and included the following:

- Humans play a direct role in mining (drilling, blasting, scaling, driving and so on), compared with the oversight and maintenance role involved in the automated processes typical of nuclear, oil and gas, and chemical plants, and mathematically accurate fault trees were difficult to generate as a result.
- No significant international failure database exists for mining, whereas it does for process facilities and aviation.
- The workforce did not 'buy in' to a computer-centric methodology (black box syndrome) and did not trust the results.

It is not true to say that QRA has no place in the resources sector. For example, some products are refined in automated systems, and the remote operation of automated mine production is being trialled now for the future. Nevertheless, several global miners use experience-based quantification (EBQ) as a standard tool across all operations.

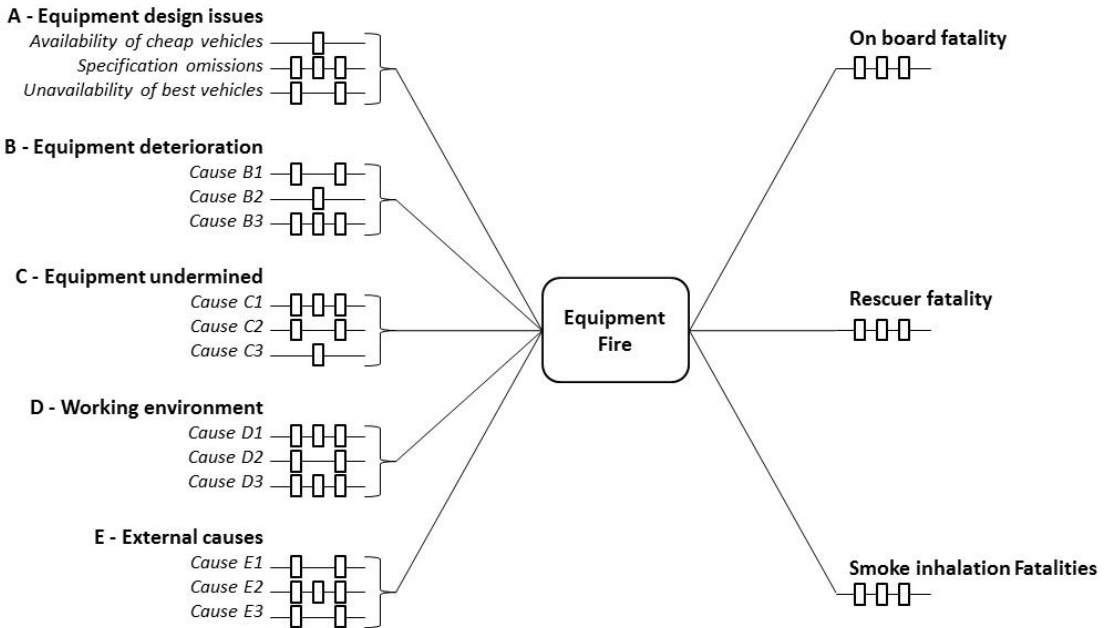
A1.9 Experience-based quantification

In response to the perceived shortcomings of QRA, Northparkes Mines worked further with the consultancy that did the original QRA to refine an EBQ approach that was not dependent on failure data collection, using instead the experience of a team of miners to estimate the frequency of reasonably common incidents and then estimate the probability of an incident progressing through various stages to a fatal event. This methodology was derived from that developed in Victoria for use by low-technology hazardous plant operators of chemical warehousing facilities and water treatment plants.

Where QRA uses a fault tree and event tree connected by the risk event, EBQ makes use of the bow-tie concept first developed by Shell and the American Bureau of Shipping. While EBQ constitutes an effective mathematical model, bow-tie analysis can be understood by a far greater number within the workforce but has no inherent mathematical value. EBQ therefore partners the bow-tie generator to a bespoke spreadsheet that calculates the risk and, by developing the bow-tie in a strict format, the combined tools assist in the identification of the most critical controls. Some EBQ tools have a fully integrated spreadsheet and bow-tie generator, whereas others use off-the-shelf products such as BowtieXP, BowTie Pro and the current version of the Shell/ABS original, Thesis.

Figure 28 provides a high-level view of the steps involved. First build a bow-tie model and, as with QRA, define the risk event first, which in the case of a bow-tie forms the knot in the centre. Then define causal categories (sometimes called causal pathways or groups) to help the assessment team in thoroughly identifying all credible causes and to help in the risk calculation later on.

Figure 28: Bow-tie outline



Next, identify separate causes under each causal category and identify any controls in place to prevent each cause resulting in the risk event (Figure 29). Having completed the prevention side of the bow-tie, do the same process for the mitigation side (outcomes and the controls intended to mitigate them).

Figure 29: Analysis of controls

Risk Event		Type
Equipment Fire on an underground vehicle whilst underground		Safety
Frequency of equipment fires per annum (f)	0.6	
BASIS FOR ESTIMATION		
There have been 8 underground vehicle fires in 20 years of operation but more in the last ten years than the first 10		
BASIS FOR ESTIMATION		
Onboard has approx 50% chance or doing the job but the emergency team is 10 times more effective (.5 x .05)		
If equipment is there it would be unusual for there to be no other people working, maybe once in 20 occasions		
Self-rescuers, conditioned FABs and a top emergency team mean something causing a lot of smoke would need to be present		
BASIS FOR ESTIMATION		
Probability of smoke inhalation fatalities (p)		
On board and emergency firefighting fails	0.025	
Area concerned unpopulated	0.95	
Successful evacuation / rescue	0.05	
Overall probability that event will lead to a fatality	0.0011875	
Overall frequency of a fatality	0.0007125	
Average outcome (c_{ave})		
Outcomes evenly balanced	1.235	
Risk = f x p x c		
0.000879938	Risk Units	
	Fatalities p.a.	
Material events		
1 material event every 1136 years		

A1.10 Comparison of strengths and limitations

While the development of a fault tree looks simple (especially with special software doing all the maths), the modeller has a very difficult task because not all failures act independently of each other. Some failures are more likely to occur if another control fails because they may be caused by common factors, including age, corrosion, design faults and fire, and the mathematical modelling of such situations is complex. A fault tree with all branches completed and with interactions between controls taken into account can be both large and complex.

Fully quantitative risk assessment is not very useful for environmental impact study risk assessments, where there are many diverse environmental and social issues that need to be evaluated and their risk communicated to the community and other stakeholders. People often do not accept the concept of placing a dollar value on 'intangible' and often emotive events. Quantitative risk assessments need to be carefully designed and implemented and to address many of the drawbacks associated with more qualitative approaches. Quantitative risk assessment is very useful for the development and justification of comprehensive risk treatment strategies and for internal business decisions that involve complex business risk events and a wide range of environmental and social issues. In such cases, the results can be readily expressed in financial terms and incorporated into the business planning process. However, the successful application of quantitative risk assessment depends on the availability of necessary data and the capacity and commitment of the organisation to manage the process and to source the required expertise.

Figures 30 and 31 are reproduced here from Section 3.7.4; they should help in the selection of risk analysis tools

Figure 30: Risk tool selection based on business phase

Phase	TOTAL RISK PROCESSES			MAJOR SUPPORTING PROCESSES		
	Informal (Step-back, Take 5 etc., JSA/JSEA etc.)	Formal qualitative (matrix, etc.)	Formal quantitative (QRA, EBQ, etc.)	Hazard identification (e.g. HAZOP)	Consequence (e.g. Monte Carlo, gas dispersion)	Control integrity (e.g. LOPA, SIL)
Concept	Red	Green	Green	Red	Red	Red
Feasibility	Red	Green	Green	Red	Red	Red
Design	Red	Green	Green	Green	Green	Green
Construct	Green	Green	Green	Red	Red	Red
Commission	Green	Green	Green	Green	Red	Red
Operate	Green	Green	Green	Green	Green	Green
Closure	Green	Green	Green	Red	Red	Red

Green - preferred risk tool, Red - non-preferred or unsuitable risk tool

Figure 31: Risk tool selection based on risk complexity

	TOTAL RISK PROCESSES			MAJOR SUPPORTING PROCESSES		
Consequence	Informal (Step-back, Take 5 etc., JSA/JSEA etc.)	Formal (matrix, etc.)	Formal (QRA, EBQ, etc.)	Hazard identification (e.g. HAZOP)	Consequence (e.g. Monte Carlo, gas dispersion)	Control integrity (e.g. LOPA, SIL)
Minor						
Significant						
Catastrophic						

Green - preferred risk tool, Red - non-preferred or unsuitable risk tool

APPENDIX 2: RISK TREATMENT— BOW-TIE ANALYSIS

Sections 3.8 and 3.9 explain the value and use of bow-tie analysis as a powerful tool to understand risks and their control. This form of analysis also enables management to identify those critical controls that require regular monitoring and reporting. This appendix explains the detailed application of the bow-tie analysis technique.

Figures 32, 33 and 34 show a basic or simplified bow-tie, the linking of bow-tie controls with a control assurance management system table and finally an advanced bow-tie that includes control failure modes and failure prevention factors. In all these figures, the unwanted event being analysed is shown in the centre of the bow-tie (also referred to as the 'knot'). The threats that could lead to the unwanted event are shown on the left side of the bow-tie along with the control measures that arrest (prevent or reduce) the likelihood that the unwanted event occurs. The consequences that might result from the unwanted event are shown on the right side of the bow-tie along with the control measures need to minimise the severity of the consequences.

Figure 32: A basic bow-tie diagram

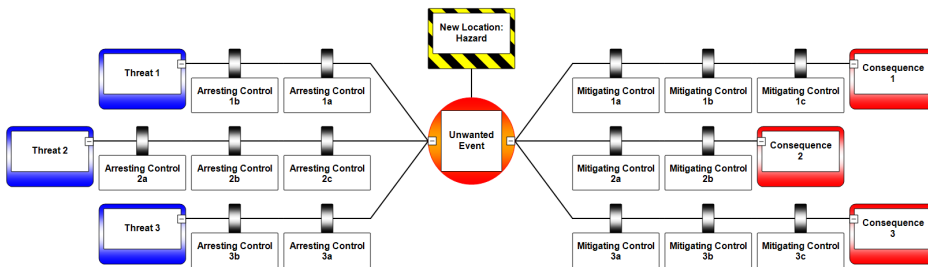


Figure 33: Basic bow-tie diagram with linkages to control assurance

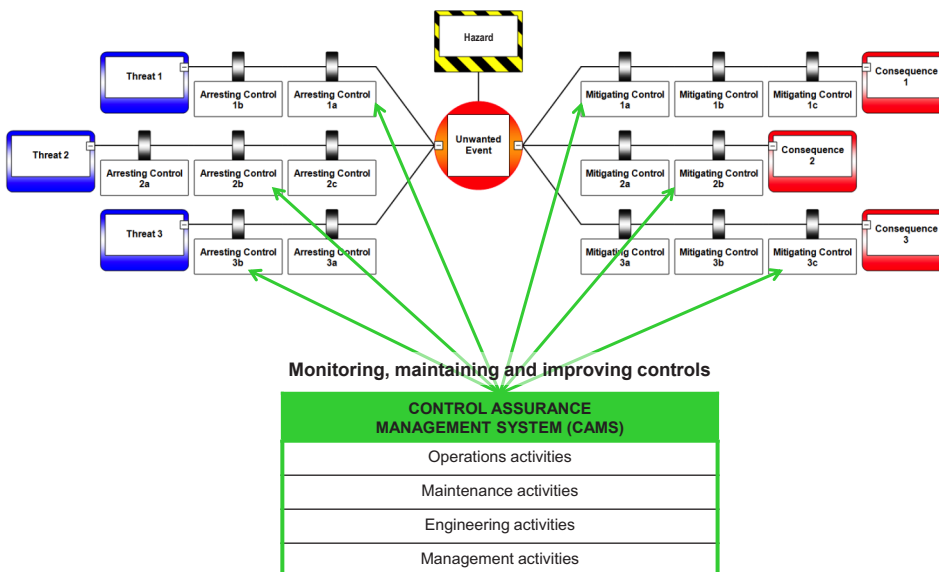
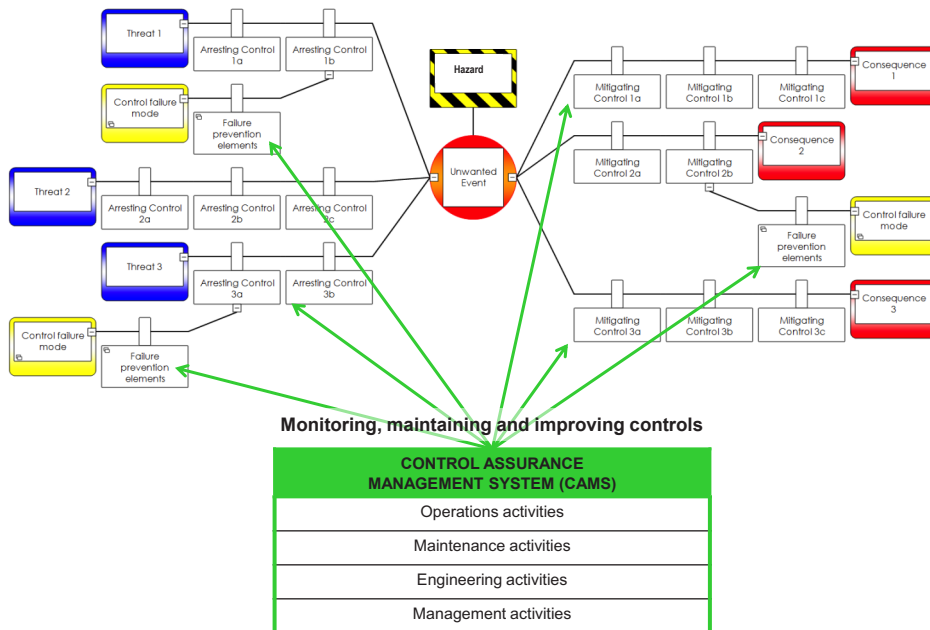


Figure 34: Advanced bow-tie with control erosion factors



The steps involved in performing a bow-tie analysis are.

1. Describe the unwanted event
2. Determine the scope of analysis
3. Identify the range of threats
4. Identify possible consequences
5. Identify prevention and mitigation controls
6. Identify failure modes for important controls
7. Determine assurance required.

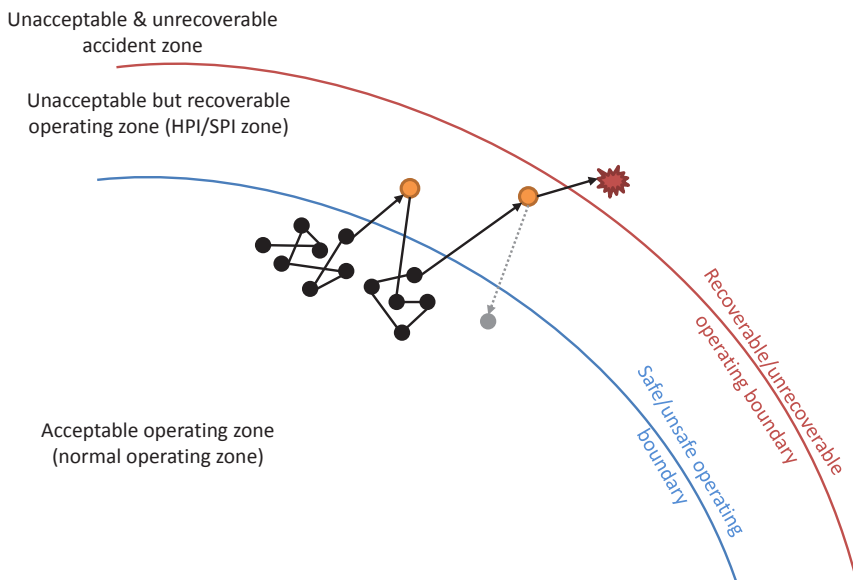
A2.1 Describe the unwanted event

To analyse an event using the bow-tie, it is necessary to describe the event. This description becomes the knot in the centre of the bow-tie. Having consistency in how the unwanted event is described assists comprehension, comparisons and benchmarking of bow-tie information across different sites, companies and possibly industries. Variability in the descriptions used for the knot will result in variability in the bow-ties and can compromise the identification of effective controls.

Ideally, the description of the unwanted event should describe the system when it has gone from being safe to unsafe, as shown in Figure 35. The description should be of the system state and not of the reasons why the system state has gone into the unsafe region. In some cases, it is clear what the description should be. For example, a fuel leak from a bulk fuel storage area (loss of fuel containment) could become the description of an unwanted event. However, in other cases it may not be clear what the description should

be. In those instances, discussion and discretion will be needed to determine the most appropriate description for the unwanted event. It may be helpful to think about describing the unwanted event as the situation that represents the last opportunity to intervene and prevent an accident. To help with this process, some good and poor examples of descriptions of unwanted events are shown in Table 5.

Figure 35: Safe/unsafe operating zone diagram



Source: adapted from Cook & Rasmussen (2005).

Table 5: Descriptions of the unwanted events that form the knot at the centre of the bow-tie

DESCRIPTIONS OF UNWANTED EVENTS FOR THE BOW-TIE KNOT	
GOOD EXAMPLES	POOR EXAMPLES
Ignition of fire in processing plant	Conveyor burnt down (This is a consequence)
Uncontrolled release of gas from storage vessel	Gas explosion (This is a consequence)
Diesel particulate emissions in workspace above acceptable limit	Diesel particulate emission overexposure (This is a consequence)
Unplanned movement or contact made by vehicle	Human error (Poorly defined generalised comment)
Falling person or object in working at heights situation	Fall arrest not used (This is an ineffective use of a control)
Exposure to uncontrolled electrical energy	Incorrect isolation (This is a poorly executed control)
Inrush event	Flooded mine (This is a consequence)
Loss of control of strata	Cave in or wall slump (These are consequences)
Misfire of explosives	Contaminated explosives (This could be a cause)

A2.2 Determine the scope of the analysis

The scope of the analysis should consider purpose and audience, boundaries of analysis and the resources available. The output should be tailored to suit its purpose and audience. Bow-ties constructed for official safety cases may be more comprehensive and detailed than those developed to communicate to frontline operations people.

The scope should be clearly defined in terms of:

- organisational areas and/or functions
- operational processes and/or functions
- spatial area
- time horizons
- people to be involved.

Bow-tie analysis should be performed by a team that includes people who understand the bow-tie process, those who understand the unwanted event and those responsible for actioning, monitoring and maintaining the controls. Others who can provide external subject matter expertise, benchmarking information, or both, should also be considered, as they may bring a different perspective to the analysis.

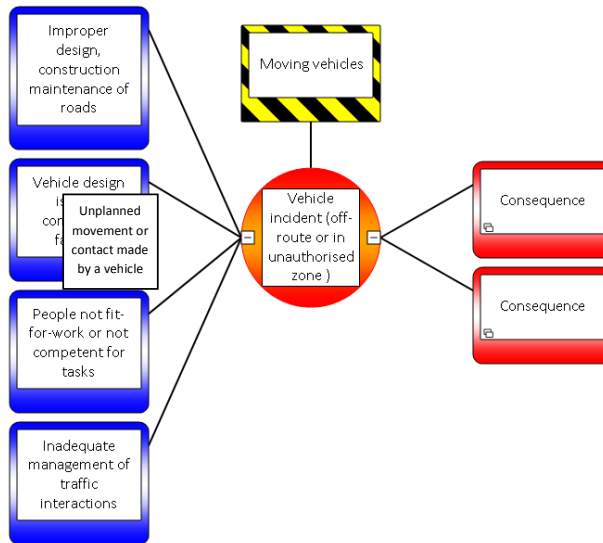
A2.3 Identify the range of threats

Unwanted events could be caused by a range of threats. The full range of causes should be considered, even those that may end up having no controls. Identifying the range of threats that could lead to an unwanted event should be done assuming no controls are in place. It should also be done using retrospective data (incident information) and prospective analysis. Generic examples for threats and causes are shown in Table 6. Specific examples of threats and causes for unwanted vehicle interactions in open-cut or surface mines are shown in Figure 36.

Table 6: Examples of threats that can lead to unwanted events

DESCRIPTIONS OF THREATS THAT GO ON THE LEFT OF THE BOW-TIE	
GOOD EXAMPLES	POOR EXAMPLES
Inadequate engineering (design and construction) of domain (includes not designing for location/climate conditions or inherent process variation, or to be compatible with interaction systems, users' mental/physical attributes and recognised standards; also includes not constructing to standards)	Building collapse (This is a consequence) Inadequate risk controls (This refers to controls) Adverse weather event (Need to design for all weather conditions)
Failure of equipment/technology or components of it (includes design, operation performance issues)	Control failure (This refers to controls)
Humans 'unfit' for work (includes competency, wellbeing and physiological aspects associated with fitness for work)	Human error Complacency (Poorly defined generalised statements)
Interaction issues between system elements—both human and technology (includes failure to manage unnecessary risk exposures and incorrect/poor instructions/compliance to managing necessary interactions)	Poor alarm management (This refers to controls)

Figure 36: Examples of threats for an unwanted vehicle interaction



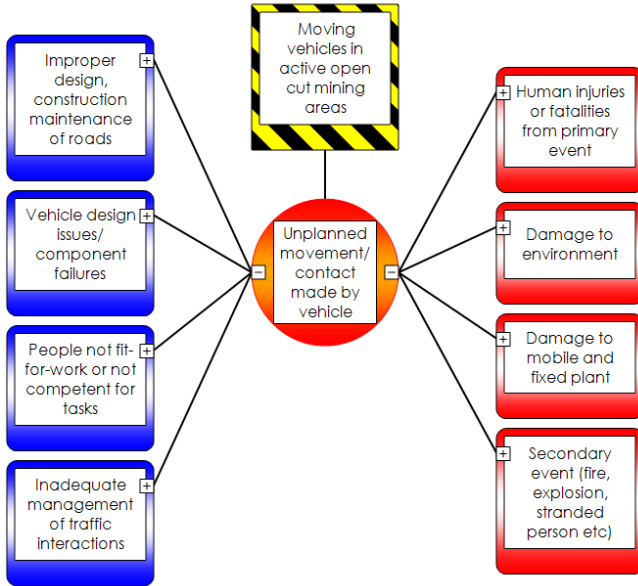
A2.4 Identify possible consequences

Unwanted events can lead to a range of impacts and outcomes, from the negligible to the catastrophic. The impact or outcome of an unwanted event is called a consequence. It is important to try to identify the full range of possible consequences that might result if the unwanted event occurs and if no mitigating controls are in place. They could include no impact (near miss) and secondary event impacts, as well as acute and chronic impacts on humans, assets, the environment, reputation and financial performance. Examples of specific consequences that may result from an unwanted vehicle interaction in an open-cut mine are shown in Figure 37. There should be an overlap between the consequences highlighted on the bow-tie and those described in the risk matrix (see Table 7 for examples).

Table 7: Examples of consequences that can result when an unwanted event occurs

DESCRIPTIONS OF CONSEQUENCES THAT GO ON THE RIGHT OF THE BOW-TIE	
GOOD EXAMPLES	POOR EXAMPLES
Secondary events (includes 'domino effect' or 'chain reaction' events such as the ignition of flammable spills or the explosion of dust clouds)	Airbag deployment (This is about control performance)
Harm to humans (includes death, acute and chronic injuries, acute and chronic health impairments)	Harm to employees (if it ignores contractors/public)
Asset damage (includes damage to own/internal and external/others' assets)	Damage to fire protection (This is about control erosion)
Environmental damages (include harm to air land, and water onsite and offsite)	Global warming (Should be more specific e.g. increase in carbon emissions)
Production losses (include loss of processing ability, loss of product quality and volumes and supply chain disruptions)	Inadequate plant design (This is a threat)
Reputational damage (includes damage within company and with communities, regulators and other stakeholders)	Number of damaging news articles (if other avenues of damage are ignored)

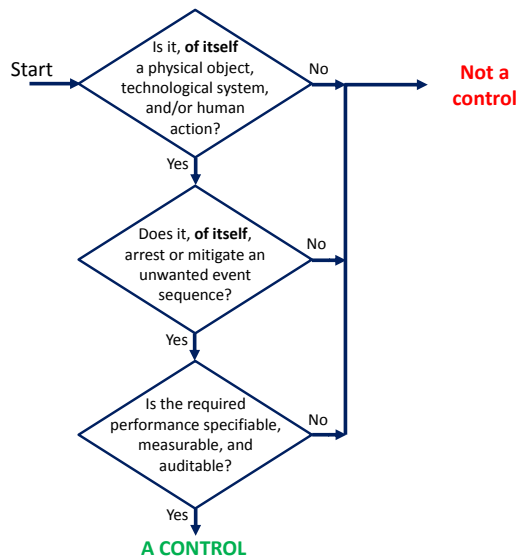
Figure 36: Examples of threats for an unwanted vehicle interaction



A2.5 Identify prevention and mitigation controls

A control is an object or human action that of *itself* will arrest or mitigate an unwanted event sequence. Arresting controls are used to reduce likelihood of unwanted events occurring. Mitigating controls limit the adverse effects of an unwanted event if it does occur. The decision tree shown in Figure 38 has been constructed to assist with the determination of a control. This definition of control means that elements such as policies, procedures and ‘common sense’ are *not* controls. These elements may be important in helping to maintain effective control and prevent control failure, which is discussed below.

Figure 38: Decision tree for determining risk controls



An example of a control that meets the criteria set out in the decision tree is shown in Figure 39. In this example, the control is a sign indicating to drivers that the safe maximum speed is 40 km/hr. Limiting driving speed to 40 km/hr is a human action and, if the limit is observed, a vehicle may be stopped with a reasonable margin of safety before an accident occurs. The reduced speed at the time of impact mitigates fatality consequences, the performance is specifiable (for example, 40 km/hr), it is measurable with speed cameras and it is auditable by collecting speed versus fatality information, as shown in Figure 39.

People may be unsure about whether particular elements are or are not controls. In such cases, it is worth asking the following questions:

- If you were the person in harm's way, would the element be something that is going to help prevent you, the plant and the environment from being harmed? And can you check to see whether the element is working or will work as required when needed? If the answer is yes, then the element is probably a control. If not, then the element may be a control failure prevention element or a control assurance management plan element.
- Is the element something critical to preventing or mitigating an unwanted event? If so, it is probably best placed as a control.

Figure 39: Example of a control



To ensure the selection of optimal control sets, it is important to consider the following:

- *Adequacy of individual controls:* This is an assessment of whether the selected control is designed to robustly and reliably deliver the desired control action when needed. If an individual control is assessed as not being sufficiently robust and reliable, it is recommended that the control be replaced by a better control or be supplemented with additional controls. The linked tables below have been provided as an example of how the adequacy of individual controls might be evaluated.
- *Adequacy of control suites:* This assessment is a check to determine whether there is a complete set of controls on each arm of the bow-tie. Ideally, there should be controls that intervene at all stages of the accident sequence from early to late on both sides of the bow-tie.

Figures 40 and 41 give examples, but before using these figures and table they should be reviewed and tailored to the event being analysed and to the particular organisational context. Guidelines can then be provided on how to assess adequacy. For example, a site could recommend that there be at least one 'highly adequate' or two 'very good' controls for each stage of the accident sequence.

Figure 40: Example of a matrix that can be used to subjectively determine control adequacy

CONTROL QUALITY	No object/technology component to control	Coverage, availability and reliability of OBJECT/TECHNOLOGY component of control				
		Works in >95% of scenarios/areas	Works in 90%-95% of scenarios/areas	Works in 75%-90% of scenarios/areas	Works in 50%-75% of scenarios/areas	Works in <50% of scenarios/areas
No human action component to control		Excellent	Very Good	Good	Poor	Very poor
Coverage, availability and reliability of HUMAN ACTION component of control	Works in >95% of scenarios/areas	Excellent	Very Good	Good	Poor	Very poor
	Works in 90%-95% of scenarios/areas	Very Good	Good	Good	Poor	Very poor
	Works in 75%-90% of scenarios/areas	Good	Good	Poor	Poor	Very poor
	Works in 50%-75% of scenarios/areas	Poor	Poor	Poor	Very poor	Very poor
	Works in <50% of scenarios/areas	Very poor	Very poor	Very poor	Very poor	Very poor

Determine quality of control with matrix above. Then use control quality and your assessment of control impact to determine control effectiveness with matrix on right

CONTROL EFFECTIVENESS	CONTROL IMPACT - Degree to which the control impacts residual risks					
	Significant impact	Impact	Slight impact	No impact	Adverse impact	
	Presence/action of control significantly reduces residual risk. Absence/failure of control significantly increases the residual risk	Presence/action of control reduces the residual risk. Absence/failure of control increases the residual risk	Presence/action of control slightly decreases the residual risk. Absence/failure of control slightly increases the residual risk	Presence/action or absence/failure of the control does not change the residual risk	Presence/action of control has potential to increase residual risk	
CONTROL QUALITY from matrix one	Excellent	Highly adequate	Very good adequacy	Marginally adequate	Poor adequacy	Inadequate
	Very Good	Very good adequacy	Very good adequacy	Marginally adequate	Poor adequacy	Inadequate
	Good	Very good adequacy	Very good adequacy	Marginally adequate	Poor adequacy	Inadequate
	Poor	Marginally adequate	Marginally adequate	Poor adequacy	Inadequate	Inadequate
	Very poor	Poor adequacy	Poor adequacy	Inadequate	Inadequate	Inadequate

A2.6 Identify failure modes for important controls

It is important to identify the failure modes for important controls. These are the factors that could cause a control to fail or could cause a control's performance to erode over time. Failure modes can be addressed in detail using advanced bow-ties or they can be addressed as discussed in Section A2.7. If the latter method is chosen, there is more potential that something will be overlooked, whereas if they are addressed with an advanced bow-tie there is more clarity as to how individual controls are going to be managed. As a minimum, identifying control failure modes should be considered for:

- controls that have a significant impact on arresting likely causes
- controls that arrest a number of different causes
- controls that mitigate catastrophic/severe consequences
- controls that mitigate a number of different consequences.

Examples of some control failure modes and failure prevention elements are listed in Table 8, while Figure 42 shows a typical bow-tie diagram using the example of an unwanted vehicle interaction in an open-cut mine.

Advanced bow-ties extend the bow-tie analysis to include:

- identification of control failure modes, which describe factors that can cause a control to fail or undermine the effectiveness of the control
- identification of failure prevention elements, which are additional controls or control assurance management system elements that are needed to address the failure modes.

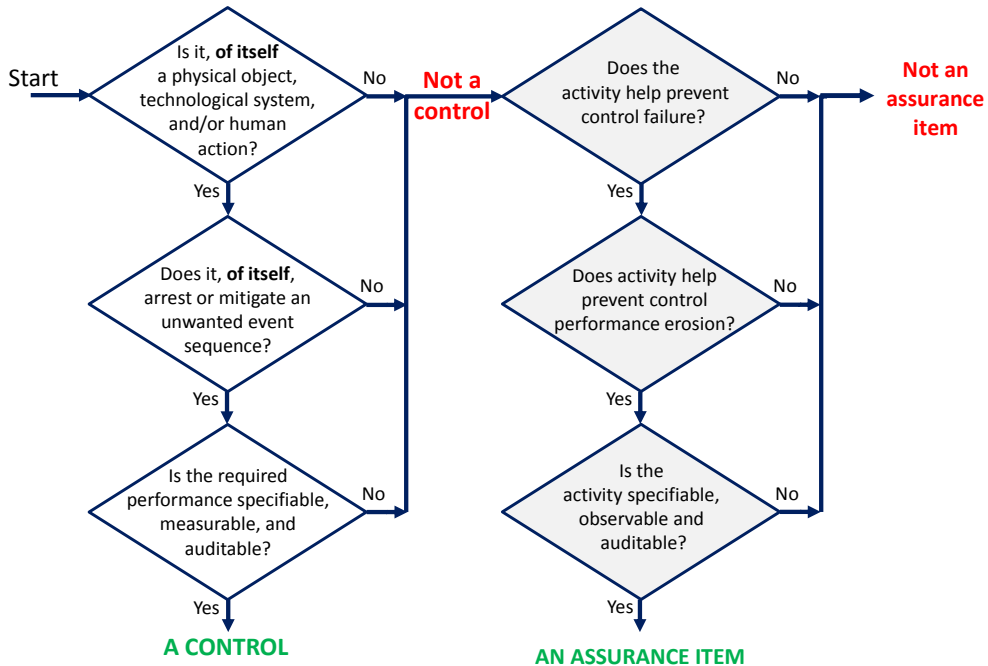
Table 8: Examples of control erosion factors and erosion prevention elements, by control type

TYPE OF CONTROL	EXAMPLES OF CONTROL FAILURE MODES BY TYPE OF CONTROL	EXAMPLES OF FAILURE PREVENTION ELEMENTS
Physical objects	Wear/corrosion Damage Incorrect placement of temporary objects	Design specifications Condition-monitoring programs Preventive and breakdown maintenance Damage response procedures
Technological system	Wear/corrosion Damage Component failure System failure Software/code changes	Design specifications Condition-monitoring programs Preventive maintenance Damage response procedures Management of change
Human action	Normalisation of deviance Desensitisation (e.g. to alarms, signs) Erosion of competencies and skills Availability factors (e.g. workload, distractions)	Induction and training programs Mentoring programs Competency-based assessments and reviews
Other	Poor situation/environmental conditions (e.g. lighting, noise, housekeeping) Failure to manage changes	Work environment standards and monitoring programs Management of change policy and process, including audit

A2.7 Determine assurance required

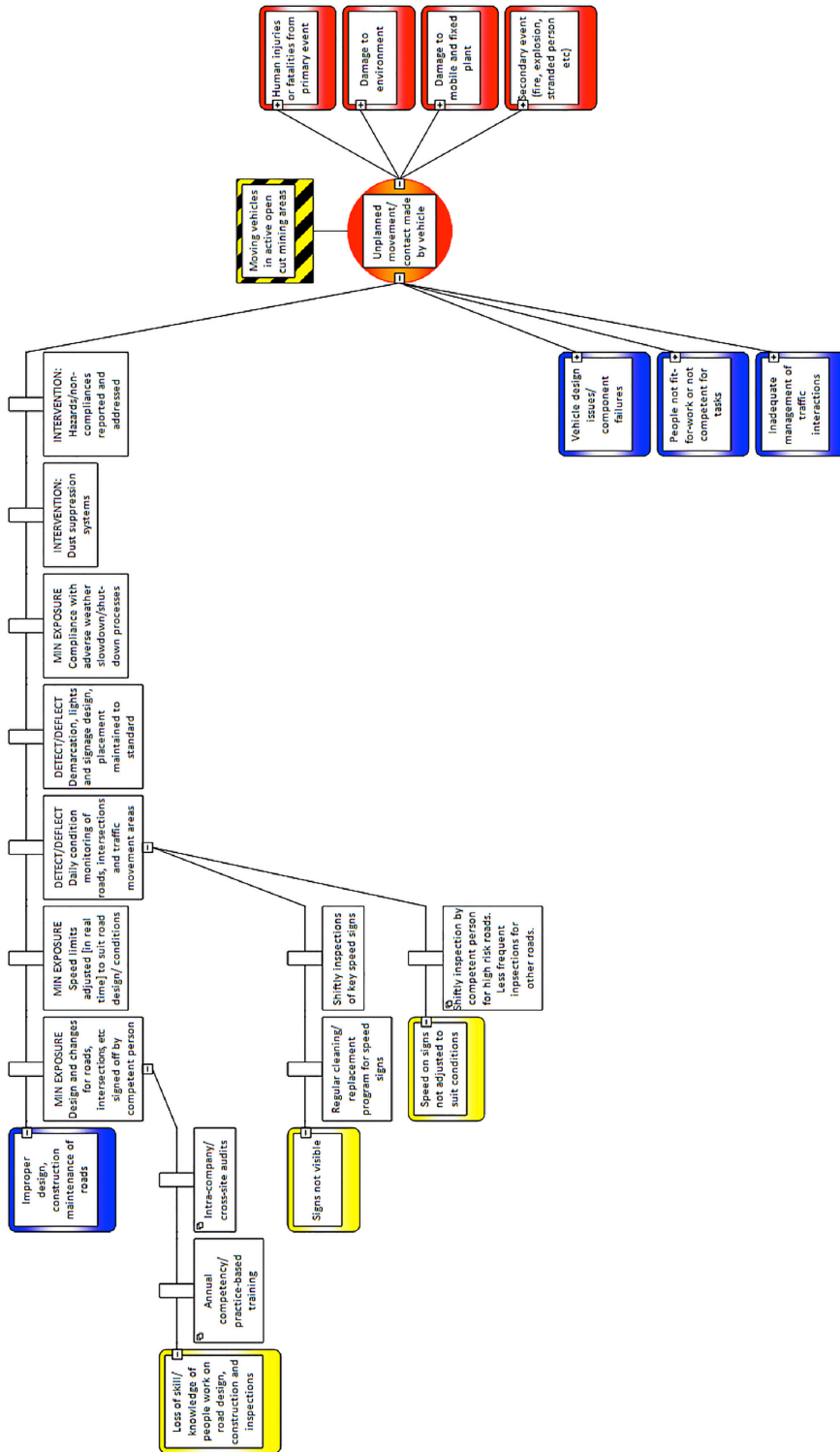
Assurance identifies those items needed to ensure that controls remain available, reliable, repeatable and responsive over time. Assurance items need to be specifiable, observable and auditable. Figure 43 shows a decision tree for identifying controls and assurance items.

Figure 43: Decision tree for controls and assurance items



In advanced bow-ties, the identification of assurance items is more detailed in that it also includes some erosion prevention elements, as mentioned in the previous section. Figure 44 shows a bow-tie with control assurance management system items for an unwanted vehicle interaction. Assurance requirements can then be summarised as a control program highlighting critical elements for monitoring.

Figure 44: Decision tree for controls and assurance items



APPENDIX 3: RISK COMMUNICATION

As discussed in Section 5.4, effective risk communication including internal and external stakeholders is crucial in achieving the best results in the risk assessment and its acceptance by others.

A3.1 Risk communication theory

Sometimes people worry about things more than they need to, and sometimes they do not worry enough. History is clearer than the future in making this point. For example, people should have been much more worried about cigarette smoking in the 1960s and 1970s when significant data on the causes of lung cancer became available, but people worried unnecessarily that a computer virus was going to bring us all to our knees on 1 January 2000, which came and went without a disruptive event.

Some people describe risk as real or perceived, with 'real' reflecting the scientific view and 'perceived' reflecting the emotional view. The problem with dismissing 'perceived' risk as insignificant in real terms is that it sometimes proves to be right. In other words, sometimes people's 'gut feeling' is right and the scientists have missed part of the story. In the resource sector, there are many examples of people's nervousness being summarily dismissed by technical 'knowledge', including in the melting of the Occidental Piper Alpha offshore platform into the North Sea in 1988, the collapse of an early block caving goldmine in Australia in 1999 and the Baia Mare cyanide spill in Romania from the Aurul gold production facility that caused an environmental disaster in three countries in 2000.

Good risk communication can therefore only be achieved if both parties recognise some validity in the other's risk evaluation system. If this sounds like an impossible state to assume, think again. There are eye surgeons who wear glasses because they do not want to undergo laser surgery yet they tell their clients, in all honesty, that the procedure has a very high success rate. There are power transmission engineers who can argue scientifically that electromagnetic radiation is harmless but will not allow their families to live beneath power lines. Most people have their own 'unexplainable fears'—another label for 'perceived risk'.

As a result of the complexity of risk evaluation methods, it cannot be assumed that quoting science will win the day. Only by entering into genuine two-way communication can that be achieved.

A3.2 What is risk communication?

Vincent Covello, Peter Sandman and Paul Slovic pioneered much of current risk communication theory in the mid-1980s, and their combined work remains unchallenged today as a foundation for good risk communication. They sometimes worked together and often alone to uncover the key essentials for good risk communication, and the following sections draw heavily from their work.

Many mining organisations regard community interaction as one of their formal organisational values, but there remains a danger that the organisation enters into risk communication believing it is doing a good deed by being patient with stakeholders who are not as well informed as it. However, this is not the way anyone outside of industry sees the situation.

In fact, industry generally did not voluntarily recognise community interaction as a major factor in, say, operating a production plant; rather, it was forced to after major disasters around the world. Initially, it was the chemical industry that was so mistrusted by the community that it was finding it hard to get approval to operate production facilities anywhere in the Western world and new heavy regulation of the industry was making business extremely difficult. The Chemical Manufacturers' Trade Association (CMTA) started the Responsible Care Program, which involved the tag line 'Track us, don't trust us'. Soon after, the oil and gas sector and the mining industry were forced to follow suit. Most of this battleground was around the health, safety and environmental risks of those operations.

It should be clearly understood that discussing the risks of mining operations openly with the community is not an act of generosity; it is a matter of seeking permission to extract precious minerals through very aggressive techniques in previously untouched ground. This is not being gracious or benevolent; it is smoothing the way to maximise profits for shareholders, which is an appropriate and even regulated expectation of the corporation's board. Dr Peter Sandman is arguably the risk communication consultant most often utilised by the minerals industry. He makes this point clear when he tells companies that it is OK to coerce a stakeholder, even if the downside is greater than the upside for that stakeholder, provided that you are sure your project is not going to physically or psychologically harm them and they cannot prolong or stop you or your project (Sandman 2008). However, he also points out that this situation is a rare occurrence in the age of social media and internet search engines.

Paul Slovic (1999) supports the idea that people power in the area of risk perception is almost unchecked and wondered at the end of the 20th century whether this was good for society as a whole, suggesting that 'the young science of risk assessment is too fragile, too indirect, to prevail in such a hostile atmosphere.'

In the decade and a half since Slovic wrote that, risk assessment and management have enjoyed considerable growth in recognition, much of it due to the pioneering risk standards AS/NZS4360:2004 *Risk management* and its offspring ISO 31000:2009 *Risk management—principles and guidelines*. However, while this standard has brought industry together around a common theme, it means little to fearful stakeholders who simply do not think of risk in the same way. Good risk communication is therefore critical for survival and not just for calming concerns.

Effective risk communication is a key part of building community trust, improving understanding within the community about mining and mineral processing and their related risks, and helping industry to better understand the views of stakeholders who may be affected by those activities. The risk communication process must be two-way to be meaningful; that is, it should involve as much listening as talking, with clear evidence of responsiveness based on this interaction. While this may sound obvious, it is common even today for an organisation to 'present' to a community group, wait impatiently for the question time to pass and then resume normal business, having ensured that the community knows all the facts and that its case has been accepted. Industry leadership involves recognising the right of those potentially affected by mining activities to become involved in the design, building, operating and closing of a mine or processing facility and then reinstating the affected area to the appropriate condition.

A3.3 Principles of risk communication

In 1988, Vincent Covello, together with Frederick Allen, wrote *Seven cardinal rules of risk communication* for the Environmental Protection Agency in the US. These seven rules are briefly explained below. The paragraph following each is not from Covello and Allen's work but is provided to help clarify the intent of the seven rules.

1. Accept and involve the public as a partner.

A partner is an equal, not a person who needs to be educated or corrected. The aim is to ensure that your partners understand the things you believe to be pertinent to their situation so that an effective discussion can take place. They do not have to support your beliefs for meaningful communication to have occurred.

2. Plan carefully and evaluate your efforts.

Not all situations are the same. Objectives, audiences and circumstances change, so a fixed formula for risk communication is seldom practicable. Analyse each communication activity individually.

3. Listen to the public's specific concerns.

Point 1 talks about the need to provide information that the stakeholder may not have, but there may be information you are missing, too. People often assess by behaviour rather than by data presented, so be sure to have considered their needs.

4. Be honest, frank, and open.

Trust is built up over time but can be lost in an instant. Never lie, withhold as little as you ethically and contractually can and whenever possible allow your commitments to be 'tracked'. Bear in mind that in the 21st century it is almost impossible to keep a secret for very long.

5. Work with other credible sources.

Peter Sandman uses the phrase 'duelling PhDs' to describe situations in which experts disagree on a risk issue, pointing out that the audience is likely to dismiss all experts rather than pick a winner. Working with others, even if a range of risk values is the agreed outcome, is better than the parties discrediting each other.

6. Meet the needs of the media.

Both traditional and social media are interested primarily in circulation and audiences or in page views, posts and retweets, respectively. In this context, relevance to consumers, drama and simplicity have greater focus than accuracy and a positive outcome for the involved parties.

7. Speak clearly and with compassion.

If people are scared, acknowledge it; if people or the environment have been harmed, empathise with those that have suffered. Allow yourself to articulate your own feelings if they are pertinent, but be careful to ensure that there is moral balance between their fears and yours (for example, never counter a moral concern with a financial concern).

A3.4 Assessing stakeholder resistance

While there are great advantages in having a single process for risk, there is also a need to avoid stakeholder outrage. The reason for this is that ISO and other risk processes are founded on a logical progression. Consider some of the problems of trying to force potential fear and outrage issues into the ISO process as a 'hazardous event'.

The risk identification step calls for the definition of the source of the hazardous event to be assessed. In health, safety and environmental terms, this is usually based on energy sources: chemical energy (for example, toxic fluids); electrical energy (shocks); (heat energy (fires); kinetic energy (collisions); potential energy (falls from heights); pressure energy (explosions); and so on. In the case of damaging energies, causing physical harm to stakeholders or the environment is covered under HSE risk work, so presumably the intent in managing stakeholder issues is to manage the risk to the organisation.

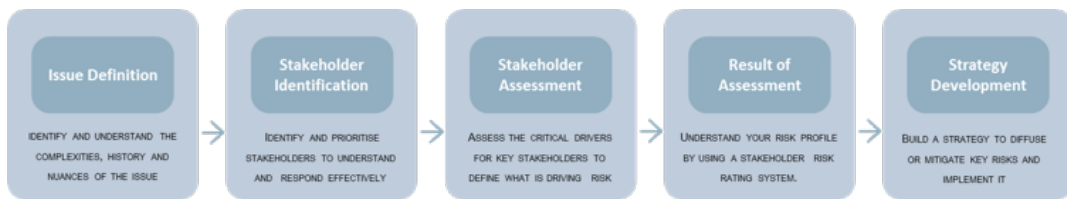
Risk analysis calls for the identification of causes and controls and the identification of the risk level. However, the causes of stakeholder distress are at least as much in the field of psychology as they are in the field of minerals extraction, health and safety or environmental science. It is worth asking, 'When does a stakeholder incident occur? Is it when a stakeholder is upset, when a stakeholder who has the power to harm the organisation is upset, or when there is a need for the business to respond?'

If placing risk communication directly into the risk process as a risk event does not work, where does it belong in the risk management process? Stakeholder outrage is a cause of delayed projects, shutdown notices from regulators, and unreasonable laws from governments, among other things. Good risk communication is a critically important control against such occurrences, and also against stress for genuinely upset stakeholders. It can therefore be argued very effectively that risk communication is a key control in avoiding stakeholder fear and dissent (outrage) that can in result in substantial operational losses for your organisation. Although some would counter that the main impact of substantial stakeholder dissent is reputation damage and not operational losses, the primary impact on the company of a poor reputation is financial, albeit via investment losses and not production losses. This argument does not prevent the organisation working hard to build a good reputation to a point where it can be distinguished from its peers by the public or other stakeholders—indeed, this is an opportunity that can be realised with the help of the risk management process. Nevertheless, it should be recognised that the avoidance of financial loss through poor risk communication is a more commonly experienced driver for risk management action in the minerals industry than is the opportunity for the development goodwill. Peculiarly enough, this realisation and the acceptance of it are likely to result in better risk communication by the organisation (see 'Trustworthy sources versus untrustworthy sources' below).

To do risk communication well, we still need to overcome the fact that we are not psychologists, and the leading practice way of doing that is to apply the research learnings and advice from the likes of Covello, Sandman, Slovic and other experts into a process that can be understood and implemented by mining operators. Decades of research by scholars has not yet distilled learnings into a single risk communications model (US Department of Homeland Security 2012:2).

Good approaches have been built up over many years by companies that have learned from their own mistakes and those of their peers, but they are not generally made widely available, although most of the major minerals companies are sharing in the area of social responsibility experience. However, for the purposes of this handbook, the proprietary process in Figure 45 is used as one example of systematically performing this critical control function well.

Figure 45: A systematic approach to risk communication



Source: GHD Pty Ltd (2015).

A3.5 Issue definition

Some risk communication issues are easy to identify because the minerals industry has been hurt by them in the past. They might include the difficulty of getting environmental or heritage approval to proceed, or a failure to convince neighbours that your facility is safe for those who live around it. However, focusing entirely on what has happened in the past may cause you to miss emerging events.

Peter Sandman grouped the many potential fear and outrage generators into 12 major factors (Sandman 2003:13), noting that risk communications researchers tend to agree that there are more than 20 fear generators in total. For the purposes of this handbook, the 12 Sandman factors have been divided into two broad categories: those that are about the perceived hazard, and those that are about the environment in which communication is taking place.

The first category can be easily used as a prompt list for identifying issues in which stakeholders may see the risk as higher than the organisation does. These are characteristics of the hazard that unnerve people. The second category cannot make the strength of reaction much greater. If the hazard factors do not exist, it is likely that the communications environment will have less effect than if hazard factors are present. Nevertheless, the second group can generate substantial outrage even if they do not generate fear. In the case of fear, good risk communication is the primary control, but in the case of outrage without fear, Vincent Covello’s seven principles of good communication still have a positive effect.

The Sandman factors were derived from the psychometric risk model of Paul Slovic and are explained below (Sandman 2004). The factors are listed in Table 9 and explained below.

Table 9: Decision tree for controls and assurance items

ABOUT THE HAZARD	ABOUT THE COMMUNICATION ENVIRONMENT
Familiar versus exotic	Voluntary versus coerced
Not memorable versus memorable	Individually controlled versus controlled by others
Not dreaded versus dreaded	Trustworthy sources versus untrustworthy sources
Chronic versus catastrophic	Responsive process versus unresponsive process
Natural versus industrial	Morally irrelevant versus morally relevant
Knowable versus unknowable	Fair versus unfair

Familiar versus exotic

In some parts of the world, people ride on elephants but would be terrified to have a ride in a car; others live and stroll about on high mountains but would be terrified of tall buildings in a city. We simply worry less about what we know well. In mining, when employees get too comfortable with explosives or unsecured ground this can be a problem and is a valid risk communication zone. However, most of the external stakeholder issues in the minerals industry involve people worrying more than the industry thinks they should. Reducing jargon in favour of terminology we can all understand can be a big help in keeping people calm.

Not memorable versus memorable

Déjà vu is the name we give to the feeling that we have experienced this moment before. Research is not clear on the cause, but what is certain is that people do not need hard data to make a persuasive connection with something that has happened previously (Lewis 2012).

Of course, if you had experienced your house near a mine site disappearing into the ground due to subsidence you would be far more concerned than most other people to hear that a mining development was coming to your town. However, a memorability linkage does not have to be that strong to have a similar effect. It may be that you saw media coverage of a similar event, or read about it in a novel or saw it in a disaster movie. It may be that a relative died in a mine when you were young and you remember your mother crying inconsolably. It does not even have to be about mining, and it may be any one of your six senses that sets it off.

When considering memorability as a prompt, remember that it has to occur within a significant number of people to constitute a potential outrage—and therefore become a potentially costly problem for your organisation to fix. If it is just one person or family, you may wish to try to alleviate this problem in some way from a company values perspective, but it is not an industrial risk communication issue for the business unless that person or family has the power to spread the concern.

Not dreaded versus dreaded

If you were told by your doctor that you have a serious illness with a 50% chance of survival, you would probably go weak at the knees. As you compose yourself and shakily ask the question, 'Is it cancer, doc?', you are relieved when she says you have mild emphysema. This is because some things, such as cancer (but not heart disease), sharks and snakes (but not mosquitos), and nuclear radiation (but not fire) somehow scare us to the core and we elevate the data-supported risk as a result. For example, all of the potential killers in the parentheses above cause more fatalities than the associated dreaded examples.

The list of things that people dread can be raised or fade over time, and one culture may well have a dread of something that another does not. Also, some dreads affect some individuals more than others and are usually labelled 'phobias'. Some of them affect a relatively large number of people, such as arachnophobia (fear of spiders) and claustrophobia (confined spaces). Others are less common but related directly to mining, such as acousticophobia (noise) and amathophobia (dust).

When considering your impact on stakeholders, you therefore need to consider where you are and whether a single individual or only a sizeable group can disrupt your business if they regard your activities as far more dangerous than you do.

Chronic versus catastrophic

There were 14,461 road deaths a year in Australia in the decade to 2013 (DIRD 2013), but the loss of 202 Australians in the Bali bombings of 2002 generated more newspaper and TV headlines than did all of the road fatalities over that decade. The Australian Government accepts that smoking causes more than 50 smoking-related fatalities each day (Australian Government Quitline online), yet smoking remains legal because those 50 people do not topple over in one location. If they did, it seems likely smoking would be made illegal within months. The damage to the fabric of society is somehow far greater when many people die in a single event.

In some ways miners know this, and one common mistake they make is to hide away from the biggest credible outcome of an event if they feel that the risk is very low and that it would worry external stakeholders to see it recognised in risk calculations. It is often argued that this is done to avoid worrying people, but the truth is usually that it is done to avoid the feared response of 'Oh, so you admit a disaster can happen!'

In fact, it is rare for a concerned stakeholder to have a lower estimate than you of just how big an event might be, and without transparency from you they may even argue the event is worse than it really is. However, if your risk calculations show that you do recognise that there could be a disastrous scenario, but the frequency of that event is very, very low, you at least open the possibility of persuading them that you are genuine (see 'Trustworthy sources' versus untrustworthy sources').

Natural versus industrial

Religious people are prepared to believe that the terrible hardships that occur on Earth, including famine and natural disasters, are part of a bigger picture that they cannot hope to understand. As a result, they accept such things as God's will. Atheists do not believe that there is an all-powerful being in control, but they generally accept that we do not have mastery of our little planet, let alone the vast universe in which it exists. In other words, the great majority of people believe that some things are just 'the way it is'. Nevertheless, the pain people are prepared to accept as a natural 'part of living' does not include anything that causes harm during the search for shareholder or personal gain.

Most people have values or principles that guide them through their lives, and one of the most common of those values is that the welfare of people and our environment is precious and cannot be the subject of financial trade-offs.

Nature versus industrial is a complex factor because it involves a sense of what is 'right', and that is a very subjective concept. In general, revolutionary scientific development is likely to be considered poorly on this factor. Today the revolution is in biotechnology, genetic engineering and even 'fracking', but aviation was thought of in the same way once: 'If God had meant us to fly, He'd have given us wings!'

However, the gap between the tolerance of harm from powerful natural forces and harm created in the name of organisational objectives is not a simple on-off switch. Some human endeavours are considered a little closer to purity than others. For example, hospitals exist to save lives and are full of hardworking surgeons and nurses trying to do that. However, a research article published in 2013 in the USA (James 2013) found that more than 400,000 people a year died from medical errors in hospitals across America during the period from 2008 to 2011. In a similar period (2009-12), there were fewer than 100 fatalities per year across all mines in the US (US Department of Labor 2015).

Now ask yourself: why would an industry that causes 4,000 times more people to die from its mistakes than mining be tolerated without revolt in the streets? The simple answer is that the primary purpose of a hospital is to reduce harm, and this fits in with our concept of what is natural and principled much more than mining does because mining's primary purpose is to increase income.

Knowable versus unknowable

When highly qualified and normally highly respected experts disagree on the answer to a safety issue, the result is often greater confusion than previously existed. Imagine that one of the two leading professors in climate change says that global warming will cause temperature to rise in Australia by 2°C by 2050 and that the other one argues vehemently that it will rise by 10°C. Sandman notes the following striking points:

- People will conclude that science does not have the answer at all, and that the truth may well be even higher than 10°C or lower than 2°C.
- Had the two professors jointly released a statement saying that the rise will be between 2°C and 10°C, everyone would have accepted that the science makes sense.

A form of the unknowable occurs when the harm feared is not immediately evident to those affected. For example, consider someone who has been told that the roof they had just cut into has asbestos in it. They do not know whether they have inhaled any of the deadly fibre, and even if they have they do not know whether they will escape without injury or will develop asbestosis, lung cancer or mesothelioma. Being in the vicinity of nuclear radiation or lead emissions is similar in this way, but if you are in the vicinity of flying rock or a cyanide release you will be left in no doubt about whether you have been lucky or not.

Any event that could eventuate at your site that could be put in this category should result in a carefully thought through stakeholder communication program.

Voluntary versus coerced

Some successful businesses around the world charge money to frighten people. Where once people thought a big dipper ride was scary and a ski run was adventurous, today people by the thousands volunteer to leap off platforms a hundred metres or more above the ground with only an elastic cord preventing impact with the ground or water far below. Terms that conjure up other extreme 'fun' activities include 'whitewater', 'G force', 'freefall', 'shark cage', 'paintball' and so on. But just imagine being forced to do any one of these against your will.

There is a big difference between choosing to do something dangerous and not being given the option. Once again, however, there are degrees of voluntariness. For example, employees in the mining and minerals industry, particularly in fly-in, fly-out arrangements, are volunteering to do a job that has inherent hazards, but even they are not volunteering to work for an organisation that does not have their safety high on the company agenda. However, people in the area who get no direct benefit from the mine or refining facility and would be quite happy if the company moved away are much nearer to the coerced end of the scale. It is true that they could move away, but that is probably not a decision that they will benefit from in the way that the company and employees do.

When encountering situations like this, each site should try to provide choice at whatever level it can to move further along the voluntary end of the scale. For example, there are many occasions when a company has deliberated long and hard over how best to minimise the impacts of an activity on the local community. However, significant movement along the voluntary scale can be gained by providing the community with the options that are available and letting them decide.

Individually controlled versus controlled by others

Most of us have been a passenger in a car when we have found ourselves trying to press a brake pedal that does not exist on our side of the car. This might be because we would brake earlier than the driver, but it is more likely that we just believe the driver should brake earlier because they are not as good at driving as we are. Studies over the decades have shown that as many as 81% of drivers believe they are above average in driving skills, which is not possible (Svenson 1981).

Assume that you are a competent handyman and are working with a first class carpenter. If one of you had to hold a nail while the other hit it with a hammer, it is likely that your preference would be to wield the hammer. It's just human nature not to put your safety entirely in the hands of someone else. This is even more the case when the 'someone else' is a large organisation charged with maximising profits for investors.

Once again, the objective is to give as much control to the external stakeholders as you can afford to allow. One approach might be to encourage representatives from the community to establish an advisory committee to the mine management, with a pre-agreed scope and modest funding to ensure that it could carry out the role effectively.

Trustworthy sources versus untrustworthy sources

Research in 2014 surveyed more than 600 Australian men and women on how 30 professions rated for 'ethics and honesty' (Morgan 2014). Nurses were top (no surprises there), but the bottom five professions were (worst last) politician, union leader, real estate agent, advertising person and car salesperson. It does not take a genius to work out that people who claim a great deal more than they can deliver lose the trust of the public, and it does not need to be explained that communications are more fruitful when each party trusts the other.

For the most part, individuals start with a clean slate on trust and have to perform badly to become distrusted, but the story is different for industry. Several global industries lost the trust of the community decades ago: the chemical industry with the Flixborough, Seveso and Bhopal disasters; the nuclear industry with Windscale, Three Mile Island and Chernobyl; oil and gas with Amoco Cadiz, Piper Alpha and Exxon Valdez; and mining with Aberfan, Val di Stava and Ok Tedi, among others. None of those industries has had a clean slate since those disasters, either.

The chemical industry was first to learn that it was going to have to regain trust to even be allowed to operate in any neighbourhood in most of the world. In 1988, the Chemical Manufacturers Association, representing nearly 200 chemical producers in the US, created the Responsible Care Program to try to slowly win back the trust they had lost (Reisch 1988). This was effectively the start of what most now call 'corporate social responsibility' to achieve and keep a social licence to operate. However, the chemical industry realised that this was going to take time and that they would not be able to count on trust in the interim. This led it to use the slogan 'Track us, don't trust us', which showed that they recognised they had lost the trust of the community and had tried to lower the 'controlled by others' factor to compensate.

A decade after the program was announced, there were mixed feelings about how successful it had been in terms of real social performance, but it was enough to save the industry from the perilous state it was in in 1988. Some successful companies such as Dow Chemical went out of their way to provide information to representatives of local communities so that people could track performance where it affected them, and won many awards for this work over the following decade.

Responsive process versus unresponsive process

One of the strange things about corporate management is that each manager tends to behave at work in a way that they know would not work at home. For example, imagine you were visiting a friend and spilled red wine over their lovely new beige carpet. You would apologise profusely for your clumsiness and go rushing for something to absorb the mess, only to be consoled by your host, saying someone was bound to christen the carpet soon, and you are to sit right down and relax because he has a simple technique to clean it up in no time.

Now imagine how different the host's response would be if you had denied all responsibility for the spill because a woman knocked your arm, and he should have had a dark coloured carpet in an entertainment area anyway. As ridiculous a tactic as this would be at home, organisations have tended to take exactly that route, often on advice from corporate counsel, when there is a debate about responsibility for an incident. Responsive process means responding quickly and responsibly for your organisation's mistakes.

Of course there is a need for legal caution, but incidents must be handled within a framework that shows genuine care, recognition that you are not as white as snow, and an intent to put things right. In the oil industry, the difference between demonstrating responsive process well and very poorly can be highlighted by consideration of the *Exxon Valdez* and *American Trader* oil spills in Prince William Sound in 1989 and off the coast of California in 1990, respectively.

Within 48 hours of *Exxon Valdez* hitting the reef, the president of the Exxon Shipping Company had tried to lay blame on the captain of the ship, the pilot and the coastguard (Devlin 2007). BP however, having learned from Exxon's pain, was ready to show both responsive process *and* legal soundness when the then BP America chairman told reporters, 'Our lawyers tell us it's not our fault. But we feel like it's our fault and we are going to act like it's our own fault' (*The Conversation* 2015). In this simple statement, BP had retained the right to debate responsibility in court while letting everyone know that its leaders felt awful and were going to fix things as quickly as they could.

The lesson here is not that BP is better than Exxon in emergency responses (both made technically sound responses); nor is it that BP as a company is better at stakeholder communication across the board, because the company was poor in its communications throughout the Deepwater Horizon disaster. It is simply evidence that technical, media and legal people can work in harmony to demonstrate a responsive process that benefits everyone after a significant community or environmental event.

Morally irrelevant versus morally relevant

Another area where organisations can easily slip up is based on the principle that a moral argument can only be countered by another moral argument. For example, a mine that is the financial backbone of a country town cannot simply pay for a higher share of reservoir water than other users during a drought. Rainwater is not seen as something that should be sold to the highest bidder—it is provided without charge by nature and the rich should not get more than their share.

In making the case for getting enough water to keep the mine open, the threat to local jobs is a real social issue that can morally be argued as a reason for keeping the mine open. Having put this problem to local government as a mutual need, the organisation can enter into discussions about supportive measures that might repay the generosity of the people (for example, by a program of modest subsidies for the excavation of larger farm dams, more efficient irrigation or the installation of household rain- or grey-water tanks).

In short, it is a morality-based bartering system, in which no money and no threats are exchanged.

Fair versus unfair

This is a simple form of risk accounting: are the people carrying most of the risk getting a reasonable share of the benefits? In this situation, it is OK to talk about money—but it is not only about money.

For example, if the plant manager lives out of the range of emissions from a smelter stack and the workforce members are all within range of the carryover, that will suggest that the manager does not really believe in the company's risk calculations, that whatever is said in the workplace about teamwork, the manager is not really one of the team, or that both those propositions are true.

People will sometimes accept a risk without appropriate reward if someone or something they care about is receiving some of the benefits. Communities have been known to put up with some risk if it benefits those unable to fend effectively for themselves, such as the homeless, the aged, the sick or the hungry. For example, a company-funded park in the local town should always have a playground, because children are a great way to earn fairness points.

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GLOSSARY

Community engagement	Deliberate and strategic liaison with communities and individuals that reside in close proximity to, and are potentially affected by, mining activity. Effective engagement typically involves identifying and prioritising stakeholders, conducting dialogue to understand their interest in an issue and any concerns they may have, exploring with them ways to address those issues, and providing feedback on actions taken.
Control owner	The person in an organisation responsible for assuring appropriate levels of control are implemented and operated effectively for a key risk area.
EBQ	Experience based quantification.
Enterprise-wide risk	The overarching risk management framework that defines the framework scope of risk types and the key risk management processes implemented across the whole organisation to manage risk in an holistic and systematic way.
Gradual risk	A risk event that occurs over a long period of time and is representative of many types of pollution of the environment (for example, slow leaks from hydrocarbon containment, acid seepage or emissions to the atmosphere).
Hazard	A source of potential harm.
HAZOP	Hazard and operability.
HSEC	Health, safety, environment and community.
JSA	Job safety analysis.
JSEA	Job safety and environment analysis.
LOPA	Layer of protection analysis
Materiality	An expression of the relative significance or importance of a particular matter in the context of the organisation as a whole.
Materials stewardship	An overarching stewardship approach that applies to resources, processes and products and, therefore, covers the full life cycle. It describes an integrated program of actions aimed at ensuring that all production, consumption and disposal of materials, processes, goods and/or services are done in a socially and environmentally responsible manner.
Monte Carlo simulation	A method for iteratively evaluating a deterministic model using sets of random numbers as inputs. The method is often used when the model is complex or nonlinear, or involves more than just a couple uncertain parameters.
Net present value (NPV)	A measure used to decide whether to proceed with an investment. It is calculated by adding together all the expected benefits and subtracting all the expected costs from the investment, now and in the future. If the NPV is negative, then the investment cannot be justified by the expected returns. If the NPV is positive, then it can be justified financially.

Non-government organisation (NGO)	A non-profit group or association organised outside institutionalised political structures to realise particular social objectives (such as environmental protection) or serve particular constituencies (such as Indigenous peoples). NGO activities range from research, information distribution, training, local organisation, and community service to legal advocacy, lobbying for legislative change, and civil disobedience. NGOs range in size from small groups within a particular community to huge membership groups with a national or international scope.
Operational risk	Those risks focused on addressing aspects of an operation which may be more systemic to the mining process and the day-to-day operation of a mine.
Outrage	Anger and resentment aroused by injury or insult.
QRA	Quantitative risk analysis.
Risk	The chance of something happening that will have an impact on objectives. It is often specified in terms of an event or circumstance and the consequences that may flow from it.
Risk analysis	The systematic process used to understand the nature of risk and to deduce the level of risk. It provides the basis for risk evaluation and decisions about risk treatment.
Risk control	An existing process, policy, device, practice or other action that acts to minimise negative risk or enhance positive opportunities.
Risk criteria	The terms of reference by which the significance of a risk is assessed.
Risk evaluation	The process of comparing the level of risk against risk criteria.
Risk management	The process and structures that are directed towards realising potential opportunities while managing adverse effects.
Risk management process	The systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context for, identifying, analysing, evaluating, treating, monitoring and reviewing risk.
Risk register	A record of the outcomes of risk identification and assessment processes in a systematic way—usually set out in a table. Defines risk scenarios, assessment outcomes, risk control actions and responsibilities.
SIL	Safety integrity level.
Similar exposure group	Groups of workers having the same general exposure profile due to the similarity and frequency of the tasks they perform, the materials and processes with which they work, and the similar way they perform the tasks.
Social licence to operate	The recognition and acceptance of a company's contribution to the community in which it operates, moving beyond basic legal requirements towards developing and maintaining the constructive relationships with stakeholders necessary for businesses to be sustainable. Overall, it strives for relationships based on honesty and mutual respect.
Stakeholders	Those people and organisations who may affect, be affected by, or perceive themselves to be affected by a decision, activity or risk.

Strategic risk	Those risks that relate to the interdependencies between an operation's activities and the broader business environment.
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Threat	The possibility that vulnerability may be exploited to cause harm to a system, environment, or personnel.



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