NSW DEPARTMENT OF
PRIMARY INDUSTRIES

RISK MANAGEMENT HANDBOOK FOR THE MINING INDUSTRY

HOW TO CONDUCT A RISK ASSESSMENT OF MINE OPERATIONS AND EQUIPMENT

AND

HOW TO MANAGE THE RISKS

MDG 1010

MAY 1997

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MDG 1010 **RISK MANAGEMENT HANDBOOK**

FOREWORD

This handbook provides information to assist mine management, departmental personnel and associated industries in the process of risk reduction and risk management.

Advancement in technology and management systems too often outstrip the ability of experts to provide exacting community standards for the safe and effective operation of management systems and equipment. The ideal workplace would have fit for purpose equipment, competent personnel, management systems in place, all within a known environment. In reality inherent hazards associated with technology and management of technology within the mining environment requires a process to be utilised not only to reduce hazards to an acceptable level but also produce management systems appropriate for the business. This demands the adoption of a structured process for the identification of hazards and evaluation and control of work related risks.

The Department of Mineral Resources is charges with the responsibility of promoting high standards of safety within the mining industry. This is assisted with an existing comprehensive legal framework under the Occupational Health and Safety Act and Coal Mines Regulation Act, requiring organisations to manage their activities in such a manner as to anticipate and prevent circumstances which may result in occupational injury or death. This handbook offers a process to meet such requirements. It is envisaged such an approach may be integrated with the management of other aspects of business performance with expected outcomes as minimising the risk to employees and others, improving business performance and assisting organisations to maintain a responsible image in the market place.

The preparation of this document through a working committee involved the input and support from the following persons and organisations. Professor Mark Tweeddale (Australian Centre of Advanced Risk and Reliability Engineering Ltd), Jim Joy (Alara Risk Services) and personnel from the Department of Mineral Resources namely A. Reczek, L. Roberts, G. Cowan, G. Jervis (Chairperson) and R. Hodson. The latter's contribution is gratefully acknowledged. It is anticipated that the handbook would be subjected to review from time to time and updated as appropriate.

Comments on any aspect of this handbook including those for consideration in future editions that add value to this document will be gratefully appreciated. All comments should be submitted in writing to:

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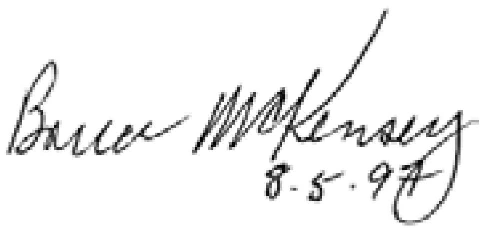

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Chief Inspector of Coal Mines.

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1. INTRODUCTION

1.1. WHY WAS THIS HANDBOOK PREPARED?

The mining industry makes a major contribution to the Australian economy and to the well being of society as a whole. For the continuing viability of the industry it is important that full advantage can be taken of advances in mining methods and procedures, design of mining machinery and equipment, and advances in approaches to management of all mining activities, including safety.

There are many Australian and overseas Standards which are relevant to mine operations and equipment, but these Standards cannot keep fully abreast with continuing development of techniques and technology, or how they interact.

Because of the inherent hazards of mining as an activity, and the complexity of mining machinery and equipment and the associated systems, procedures and methods, it is not possible to be inherently safe. Regardless of how well machinery or methods are designed, there will always be the potential for serious accident. It is therefore not possible for any external agency to ensure the safety of an organisation such as a mining company, nor of the machinery or methods it uses. The principal responsibility for the safety of any particular mine, and the manner in which it is operated, rests with the management of that mine.

It is now widely accepted within industry in general that the various techniques of risk assessment contribute greatly toward improvements in the safety of complex operations and equipment. In many industries there is a legislative requirement for risk assessment to be undertaken of all hazardous equipment, machinery and operations, taking account of the procedures used for operation, maintenance, supervision and management.

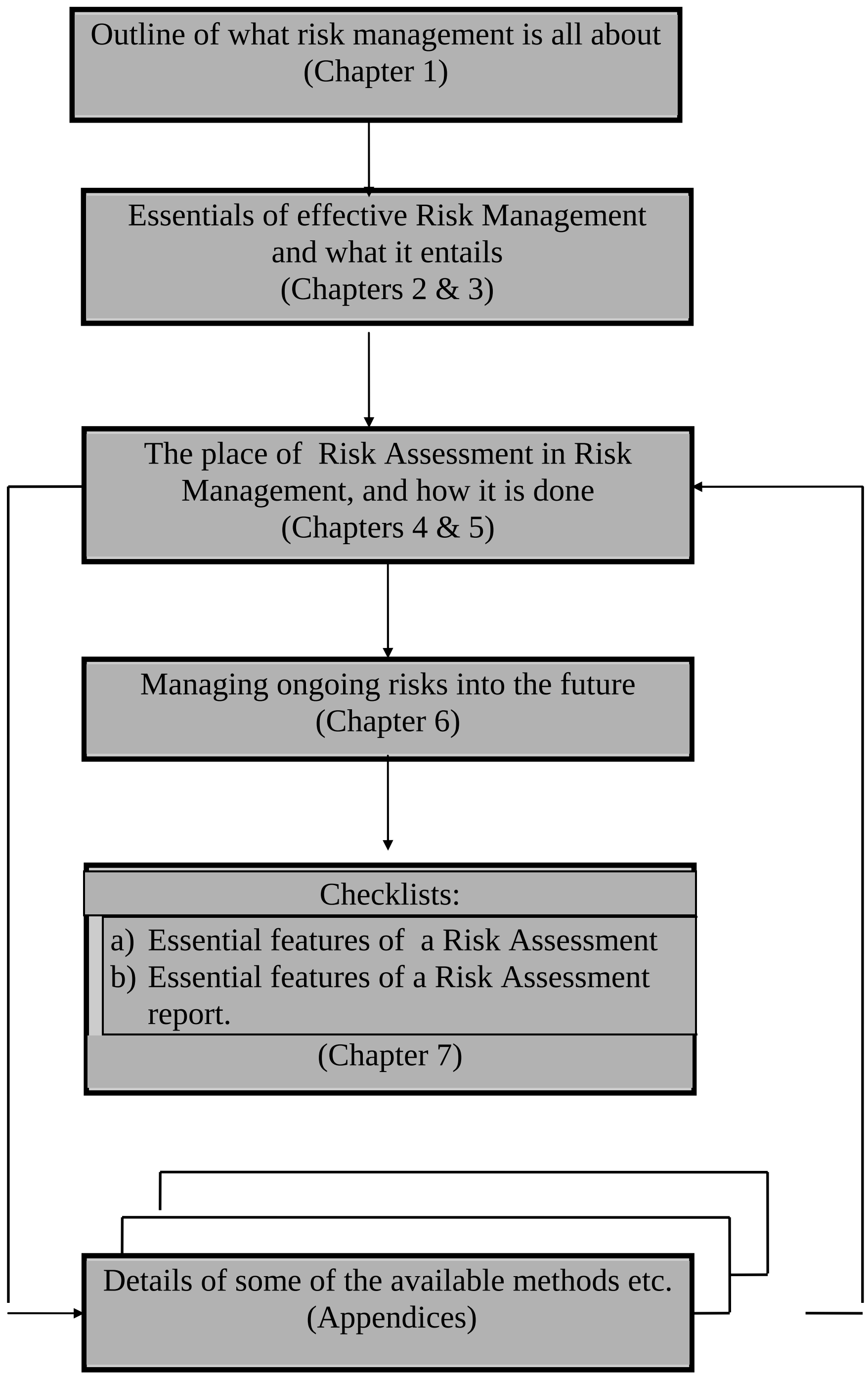
The Department of Mineral Resources is charged with the responsibility of promoting high standards of safety within the mining industry. In exercising that responsibility, the Department requires that equipment and operations either comply in detail with relevant Standards, or is subjected to a formal risk assessment covering those features which do not comply fully or for which there is no applicable Standard.

Consistent with the requirements of quality assurance, the Department has defined the essential requirements of such a risk assessment.

This Handbook sets out the requirements, and outlines some of the approaches which can be used to meet those requirements.

It is not intended that this Handbook prescribe the particular methods to be used in risk assessment (although examples are included), as this could inhibit future developments. Rather the Handbook sets out a “process”, and defines the essential features of it.

1.2. STRUCTURE AND CONTENTS OF THIS HANDBOOK



1.3. WHAT ARE THE OBJECTIVES OF THE HANDBOOK?

1.3.1. Objectives Risk Management

Risk management aims to reduce the likelihood and impact of mishaps of all kinds. In the mining industry, with its inherent potential for major accidents which could injure or kill many people, damage the environment, cause serious loss of production and hence profit, there is a particular need for a sound approach to the process of risk management.

1.3.2. Objectives of Risk Assessment

Risk assessment aims to assist in effective management of risks, by identifying:

- which risks are most in need of reduction, and the options for achieving that risk reduction,
- which risks which need careful on-going management, and the nature of that on-going attention

1.3.3. Objectives of this Handbook

This Handbook aims to assist:

- mine managers to undertake risk assessment studies in an effective manner without placing undue demands on skilled staff resources, and to make effective use of the findings in their risk management programmes;
- suppliers of equipment, machinery and services to mining organisations to undertake risk assessments of what they are supplying, or to contribute effectively to risk assessments undertaken by the mining organisations;
- staff of the Department of Mineral Resources to guide and review risk assessments undertaken by organisations operating mines or supplying equipment, machinery or services to mines.

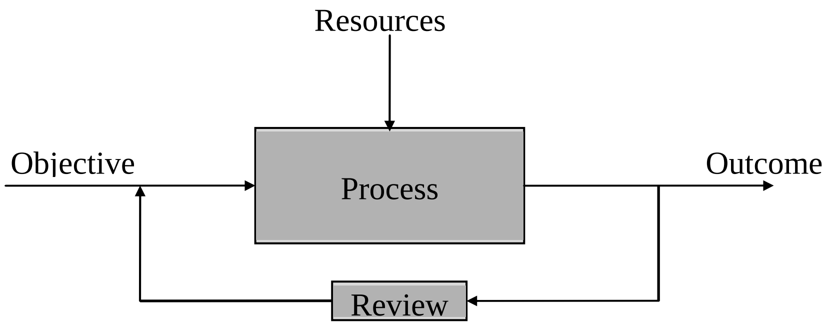
1.4. THE CLOSED LOOP OF MANAGEMENT CONTROL

This Handbook illustrates how the principles of management control, shown below, are applied in management of risks.

Management control has the same essential elements as the control systems of machinery, or indeed control of any activity, whether manual or automated.

Those elements are:

- a defined objective, standard, setpoint etc. determining the outcome required;
- a process which is intended to produce the desired outcome, making use of resources;
- measurement of the outcome and comparing it with the defined objective;
- taking action to vary the input resources or the process itself so as to eliminate any difference between the achieved outcome and the defined objective.



1.5. EXPLANATION OF TERMS USED IN THIS HANDBOOK

The following definitions or descriptions are taken from a variety of sources, including AS/NZS4360 - 1995 *Risk Management*,[1] which is a strongly recommended reference.

"Delphi": *"An approach to estimation of data which uses a team of people who undertake successive cycles of independently estimating a required quantity (e.g. the severity of the outcome of an accident, or the frequency of an event) followed by sharing of the estimates and the reasons for them, until consensus is reached about the value to be used."*

Event Tree Analysis (ETA):
"A technique for systematically analysing the range of possible outcomes of an unwanted event or accident, to facilitate understanding of the possible impacts and quantification of the relative likelihood of those impacts."

Failure Mode and Effect Analysis (FMEA):
"A technique for identifying the possible modes of failure of equipment and machinery, and the possible outcomes of those various impacts."

Failure Mode and Effect Criticality Analysis (FMECA):
"An extension of FMEA which includes estimation of the severity of the outcome and the likelihood of each of the identified modes of failure, so as to facilitate ranking of the risks related to those failure modes."

Fault Tree Analysis (FTA):
"A technique for systematically analysing the logical structure of the possible causes and contributory factors leading to a defined unwanted event or accident, to facilitate understanding of the possible causes, estimation of the likelihood of occurrence, and identification of the options for risk treatment."

Hazard: *"A source of potential harm or a situation with a potential to cause loss"*

Hazard and Operability (Hazop) Study:
"A technique for identifying hazards and potential operability problems, in simple or complex equipment, processes or plants, in which a team uses 'keywords' to prompt recognition of deviations from normal operating conditions which could have adverse effects on safety, environment, operability or performance."

Potential Human Error Identification (PHEI):
"A technique for identifying hazards inherent in manual operations, making use of 'keywords' to prompt recognition of possible accident scenarios arising from inappropriate human activities or omissions."

Machinery Hazard Identification (MHI):
"A technique for identifying hazards inherent in the design of a machine, making use of 'keywords' to prompt recognition of possible accident scenarios arising from machinery malfunction or maloperation, including those triggered by poor design or equipment failure, as well as inappropriate human actions in relation to the machine"

Risk: *"the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood."*

Risk Analysis: *"A systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences."*

Risk Assessment: *"The process used to determine risk management priorities by evaluating and comparing the level of risk against predetermined standards, target risk levels or other criteria."*

Risk Treatment: *"Selection and implementation of appropriate options for dealing with risk."*

Workplace Risk Assessment and Control (WRAC):
"A participative approach for identifying potential production or maintenance operational losses."

2. THAT ARE THE REQUIREMENTS FOR EFFECTIVE MANAGEMENT OF RISKS?

KEY POINTS OF THIS CHAPTER

1. **Risk assessment is only one part of Risk Management.**
2. **The *foundations* of Risk Management are:**
   - **understanding of what could happen and how;**
   - **real and visible commitment to managing the risks.**
3. **The *structure* of Risk Management programme comprises:**
   - **physical facilities, equipment and other "hardware";**
   - **management systems and procedures;**
   - **people, and how they are organised and work together;**
   - **emergency capability**
4. ***Management* of risk (or any activity) entails:**
   - **planning;**
   - **organising;**
   - **controlling;**
   - **leading.**

2.1. THE REQUIREMENTS

There are various ways in which the essential requirements for effective management of risks can be defined. One such structure is that defined by Hawksley[2] initially for hazardous chemical plants but since adapted and used in many fields involving heavy industrial and other activity. Suitably adapted for the mining industry, they are:

1. The hazards (i.e. the potential for different types of accident) must be understood by everyone involved, including an understanding of how the accidents may arise, how serious they could be, and the nature of the preventive and protective “barriers”.

2. The appropriate facilities, machinery and equipment must be provided to match the hazards.

3. The appropriate systems and procedures must exist to match the hazards and the facilities, machinery and equipment. These systems fall into several classes:
    - those for operating to high standards, including selecting, operating and maintaining equipment correctly;
    - those for monitoring performance, including supervising and managing the performance of machinery and people;
    - those for progressing improvements;
    - those for auditing the systems for monitoring, supervising and managing the operations, and for progressing improvements.

4. The appropriate organisation should be provided, with appropriate staffing levels, communication systems and training.

5. There should be a high level of emergency preparedness, including means of detecting the onset of an emergency early and responding to it effectively and promptly.

6. Safety and risk management must be actively and visibly promoted by management.

2.2. THE IMPLICATIONS OF THESE REQUIREMENTS

The above requirements have a number of important implications for mine safety.

1. Risk assessment is not a once-off activity which, once done, can be put aside so that mining operations can continue as before. Risk assessment is one part of an on-going process of risk management. It aims to improve the understanding of the potential for accidents, their possible consequences, and the adequacy (or inadequacy) of the various safeguards.

2. The *foundations* of effective risk management are:
    - understanding, by all those involved, of the possible causes of accident or other mishap; and
    - real and visible commitment to managing the risks by staff at all levels.

3. The *structure* of an effective risk management programme comprises:
   - physical facilities, equipment, and other “hardware”;
   - systems and procedures of many kinds;
   - suitably trained and experienced people, working in an organised manner, with good formal and informal communications;
   - emergency capability, comprising understanding of the potential for emergency, together with appropriate emergency equipment, procedures, staffing, training etc.

4. If a mine manager wishes to review the adequacy of the risk management approach being used, it is helpful to structure the review about the six requirements set out above in Section 2.1, considering how well they are met. They are all equally important.

5. It is also helpful to remember that management comprises:
   - planning
   - organising
   - controlling
   - leading and motivating.

Thus any manager who is managing risks will have stated objectives and a plan, will have organised for it to be implemented, will be monitoring progress and taking corrective action where it is not going according to plan, and will be showing active leadership and commitment to achieving the plan. Where these are missing, the manager is *not managing risks*, but (at best) reacting to risks, i.e. being *managed by the risks.*

3. WHAT ARE THE STEPS IN A RISK MANAGEMENT PROGRAMME?

KEY POINTS OF THIS CHAPTER

1. **The steps of Risk Management are:**
    - **Establish the Context (including defining the objectives and scope of the risk management task).**
    - **Identify the Risks**
    - **Analyse the Risks, so as to understand their causes, likelihood and possible consequences.**
    - **Assess the Risks, to determine the need and priority for attention.**
    - **Treat the Risks by planning and undertaking initiatives in operation, engineering or management.**
    - **Monitor and review progress and performance**
2. **Many risk management initiatives fail because of insufficient attention to defining their objectives and scope.**
3. **Effective risk management does not require mathematics, but there are times when mathematics can help sharpen the focus on the main problems.**
4. **There is no single "correct" way of undertaking a risk assessment or risk management initiative, but there are principles which should be observed.**

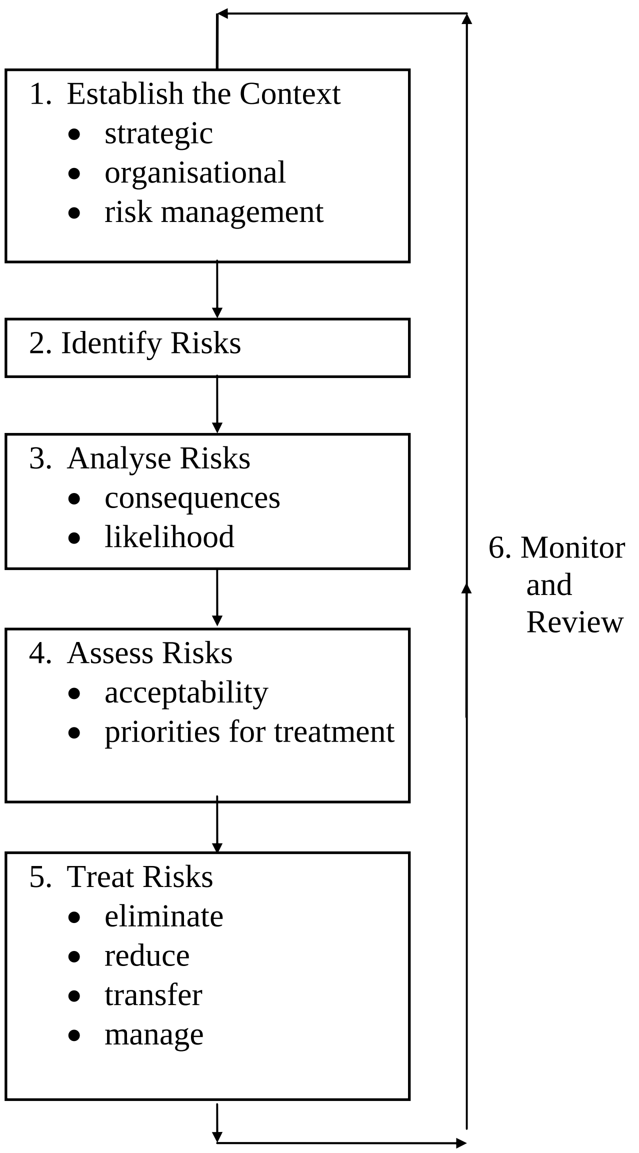
The application of these steps is discussed for a variety of situations which can occur at mines.

3.1. THE STEPS IN RISK MANAGEMENT

The Australian Standard on Risk Management[1] sets out the steps of risk management as:

- Establish the Context
- Identify Risks
- Analyse Risks
- Assess and Prioritise Risks
- Treat Risks
- Monitor and Review

These form a continuing process, illustrated below:



These are discussed below in general terms, then in more detail for specific types of application in later sections.

While the process of risk management is not difficult in concept, it is often very valuable for initial studies to be facilitated by someone with previous experience in risk assessment and risk management programmes, and with an awareness of the special nature of mining operations and the risks which arise from them.

3.2. ESTABLISH THE CONTEXT

This entails review of and briefly documenting the strategic, organisational and risk management situation. These are discussed below.

- **Strategic context**

  This entails considering the relationship between the mine's operations and its environment. By environment is meant the physical environment, the stakeholders of various kinds, and the political environment.

  - physical environment (e.g. natural environment, neighbours whether agricultural, residential or industrial etc.);
  - stakeholders (e.g. the owners of the organisation, employees at all levels, customers, suppliers, local community, interest groups and society as a whole including the various levels of government);
  - political environment (e.g. relationship between the particular mine or the mining industry in general with local government, state or federal governments etc.);

- **Organisational context**

This entails considering both the goals and objectives of the organisation in relation to risk management, and as its capabilities. For example, the organisation may not know whether its risks are well controlled or not; it may regard its performance as quite good, and needing only a tune-up; or it may recognise a need for a rapid and major improvement. It may, or may not, have staff able to undertake the steps in the risk assessment and the risk management programme. It may see its priorities for risk management as principally relating to safety, rather than the environment, property damage or loss of production.

These all affect the objectives, scope and methods of the risk assessment to be undertaken and of the risk management programme of which the risk assessment study is part.

- **Risk management context**

  This entails defining and recording:

  - the goals of the risk assessment study, and of the risk management programme
  - the scope and limits of the study (in time, location, depth, breadth etc.)
  - the specific studies to be undertaken

Beware of rushing into the study without giving a lot of thought to the scope, to determine the nature of the risks to be considered, the bounds of the activities or facilities to be studied, and the purpose of the assessment.

These determine the selection of the methods to be used in the study.

If in doubt, seek advice from someone with experience.

3.3. IDENTIFY RISKS

This is perhaps the critical step of a risk assessment. A risk which is not identified cannot be actively managed.

There are many techniques available for identifying risks, but none of them can be expected to identify all the risks, large and small. The aim, in risk identification, is to be *confident* (not *certain*) that no significant risks have been overlooked.

Having recognised the existence of risks, it is necessary to consider possible causes and scenarios.

It is said that *"time spent planning is seldom wasted"*, because the usual fault in planning is that too little is done; rarely is too much done. Similarly, in risk assessment, time spent identifying hazards is seldom wasted.

There are many techniques available for identifying risks. Some of these are listed below.

- Action Error Analysis - a method of postulating and analysing possible human errors, by considering each step in a procedure against a checklist of possible errors, such as: error of omission; error of time; extraneous act; transposition; error of selection; error of sequence; miscommunication, qualitative errors; etc.
- Failure Mode and Effects Analysis (FMEA)[1] - a systematic review of the effects of different types of failure of each component of a machine or item of equipment;
- Failure Mode and Effects Criticality Analysis (FMECA)[1] - similar to FMEA, but with addition of estimates of the severity of the effects and the likelihood of occurrence;
- Fault Tree Analysis (FTA)[2] - a method of analysing possible causes of defined unwanted events, by starting with the defined unwanted event, identifying possible causes, then analysing the factors leading to those causes etc, until "root causes" have been identified;
- Hazard and Operability Studies (Hazop)[3] - a systematic review of the consequences and likelihood of different process or system abnormalities, such as excessively high or low flow, pressure, temperature, etc. It can be adapted to a wide range of types of industry and operation. Its general approach is the foundation for other methods such as MHI and PHEI (see below).

[1] See Appendix A1
[2] See Appendix A2
[3] See Appendix A3

Machinery Hazard Identification (MHI)[4], in which plant or machinery is considered, by sections or components, considering the potential for a range of injuries to people by studying a checklist of possible causes.
- Potential Human Error Identification (PHEI)[5], which is a variation on Action Error Analysis.
- Rapid Ranking[6] - a method developed initially for ranking identified risks, but which has been developed to include hazard identification.
- Workplace Risk Assessment and Control (WRAC)[7], which is a process for identifying potential production or maintenance incidents and losses, and uses a matrix approach to define risk levels from estimates of consequence and likelihood.
- What-If? Analysis - a method of examination of the consequences of a wide range of types of occurrence, drawn from a comprehensive checklist designed to suit the particular type of operation.

There are many methods available for identifying risks. There is no single method which is the only correct one for any particular situation.

There are, however, a number of important principles which should be adopted. They are:

- **don't expect one person to identify risks; use a team with a range of experience and expertise;**
- **use a systematic approach in sufficient detail to match the objectives and scope of the study.**

All effective methods of risk identification rely on several essential principles. They are discussed briefly below.

- ***Team with Diverse Expertise***

Anyone can identify hazards. The difficulty comes when one is required to identify *all* the hazards, and *all* the ways in which those hazards can give rise to an accident.

No single person has complete knowledge. Further, while we may be aware of some of the fields of knowledge which we know little about, we cannot know of information which we have never heard of. We all have "blinkers", and are unable to comment on what is outside our field of vision.

Therefore, in practice, it is never possible to be certain that we have identified all the hazards or all the routes to an accident. The aim is to be confident (rather than certain)

[4] See Appendix A4
[5] See Appendix A5
[6] See Appendix A6
[7] See Appendix A7

that we have identified all the main hazards, and most of the routes by which a major accident could arise from each, or at least the critical components of most types of major accident.

Our background and experience determine our outlook. Therefore, one of the principles of hazard identification is:

> ***"Hazard identification should be undertaken by a team of people, with a variety of relevant backgrounds"***

It is good practice to include in the team people with a variety of technical expertise, and from varying levels in the organisation. Typically a team studying machinery risks will include people with production and engineering experience and expertise, and both managerial and operating or trades roles in the organisation.

An important benefit obtained by the use of a team is that each person learns from the experience of others, resulting in both a greatly increased understanding of the risks (the first requirement set out by Hawksley), and consensus about the nature and scale of the risks is reached quickly across the various sections of the organisation represented in the team once a shared understanding is developed.

- ***Systematic and Detailed Approach***

In aiming to identify hazards, and the dangerous scenarios to which they can give rise, it is important to cover the possibilities fully, rather than darting from possibility to possibility as the discussion leads. This leads to another principle:

> ***"Hazard identification should be undertaken systematically, aiming to cover the full field of possibilities"***

Most techniques for identifying hazards meet this principle by subdividing the operation or equipment into an appropriate number of elements, and for each element to be considered in turn against a comprehensive checklist of possible problems, mishaps, abnormalities etc.

When aiming to identify the range of possible ways in which an accident could arise from a hazard, it is important to investigate in as much detail as is appropriate to the objectives of the investigation. When undertaking the first study of a mine in which there has been no previous formal risk assessment, any attempt to identify all risks in detail would result in an extremely long list, of which only the most severe could be analysed, assessed and treated in the foreseeable future. Again, at the early stages of a new design, it is only necessary and possible to identify major hazards and typical routes to a major accident, so as to guide the broad design concept. When a completed procedure, method or design is being studied, a fully detailed investigation is appropriate, so that as many as possible of the small "bugs" in the design, and opportunities for problems with maloperation, can be identified and eliminated or avoided.

This leads to the following principle:

> ***"The degree of detail in hazard identification should be appropriate to the objectives of the investigation"***

3.4. ANALYSE RISKS

As set out earlier, risk analysis is *"A systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences."*

Analysis of risks entails understanding the nature of the risks which exist, the nature of the existing controls and "barriers", and assessing the *likelihood of occurrence* of mishaps, and the *severity of the consequences* of those mishaps.

It is often thought that the likelihood and severity must be expressed in numbers. This is not correct. Certainly, where they can be quantified this should be done, but in the mining industry there are many factors affecting the likelihood and the consequences which cannot be expressed in numbers, and which need to be expressed in words.

In some industries, such as the oil and chemical industries, it is possible to calculate the size of the possible accidents, such as the heat radiated from a jet of burning gas, or the toxicity of a poisonous gas at a distance downwind from a leak.

In the case of risks arising from the operations and equipment at a mine, it is likely that a significant proportion of the identified risks will not be suitable for mathematical analysis. In most cases, the likelihood of accidents and the severity of their possible consequences can only be estimated, using experienced judgement, and drawing on mine site and industry-wide accident and incident data whenever appropriate and available.
These estimates of consequences and likelihood may be expressed in numbers on a scale, e.g. ranging from 1 to 5 for low to high, with different scales being used for risks of different types.

For example, the *consequences* of risks can be estimated in terms such as those below:

- *risks to people:* the numbers of injuries of different severities;
- *risks to property and production:* the monetary value of the damage or production lost;
- *risks to the environment:* the extent and severity of the environmental damage, or the extent of public reaction.

Likelihood can be expressed in terms of the frequency per year, or the expected time between occurrences (e.g. 10 years).

When estimating consequences, it is important to take account of both tangible and intangible consequences. For example a major accident which resulted in many fatalities would be expected to have a major impact on the future operations of the mine, but there the nature and extent of that impact would have both tangible and intangible dimensions, such as the increased costs of additional safeguards (tangible) and the difficulty of recruiting miners afterwards (intangible).

As the basis for deciding the priority to be given to treating the various identified risks will be decided on the basis of the assessed likelihood and consequences, it is important that the estimates be made by people with sufficient experience for their judgement to be reliable, i.e. as good as anyone else, and with good credibility within the organisation.

As with risk identification, different people can bring different insights to the estimates. This leads to another principle:

> ***"Where the likelihood or consequences (or both) of identified risks cannot be calculated mathematically, then they should be estimated by consensus of a group of people with varied relevant experience and expertise."***

The magnitude of each of the risks is obtained by consideration of both its likelihood and potential consequence. Where there are mathematically determined values for likelihood and consequence, the quantitative risk is determined by multiplying them. Where the likelihood and consequence are each defined according to some nominal scale, a table can be used which embodies the same approach. (It is important to ensure that the scales used for the likelihood and severity are consistent. The risk table shown in Appendix A8 meets that requirement, as the steps between each level of likelihood and consequence are identical - factors of 10 in each case.)

Various approaches may be used for systematically analysing the identified risks. Some of these follow the risk identification step, while some are integrated with it. Some suitable methods are listed and outlined in the Appendices.

3.5. ASSESS AND PRIORITISE RISKS

Risk assessment is *"the process used to determine risk management priorities by evaluating and comparing the level of risk against predetermined standards, target risk levels or other criteria."*

This explicitly requires the existence of *"predetermined standards, target risk levels or other criteria"*. The nature of these is discussed later.

Implicit in the definition of risk assessment is the assumption that it is not possible fully to treat all risks at once, and that there is a need to sort out those which will be treated at once from those which will be treated later, and from those which are too small to need treatment. Some methods of assigning priorities are discussed later.

In the case of operations and equipment at mines, it will generally not be possible to determine the absolute level of risk with any confidence, although it is likely that a broad impression will be formed in many instances. Various degrees of detail may be possible in expressing the level of risk. For example:

- *"It is very difficult to see how anyone could be seriously injured when using this equipment."*
- *"This procedure appears to have a loophole such that it is entirely credible that someone could be killed in the next 5 years."*
- *"It is entirely credible that several people could be killed in the event of malfunction of this machinery, because of its size and purpose, but it would require failure of a number of very reliable 'barriers' before that could happen."*

"The rock in this section of the mine has resulted in minor roof falls such that we feel that it is likely that one or more people could be killed in a fall within the next five years unless the bolting procedure is changed."

"If the current design is not changed, we would expect that someone would be seriously injured during a 10 year life of the machine."

- *"We believe that there is a 10% chance of someone being seriously injured during the 10 year life of this machine."*

This sort of information is very valuable when deciding the degree of effort to be put into reducing risks.

When deciding the degree of effort to be put into reducing risks, one of two possible approaches must be selected. They are:

- comparing the assessed magnitude of the risks (e.g. as expressed above) with a statutory requirement, or a organisational policy on safety, or with a consensus view of what "good practice" or "due diligence" would require (with one test of due diligence being whether one would be comfortable explaining the approach to a court!);
- deciding on an amount of capital or staff effort which can be allocated each year to risk reduction and risk management.

There are a number of methods by which the risks can be prioritised for treatment. But first it is important to recognise that there are two main classes of treatment which may be needed. They are:

- ***risk reduction*** - needed for risks which individually or in total are excessive when compared with some standards or criteria;
- ***risk control*** - needed for risks which could have very serious consequences if they were realised, but which are not regarded as high risks because of their low likelihood. (If they are not monitored and controlled, they may be expected to increase in likelihood and become high risks).

Examples of methods by which risks can be prioritised are listed and outlined in Appendices 6 and 7.

3.6. TREAT RISKS

Risk treatment is *"selection and implementation of appropriate options for dealing with risk."*

Typically the options comprise:

- acceptance (particularly applicable to low risks); i.e. deciding to do nothing to reduce the risk or to control it;
- reduction (particularly applicable to high risks); i.e. acting to reduce the likelihood or the consequence of the potential mishap - or both - (by changing designs, procedures, management methods etc.);
- transfer (particularly applicable to risks with serious consequences and low likelihood); by such means as insurance or contractual arrangements;
- on-going management (particularly applicable to risks with serious consequences and a low likelihood which could increase unless actively managed);
- retain the risk (particularly applicable to residual risks, left after risk reduction, which may require financing).

The full value of a risk assessment becomes evident when consideration is given to the actions needed to treat the risks.

The risks from any particular machine or equipment will have been found to take a number of forms, to arise from various features of design and operation, and to have a number of possible causes. In the analysis, the likelihood and consequences have each been assessed, either in numbers or in words, and the causes and safeguards understood.

The main reasons for any individual risk needing treatment are thus displayed for examination, together with their contribution toward the total risk. What is needed is selection of the most cost-effective combination of actions to reduce the total risk, and a work plan for undertaking those actions. The options can be developed by consideration of the six principles postulated by Hawksley: understanding, equipment, procedures, staffing and training, emergency preparedness, and promotion.

This leads to another requirement, without which any risk assessment is a sterile document:

> ***"A risk assessment should include***
> - ***a list of the actions planned:***
>   - ***to reduce high risks;***
>   - ***to control the likelihood of potentially serious accidents even if the likelihood is seen as low;***
> - ***a programme for undertaking at least the first steps of implementation."***

3.7. MONITOR AND REVIEW

As set out earlier, a well-recognised role of management is *control*. Control, in turn, entails:

- setting a standard
- monitoring or measuring the actual performance
- comparing the actual performance with the standard
- acting to correct any deviation from the standard.

Thus an essential part of any risk management programme is monitoring of performance compared with the standards and the plans, and review of the standards themselves, the plans, the way work is organised and monitored, and the nature of and reasons for the problems or shortcomings identified.

A "Risk Assessment" entails Steps 1 to 4, and includes an outline of the programme of work planned under Steps 5 and 6.

4. WHERE IS A RISK ASSESSMENT NEEDED?

KEY POINTS OF THIS CHAPTER

- There are many different circumstances in which a risk study may be appropriate. They include:
  - wherever a mine has not had a formal risk management programme to date
  - wherever there are so many risks that it is important that they be treated with an appropriate priority and in an organised way
  - wherever there is a particular risk which could have serious consequences and where the causes and adequacy of safeguards are not entirely clear or understood;
  - wherever there is a change planned to equipment, machinery, procedure, manner of working etc.

- There are many different methods available for undertaking a risk study. Selection of the appropriate method depends on the circumstances of the study. Even then, there are usually several methods which can be used which will give comparable results

In everyday life everyone assesses risks. Fortunately these are mostly minor, such that inadequate assessment, and the consequent mishaps, do not matter greatly.

In principle, a systematic risk assessment should be undertaken wherever there is:
- potential for a mishap which could have serious consequences
- a large number of risks with varying consequences and likelihood, where the priority of them is not clear.

Examples of such situations include:

- a mine which has not previously undertaken a formal risk management programme wishes to do so, but has limited resources (financial, staff) to make dramatic improvements at once;
- a “near miss” has occurred, and management wish both to act effectively to prevent a recurrence leading to an accident, and to broaden the approach to prevent other serious mishaps which have not yet given “early warning” by means of a near miss;

- a modification is planned to a procedure which could affect some important mining safeguard;
- a new type of equipment or machine, or equipment or machine which has been extensively modified, is to be purchased;
- equipment or a machine is to be modified;
- an established method of undertaking a mining operation is to be modified;

These can be summarised as

1. wherever a mine has not had a formal risk management programme to date, a broad brush risk assessment should be undertaken to identify the principal priorities (e.g. improvements in understanding, equipment, procedures, organisation, emergency preparedness, commitment etc, as set out in Section 2.1 above);
2. wherever there are so many risks that it is important that they be treated with an appropriate priority and in an organised way, to achieve most rapid overall risk reduction with the limited resources.
3. wherever there is a particular risk which could have serious consequences and where the causes and adequacy of safeguards are not entirely clear or understood;
4. wherever there is a change planned to equipment, machinery, procedure, manner of working etc. with the potential to affect the magnitude or likelihood of some inherent mining hazard, or the effectiveness of some safeguard or "barrier".

(The present (August 1996) regulatory requirements for risk assessment are as follows.

1. The Notice *"Specification of Requirement for Approval - Powered Winding System"*, gazetted on 18 June 1993, requires a documented risk assessment to be provided with any application for approval of a powered winding system or any variation to an existing approved system. This requirement specifically covers winding systems operating between the surface and underground and includes: a) shaft sinking projects, and b) winders with the prime function of transporting materials, as people are transported by them to perform duties such as shaft inspections and accompanying materials which are being transported.
2. The *Notice of Appointment of Accredited Assessing Authorities* requires that any risk assessment conducted for approval purposes shall be audited by an independent body.
3. The independent body shall have the appropriate qualifications, knowledge and experience in risk assessment methodology available for the audit task.

These requirements are covered by the above summary.)

5. HOW DO WE UNDERTAKE A RISK ASSESSMENT?

KEY POINTS OF THIS CHAPTER

- The approach taken to a risk study in any circumstances should be structured broadly around the steps set out in AS/NZS 4360, although the particular methods used to identify, analyse, assess and treat the risks will vary.
- The various methods available for use in risk studies generally all use the same broad principles, and so, provided that they are applied with care to adapt them to suit the nature of the mining operation or equipment to be studied, several of them could be used with equal success.
- It is not the documentation of a risk study which leads to effective risk management; it is the insights, understanding, communication and actions which result. Good documentation aims to assist these, not to be an objective in its own right.

5.1. INTRODUCTION

While there is a general structure to undertaking risk assessment as an aid to risk management, the details of how it is done in different situations vary a great deal.

Possible approaches are set out below for different situations. These are suggestions only, intended to be helpful without limiting what is done in any particular case.

The approach to risk assessment is described most fully for the first example (Broad Brush Risk Assessment of a Mine). The description of the approach in the subsequent cases is based on the description of that case, and assumes familiarity with that description.

5.2. BROAD BRUSH RISK ASSESSMENT OF A MINE

5.2.1. Introduction

A Broad Brush Risk Assessment is one which covers the full operations of the mine, or at least a high proportion of the activity. By being broad, it cannot be expected to go into a high degree of detail.

The circumstances in which a broad brush risk assessment of a mine may be appropriate include:

- a need by management:
  - to feel confident that they have an understanding, not only of the risks involved in the operations of the mine (which any experienced mine manager would have already), but also of their relative magnitude and the range and adequacy of the safeguards of all types;
  - to identify which safety-related controls need most careful on-going attention in order to ensure that the risks of major disaster remain extremely low;
  - to narrow down their field of attention for risk reduction; to identify which parts of the mine, or which operations, or which particular hazards need most attention;
  - to be confident that they are using “due diligence” to prevent accidents, thus meeting their responsibilities under various safety legislation (noting that failure to conduct a “risk assessment” is becoming increasingly regarded in many industries as negligence);
- a continuing record of mishaps, accidents and near misses such that it is clear that much needs to be done to reduce risks, but before a programme of improvement work can be prepared which will result in a rapid and cost-effective risk reduction it is necessary to determine which risks have the highest priority for risk reduction;
- unease amongst employees in the various parts of the organisation about the level of safety, and unproductive debate about what should be done to improve it.

5.2.2. Establishing the Context

5.2.2.1.Strategic Context

In this instance, definition of the context means determining the statutory and other pressures which bear on the organisation. For example:

- Is the organisation being criticised by statutory authorities or other external bodies for poor performance in relation to safety or the environment?
- Is there pressure from the owners (e.g. parent companies) for an improvement in safety or environmental performance?
- Are changes in the relevant legislation, or the regulatory regime, such that there is a need to take action so as to stay ahead of the game?

5.2.2.2.Organisational Context

In this instance definition of the context starts with defining the nature of the organisational need which calls for a broad brush risk assessment, i.e. defining which of the situations set out in Section 5.2.1 above, if any, or what other situations, suggest the need for a broad brush assessment.

Risk assessment methods can be adapted to cover a range of types of risk simultaneously, or can be focused on one type of risk as necessary, and in making such a decision, it is important that the needs of the organisation as a whole are considered so as to get most benefit from the effort. Therefore it is important to clarify the nature of risks which the organisation is concerned about: e.g. risks of injury to people, damage to the environment, damage to equipment, loss of production, loss of reputation etc..

5.2.2.3.Risk Management Context

There are various approaches which can be taken to risk assessment. The particular one selected, and the nature of any adaptations of it, depend on both the particular objectives of the study (e.g. types of risk to be considered), and the resources and limitations of the organisation in approaching the task.

At this point it is necessary to consider the attitudes within the organisation. For example:

- Is there agreement amongst those who work at the mine about the need?
- Is there agreement amongst those who work at the mine about the approach which should be taken?
- Who will be most instrumental in making any improvements which are found to be necessary? What are their views on what is needed?
- Are there any established or preconceived views about the most important risks and the methods of approaching them?
- Is there any active opposition to an organised programme of risk assessment and risk reduction? Why? Do the opponents have a case? How can their requirements be included in the objectives and scope of a risk assessment and management programme?

5.2.3. Identifying the Risks

There are several approaches to risk identification which combine risk identification and a form of initial risk analysis (entailing subjective and brief estimation of both consequences and likelihood so as to form estimates about the magnitude of the risks). These approaches include: **Failure Mode Effect Criticality Analysis -** see Appendix A1; **Hazard and Operability Studies (“Hazop”) -** see Appendix A3 - in an extended form; **Rapid Ranking** - see Appendix A6; and **Workplace Risk Assessment and Control** - see Appendix A7.

In a broad brush risk assessment, it is not appropriate to use a method which requires great detail, as the work required and the resultant elapsed time would be excessive.

A suitable method for most broad brush studies is Rapid Ranking. It has the following advantages:

- the depth of detail can be set to suit the needs of individual studies (noting however that the less the detail, the greater the chance of overlooking an important risk);
- it is ideally suited to teamwork;
- it is easily learned without a strong technical background;
- it is a very effective way of raising understanding of risks;
- it is a very effective way of building consensus about the most important risks and how they should be tackled.

The Rapid Ranking method has been used in a wide range of applications, from railways to steel-making, from warehousing to oil refining.

Both Hazop studies and FMEA are too detailed for general use in a "broad brush" risk assessment.

Two particularly important questions which should be asked when undertaking any risk assessment are:

1. ***"Can a failure of a single component of a machine or item of equipment result in a high-consequence event?"***
2. ***"Can a single human error result in a high-consequence event?"***

Where any such failures or errors are found, close attention must be given to ensuring that the risk is very low. This entails "risk treatment", which is discussed in Section 5.2.6 and later sections.

5.2.4. Analyse Risks

In the Rapid Ranking method, the consequences and likelihood of the various risks are estimated by the team, using scales for the severity of the possible consequences and their likelihoods defined at the start of the study. Different consequence scales are needed for each type of risk; it is not possible to use the same scales for safety, the environment, and property damage, but the likelihood (frequency) scales are the same.

The absolute values of the estimates is not critical; the principal requirement is their relativity. It is found that, once a few estimates have been made of consequence and frequency of each type of risk, that a judgement can be formed about the magnitude of the risk.

There are a number of possible variations to the Rapid Ranking method. One such variation is shown in AS/NZS 4360 Appendix F as a "Risk Register", but is presented in the Standard as a form of documentation summarising the findings of a risk assessment, rather than as the framework and documentation of the method itself. The methods outlined in Appendices A6 and A7 of this Handbook is a well-proven approach in which the results of the study are directly recorded in a form similar to the "risk register" on a computer spreadsheet to facilitate sorting to separate the different types of risk and then to rank the risks of each type according to their magnitude or their potential consequences.

This sorting process proves most instructive in separating the vital “few high” risks from the “trivial many” risks of lower priority.

5.2.5. Assess and Prioritise Risks

The **Rapid Ranking** approach should be used to produce two lists of scenarios; one ranked according to their total risk score, and the other ranked according to their severity score.

Assessment entails consideration and evaluation of the significance of the risks. While AS/NZS4360 indicates that this should be undertaken in relation to predetermined standards or acceptance criteria, this is not always possible as such standards may not exist and may not be possible to define fully in tangible numerical terms.

It is important to recognise that risks cannot be fully characterised with numbers. In fact, there are good reasons to consider risks as comprising both tangible and intangible components, with the tangible components usually being expressed in numbers, and the intangible components being expressed in words.

> *For example, it may be estimated that a serious accident, which may result in many fatalities, has a low likelihood of occurrence, and estimates may be made of both the number of fatalities and the likelihood (e.g. 10 people, and a frequency of 1 in 1000 per year). Active consideration of the intangible dimension of the risks may suggest that the programme of monitoring for unsafe conditions has become rather relaxed and informal, so the intangible component is becoming high. The informal and hence dubious standard of the monitoring programme could be described by including examples of weaknesses observed by those working in the area and by anecdotal evidence, providing a basis for focusing on the correct action in the next stage of “treating risks”.*

(It is sometimes believed that it is safer, from the viewpoint of legal liability, not to record weaknesses in case those records are produced at some later date as evidence in an accident investigation. This is fallacious. Failure to identify weaknesses can equally be held to be evidence of negligence.)

Because the limits of acceptability of risk are often largely subjective and intangible, and hence not clear-cut, it is important that those exposed are involved in any decision about where the cut-off line is drawn.

In the case of the risks which have been ranked in order of total risk score, it is common to draw a *provisional* cut-off point below the scenario which, together with those above it on the ranked list have a cumulative risk score totalling around 80% of the total risk score for all the scenarios. At this stage, a group of people representing a range of experience and viewpoints should review the list, considering both the numbers (e.g. severity score, initiation frequency, mitigation failure probability) and the intangible factors relating to the scenarios close to the cut-off line, both above and below it, to form a view about whether the risks presented by those scenarios need be included in the work programme for immediate attention with a view to risk reduction, or whether they have a lower priority and must be left till the first priority risks have been dealt with. This consideration of both the numbers and the intangible factors can result in the priorities for action not being in the same order as the ranked list of scenarios.

It is important to recognise that it is not possible to remedy all problems at once. But it is normally regarded as reasonable to “do the first things first”, then to move on to the tasks with the next level of priority. So it is evident that this review needs to take into account the real-world limitations on the resources (money, skilled people etc) who can be made available at once, or in the first year for example, to reduce the risks.

As discussed above, the list of scenarios ranked according to the total risk score are considered with a view to *risk reduction*, as they have been judged to have high risks. As discussed earlier, scenarios with a potential for serious incident, even if the risk is judged to be low because they are very unlikely to occur, are in need of active managerial control to ensure that the likelihood continues to be low. So the list of scenarios ranked according to their severity scores are now considered with a view to *risk control*. (Both risk reduction and risk control are forms of *risk treatment*, as listed in AS/NZS4360.)

In the case of this list, the cut-off line may be drawn at the point where the severity score is relatively minor compared with the severity scores toward the top of the list.

5.2.6. Treat Risks

The classes of action which can be taken to treat the risks may be classified according to the six requirements as set out by Hawksley. They are:

- development of improved understanding of the hazards (i.e. the potential for accident), and the safeguards;
- improved facilities and equipment, to reduce the impact or the likelihood of possible accidents;
- improved systems and procedures, to reduce the impact or the likelihood of possible accidents;
- improved organisational structure, manner of working and communications, improved staffing and training;
- improved emergency capability (ability to recognise early warning signs and the onset of an emergency and ability to respond appropriately and promptly);
- improved promotion of safety in design, procurement, operation, maintenance and supervision, and of risk management in general.

In the case of the scenarios which were shortlisted because of their *high risk scores*, the process of “treatment” may comprise:

- a more detailed analysis of the possible causes, severity and likelihood of the postulated risk, if these are imperfectly understood;
- careful review of the technical and managerial options for:
  - reducing the severity of the impact, in the event of the postulated incident occurring;
  - reducing the likelihood of occurrence;
  - reducing both severity and likelihood.

In the case of the scenarios which were shortlisted because of their *high severity scores*, the process of treatment may comprise:

- review of the arrangements for operating, maintaining and supervising the activity or operation, to ensure that it is established to "quality" principles (i.e. fit for purpose, with clearly defined standards, properly defined instructions and appropriate training etc. so that those undertaking the work have a clear understanding of what they are to do and means of assessing their own performance, and of possible mishaps, how to recognise the early warning signs and how to respond);
- review of the arrangements for monitoring performance by supervisors and management, and implementation of improvements to ensure that there is effective ongoing routine control of the activity;
- review of the programme for auditing:
  - the understanding of the risks and their possible causes and safeguards
  - the facilities and equipment
  - systems and procedures;
  - the effectiveness of the organisation, staffing, communications and training
  - the standard of emergency preparedness
  - the extent of ongoing managerial promotion of safety and general risk management.

Where a single equipment failure or human error could result in a high-consequence event it is important, in addition to consideration of the actions listed above, as far as possible to provide at least a "second line of defence", or a "belt and braces" approach by means of additional equipment, changed procedures etc., to make the event impossible without at least two independent failures or errors.

5.2.7. Monitor and Review

The programme of work listed when preparing the risk treatment plan (Section 5.2.6 above) must be managed, just as any other programme. It is preferable for the risk management tasks to be incorporated into the same list as is used for the other projects being undertaken by the mine, and managed by the same team in the same meetings. This is because risk management is an integral part of operations management, not a separate activity.

The success of the programme needs to be reviewed periodically by consideration of:

- the degree of completion of the listed tasks ("inputs");
- the performance of the mine in relation to the defined criteria ("outputs").

The result of such a review will be:

- recognition of any shortcomings in the risk management programme, possibly necessitating additional resources being directed to specific tasks, or a change in emphasis of the programme;
- identification of the risks to be treated next in priority;
- preparation of an updated risk management programme (entailing initiatives in a range of fields including design, procedures, organisation and training, and promotion of risk management)

5.3. RISK ASSESSMENT OF A SINGLE SPECIFIC RISK

5.3.1. Introduction

The circumstances in which a risk assessment of a single specific risk include:

- an accident or a “near miss” which suggests that there may be a substantial risk;
- a request from a statutory authority or some other external source (e.g. a union) for a specific risk to be studied;
- an impending change in legislation in relation to a specific activity;
- a change in the situation in which a mining activity is carried out, such that an activity which was previously assessed as having a low risk has the potential to have a higher risk;
- a change in mine operations (equipment, machinery, manning, procedures etc.) such that a particular activity is likely to be undertaken more often, or in a different way.

5.3.2. Establishing the Context

5.3.2.1.Strategic Context

This entails consideration of whether such questions as:

- Is there any statutory or other external pressure for this particular risk to be reduced?
- Is this risk one which is inherent in the nature of the current operations, or of future operations, either because of the nature of the mine itself, or of the equipment, machinery, manning or procedures etc. which are to be used?
- Has there been an accident, or a near miss, suggesting that this risk is significant?

5.3.2.2.Organisational Context

This entails consideration of any organisational pressures for this particular risk to be studied. These may include:

- organisational concern about similar risks which have been identified by active review of historical events in other mines operated by the same or other companies (i.e. “Could it happen here?”);
- concern expressed by those involved in the activity, or others exposed to any risk which arises, or expressed by anyone else working at the mine;
- existence of a mine policy of any new situation, procedure etc. being submitted to a risk assessment.

5.3.2.3.Risk Management Context

At this stage it is necessary to consider and formally define the scope of the study: the objectives, the nature of the risks considered (safety, environment, property damage, production continuity), the bounds of the study (what will be included and excluded) etc.

It is also necessary to consider the questions set out in Section 5.2.2.3, as well as the following:

- Who are exposed to this risk?
- Who is responsible for managing this risk at the first line of supervision and further up the management structure?

- Who is best placed to give advice on the technical components of this risk?
- Who is best placed to give advice on the procedural components of this risk?
- Who is best placed to give advice on the behavioural components of this risk?
- Who is most likely to be critically involved in implementation of the findings from this study?

Consideration of the answers to these questions will provide guidance for selection of those to be involved in clarifying the objectives of the study, its scope, and for participating in the study itself.

5.3.3. Identifying the Risks

For a single source of risk, it is usually appropriate to adopt a more detailed approach than Rapid Ranking to identify the risks. Most such approaches use a systematic way of considering, for each subsection of the activity or equipment in turn, a range of possible mishaps or causes of mishap.

If the risk relates to a processing operation, then a suitable adapted form of **Hazop study** may be the appropriate technique - see Appendix A3.

If the risk is from mechanical equipment, then the appropriate approach may be "**Machinery Hazard Identification**" - see Appendix A4, or **FMEA** - see Appendix A1.

If the risk relates specifically to a manual operation, with potential for serious consequence from human error, then the appropriate technique may be **"Potential Human Error Identification"** - see Appendix A5.

Workplace Risk Assessment and Control (WRAC) may be applied generally - see Appendix A7.

5.3.4. Analyse Risks

Once a list of the possible scenarios has been prepared, by using any appropriate technique, including those listed above, it is necessary to determine or estimate both the consequences and likelihood of each scenario.

It is likely that the consequences will need to be estimated by comparison with some form of scale, as outlined in Section 5.2.4, preferably working to consensus by a small group, and possibly using the **"Delphi" method** - see Appendix A8 - to aid in forming consensus.

In some cases, where several different situations could apply at the time of the accident occurring (e.g. many people present; few people present), it may be appropriate to use **"Event Tree Analysis"** (ETA) - see Appendix A2 - to weight the different consequences accordingly. However, this degree of detail is probably warranted only in the case of very thorough analysis of a specific risk where the consequences in some circumstances could be very serious, and the conditions resulting in those serious consequences need to be fully explored and understood.

The likelihood or frequency of occurrence will probably also need to be estimated rather than calculated, again using a suitable small group of experienced people, possibly also using the Delphi method.

In some cases, where there is a complex variety of possible causes and safeguards, it will be necessary to analyse the cause-effect structure using **"Fault Tree Analysis"** (FTA) - see Appendix A2.

In some cases, where an accident could be triggered by one event, and where the serious consequences would only follow in the event of failure of several independent barriers or protective systems, it is possible to estimate the frequency of the serious consequences as below:

Frequency of Serious Consequences = **Frequency of initiating event**
x **Probability of failure of Barrier 1**
x **Probability of failure of Barrier 2**
x **etc., etc.**

However, care must be taken to ensure that the various barriers are truly independent, i.e. the various possible causes of failure of Barrier 1 are different from those of Barrier 2. If this is not the case, then **Fault Tree Analysis** - see Appendix A2 - will be needed.

In undertaking this analysis, it is important to record the non-quantifiable factors which have a bearing on the magnitude of the consequence and the likelihood of occurrence. These are often much more important than the rigorously quantifiable factors.

A Note about Human Error Analysis: There are various techniques available for analysing the potential for human error (e.g. **PHEI** - see Appendix A5), some of which also explore those factors which would be expected to increase or decrease the likelihood of error. These methods are very helpful in risk management, as they provide insights about the actions which can be taken to reduce the likelihood of error.

However, none of the methods which aim to quantify the likelihood of human error has survived validation. So estimating the likelihood of human error remains the province of experienced judgement.

5.3.5. Assess and Prioritise Risks

When the various factors and events which contribute to the total risk of the activity being studied have been estimated, it is possible to identify and rank the major contributors by inspection, and to plan the appropriate improvements.

It may be helpful to use the **Risk Matrix** - see Appendix A8, identifying which cell the risk best fits, to aid discussion about whether the risk is high, low, or medium etc.

5.3.6. Treat Risks

In considering the options for treatment of any risks which are significant, it is important to consider all six of the requirements listed in Section 2.1. It is then possible to select the combination of actions which will form a consistent and mutually-supporting "package".

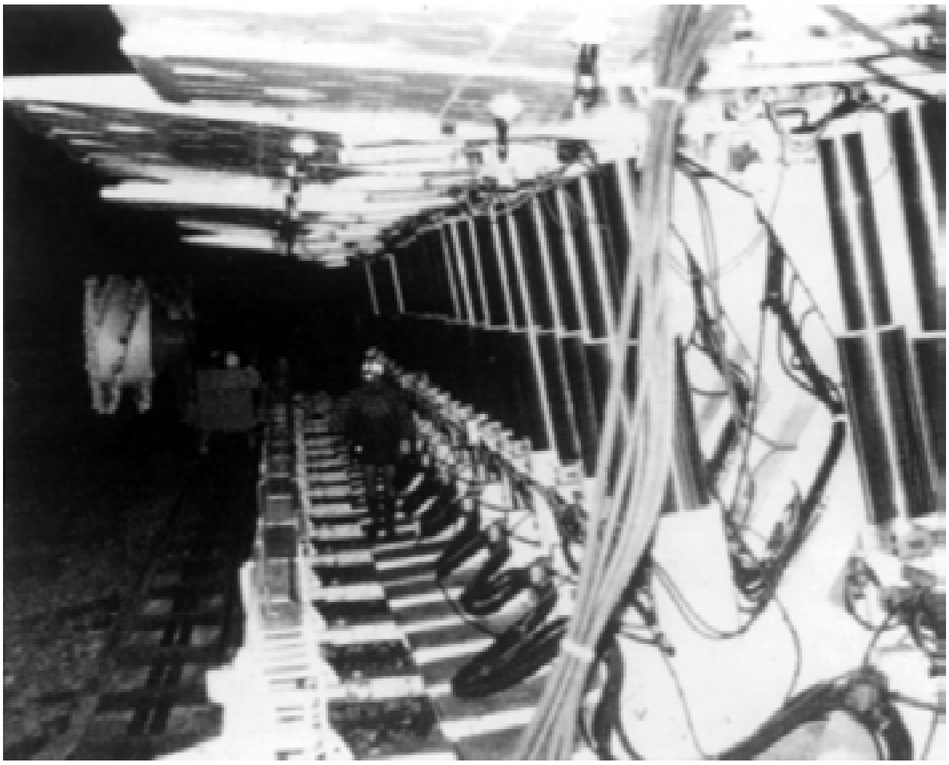
In the case of contributors which are estimated to have low likelihood, it is necessary to consider the managerial action needed to ensure that the likelihood is, in fact, low and remains so.

The selected actions both to reduce risk, and to control risk at a low level, need to be incorporated into work programmes and schedules.

5.3.7. Monitor and Review

See Section 5.2.7.

5.4. RISK ASSESSMENT OF MINING EQUIPMENT OR MACHINERY



5.4.1. Establishing the Context

5.4.1.1. Strategic Context

Definition of the strategic context entails consideration of the external pressures influencing the selection or design of equipment.

Because of the economies of scale, much mining equipment is physically large. Some of this equipment, because of its size, poses special risks. For example, maintenance of large earthmoving equipment may necessitate manual handling of heavy and bulky components in congested and confined spaces, such that injury to the tradesman is just a matter of time.

Some equipment, because of where and how it is designed to be used, necessarily exposes those operating it to substantial risks.

In some industries, statutory pressures (e.g. on noise) have led the industries to set specifications in supply contracts which have forced suppliers to improve their designs. It is conceivable that the mining industry, by undertaking risk assessments of commonly-used machinery and equipment, could provide the incentive for suppliers to improve the designs of their equipment such that safety is given priority along with productivity.

The external statutory pressures to improve the safety of machinery and equipment, and the opportunities which collaborative working within the industry, both should be considered at this stage.

5.4.1.2. Organisational Context

The pressures within the organisation for selection of design of safer equipment and machinery should be considered, together with the limitations placed by the performance required and the inevitable cost limitations.

For example, there may be a history of accidents with a particular type of equipment. When more equipment of the same general type is to be purchased, it is important that a risk assessment of the existing equipment be undertaken to identify possible design changes which could be specified so as to reduce those risks. If the same equipment is purchased without such a study a clear message will be sent throughout the organisation that safety is of lower priority than production or economics.

It is sometimes thought that risk is inversely proportional to expenditure; i.e. that safer equipment will cost more. This is not necessarily correct. If attention to safety is given at the outset of design, or at the equipment specification stage of a purchasing contract, it can often be gained at no extra cost. It is when a basically unsafe machine is purchased, and it is necessary to add-on safety, that the large expenditures are often involved.

5.4.1.3. Risk Management Context

At this stage it is necessary to consider and formally define the scope of the study of the machine or equipment: the objectives, the nature of the risks considered (safety, environment, property damage, production continuity), the bounds of the study (what will be included and excluded) etc.

It is also necessary to consider the questions set out in Section 5.2.2.3, as well as the following:

- Who are exposed to this risk, by operating the machine or equipment, or working in the vicinity?
- Who is responsible for managing this risk at the first line of supervision and further up the management structure?
- Who is best placed to give advice on the technical components of the risks associated with this machine or equipment?
- Who is best placed to give advice on the procedural components of the risks associated with this machine or equipment?
- Who is best placed to give advice on the ergonomic and behavioural components of the risks associated with this machine or equipment?
- Who is most likely to be critically involved in implementation of the findings from this study?

Consideration of the answers to these questions will provide guidance for selection of those to be involved in clarifying the objectives of the study, its scope, and for participating in the study itself.

5.4.2. Identifying the Risks

Various approaches can be used to identify the risks from machinery or equipment.

There are, in this case, two directions from which the identification can be undertaken. There is a strong case for using both. They are:

- focusing on the machine or equipment, and studying each section or operation which it performs (using an approach such as, or **Machinery Hazard Identification** - see Appendix A4, which is, in effect, such a form of adapted Hazop study, or **FMEA** - see Appendix A1, or **WRAC** - see Appendix A7
- focusing on the tasks performed by the people who use the machine or equipment, or who work in the area, seeking to identify ways in which their duties, analysed step by step, could expose them to danger. Suitable approaches include a form of **Hazop study** - see Appendix A3 - with the keywords adapted to the type of manual operations involved, or **Potential Human Error Identification** - see Appendix A5 - which is also a form of adapted Hazop study.

5.4.3. Analyse Risks

For discussion of the available methods, see Section 5.3.4

5.4.4. Assess and Prioritise Risks

Where many distinct scenarios are identified which could result in injury or other forms of loss, the **Risk Matrix** - Appendix A9 - can be used to determine where each risk should be placed on the range from low to severe. **WRAC** (Appendix A7) also includes a risk matrix for determining the level of risk. It covers different forms of impact in addition to safety, as does Rapid Ranking (Appendix A6).

For discussion about the approaches to prioritising risks, see Section 5.2.5.

5.4.5. Treat Risks

For discussion of possible approaches, see Sections 5.2.6 and 5.3.6.

5.4.6. Monitor and Review

For discussion of possible approaches, see Sections 5.2.7 and 5.3.7.

5.5. RISK ASSESSMENT OF A MODIFICATION TO PLANT, A MACHINE, EQUIPMENT OR A PROCEDURE

5.5.1. Introduction

Where a modification is made to plant, a machine, equipment (e.g. to improve its production capacity etc., or even with the aim of improving its safety) or a procedure, it is quite possible that an unexpected and unnoticed risk can be introduced. In a variety of industries, serious accidents have arisen from apparently simple and minor modifications.

It is good practice, whenever such a modification is planned, for management to call for a careful review of the potential for accident or other mishap, taking due account of the environment within the mine within which the modification is to be used.

Kletz[3] suggests a three-pronged approach to minimising the risk of any serious risk being introduced by such modifications. They are:

1. Any proposal for modification of plant, machinery or equipment should be reviewed by several experienced people.
2. Those people should have a checklist of questions to consider when undertaking that review.
3. There needs to be a programme of explanation and training to encourage people to follow the procedure, and not to bypass it.

A suitable procedure, in outline, is as follows.

1. The person proposing a modification to plant, a machine or equipment, completes a simple form which contains the following sections:
   - Title
   - Objective of the Modification
   - Brief Description of the Modification
   - Signature of Proposer
   - Signature of Mine Deputy
   - Signature of Mining/Mechanical/Electrical Engineer (as appropriate)
   - Comments by Signatories.

   On the reverse side of the form is the checklist of questions to be considered by each person signing. Such questions could include:

   Could the modification:
   - *affect the mine environment, e.g. ventilation, roof control, electrical distribution system integrity, gas management plan, transport rules etc?*
   - *affect the structural soundness of the plant, machine or equipment?*
   - *increase the inherent hazard of the plant/machine/equipment e.g. by increasing the weight, speed etc.?*
   - *increase the physical effort needed by those using it?*
   - *increase the risk of personal injury by those using it?*
   - *increase the complexity of the operations performed by those using it?*
   - *require additional training of people?*
   - *require development of new procedures or modification of existing procedures?*

2. The proposer marks any of the questions on the reverse which could be answered in the affirmative, and passes the Modification Approval Form to the first reviewing signatory.

3. The form is reviewed by the first signatory, who reviews it, and also marks any of the questions on the reverse which could be answered affirmatively. If he believes that the proposal is acceptable, he signs the form and passes it to the next signatory, who repeats the process.

4. If more than a defined number of the questions has attracted an affirmative answer (even if all the signatories have approved the proposal), or if any of the signatories specifically requests it for any reason such as a tangible fault being identified or having a nagging doubt about whether there may be a hidden weakness, then the proposal must be submitted to a detailed risk study such as set out in Section 5.3 above. If all signatories approve the proposal without the defined number of questions being flagged, then the proposal is approved, and the necessary modification is carried out, with a copy of the Modification Approval Form being attached to the work order requesting the modification.

5. Periodically a review is made of the Modification Approval Forms by the Mine Manager or his nominee, to ensure that it is being used correctly.

It is important to note that the basis for selection of those proposed modifications which need a full study is ***not*** *their cost, nor their complexity, but their potential for changing factors which are important for safety.*

6. HOW DO WE MANAGE THE ON-GOING RISKS IN THE FUTURE?

KEY POINTS OF THIS CHAPTER

- Management of risks comprises the same tasks as management of any other mining activity, and involves:
  - planning
  - organising
  - controlling
  - leading and motivating

- If any of these components are not being done, then risks are not being effectively managed.

- Management of the risks of an activity is an integral part of the responsibilities of the person responsible for managing the activity itself. So every manager must manage his or her risks.

- It is very helpful to establish an annual cycle for ongoing management of risks, linked with the budgeting cycle, so that expenditure for risk reduction and control can be built into the budget

6.1. RISK MANAGEMENT

As set out earlier, one classification of the role of management is:

- *planning*
- *organising*
- *controlling*
- *leading and motivating*

Controlling (whether mechanical control or managerial control) in turn comprises:

- *setting a standard* or target;
- measuring or *monitoring actual* performance;
- *comparing* the actual performance with the standard or target;
- *taking action* to eliminate any difference between the actual and the standard or target.

For effective on-going risk management, all these need to be addressed. It may be appropriate to establish an annual cycle, as below.

1. Review the risks at the mine at the start of the annual budgeting cycle (by such means as updating the full list prepared initially by Rapid Ranking), in the light of experience in the past year.
2. Prepare specific objectives for risk reduction actions and implementation of additional risk controls during the coming year, with the costs and benefits included in the annual budget;
3. Prepare a work programme to implement the actions and controls.
4. Arrange for the appropriate people to undertake the work, suitably organised, with appropriate resources, as part of their normal work.
5. Periodically (e.g. monthly) review progress on the actions compared with the plan, and arrange for action to be taken to overcome any undesirable deviation from the plan (e.g. by allocation of additional resources).
6. At the same time (e.g. at a monthly management meeting) review any occurrences of early warning signs of slipping standards in relation to any of the six requirements for effective risk management (see Section 2.1),or of the hazardous scenarios identified in the Rapid Ranking study, or of any other incidents which could have risk implications. (Of course, if there are any instances at any time of conditions or events which meet the specification of pre-defined "triggers", then the appropriate action should be taken at the time). In each case, the review should consider the root causes, and if these are not clear, or if the appropriate response is not clear, then a full investigation is warranted.
7. Arrange for an audit (e.g. annually) of the risk management process to be conducted by someone not otherwise involved.
8. Provide continual encouragement and personal example to those involved.

It is desirable for Step 5 (periodic review) to be part of a routine periodic review of performance of other mine activities, such as production and cost performance, so that risk management is not seen as an optional activity divorced from the other responsibilities which everyone has, but an integral part of them.

6.2. REVIEWING RISK MANAGEMENT PERFORMANCE

6.2.1. Introduction

It is comparatively simple to review performance in relation to lost time injuries, as there are usually sufficient of them each year for an upward or downward trend to be obvious.

However, in the case of major accidents, such as single or multiple fatality accidents or major mishaps affecting production, a record of no such accidents in the previous few years is no evidence that the risk is low; it could be high and rising, but the accident has yet to occur.

It is not possible to identify the full range of possible hazardous scenarios. Therefore any programme of risk management which is based solely on identification of specific scenarios will have gaps, some of which may be serious. ***Therefore, as well as monitoring and taking action to control any precursors of defined scenarios as part of the management programme outlined above, it is necessary to monitor and control the situation in relation to the six general requirements for effective management of risks*** (see Section 2.1), because a weakness in one or more of these could precipitate a serious accident, the scenario for which was not envisaged in the structured identification of risks. For example, the range of accident scenarios which could result from employing an untrained and inexperienced miner underground, without appropriate supervision, is very large.

The six requirements for effective risk management are discussed below in more detail than earlier when introduced in Section 2.1.

6.2.2. Understanding

It is essential that all those involved in mining operations, not just supervisors and managers, have a full understanding of the hazards inherent in their activities, the early signs of impending trouble, and the safeguards in place and how their reliability is ensured.

Without this understanding it is possible that people will occasionally act in a manner which threatens the safety of themselves and of others with whom they work.

It is important for supervisors to periodically test and reinforce this understanding,(by both formal training and informal conversation)

6.2.3. Facilities and Equipment

In the case of mines, facilities and equipment includes the mine itself. Clearly the condition of the mine, the machinery and the equipment used in the mine and in associated operations is one of the fundamental factors influencing safety in relation to both the potential for major accidents and for less serious “occupational” accidents.

For effective on-going risk management, it is important that the condition of mine itself, the facilities, machinery and equipment are all of an appropriate design or type, and kept to an appropriate standard. This calls for continual care in mine design, specification and selection of machinery and equipment, maintenance etc. It is appropriate, in an ongoing programme of risk management, for the standard of these to be reviewed formally on a periodic basis, e.g. annually, in addition to any actions taken during the year as a result of an identified weakness.

Mining operations are invariably variable (due to such factors as the variability of roof strength) introducing uncertainties which need to be constantly borne in mind, as this necessitates greater safety factors being used than would be the case if the variability were not present.

6.2.4. Systems and Procedures

There is a very large variety of systems and procedures needed for effective control of risks in mines. Some of these are required by legislation; some are developed for specific mines in response to local conditions or work practices.

These procedures can be classified into a number of groups. They are:

- ***Routine safe operation:*** examples are Standard Operating Procedures, maintenance procedures, equipment selection, programmes for routine checking of the condition of safety-critical equipment, schedules for routine testing of all protective equipment such as gas testing equipment and alarms, etc.;
- ***Performance monitoring and control:*** procedures for monitoring and reporting on the safety of the performance of machinery, equipment, systems, procedures and people, including accident reporting and investigation, informal tours of inspection by check inspectors, supervisors and managers;
- ***Progressing of improvements:*** examples include project work programmes and project review meetings;
- ***Safety auditing:*** these include formal and informal inspections conducted by people with no responsibility for the operations themselves, including inspections by district check inspectors, statutory inspectors, visits by staff of other mines etc.

6.2.5. Organisation, Staffing, Communications, Training

The way in which the various members of the organisation work together, who leads whom, who works alongside whom, who seeks help from whom, how effectively those activities are performed, and how effective is the communication between all those people (adequacy, accuracy and promptness of information flow) are all fundamental to safe operation of a mine. They need continual monitoring and review by mine management.

Similarly the adequacy and appropriateness of training and retraining, in both formal training courses and informal on-the-job instruction and correction, are similarly fundamental to safety, and need continual monitoring and review by mine management.

6.2.6. Emergency Capability

Emergency capability includes being constantly on the alert for early warning signs of impending emergencies, knowledge of the correct preventive action to take to forestall the emergency, having the necessary emergency equipment available and being able to use it, and having the appropriate emergency procedures and command structure defined and regularly practised.

6.2.7. Promotion of Safety and Risk Management

There is no single “best” way to promote safety and risk management which is guaranteed to build commitment throughout the organisation.

However, perhaps the two most important requirements are:

- ***visible commitment*** of the senior managers through active personal involvement in safety, using such methods as those listed below;
- ***active involvement*** in all phases of the risk management programme of all those (or representatives of them) in all parts and all levels of the organisation who will be involved in reducing or controlling the risks.

Among the approaches which can be adopted to promote effective risk management are:

- undertaking a regular schedule of “walk and talk” inspections; with supervisors and senior managers walking around the mine (above and below ground) with the specific aim of observing good and bad safety practices, and talking about them to those they see (in an educative role, not a punitive one);
- instituting competitions for safe work (but care should be taken, as these have a dubious record, providing an incentive for people not to report accidents);
- undertaking skill development programmes;
- working with each section to define safety and risk objectives specific to that section;
- setting safety awareness as a criterion when recruiting;
- including safety in job descriptions
- promoting active communication between all levels of the organisation during all types of meeting
- making information available about safety
- holding discussions about accidents in other mines and the lessons to be learned (e.g. *“Could it happen here?” “How can we prevent it?” “What are the signs that our risk of such an accident is rising?”*)
- holding risk identification and ranking studies with vertical slice of organisation
- getting specialists from elsewhere to give talks (e.g. on accident investigations)

7. WHAT ARE THE ESSENTIAL FEATURES OF A RISK ASSESSMENT?

7.1. ESSENTIAL FEATURES OF THE RISK ASSESSMENT PROCESS

For a risk assessment to contribute to an effective risk management programme, it must be consistent with the Australian Standard on risk management. In particular, it must include the essential features set out below.

ESSENTIAL FEATURES OF THE RISK ASSESSMENT PROCESS

1. Use of a risk assessment leader with the appropriate qualifications, knowledge and experience.

2. Use of a team with appropriately varied and relevant experience for risk identification.

3. Use of a detailed and systematic approach for risk identification.

4. Use of a comprehensive checklist of possible problems as part of the systematic approach.

5. Definition of the key questions to be answered and decisions to be made before undertaking the risk assessment, as a means of ensuring that the assessment provides the answers which are needed. (Examples of typical questions are listed in Appendix A9).

6. Definition of a safety standard to be reached, either in words or in figures; or definition of the level of expenditure of financial or staff resources to be devoted to risk management.

7. Identification of both those high risks which need to be reduced, and those possible high consequence events which need to be prevented.

8. Listing of the risk reduction actions to be taken, and a timetable for the early stages of the work

9. Listing of the routine management actions to be introduced or continued with the aim of preventing occurrence of the high consequence events (including a monitoring programme for operational employees at appropriate levels in the organisation, and an auditing programme for people outside the line management)

7.2. ESSENTIAL CONTENTS OF A RISK ASSESSMENT REPORT

The essential features of a risk assessment report are set out below.

ESSENTIAL CONTENTS OF A RISK ASSESSMENT REPORT

1. A brief description (with diagrams if appropriate) of the machinery or equipment being studied.

2. A brief summary (e.g. 1 to 2 pages) of the context from the strategic, organisational and risk management viewpoints.

3. A list of the people involved in the risk identification step, together with their organisational roles (and hence experience which they brought to the study).

4. An outline of the approach used to identify the risks , including a list of the keywords if Hazop or a similar method were used.

5. An outline of the method adopted for assessing the likelihood and consequences of the risks.

6. Two lists of the identified risks, ranked according to:
List A. the assessed risk;
List B. the magnitude of the consequences.

7. A discussion of the basis used to define the safety standard to be achieved, or the level of expenditure of financial or staff resources in managing risks.

8. A list of the main actions proposed to reduce the risks from those ranked highest of List A.

9. A list of the controls (equipment or procedures etc.) in place, or proposed, for management of the risks ranked highest on List B.

10. An outline of the timetable for implementation of the main actions, including a date for completion of implementation of all listed actions.

8. REFERENCES

1 AS/NZS 4360:1995 *Risk Management*. Standards Australia

2 Hawksley, JL (1987): *Strategy for safety assurance for existing installations handling hazardous chemicals*. WHO Conference on Chemical Accidents, Rome, July

3 Kletz TA (1976): *A Three Pronged Approach to Plant Modifications*. Chemical Engineering Progress, November, pp 70-76.

APPENDIX A1: FAILURE MODE AND EFFECT ANALYSIS AND FAILURE MODE AND EFFECT CRITICALITY ANALYSIS

A1.1 INTRODUCTION

Failure Mode and Effects Analysis (FMEA) is a form of non-quantitative analysis which aims to identify the nature of failures which can occur in a system, machine, or equipment by examining the subsystems or components in turn, considering for each the full range of possible failure types, and the effect on the system of each type of failure. Failure Mode and Effects Criticality Analysis (FMECA) is an extension of FMEA which assigns a rating to both the severity of the possible effects and their likelihood, enabling the risks to be ranked.

FMEA and FMECA are most applicable when only one type of impact is being considered, such as production loss, or safety, or environmental damage, not a combination of them. Where a combination of types of impact is to be considered, it is preferable to use Rapid Ranking which is structured and designed for computer sorting, and is thus more flexible.

A1.2 FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

FMEA is often undertaken by one person alone, but to meet the requirements of effective risk identification it is very desirable that it be undertaken by a small team (e.g. 3 people) with a variety of backgrounds (such as design, production, maintenance).

Typical applications of FMEA include:

- identification of specific scenarios when undertaking a risk assessment of mining equipment or machinery;
- identification of specific scenarios when undertaking a risk assessment of a modification to mining equipment or machinery;
- identification of the specific scenarios when studying a single risky activity.

The steps in FMEA are:

1. Define the scope of the study, by defining the limits of the machine, machine section, system or subsystem to be studied. This is often specified most clearly by listing the main features which are included, and the main features (if any) which are explicitly to be excluded.

2. Decide the level of analysis. This can be difficult to decide, as there is always the possibility that going into extra depth of detail may uncover a further problem which needs to be tackled. However, if the dangers of “analysis paralysis” (i.e. spending so much time on analysis that the marginal cost greatly exceeds the marginal benefit and other productive efforts grind to a halt) are borne in mind, a reasonable balance can be found. The level of analysis is determined by the selection of the elements for study. A detailed study of a machine could, in the extreme, consider each individual physical component in turn as an element for separate study, whereas in a broad study the main subsystems may be regarded as the elements.

   For the types of element selected, identify and list the variety of failure modes possible. For individual mechanical components these could include:
   - mechanical breakage
   - excessive wear
   - corrosion
   - deformation (elongation, compression, bending)
   - etc., etc.

   For electrical components the failure modes could also include:
   - open circuit
   - short circuit
   - increased resistance
   - reduced resistance
   - insulation breakdown
   - etc., etc.

   Instrument failures could include:
   - reading too high
   - reading too low
   - seizing / not moving
   - responding too slowly

On the other hand, if the analysis is limited to consideration of subsystems, rather then components, then the failure modes would be those for such subsystems. They could include:
- premature operation;
- failure to operate when needed;
- intermittent operation;
- failure to cease operation when needed;
- loss of output or failure during operation;

3. unsatisfactory output.For each element (whether component or subsystem) to be studied, consider each of the listed possible failure modes, and identify the effect on the machine or system as a whole, and the relative importance of those effects. These effects could include:
   - injury to people
   - damage to the environment
   - damage to equipment
   - loss of production
   - reduced quality of production
   - increased cost of operation

4. For each failure mode for each element studied, identify:
   - the means of preventing the failure by design, operating and maintenance practices and management;
   - the means of detecting the failure and responding effectively to it;
   - means (if any) of limiting the impact of the failure, particularly by design changes.

5. On completion of the analysis, review the options for reduction of the likelihood or effects of the failures, and document the recommendations for action.

A1.3 FAILURE MODE AND EFFECTS CRITICALITY ANALYSIS (FMECA)

Failure Mode and Effects Criticality Analysis is an adaptation of FMEA to enable a semi-quantitative examination of the risks arising from the potential failures. In essence, it entails assessment of the severity of the impact from each potential failure scenario (i.e. combination of failure type and failure cause), and of the frequency of occurrence. The risks associated with each failure scenario is then determined by some means, such as:

- multiplication (if the consequences and likelihood have been expressed in numbers representing their actual magnitude);
- a risk matrix (if the consequences and likelihood have been expressed in words - e.g. low, medium, high - or defined on some nominal scale such as low = 1, high = 5).

A simple non-quantitative form of risk matrix is illustrated in Figure A4.1. Other more quantitative forms are shown elsewhere in this Guide, and in Appendix D of AS/NZS 4360-1995 “Risk Management”.

FIGURE A1.1 EXAMPLE OF RISK MATRIX FOR USE WITH FMECA

Severity / Frequency	LOW	MEDIUM	HIGH
HIGH	**Medium Risk**	**Medium-High Risk**	**HIGH RISK**
MEDIUM	Low-Medium Risk	**Medium Risk**	**Medium-High Risk**
LOW	low risk	Low-Medium Risk	**Medium Risk**

Typical applications for FMECA include:

- Identification *and ranking* of the specific scenarios when studying a single risky activity
- Identification *and ranking* of specific scenarios when undertaking a risk assessment of mining equipment or machinery
- Identification *and ranking* of specific scenarios when undertaking a risk assessment of a modification to mining equipment or machinery

If the severity of the consequences and the frequency of occurrence can be estimated (in broad groups with scales which are orders of magnitude (e.g. 1, 10, 100, 1000 for the severity, and 10, 1, 0.1, 0.01 per year for the frequency) then the risk matrix can be calibrated accordingly and the risk magnitude calculated in numerical terms as the product of the two scales. Cells in the matrix which lie on a diagonal can be seen to have equal risk magnitudes (*but this only applies if the steps severity and frequency scales are calibrated using the same steps between them*).

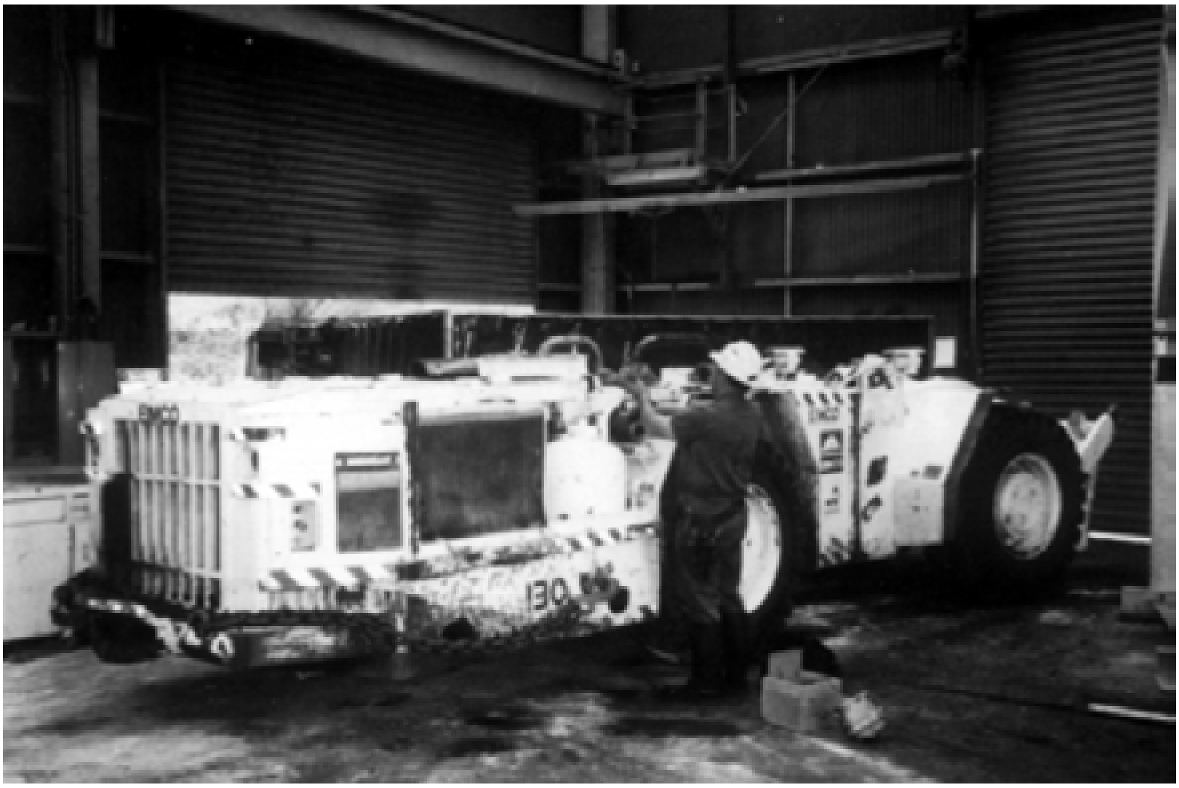
It should be noted that both FMEA and FMECA rely on the judgement of those undertaking them, as do most simple methods of risk assessment.

APPENDIX A2: FAULT TREE ANALYSIS (FTA) AND EVENT TREE ANALYSIS (ETA)

A2.1 INTRODUCTION

Fault tree analysis is used in risk assessment to analyse, understand and display the logical structure of events and situations which can lead to major undesired events, such as major accidents.

Development of fault tree starts with definition of the major undesirable event (e.g. gas explosion), and the events and situations which can lead to that outcome, either singly or in combination, are shown diagrammatically, linked via "AND" and "OR" logical connections. The resulting diagram somewhat resembles the trunk of a tree (the unwanted outcome or "top event") with the root structure supporting the trunk being developed progressively downwards, branching at the logical connections. The analysis is continued downwards until the base events are sufficiently simple and understood to be regarded as "root causes".



Event tree analysis, on the other hand, is used to estimate the range of possible outcome from a single major undesirable event, such as the gas explosion suggested above. Depending on the conditions at the time of the hypothetical gas explosion, the outcome could be numerous fatalities, or none; severe damage to the mine, or minimal damage etc. An event tree starts with the postulated major undesirable event, and branches from there to consider the possible outcomes. The structure of the branches is developed by considering each of the factors which could influence the outcome in turn (such as the manning in the vicinity at the time of the explosion, the extent of the gas cloud at the time of ignition etc.) with a probability being estimated for each of the alternatives considered.

The result is a branch structure, with the tips of the branches representing the various possible outcomes, each with an estimated probability and estimated consequence. From these estimates can be determined the worst credible outcome, the least severe outcome, the most likely outcome, and the weighted best estimate.

Commonly, for convenience of drawing, an event tree is set out horizontally, branching from the left toward the right. Where there are "yes/no" decisions, the "yes" alternative is on the upper branch. (In some circumstances, however, there are several possibilities, in which case there are more than two branches from the one point: in such cases the individual branches should be labelled for clarity.)

A2.2 FAULT TREE ANALYSIS

A2.2.1 Typical Applications of Fault Tree Analysis

FTA is typically useful when the logical structure of the causes of a major unwanted event is not immediately clear, e.g. where there are several possible causes of a postulated serious unwanted event, and where those causes in turn have various root causes as well as preventive measures and means of responding to them. Use of FTA provides a structured approach to developing a good understanding of how the causes and the safeguards are logically linked, for recognising weaknesses in the safeguards, and for identifying the most appropriate means of reducing risks.

It is also a very valuable form of analysis where there is a need to estimate the likelihood of occurrence of an unwanted event or situation in quantitative terms.

A2.2.2.Structure of a Fault Tree (See Figure A2.1)

In the example shown in Figure A2.1, the possible causes of gas explosion are analysed in simplified form to illustrate the principles. The diagram shows a gas explosion needing both a flammable gas/air mixture to be present, AND an ignition source. The flammable gas/air mixture can be present if either there is continuing release of gas and insufficient ventilation to keep the gas below the lower explosive limit, OR there is an outburst. The possible ignition sources include faulty electrical equipment, OR faulty machinery, OR spontaneous combustion in the coal within the flammable gas region, OR some other source.

Clearly the bottom events on this simplified fault tree could be analysed further, to find the root causes.

A2.3 EVENT TREE ANALYSIS (ETA)

A2.3.1 Typical Applications of Event Tree Analysis

An Event Tree can be very helpful in identifying the various possible outcomes of a single hazardous event, such as a gas explosion. It is also useful, when estimates of the probabilities of each of the postulated alternatives have been inserted, in highlighting the situations which have most effect on the outcome.

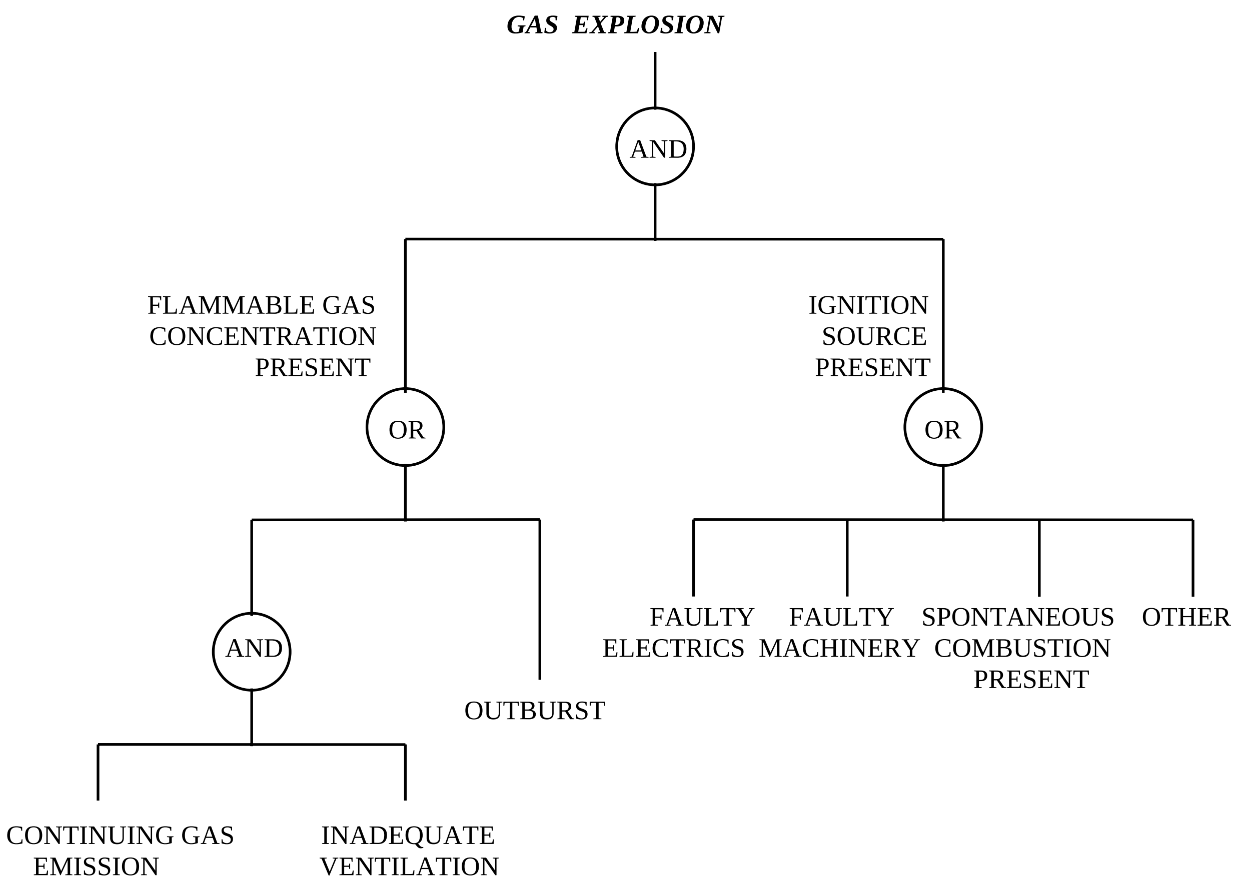
The main difficulties, and hence limitations, arise from:

- the difficulty of defining some of the alternatives;
- making the estimates of the probability of each of the alternatives.

A2.4 STRUCTURE OF AN EVENT TREE

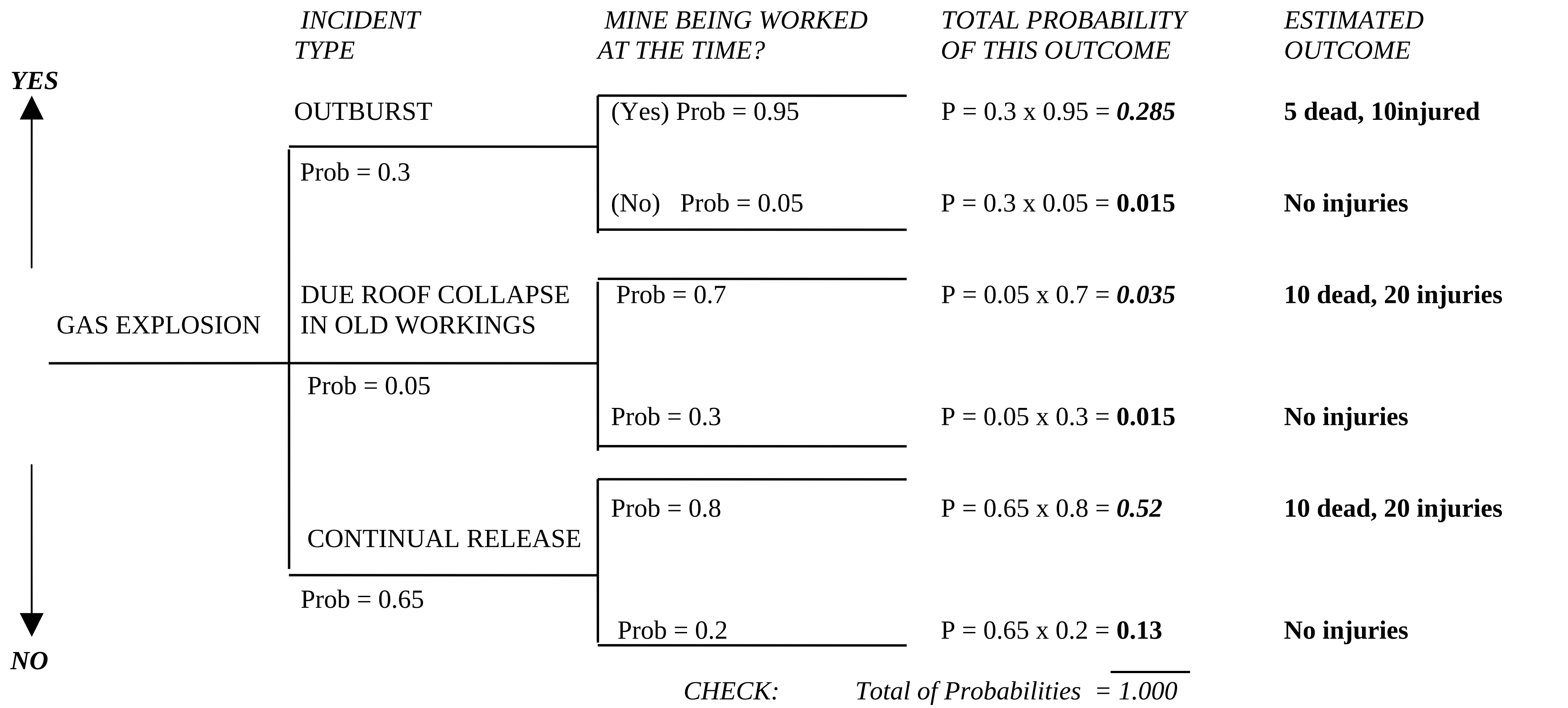
See Figure A2.2

FIGURE A2.1: EXAMPLE OF A SIMPLE FAULT TREE



(The mathematics for assessing the frequency of the "top event" - in this case, gas explosion - is not always straightforward. Experienced assistance is recommended when starting use of fault tree analysis. The mathematical methods are not discussed here.)

FIGURE A2.2: EXAMPLE OF A SIMPLE EVENT TREE



If the likelihood of a gas explosion in the mine were estimated to be 1% per year, then the frequency of accidents in which people would be killed would be:

0.1 per year x *(0.285 + 0.035 + 0.52)* = 0.0084 per year.

APPENDIX A3: HAZARD AND OPERABILITY STUDIES

A3.1 PRINCIPLES OF HAZOP STUDIES

When the detailed design of a process, machine, equipment item or a procedure is effectively complete, it is possible and very valuable to conduct a Hazop study.

In such a study, the design is subjected to a systematic and very detailed study, by a team of people with a range of backgrounds and expertise, looking for ways in which abnormal circumstances or upsets could occur with serious safety and operational results.

Typical applications include:

- Risk identification in risk assessment of a single risk source
- Risk identification in risk assessment of mining machinery or equipment
- Risk identification in risk assessment of a modification which is seen to have the potential for introducing unidentified hazards.

A3.1.1 OBJECTIVES

The objective of Hazard and Operability Studies (Hazop) is:

- to facilitate smooth, safe and prompt commissioning of facilities or implementation of procedures etc., without extensive last-minute modifications, followed by trouble-free continuing operation.

The track record of Hazop studies is impressive. Wherever the technique has been applied in accordance with the principles set out below, the results have been:

- smooth, trouble free commissioning and startup
- greatly reduced (expensive) last minute modifications
- well briefed staff
- smooth subsequent operation, (except where Hazop recognised possible problems which were not subsequently resolved)

A3.1.2 BENEFITS FROM OF APPLICATION OF HAZOP

A chemical plant for making a common plastic, from a hazardous liquefied flammable and toxic gas, was submitted to a Hazop study. This resulted in over 1300 actions being identified, mostly minor, but some more important. Most of them related to avoidance of operational problems, with around 30% being related to safety and environment protection. An assessment of the benefits of the study showed that the cost of carrying out the study (staff time, cost of changing the design, cost of additional equipment etc) would be recouped twice before the plant started up by avoiding the need to make essential changes during construction. There would also be a return of around 30% per year subsequently because of the improved performance of the plant in ways which it would be uneconomic to attempt if the changes had to be made to physical plant rather than on the drawing board.

The procedures for automatic operation of a large fuel depot, with limited manning, was studied, to check the proposed manner of operation and the controls and alarms to be incorporated in the computer-based control, protection and security interlock system. Numerous potential problems were identified, leading to a much more reliable, secure and operable system.

Many machines and manual operations have been studied by Hazop, identifying ways in which people could be injured by abnormal circumstances.

A3.1.3 ESSENTIAL FEATURES OF A HAZOP STUDY

Hazop studies can take a variety of different forms, which can lead the casual observer to wonder what it is that makes a Hazop study different from some other form of meeting or review.

The essential features of a Hazop study are:

- It is a **systematic, detailed** study following a preset agenda
- It must be conducted by a **team** comprising members with a **variety of backgrounds and responsibilities**, representing all the groups with a responsibility for the operation (e.g. a Hazop of a new project in design would have representatives from design, construction and ultimate operation)
- It concentrates on exploring the possibility and consequences of **deviations** from normal or acceptable conditions.
- It is an audit of a nominally **completed** design.

In outline, a study takes the form of a discussion, examining each element of a design or operation in turn, considering a checklist of possible deviations for each element. For each postulated deviation, an attempt is made to envisage ways in which the deviation could occur, and for each such way a judgmental estimate is made of both the severity of the possible consequences and of the likelihood. If the meeting comes to the view that the combination of the severity and the likelihood together is sufficient, the deviation is noted as a problem to be resolved. If resolution is likely to require little discussion, it may be tackled in the meeting. Deviations apparently requiring significant effort for resolution are listed for attention outside the meeting.

A3.2 RUNNING A HAZOP STUDY (See also Kletz[8])

A3.2.1 TIMING IN A PROJECT

Normally in a new project (for development of a new machine or type of equipment, or a modification to an existing machine or equipment, or a new or modified procedure), a series of reviews are held in the course of design to ensure that the design will be able to perform the duty required. These give rise to series of revisions.

[8] Kletz TA (1992): *Hazop and Hazan, Third Edition.* Institution of Chemical Engineers, Rugby, UK

When the design is at a stage ready to be frozen, the Hazop should be scheduled.

(If it is found, in the Hazop study, that the design is not quite firm, then it is necessary to defer Hazop of that section until it is firm. An attempt to finish off the design during the Hazop will prove to be frustrating, and it undermines a principle of Hazop, i.e. to audit a completed design).

A3.2.2 SELECTING THE TEAM

It is important to assemble a good team. The essential requirements are representatives of all groups involved, such as design, construction, operation etc with the representatives bringing both technical know-how and sufficient organisational seniority to have the agreed actions implemented. There must also be at least one person who knows how to run a Hazop study.

It is not essential to have an independent chairman, but in big projects where the meetings may have a large attendance (e.g. 8 to 10) it can be helpful to have the proceedings led by someone whose prime task is to watch the pace and the dynamics of the meeting. (The role of the study leader or chairman is discussed in more detail later)

In a study of a design for a small new facility, machine or item of equipment, the team could comprise the following as a bare minimum:

- the designer
- the project engineer, or the person responsible for managing the construction
- the plant supervisor, or the person who will be responsible for operation or use of the facility, machine or equipment.

From these, it is important to appoint as leader someone who has experience in the conduct of the studies.

For a larger new project, the team might comprise:

- the senior design engineer
- the design engineer responsible for the section being studied
- specialists, such as an instrument engineer, or a mechanical engineer
- the project engineer
- the operations superintendent (designate)
- people who will be involved in the operation
- an independent chairman (not essential)

For a study of an existing facility, machine, equipment or procedure, the team might comprise:

- the plant superintendent
- the plant engineer
- a suitable representative of the technical support departments
- a supervisor or foreman
- an operator or a tradesman or both

- There is sometimes reluctance to include operators or tradesmen, but if the climate permits, there can be big benefits:
- from their close contact with the operation they can make an important contribution to the understanding of what actually happens
- they learn more about the way the facility is intended to be operated and why
- teamwork is developed

A3.2.3 ROOM LAYOUT AND EQUIPMENT NEEDED

One effective way of setting up the room ready for the study is illustrated in the following diagram.

LAYOUT OF ROOM FOR STUDY

The features of the layout and equipment are:

- the relevant drawings (diagrams, layouts, detail drawings, lists of steps in the procedure etc) are fastened to a wall;
- the members of the study team sit in a semicircle around the drawings;
- there is no table in the room;
- the study chairman sits at one end of the semicircle, with a bench or shelf at his side, on which is placed the open book of guide-words which are used to prompt the discussion;
- next to the wall on the side opposite the chairman is an easel with butchers' paper to be used by team members to illustrate their ideas;
- the study secretary uses a clipboard rather than a table;
- the team members do not have their own copies of the drawings;
- there is only one row of seating.

Briefly, these arrangements have evolved for the following reasons:

- if individual team members have their own drawings, they tend to start private discussions with their neighbours, rather than concentrating on the main discussion;
- an important feature of Hazop studies is the informality of discussion, with members free to get up and go to the drawings, or the flipchart board to illustrate a point. Having a table in the room can inhibit that freedom of movement;
- with only one drawing in use, it becomes the focus of attention, and changes marked up on it are official;
- if some of the team members are in a second row, they become second-class citizens, and cannot contribute as effectively to the discussion. Visitors, such as senior managers, can inhibit discussion if they are sitting at the back, so such visitors can be accepted only if they join the semicircle and become team-members for the duration of their visit, being expected to contribute with the rest;
- a flipchart board is preferred to a blackboard, as its record is permanent and can be referred to in later studies.

In summary, the equipment needed comprises:

- book of keywords;
- bench to stand or prop the book on;
- easel and flipchart board with paper;
- clipboard and record sheets (see later) for the secretary;
- "Bluetack" or masking tape etc for fastening drawings to the wall;
- felt-tipped pens of different colours for use on the flipcharts;
- highlighter pen (yellow or green suggested) for indicating the design detail under discussion at any time;
- fine fibre-tipped red pen for marking agreed changes on the drawings.

A3.2.4 CONDUCT OF THE STUDY

The procedure is as follows:.....

1. At the first meeting of a team, if there is anyone present who has not taken part in a Hazop, the chairman outlines the study procedure. This normally takes around 5 - 10 minutes. This may cover the following points:
    - objectives of Hazop;
    - essential features of Hazop;
    - Hazop focuses on identifying abnormal circumstances which could upset normal operation;

- because of this focussing on abnormalities, and the team approach, it is normal in Hazop for even the best designs to be found to have potential for improvement, and that it is no reflection on anyone if faults are found;
- a brief outline of the steps in a study.

2. The chairman then asks someone with a good understanding of the design of the facility, machine, equipment or procedure to outline the broad purpose of the section of plant covered by the drawing under study, and its normal mode of operation or use. This should be kept to just an outline, as the details will be covered later in the discussion. (Allow 5 to 10 minutes). Following that, questions are invited where clarification of the purpose or mode of operation or use is needed, but questions about detail are deferred until later.

3. The detailed study of the first section then starts. The chairman marks the selected section with the highlighter pen, using a dotted line. He then asks someone to describe the section of the facility, machine, procedure and its purpose, its normal operating condition, and its normal method of operation. There is then a short period of general discussion, limited to around 10 minutes, as there is a tendency for the discussion to become a random questioning of design features which will be more systematically covered later.

4. The chairman then uncovers the first keyword, e.g. *"High Speed"*. He asks two questions:
   - *"What are the possible consequences of too high a speed?"*
   - *"How can too high a speed occur and how likely is it?"*

5. If the group, in discussion, form the view that the combination of the severity of the consequences of an event related to too high a speed with the likelihood of its occurrence is unacceptable, then the event is defined as a problem needing resolution.

Resolution of an identified problem can be undertaken in the meeting if the expectation is that it will be complete in around 5 minutes, but if it is apparent that more time will be needed, or if someone outside the meeting needs to be consulted, or files consulted, or a calculation done, then resolution outside the meeting should be arranged.

6. The secretary should record:
   - resolved problems with their solution
   - unresolved problems, and the person nominated to arrange for resolution outside the meeting

Where appropriate, the solution is marked up on the drawing on the wall using the fibre tipped red pen.

Generally no record need be kept of the discussion where no problem is found, as this inhibits the free flow and creativity of the meeting.

7. When no further problems are identified for the first keyword, the chairman turns to the next keyword. (There is no reason why the card cannot be turned back if someone later thinks of an avenue to be explored)

8. When all the first group of keywords have been used for the first section of pipeline, or the first step in a batch operation, then the chairman marks in that section of pipeline with the highlighter pen, using a continuous line as a sign that that section is complete.

   Suggested keywords for this stage follow. The keywords selected will depend on the nature of the operation being studied. Other suitable sets of keywords may be prepared by the team. This is discussed in more detail later.

SPEED:	high, low, reverse
LEVEL:	high, low
LOAD:	overload, underload
LOCATION:	wrong horizontal/vertical location
DIRECTION:	to one side, upwards, downwards, reverse
TIMING:	Start too early, too late; stop too early, too late; duration; sequence.
FORCE:	high, low
PRESSURE:	high, low, vacuum
TEMPERATURE:	high, low
QUALITY:	concentration, impurities, cross-contamination, side reactions, inspection and testing,
PHYSICAL DAMAGE:	impact, dropping, vibration
CONTROL:	response speed, sensor and display locations, interlocks
PROTECTION:	response speed, independence, testing

9. The next section is then selected, and marked with a dotted line using the highlighter pen, and the above process is repeated.

10. When all sections of the facility, machine, equipment or procedure have been covered, then the chairman moves to the second group of keywords which are used to guide an overview of the whole drawing.

    These overview keywords may be selected from the following, possibly with others added to suit the particular type of technology being studied:

MATERIALS OF CONSTRUCTION:	Suitability for abnormal conditions; e.g. corrosion, erosion, wear.
SERVICES NEEDED:	Air, nitrogen, water, steam, power etc.
COMMISSIONING:	Authorities, training, supervision, compliance checking.
STARTUP:	Sequence, problems.
SHUTDOWN:	Isolation, purging.
BREAKDOWN:	Loss of services, "fail safe" response, emergency procedures.
ELECTRICAL SAFETY:	Area classification, electrostatic discharge, earthing.
FIRE & EXPLOSION:	Prevention, detection, protection, control.
TOXICITY:	Acute, long term. Adequacy of ventilation.
ENVIRONMENTAL CONTROL:	Effluent: gaseous, liquid, solid. Noise. Monitoring.
ACCESS:	For operation, maintenance, means of escape.
TESTING :	Raw materials, products, equipment, alarms and trips.

SAFETY EQUIPMENT:	Personal equipment, fixed safety equipment.
OUTPUT:	Sources of unreliability, bottlenecks.
EFFICIENCY:	Potential for loss of material or performance.

Although this second group of keywords appears formidable, discussion with them rarely takes more than around 20 minutes, as nearly all of the issues will have been raised earlier.

11. When the overview is complete, then the chairman signs the drawing as complete, and arranges for issue of the record sheets and for follow up of the outstanding actions.

A3.2.5 SELECTION OF KEYWORDS.

There is nothing special about any particular set of keywords. There are many variations in use. But they all have a common factor: they prompt discussion about all significant types of deviation from all the required "qualities" such as speed, level, load, sequence, and so on. So, when planning a Hazop study for an unusual machine, procedure or operation, the leader should (preferably in discussion with others) identify the important qualities and modify the keywords as necessary to ensure that all significant deviations will be discussed.

Where an operation involving a machine is to be studied, some of the keywords in Machinery Hazard Identification could be used as keywords in the Hazop. Where an operation or a procedure involving extensive human activities is being considered, some of the keywords from Potential Human Error Identification could be used.

It is better to have rather too many keywords than too few. If a particular keyword is inapplicable in a particular case, it can be passed over with no loss of time.

A3.2.6 STUDY RECORDS OR MINUTES

For a small study, such as for a small modification of an existing machine etc, the minute sheet may be of the form shown as Figure A1. However, where several meetings will be needed, and many changes are thus to be expected, followup is aided by using a separate sheet for each identified problem as shown as Figure A2.

The secretary, whose main task is to record the details of the identified problems, and the nature of the solution agreed, or the nature of the investigation to be undertaken outside the meeting, needs to be very familiar with the project and competent to interpret the thrust of the discussion in deciding the wording to be used in the minutes.

After each meeting, the secretary sends a photocopy of each minute sheet to those named for action on it (either to have a problem resolved, or to implement a solution agreed at the meeting), and keeps the master sheet in a folder. As each action is completed, the lower half of the minute sheet is filled in by the person responsible, and a photocopy of the completed sheet sent to the secretary, who files it in the master folder, removing the uncompleted original sheet. Then the status of the actions can be easily seen at any time by flipping through the master folder, and noting which of the original sheets have not yet been replaced by one with the lower half completed.

A3.2.7 FOLLOW UP OF HAZOP MINUTES

There are various ways in which the actions specified on Hazop minutes can be followed up.

For small projects, possibly using the minute sheet listing many actions, is may be sufficient for the project manager to review progress with the responsible people on a regular basis, and to mark the actions as they are completed.

For larger projects, typically with hundreds or even thousands of actions, it is preferable to use a single sheet per Hazop action. At the end of each study meeting, the secretary files a copy of each minute sheet, and arranges for each person to receive a copy of any minute sheet for which he or she is responsible. After the required action is taken, it is noted by the responsible person on the bottom half of the minute sheet and a copy is returned to the secretary who puts it in the file in place of the original copy. Then the secretary or the project manager can check which actions are outstanding by browsing through the secretary's file.

A3.2.8 ROLE OF THE CHAIRMAN

Whether the study chairman is one of the project team, or someone from another area, the role is the same: to ensure that the technical result of the Hazop is sound, without inefficient use of people's time.

A sound technical result is one in which all the significant hazards and operational problems have been identified, and a proper balance found between eliminating the problems and managing them.

It is sometimes said that Hazop results in overdesigned plants. It is the responsibility of those present to ensure that this does not happen, and it is the responsibility of those selecting the participants that they choose people whom they can rely on to find a proper balance between eliminating and managing problems.

The chairman must constantly aim to have the team achieve these objectives.

In doing so, the points he or she should pay attention to may be summarised as

- **"Group Dynamics"**
- **Technical standard**
- **Pace**

Leadership of Hazop studies has some special points worth noting. In the field of group dynamics, the main points are:

- watching that those who would be expected to make a contribution on a particular topic have the opportunity to do so
- ensuring that debates or arguments are resolved on rational grounds rather than on seniority or force of personality

- keeping track of all the points raised during discussion of any particular keyword, to ensure that those which are slightly peripheral to the main thrust of the discussion are not forgotten but picked up and considered before moving on to the next keyword.

Maintaining a good technical standard is not difficult if the right people have been selected for the study team. However, even the best team may need an occasional prod. The main points are:

- ensuring that important topics, or critical sections of what is being studied, are fully discussed.
- maintaining an independent judgment about the technical standard of the solutions agreed at the meeting, and about the feasibility and durability of managerial action defined to cope with residual risks where it is decided that these cannot reasonably be further reduced
- aiming to have problems tackled systematically, seeking to:
  - reduce or eliminate the inherent hazard or problem
  - improve containment or control, so that the likelihood of a problem arising is reduced
  - improving protective systems and response, to improve the chance of stopping an initiated problem early ("nipping it in the bud")
  - limiting the damage by providing separation, or by strengthening the buildings or structures potentially exposed.
- making sure that a mature judgment is reached about which hazards should be reduced or eliminated by expenditure on equipment, and which should be recognised and managed. It is sometimes helpful to remind the team that it is their responsibility to ensure that no-one outside the meeting can fairly make the accusation that the results of the study are unbalanced.

A common problem of Hazop studies is that they slow down in the interests of not missing anything. The result is that they take so long that no-one can spare the time for future studies, or else those chosen are too junior and inexperienced for the studies to be effective. It is important that the chairman keep the study moving on at a good pace. It is better to find 90 % of the problems (i.e. be confident of finding *all* the major problems) and continue doing studies in future, than to do one study to perfection and then stop.

The chairman must be constantly trying to get the group to move on, while being alert to any issue which still needs exploration.

FIGURE A3.1 **HAZOP STUDY RECORD** **SHEET NUMBER:.........**

MINE: …………………………………… _______

PLANT NAME:... **DATE:...../...../.....**

PLANT SECTION:... **PRESENT:...**

No	Problem	Action	Resp

FIGURE A3.2

MINE: ………………………………. HAZOP STUDY RECORD SHEET NUMBER:.........

PLANT NAME:... DATE:...../...../.....

PLANT SECTION:... PRESENT:...

<u>IDENTIFIED PROBLEM</u> **<u>PERSON RESPONSIBLE FOR ACTION</u>:.........**

<u>ACTION DEFINED AT MEETING</u>

<u>DEFINED ACTION</u>

SIGNED: ....
DATE: ...../...../.....

APPENDIX A4: MACHINERY HAZARD IDENTIFICATION[9]

A4.1 INTRODUCTION

This method of analysis has much in common with Hazop approach, but is specially adapted to consider the risks inherent in a wide range of machinery, in a wide range of applications.

Typical applications include:
- Risk identification in risk assessment of a single risk related to mechanical (etc.) equipment
- Risk identification in risk assessment of machinery or equipment in general
- Risk identification in risk assessment of a modification to machinery or equipment

The analysis should be carried out by a team of not fewer than three members, nor more than around eight.

The team should include:
- someone who can answer fairly detailed technical questions: e.g. "*Why is this designed this way?*"
- someone who has a good idea about how the machine will be operated
- someone who has a good idea about how the machine will be maintained
- someone who has a good understanding of the types of accident which can occur with machinery of this general type
- someone with good contact with the people who will actually be operating and maintaining the machine.

A4.2 PREPARING FOR THE ANALYSIS

The steps are:
- Define the scope of the study; i.e. the limits of the machinery to be studied.
- Obtain a description of the machinery, including functional specification, drawings, photos etc.
- Obtain operating instructions or the user manual
- Inspect a similar machine, prototype etc if possible

A4.3 THE ANALYSIS

The steps are:

1. Ensure that all team members are briefed about the machinery to be studied

2. Subdivide the machine into functional parts, e.g.:
    - machine frame or equipment structure
    - moving parts, subassemblies of moving parts, mechanisms, etc.

[9] Derived from Machinery Concept Hazard Analysis, developed by Worsell N and Wilday J; Health and Safety Executive, UK (unpublished)

- power supplies
- control

3. List the phases of use of the machine, e.g.:
    - erection or on-site assembly
    - setting up and commissioning
    - training of operators and maintenance people
    - operation and routine cleaning
    - maintenance
    - fault finding

4. Undertake the analysis, using the worksheet (attached) and each keyword in turn, discussing:
    - possible hazardous situations
    - possible hazardous events
    - likely consequence
    - effectiveness of existing or additional preventive and protective devices
    - any further comments to be made

A suggested list of keywords and sub-keywords to aid in hazard identification is shown below. They can be written on flip cards (similar to Hazop cards) as an aid to the chairman.

For any specific type of machinery the keywords and sub-keywords can be edited, after some experience with the full range of them, to omit those which are agreed to be inapplicable, or to modify or add to them to reflect the particular technology of the machinery under study.

A4.4 KEYWORDS FOR USE WITH MACHINERY HAZARD IDENTIFICATION

The following keywords are suggested. (A selection of them may be found valuable for use in Hazop studies).

CONTACT WITH MOVING PARTS

- Ejection of materials (e.g. coal, rock) or components of the equipment
- Cutting / Shearing / Severance
- Impact / Crushing
- Stabbing / Puncture
- Abrasion
- Trapping / Entanglement / Drawing in
- Anything else

STABILITY

- Roll over
- Directional instability
- Fragment / Break up
- Anything else

ELECTRICAL

- Electric shock/burn
- Electrostatic phenomena
- Anything else

THERMAL

- Burns/Scalds
- Cold burns
- Fire/Explosion (possible explosive atmosphere?)
- Sunburn
- Dehydration
- Anything else

NOISE

- Gradual Hearing loss / Sudden ear damage
- Anything else

VIBRATION

- Physical / Neurological disorders
- Anything else

RADIATION

- Electric arcs
- Lasers
- Ionising radiation sources
- High frequency electromagnetic fields
- Anything else

TOXIC

- Vehicle exhaust
- Release of asphyxiant / toxic gases
- Waste
- Inhalation of dust, mist, fumes or fluids
- Ingestion of dust, mist, fumes or fluids
- Skin contact with dust, mist, fumes or fluids
- Anything else

BIOLOGICAL

- Viral
- Bacterial / Fungal
- Anything else

HYDRAULIC

- Unexpected loss of pressure (hose burst etc)
- Pressure too high
- High pressure fluid jets
- Anything else

POOR ERGONOMICS

- Injuries due to posture / manual handling injuries
- Repetitive strain injury / discomfort / fatigue / physiological stress
- Effects of Personal Protective Equipment
- Visibility (lighting, sightlines, blind spots)
- Layout and nature of controls and indicators
- Throw-off (mobile machinery)
- Slips, trips and falls
- Anything else

HAZARDS TO ENVIRONMENT

- Water, air, soil pollution
- Other damage
- Anything else

HAZARDS FROM THE ENVIRONMENT

- floor heave
- roof fall
- physical congestion and limited clearances e.g. roadway dimensions
- gas outburst
- coal dust
- spontaneous combustion
- windblast
- inrush water
- methane
- other mine gases (carbon monoxide, carbon dioxide, hydrogen, hydrogen sulphide, diesel exhaust gases
- lightning strikes
- electromagnetic induction
- noise

ANYTHING ELSE

As noted earlier, the method is clearly similar in concept to Hazop, except that the method of recording the findings is different, as are some of the questions asked about each identified problem.

(One possible improvement to the record sheet would be to add a column for "PREVENTIVE MEASURES" before the one entitled "PROTECTION", to emphasise the importance of preventing dangerous situations from arising, rather than relying on an effective response in such a situation.)

(It is suggested that the following worksheet be enlarged to A3 size)

MACHINERY HAZARD IDENTIFICATION RECORD

MACHINE: **FUNCTIONAL PART:** **DATE: / /** **SHEET .... OF ....**

REF No.	KEYWORD	HAZARDOUS SITUATION Consider each phase of use in turn.	HAZARDOUS EVENT / ACCIDENT SCENARIO Consider sub-keywords in turn. How can the hazard be realised. Consider the chain of events. (Only enter information where a hazardous scenario is identified)	CONSEQUENCES OF THE POSTULATED SCENARIO * Describe and give estimate of whether fatal, major or minor.	ACTUAL OR POSSIBLE MEASURES TO ***PREVENT*** OCCURRENCE	ACTUAL OR POSSIBLE MEASURES TO ***RESPOND*** TO THE ONSET OF A SCENARIO	AGREED ACTIONS TO BE TAKEN

Adapted from: Worsell N and Wilday J

APPENDIX A5: POTENTIAL HUMAN ERROR IDENTIFICATION

A5.1 INTRODUCTION

As Trevor Kletz says: *"To blame human error for accidents is as superficial and unhelpful as to blame gravity for falls."*

Any engineer knows that gravity will cause things to fall and structures to collapse if not properly designed, constructed, operated and maintained. The task is to recognise the potential for gravity to cause mishaps, and to design and to manage so as to prevent them.

Similarly the task is to recognise the potential for people to make errors and for human errors to cause accidents, then to design and manage so as to prevent them.

This method of Potential Human Error Identification was adapted from an approach (Hazardous Human Error Analysis) developed by the UK HSE (Worsley N and Wilday J).

This method is undertaken with a team, which should include people who can answer technical questions, who are familiar with the duties of people in relation to the machinery, and who are aware of the types of accident which people can have with plant and equipment.

Typical applications include:

- identification of a single risky activity where there is potential for human error leading to serious consequences;
- identification of the potential for human error when studying the risks associated with mining equipment or machinery;
- identification of the potential for human error when studying the risks associated with a modification to a procedure or to equipment or machinery where there is potential for human error with serious consequences.

A5.2 THE METHOD

In concept, the method is similar to that of Hazop, but using keywords specifically selected to relate to human activities and error types.

In detail, the method is similar to that of Machinery Hazard Identification, except that instead of focusing on details of the components of a machine, it focuses on details of tasks performed by people.

In some instances, it may be appropriate for a new machine to be studied from these two viewpoints: the inherent hazards of the machine (using MHI) and the inherent error potential of the tasks to be performed by people operating the machine or working in its vicinity (using PHEI).

The study takes the following form:

1. The team is briefed on the equipment, and on the tasks undertaken by people around it.

2. A list is then compiled of the key tasks performed, each of which is then subdivided into sub-tasks and possibly into elements.

3. Each task element is then studied in turn by the team, using a checklist of possible types of human error, such as that below.

Error Type	**Explanation**
Omission	Failure to perform an action; absence of response
Wrong timing	Action performed but not at, or within the proper time (start, stop, duration, etc)
Extraneous act	Unnecessary action not required by procedure or training
Transposition	Correct action but on wrong unit, system, or component
Wrong selection	Selecting the wrong item, control, action, etc
Wrong sequence	Performing the correct actions but in the wrong sequence
Miscommunication	Not communicating or receiving information correctly, or failing to communicate or receive at all.
Quantitative error	Performing the task to excess, or insufficiently
Qualitative errors	Not performing the task to the quality required
Other	Anything else

Where there is seen to be the potential for one of the above errors to result in noteworthy adverse effects, it is recorded on the record sheet.

4. Then the team discusses:

1) *What are the possible root causes of such an error?*
2) *What factors could increase or decrease the likelihood of the error occurring?*
3) *What actions or factors could increase or decrease the consequences if the error occurs?*
4) *What existing safeguards exist to prevent the error being made, or the adverse consequences resulting?*
5) *What additional safeguards could be suggested to prevent the error being made, or the adverse consequences resulting?*
6) *What actions are needed, in the light of the foregoing discussion?*

(It is suggested that the following worksheet be enlarged to A3 size)

POTENTIAL HUMAN ERROR IDENTIFICATION SHEET OF

MACHINE: .... KEY TASK: .... DATE: / /

TEAM:...

Ref. No	SUB-TASK OR ELEMENT	POTENTIAL HUMAN ERROR	HAZARD EXPOSED TO / POSSIBLE OUTCOME	POSSIBLE ROOT CAUSE(S) OF ERROR	POSSIBLE CONTRIBUTORY OR FACTORS*	EXISTING MITIGATING FACTORS	SUGGESTED ADDITIONAL SAFEGUARDS*	AGREED ACTIONS

* These columns refer to anything which affects the likelihood of human error; the likelihood of exposure to hazard; and the severity of the consequences. Adapted from: Worsell N and Wilday J

APPENDIX A6: RISK IDENTIFICATION AND PRIORITISING BY "RAPID RANKING"

A6.1 THE NEED TO SHORTLIST

In any large organisation or undertaking, there are usually far too many identifiable hazards and risks for them all to be investigated at the outset. Some will be pressing and will demand immediate allocation of resources (skilled people, money etc), and others will have to wait until the necessary resources are available.

In the real world, it is never possible to do everything which needs doing at once.

"Rapid Ranking" is an excellent method for defining the scope for detailed risk analyses.

A6.2 TWO CLASSES OF RISK FOR ATTENTION

It is important to recognise that there are two classes of risk which need detailed attention, and each needs a different type of attention.

They are:

A. **High risks**, **needing investigation** to understand the reasons for the risk being high (high consequences, high probability) **and action** to reduce the risks;

B. **Low risks**, comprising a high potential severity combined with a low probability, **needing managerial action** to ensure that the probability is indeed as low as believed, and that it remains low. This action may include establishment of "*risk based inspection*", or "*reliability centred maintenance*.

This classification, and its importance, are discussed in more detail later.

A6.3 AN IMPORTANT PRINCIPLE: THE *"PARETO PRINCIPLE"*

The Pareto Principle was named by Dr J M Juran (noted for his work in quality management) in honour of an Italian economist who noted that the majority of the wealth of the country was concentrated in the hands of a few of the families.

The principle applies very widely to many forms of activity.

For example:

- the majority of the sales revenue of a company will come from a small proportion of the customers;
- the majority of the quality complaints about a product will result from a small proportion of the causes;
- the majority of the lost production time of a factory will be caused by a small proportion of the causes;
- most of the risk faced by an organisation will arise from a few of the causes.

The Pareto Principle can be stated as:

"MOST OF THE EFFECTS ARE DUE TO A FEW OF THE CAUSES".

(This is sometimes known as the 80-20 rule; i.e. *"80% of the problems are due to 20% of the causes"*. This is a little unfortunate, as the relationship is usually different from 80-20. It is often 70-30, or even 90-10).

We use the Pareto Principle in management to focus our attention on the most important tasks; the ones with the potential to produce most benefit.

In risk management, we apply the Pareto Principle in the following way:

1. For the activity concerned (e.g the factory), list the sources of risk. (The methods for doing so will be explained in a later section).

For example:	*Source A*
	Source B
	Source C
	Source D
	Source E
	Source F
	Source G
	etc.........

2. Assess the magnitude of the risk due to each source.

For example:	*Source A*	*4 units*
	Source B	*8*
	Source C	*18*
	Source D	*2*
	Source E	*3*
	Source F	*1*
	Source G	*25*
	etc. (total of 4 more items)	*1*

3. Rank the sources in descending order of risk.

For example:	*Source G*	*25 units*
	Source C	*18*
	Source B	*8*
	Source A	*4*
	Source E	*3*
	Source D	*2*
	Source F	*1*
	etc.........	*1*

4. Starting from the top, calculate the cumulative total, and the cumulative percentage total.

For example:

	Risk	Cumul Total	Cumul Percent
Source G	*25 units*	*25*	*40*
Source C	*18*	*43*	*69*
Source B	*8*	*51*	*82*
Source A	*4*	*55*	*88*
Source E	*3*	*58*	*93*
Source D	*2*	*60*	*96*
Source F	*1*	*61*	*98*
etc.........	*1*	*62*	*100*
Totals	***62***		

5. Note which sources have contributed to 80% (or some other high proportion) of the total risk.

   In the example, 82% of the total risk has been contributed by just three of the 11 sources (A - G plus the 4 sundries), i.e. 82% has been contributed by 27% of the sources.

6. Focus initial attention on those sources, as between them they contribute most to the risks. If attention were directed toward those lower on the list, the maximum risk reduction would be 20% even if they were totally eliminated (a highly unlikely outcome).

The managerial use of the Pareto Principle is to identify and concentrate on the VITAL FEW causes, and leave the TRIVIAL MANY until later, if ever.

A6.4 RANKING THE HAZARDS AND THE ASSOCIATED RISK SCENARIOS

The approach outlined here can be used to rank hazards and risks identified by any method (e.g. Hazop, FMEA, MHI, or PHEI), or can be used as a stand-alone method for both identification and ranking. It can be adapted to use the keywords suggested in the other methods, as a way of tailoring it especially for machinery, It can be undertaken manually on paper, but there are real advantages in using a computer spreadsheet.

Typical applications include:

- identifying and ranking risks in a “broad brush” risk assessment, where it is expected that the number of scenarios identified will be too large for them all to be studied in detail;
- identifying and ranking risks in a risk assessment of a complex machine or equipment;
- identifying and ranking risks in any situation where there are expected to be numerous risks, particularly where the risks may have different types of impact, e.g. safety, environment, property damage, loss of production etc.

The approach has several benefits, if undertaken appropriately. These include:

- increasing awareness of the hazards, and of engineering and managerial requirements for control of the risk;
- defining a cost-effective sequence of undertaking risk reduction work;
- defining priorities for development of systems for maximising, monitoring and auditing ongoing risk standards;
- developing consensus about the appropriate priorities for risk reduction, and for ongoing risk management, thus facilitating prompt action, rather than ongoing debate and inaction.

To get all these benefits, it is important to plan the way in which the steps are carried out, as well as what will be done in each step.

The key principle is to *involve from the outset all those who will have a key role in implementing the findings, and in maintaining the ongoing performance at a high level.*

For a full discussion of the method, and its use in various types of application, see Tweeddale and others[10]An effective way to undertake a more detailed review and ranking of the hazards on a site or in an operation is as follows:

1. With a small team of people, subdivide the machine, equipment, process, procedure etc into a number subsections or components for detailed study.

2. Study the machine, equipment, operation or procedure, and list the types of mishap which could, in principle, occur. These will vary depending on what is being studied. If the scope of the study is limited to safety of people, then the list could include:
   - fire, explosion etc.
   - mechanical failure
   - structural failure
   - instability (of machine or person, including toppling overturning, trips and falls)
   - electrical
   - contact with moving parts (striking, crushing etc)
   - manual handling problems
   - thermal injury (burns, scalds etc)
   - acute toxic injury

   (Problems due to long term exposure to noise, vibration, radiation, some toxic chemicals and gases etc. cannot be easily analysed using this method. They need to be studied by an occupational hygienist).

   If the study is to include risks to the environment and of property damage, then the list would need to be extended appropriately.

[10] Tweeddale HM, Cameron RF, Sylvester SS (1992): Some experiences in hazard identification and risk shortlisting. J.Loss Prev. Process Ind., 1992, Vol 5, No 5

3. For each subsection in turn, consider the feasibility of each type of postulated mishap.

4. For each feasible mishap, note the types of impact which it could have, limiting the range to those within the scope of the study. For example, it may have been decided to cover a wide scope including injury to people, damage to the environment, damage to equipment and property, and loss of production.

5. For each type of impact, have the team indicatively estimate the severity of the consequences of the incident, using a benchmark scale developed for the purpose. (See Section A6.5 below).

6. For each postulated mishap, identify the initiating event, “trigger event” or "cause", and indicatively estimate its frequency or likelihood (e.g. 1 per year, 1 per 10 years, 1 per 100 years, 1 per 1000 years etc).

7. For each postulated mishap, identify the various protective responses (both human and equipment) which would be expected to prevent the incident, if initiated, from resulting in consequences as severe as estimated in Step 5 above, then estimate indicatively the probability that the protective response would ***fail*** to prevent those consequences (e.g. 1 = no protective response, 0.1 = 1 chance in 10 that the protective response would fail, 0.01 = 1 chance in 100 that the protective response would fail - such as a simple trip system on its own - etc.).

8. For each postulated mishap, multiply the following:
   - severity of consequences;
   - frequency of initiation;
   - probability of failure of protective response;

   ... to obtain the risk score, which is a measure of the risk. The higher the number, the higher the nominal risk.

8. Rank the incidents according to their indicatively estimated risk scores. Then carefully review the ranking for consistency (remembering that the data used is very rough and indicative only and is bound to have inconsistencies at first) then make any adjustments to the data (and hence the risks) to obtain consensus that the ranking is a reasonable estimate.

9. Starting from the top, calculate the cumulative total risk from the list. Identify those incidents which amount to 80% (say) of the total risk, and regard these as the shortlisted incidents for detailed hazard analysis, risk assessment, risk reduction and continuing review by operating and managerial staff.

   (As described above, the ***Pareto Principle*** focuses attention on the "vital few" causes which contribute most to the total risks which the organisation faces, and separates them from the "trivial many" risks which contribute little in total, and which can be left till later).

   Once one has reviewed the results so far, the spreadsheet can be extended with additional columns with estimates of the potential for risk reduction, the resources needed to achieve that reduction, the elapsed time required, etc, and new rankings can be decided by sorting the shortlisted risks according to such indicators as the risk reduction per unit of resources used, or the risk reduction per unit of elapsed time.

10. Rank the incidents according to their indicatively estimated consequence severity.

11. Where the incidents with large estimated consequences are not included in the shortlist derived in step 9 (selection by total risk), they cannot be ignored as they are "insignificant" risks only if the estimated (low) frequency of occurrence or the probability of failure of the protective response is correct, and if they are maintained at those low levels in the future.

    These high-consequence low-frequency incidents are prime targets for an immediate audit, to ensure that the estimates of initiation frequency and response failure probability are indeed low, and for incorporation in a routine managerial monitoring system to ensure that they remain low.

This method may seem laborious, but for any individual facility it can be done quickly by the plant staff after very little assistance at the outset from an experienced facilitator. It is used in a wide range of types of industry and activity.

The worksheet can be used to rank risks identified by other methods of hazard identification, such as Hazop studies, HMI, PHEI, FMEA etc.

A6.5 SCORES FOR SEVERITY, FREQUENCY, RESPONSE FAILURE PROBABILITY

It is important that the team develop their own benchmark scales for use when estimating the severity of impact, the frequency of initiation, and the probability of failure of the mitigating factors to prevent the initiated mishap from leading to the estimated severity of impact.

The following scales illustrate the types of scale which can be used. It is important, however, that the team review these and adapt them to suit the needs of the particular study.

SCALE OF SEVERITY OF EFFECT ON PEOPLE

EFFECT	SCORE
Several dead (e.g. five)	number dead e.g. 5
One dead	1.0
Significant chance of fatality	0.3
One permanent disablement / Small chance of a fatality	0.1
Many lost time injuries	0.01
One lost time injury	0.001

SCALE OF SEVERITY OF EFFECT ON THE ENVIRONMENT

In principle, it is possible to define a scale for environmental damage based on the predicted environmental effect. In practice, this can be difficult, and the assistance of an environmental scientist would be needed.

Other approaches include basing the scale on:

- the amount of environmentally damaging material released;
- the degree of statutory action (e.g. one excursion beyond licence conditions =1.0, prosecution = 100)
- the degree of public response (e.g. one complaint = 1.0, main front page headline in a major newspaper = 10,000)

SCALE OF EFFECT ON EQUIPMENT AND OTHER PROPERTY

This is most easily estimated as the monetary value of the damage, usually in thousands of dollars damage. For example:

DESCRIPTION		SCORE	
Damage of	$ 1,000	1	
	$ 10,000	10	
	$ 100,000	100	
	$1,000,000	1000	etc.

SCALE OF FREQUENCY OF INITIATION

A scale of for the ***frequency*** of initiation could be developed as follows. The figures shown in the first column (Score A) represent the frequency per million years. This approach is used to avoid having numerous decimal zeros in the calculated risk values. Alternatively, the frequency itself could be used as the score, shown in the second column (Score B).

DESCRIPTION	SCORE A	SCORE B
Very frequent*(Expected around annually)*	1,000,000	1.0
Frequent*(e.g. once per three years approx)*	300,000	0.3
Probable in the lifetime of the activity *(e.g. 1 in 10 years, several times in a working career)*	100,000	0.1
Possible but not probable in the lifetime of the activity*(possible during a working career, but not to be expected)*	10,000	0.01
Unlikely*(Possibly heard of this event or something similar elsewhere)*	1,000	0.001
Highly unlikely	100	0.0001
Barely credible	10	0.00001

SCALE FOR PROBABILITY OF MITIGATION FAILING

Mitigating factors include:

- manual intervention when the onset of a mishap is detected;
- automated intervention
- physical barriers
- circumstances (e.g. nobody being in the area at the time of the explosion)

Taken individually, the following scores may be taken as a guide:

Manual Intervention	**Failure Probability**
No intervention likely	1.0
Reasonable manual intervention, given good warning	0.1
Very good manual intervention, given good warning etc	0.01

Manual Intervention	**Failure Probability**
No automatic intervention provided	1.0
Simple automatic intervention	0.1
Normal good automatic trip system, tested regularly	0.01
Outstanding automatic system, very tight maintenance	0.001

The failure probability of physical “barriers” would need to be estimated individually, to take account of the physical features of the surroundings, and the barrier itself.

The probability of situational factors (such as no-one being present at the time of the mishap) similarly need to be estimated directly using knowledge of the local arrangements. For example, if someone is present for only 10% of the time, the failure probability due to the situation would be 0.1

Provided that the various mitigating factors (manual intervention, automatic intervention, physical barriers, situational factors) are all truly independent of each other, the mitigation failure probability is the mathematical product of them all.

FIGURE A6.1 EXAMPLE OF "RAPID RANKING" WORKSHEET

Ref No	Machine, Equipment, or Procedure being studied A	Sub-Section B	Mishap Type C	Mishap Effect Type D	Mishap Severity Score E	Typical Cause(s) F	Initiat'n Freq. G	Mitigation Responses / Factors H	Mitig'n Fail Prob J	Risk Score K	Cumul Risk Score L
1											
2											
3											
4											
5											
6											
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APPENDIX A7 WORKPLACE RISK ASSESSMENT AND CONTROL

A7.1 INTRODUCTION

This participative approach is very powerful for identifying potential production or maintenance operational losses. It has commonly ben applied in the mining industry since 1989.

Before starting a WRAC study, the risk assessment should be scoped to establish a clear objective, as well as the boundaries of the system to be reviewed, the method of breaking down the system and the depth of analysis. This discussion should also identify major hazard issues, risk scoring detail and the required team.

A WRAC exercise is done by a team of mine personnel using the step-by-step method to lead them through examining the operation or process to be reviewed. The objective of the risk assessment and the process or operation must be well defined. The team should be a relevant cross-section of personnel. A typical mine team, concerned with equipment risks related to operation and maintenance, might comprise representatives from:

- management
- engineering
- production supervision
- maintenance supervision
- operators
- electricians, fitters
- union representatives

The group is led by a competent process facilitator through the step-by-step method. Early in the exercise the team breaks the operation or process down into discrete steps, perhaps using a flow chart technique. When this is done, the facilitator's role is to ensure systematic and consistent application of the WRAC method throughout the exercise.

A7.2 METHOD

Specifically, the group exercise operates as follows:

1. Participants are given the brief for the equipment risk assessment, the types of hazards to be considered (to the equipment, from the equipment, or both) and the expected outcomes of the assessment (e.g. purchasing specification, operating guidelines, modification design etc.)

2. The team is provided with the direction on the hazard areas that needed to be examined (based on historical data or technical input) from which a list of the major types of risk concerns is prepared by the team (e.g. if risks "to equipment" - types of damage or efficiency losses; if "from equipment" - damage to people, other assets, production etc.).

3. A process model for the specific operation is useful to develop with the team in order to review each relevant step in its operation. A flow chart style of model is often used to create a clear operational process image (Buys and Clark, 1978).

4. Any reasonable operational deviations (planned or unplanned) from the process model that might be likely to occur should be identified and added to the flowchart.

5. Next, a review of the model is done, step by step, identifying the "what if" potential accidents (loss scenarios) that might occur, using the list from Step 2, to stimulate thinking. The following WRAC format is used at this point.

Step in Model	Potential Incident or Loss	Probability	Consequences	RISK RANK	Existing or Planned Controls	New Potential Controls

6. A Risk Rank is created for each loss scenario by defining risk as the combination of CONSEQUENCES and PROBABILITIES where the former may involve people, equipment or production losses. Quantitative scoring methods are used, similar to those presented in the U.S. Department of Labour information on System Safety Engineering (Rankin 1978). An example of the qualitative risk approach follows.

EXAMPLE OF RISK RANKING TABLES
(For other examples, see Appendix 9 and AS/NZS 4360)

TABLE A7.1 PROBABILITY OF THE EVENT

A	**-**	**common or frequent occurrence**
B	**-**	**is known to occur or "it has happened"**
C	**-**	**could occur or "I've heard of it happening"**
D	**-**	**not likely to occur**
E	**-**	**practically impossible**

TABLE A7.2 MAXIMUM REASONABLE CONSEQUENCES FROM THE EVENT

People Losses	Equipment Damage	Production Loss
1 fatality or permanent disability	1 more than $500K damage to equipment	1 more than $500K production delay
2 serious lost time injury or illness	2 $100K to $500K damage	2 $100K to $500K delay
3 moderate lost time injury or illness	3 $50K to 100K damage	3 $50K to $100K delay
4 minor lost time injury or illness	4 $5K to 50K damage	4 $5K to $50K delay
5 no lost time	5 under $5K damage	5 under $5K delay

The three consequence ratings are often all considered, with the highest risk rank in any category (1 is the highest rank) selected as the level of consequence. The method of deriving a Risk Rank is illustrated in Table A7.3 below.

TABLE A7.3 RISK RANKING

		PROBABILITY				
		A	**B**	**C**	**D**	**E**
CONSEQUENCES	**1**	1	2	5	7	11
	2	3	5	8	12	16
	3	6	9	13	17	20
	4	10	14	18	21	23
	5	15	19	22	24	25

7. Scores are used to rank all the loss scenarios in order to devise methods to reduce the risks. The discussions occur for all the “unacceptable” risk ranking scenarios (rank 1 to 15).

8. Finally the group identifies planned and potential additional control methods for reducing the probability and consequences for each risk starting with the highest risk (1 is the highest). At this point there is an opportunity to introduce improved safety engineering, management systems or other loss control procedures.

9. The exercise is closed after documentation of potential controls for the priority risks and the results documented for review by the client (usually management). The results from Step 8 should include alternative design or operational ideas that may require additional discussion and, perhaps, cost-benefit analysis before the final action plan is developed.

The final product of the exercise is a list of current, planned or potential new controls to reduce priority equipment risks. This list can then be used to develop other outcomes specific to the step in the equipment or equipment life cycle.

A7.4 REFERENCES

Buys JR and Clark JL (1978): *Events and Causal Factors Charting.* US Department of Energy Document No 76-45/14 US Government Printing Office, Washington D.C., USA

Joy JT (1994): *Workplace Risk Assessment and Control (WRAC) Manual*. CCH Publishing, North Ryde, NSW

Rankin JE (1978): *System Safety Engineering*, *Safety Manual No 15* US Government Printing Office, Washington D.C., USA.

APPENDIX A8: ESTIMATION OF THE MAGNITUDE OF THE CONSEQUENCES, OR THE FREQUENCY, OF OPERATIONAL LOSSES

A8.1 INTRODUCTION

In principle, where the incident being estimated is not of a type for which mathematical methods exist for estimation of the consequence, estimation or assessment of the magnitude of the consequences requires:

- reference to the **history** of similar incidents elsewhere;
- creative thought about what **could** occur, even if it has not happened elsewhere previously;
- use of **judgement**

For example, if a batch of molten metal escapes from its containment, and flows over the ground, estimation of the injuries or fatalities which could result would he undertaken by envisaging the possible places where such an escape could occur, the probable number of people within the area of the spill, and their chances of escaping unhurt. The number of injuries can be estimated by judgment well enough for effective risk management, although there is no formal mathematical method available. In coming to the estimate, account would be taken of the history of such escapes elsewhere, creative thought about the particular situation being considered, and application of judgment to that information.

In many cases, it will be found that there are a variety of outcomes to be considered, ranging from "worst possible", to "most likely".

For example, a leak of LPG could result in a fire, which could be large or small, or a Bleve of the stocktank, or a flash fire or vapour cloud explosion.

For each of these possible outcomes, it would be necessary to visualise the physical outcome, and estimate the consequences in terms of any relevant units, such as fatalities, damage to plant and equipment, public outcry, etc.

In many of the scenarios which an organisation will need to assess, there will be no better estimate possible than a judgment reached by a small group of suitably chosen staff, based on consideration of history in the organisation and elsewhere, and creative thought. There will sometimes be no mathematical method available, especially in the case of incidents of a type which have not been subject to the intensity of study which oil and chemical industry hazards have.

A8.2 METHODS OF ESTIMATING FOR SHORTLISTING PURPOSES

Methods which can be used to aid formation of a sound judgement include:

- Authorising one person to prepare the estimates, and then having them reviewed.
- Arranging a led group discussion, with the group arriving at a consensus.
- Using the **"DELPHI"** method.

A8.3 THE DELPHI METHOD OF ESTIMATING

The Delphi Method of estimating is as follows.

1. Each member is asked for an independent estimate without any discussion or reference to other opinions.
2. The estimates are collated.
3. The people with the high estimates, and the people with the low estimates, are each asked to explain the basis for their estimates;
4. After further discussion, and repeating the process with further estimates, the members usually reach consensus. If they do not, the process can be repeated, or it may be agreed that the average will be used as an acceptable compromise.

Where to apply the Delphi Method: The Delphi method can be used for estimates of all types, but is particularly applicable where it is not possible to *calculate* the required value and where, as a result, experience and opinion are the main available bases for the estimates.

The main weaknesses of the Delphi method:

- The members of the group may have made very different assumptions in arriving at their estimates. It may be difficult to reconcile these assumptions, as all may be valid. (The best method of reconciling these different assumptions is to incorporate them all by means of an "Event Tree".)
- The method can take considerable time (for example, to arrive at a single estimate may take the group typically 20 - 30 minutes if there are many factors to consider).

Group discussion (either in a led discussion or as part of the Delphi approach) is very helpful in identifying the factors which can influence the outcome.

Approaches similar to those above can be used for estimating the cost of the damage arising from such incidents, first visualising the extent of the damage (e.g. as a percentage of the new cost of plant then multiplying that by the cost of that equipment, or as a repair cost directly).

A8.4 INCIDENTS ARISING FROM HAZARDOUS MATERIALS ETC

In the case of incidents arising from processing, storage or transport of hazardous materials, it is possible to estimate the potential consequences using methods developed over the last 15 years by the chemical and oil industries.

Formal assessment of the consequences of fires, explosions, toxic gas escapes etc requires use of mathematics and methods beyond the scope of shortlisting. However, very indicative graphs are included here, to aid judgment of the potential severity of the consequences for shortlisting purposes.

A8.5 ENVIRONMENTAL DAMAGE

In the case of many types of environmental risk, the extent and duration of any environmental impact is unclear, as the ecological effect of the material which could be accidentally released to the environment may not have been studied. While such study may be initiated as a result of hazard analysis identifying the risk, such study may require a long time period and be very costly. It is often not possible to delay risk management action until such studies have been completed. Therefore a judgment will need to be made about the approximate scale of the effect ("large", "medium", or "small"; "long term, "short term" etc), using benchmarks such as outlined in Section 6. In making such judgments, it may be necessary to use information about similar materials, and to consult with statutory authorities for their views about the relative ecotoxicity.

A8.6 INTERRUPTION TO SUPPLY OF GOODS OR SERVICES

The impact on a community, and hence on the organisation, can be very large, especially in the case of national or state utilities such as generation and distribution of electric power, natural gas, water, and provision of drainage. Similarly, for commercial organisations, an interruption to the ability to supply customers with goods or services can lead to long term loss of customers, in addition to the loss of income for the duration of the interruption. Estimation of the commercial effect of such losses can be done indicatively by judgment, considering the likely duration of the interruption, and the expected subsequent behaviour of the "Vital Few" major customers. This will entail estimation of the amount of sales lost, the loss of revenue resulting from that, and the net change in production cost. (Note the application of the Pareto Principle in estimation of the consequences; don't be sidetracked by the difficulty of estimating the behaviour of the "Trivial Many" customers).

APPENDIX A9: THE RISK MATRIX METHOD FOR PRIORITISING RISKS

A9.1 INTRODUCTION

A number of the methods for identifying risks incorporate means of prioritising risks. These include:

- Hazop Studies
- Failure Mode Effects Criticality Analysis
- Rapid Ranking

However, where another method is used, the following approach can be used. It is based on the US Military Standard MIL STD 882C Task 204 and AS/NZS4360-1995

A9.2 RISK MATRIX

A9.2.1 INTRODUCTION

Risk analysis, risk assessment and risk management can be undertaken very effectively even where it is not possible to put numbers onto the severity and the frequency of occurrence of hazardous incidents.

It is possible to ascribe a number to a judgment (or even a "gut feeling") about the magnitude or likelihood of a hazardous incident, by preparing lists of descriptions of effects and of likelihoods, and putting numbers to them.

Of course, those numbers are no more valid than the judgment which derived them, but important decisions are made every day about matters which cannot be quantified, relying solely on judgment.

By putting indicative numbers to the components of risk it is possible to adopt more systematic approach to ranking and shortlisting risks for attention. For that reason it is strongly recommended, if purely descriptive approaches to risk management as planned, that you seriously consider converting those qualitative estimates into numerical “scores”.

One method of ranking risks without using numbers at all is to prepare a matrix of consequence (rated "High", "Medium", and "Low") against likelihood (rated "Very Likely", "Possible", "Very Unlikely"). Then a dividing line can be drawn to separate the high risk elements from the others. See Figure A9.1 below.

FIGURE A9.1 RISK ESTIMATION MATRIX

LIKELIHOOD

Very likely	**Medium Risk**	**High Risk**	**VERY HIGH RISK**
Possible	Low Risk	**Medium Risk**	**High Risk**
Very unlikely	Very Low Risk	Low Risk	**Medium Risk**
	Minor	**Medium**	**Severe**

CONSEQUENCES

However, this is rather unsatisfactory, as the differences between the various levels are unclear and probably inconsistent.

It is usually desirable to use a more advanced version of the above approach, including an element of indicative and subjective quantification. A simple example is shown in the table overleaf (Figure A9.2). While that example is structured for "safety", i.e. risks of injury to people, the approach can equally be used for any other type of risk provided scales can be developed for severity and likelihood.

Note that the magnitudes of severity and likelihood increase from bottom to top, and from left to right, by steps of the same magnitude in all cases. This is important if the diagonal equality of risk scores is to be maintained.

Either of the above approaches can be used as a basis for shortlisting, e.g. selecting the scenarios with "HIGH " , VERY HIGH" and SEVERE" risk ratings, or even using a scoring system based on the numbers shown for the frequency and consequence, multiplied to produce a simple risk score. This latter approach could be put onto a spreadsheet.

Figure A9.2 EXAMPLE OF A SAFETY-ORIENTED RISK MATRIX

Severity / Frequency	1 Medically Treatable Injury (MTI)	1 Compensable Injury (CI) or 10 MTI	10 CI	1 Permanent Disablement (PD)	1 Fatality	10 Fatalities
Frequent: 1 or more per year	MEDIUM	HIGH	VERY HIGH	SEVERE	SEVERE	SEVERE
Several times during a career: 0.1 per year	MEDIUM / LOW	MEDIUM	HIGH	VERY HIGH	SEVERE	SEVERE
Unlikely but possible during a career: 0.01 per year	LOW	MEDIUM / LOW	MEDIUM	HIGH	VERY HIGH	SEVERE
Very unlikely during a career: 0.001 per year	LOW	LOW	MEDIUM / LOW	MEDIUM	HIGH	VERY HIGH
Barely credible: 0.0001 per year	LOW	LOW	LOW	MEDIUM / LOW	MEDIUM	HIGH

KEY TO RISK CLASSES

Class	**Risk Units***	**Shading**
SEVERE	0.1 or more	
VERY HIGH	0.01	
HIGH	0.001	
MEDIUM	0.0001	
MEDIUM / LOW	0.00001	
LOW	0.000001	

* Where 1.0 = 1 fatality per year or "equivalent".

APPENDIX A10: EXAMPLES OF QUESTIONS WHICH A RISK ASSESSMENT MAY NEED TO ANSWER

A10.1 INTRODUCTION

For a risk assessment to meet the principles of quality assurance, i.e. to be "fit for purpose", it is important for the purpose to be made clear very early in the study. Although the objective should be defined, at least in general terms before starting the study, it is also appropriate to sharpen the focus once the range of risks to be studied has been defined, e.g. after completion of the risk identification and shortlisting stage.

A very effective way of sharpening the focus, as a means of defining the information to be collected and the analysis which is needed, is to define:

- the stakeholders who need to have questions answered and to make decisions;
- the questions which need to be answered and the decisions to be made by the various stakeholders;
- the nature of the information needed to answer those questions or to guide those decisions
- the form in which that information needs to be presented to be most useful in answering the questions and making the decisions.

A10.2 EXAMPLES OF TYPICAL QUESTIONS

1. Is the proposed equipment or process one which should be considered at all? Is management capable of carrying out the proposal?
2. Should the proposed equipment or process be allowed at all? Is it able to be made consistent with the intent of existing regulations, standards, codes and guidelines?
3. Should the proposed equipment or process be operated or carried out in the existing colliery environment?
4. If the proposed equipment or process is established, what restrictions should be placed on the environment inside or outside the colliery holding?
5. Should the equipment or process be built or utilised to the proposed design?
6. How can the proposed design of equipment or process be made safer in relation to the potential effects its operation could have on the environment?
7. What are the most cost-effective ways (in relation to improvement per unit of expenditure of financial or staff resources etc.) of making the equipment or process safer?
8. Is the proposed equipment or process within the capability of the organisation to operate without mishap?
9. What special operational requirements are there for the proposed equipment or process to be operated without mishap?
10. What external controls should be imposed on the operation of the proposed equipment or process?
11. What does the public need to know about the proposed equipment or process?
12. What on-site and off-site arrangements need to be made to handle possible emergencies resulting from failure of the equipment or process?

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