Ranking Occupational Health Risks in Mining and Minerals Processing

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Introduction

In order to prioritise the implementation of control measures, it is useful to rank occupational health risks in order of importance. I have recently constructed hazard risk assessment matrices that facilitate ranking of occupational health risks.

The aims of this paper are to:

- Briefly review conventional hazard risk assessment
- Describe the two matrices designed to rank occupational health risks
- Show how the qualitative matrix can be used to estimate the ranking of current occupational health risks in coal mining and in metalliferous mining and minerals processing
- Show how the semi-quantitative matrix, which uses an epidemiological measure of probability, can be used to compare the relative importance of classic hazard-disease combinations in mining and minerals processing, drawing on historic data from the literature
- Outline a method which should enable accurate risk assessments of current occupational health hazards

Hazard Risk Assessment

Risk assessment techniques have been used in mining for several years to determine the risks posed by hazards and to rank them in order of importance for the purposes of control. The risk presented by a hazard is typically determined using a hazard risk assessment matrix [1-3]. This involves combining the probability of an undesired event and the consequences it would have. These two variables may be qualitative or quantitative.

For example probability may be classified using qualitative terms such as [1-3]:

- Frequent - is likely to occur frequently
- Probable - is likely to occur several times in the life of the operation
- Occasional - is likely to occur sometime in the life of the operation
- Remote - is unlikely but possible to occur sometime in the life of the operation
- Improbable - is so unlikely that it can be assumed that it may never occur

Alternatively quantitative frequency (f) strata such as [1,2]:

- $f > 10^{-1}$
- $10^{-1} > f > 10^{-2}$
- $10^{-2} > f > 10^{-3}$
- $10^{-3} > f > 10^{-6}$
- $f < 10^{-6}$

may be used, where 10^{-4} for example may represent one accident in 10,000 shifts.

Consequences may be classified by qualitative terms such as [1-3]:

- Catastrophic
- Critical
- Marginal
- Negligible

Alternatively consequences can be expressed by quantitative cost strata.

Figure 1 is an example of a hazard risk assessment matrix using qualitative categories of probability and consequence. The numbers represent rank order of importance and come from a hazard risk assessment matrix in the US Military Standard: System

Safety Programme Requirements (MIL-STD-882C) [1].This is a reference document on which many hazard risk assessment matrices are based. The numbers are referred to as risk assessment codes (RAC) and simply reflect the relative importance of each issue and the need for control. Typical risk acceptability criteria are [1]:

- RAC 1 - 5 Unacceptable - risk must be reduced
- RAC 6 - 9 Undesirable - all practicable controls must be used - with documented acceptance of residual risk
- RAC 10 - 17 Acceptable with documented acceptance of residual risk
- RAC 18 - 20 Acceptable

Figure 1. Hazard Risk Assessment Matrix

		Consequences			
		Catastrophic	Critical	Marginal	Negligible
Probability	Frequent	1	3	7	13
	Probable	2	5	9	16
	Occasional	4	6	11	18
	Remote	8	10	14	19
	Improbable	12	15	17	20

Calculating Probability

To calculate a frequency of occurrence one needs to know how many accidents of interest occurred within a defined period and the number of workers potentially at risk of having the accident during that period.

Accidents generally occur abruptly during a brief transfer of energy and the frequency of accidents is easy to count. Acute occupational diseases such as heat exhaustion occur after a relatively brief exposure and their frequencies of occurrence are also easy to count. There is difficulty however with chronic occupational diseases which only occur after prolonged exposure to the relevant hazard. Sometimes the diseases occur after the worker has left the industry so it is difficult to count how many cases have occurred. This is especially so for diseases where an occupational cause may not be readily apparent in ex-workers. An example would be lung cancer in a smoking, retired, underground metalliferous miner where exposure to the human carcinogens radon, crystalline silica, and arsenic may be overlooked. It is also much more difficult to assess the length and intensity of exposures incurred by each of the workers at risk of developing the disease.

In order to overcome these difficulties epidemiological studies are required. Frequently retrospective cohort studies are undertaken. These compare the mortality experience of a group of workers with that of a reference population over a defined period, for example the workforce of a coal mine and the state of Queensland from 1975 - 1995. All workers are followed up to determine if they are still alive, and if not, the cause of death is ascertained from death certificates. A calculation is done of the number of deaths expected for each cause, based on the person-years under study in each age group and the mortality rate for the reference population in that age group during the relevant time period. A comparison is made between the real, observed numbers of deaths and the calculated, expected numbers of deaths to determine if an excess of deaths has occurred in the occupational group. This excess is termed the attributable risk and is expressed as the number of cases per 10,000 person-years (PYR) of observation.

Attributable risk can also be used as a measure of the frequency of occurrence of acute occupational diseases. For example 50 cases of heat exhaustion occurring in a mine of 1000 workers during one year would give an attributable risk of 500 / 10,000 PYR.

Hazard Risk Assessment Matrices for Occupational Health Hazards

I have recently constructed two hazard risk assessment matrices for ranking occupational health risks. The first uses qualitative measures of both probability and consequence and can be referred to as a qualitative matrix. The second uses attributable risk as a quantitative measure of probability and can be referred to as a semi-quantitative matrix.

Consequence is classified in both matrices as:

- Death
- Permanent major disability
- Permanent minor disability
- Temporary disability.

The qualitative matrix uses the conventional categories of probability:

- Frequent - is likely to occur frequently
- Probable - is likely to occur several times in the life of the operation
- Occasional - is likely to occur sometime in the life of the operation
- Remote - is unlikely but possible to occur sometime in the life of the operation
- Improbable - is so unlikely that it can be assumed that it may never occur

The semi-quantitative matrix uses attributable risk strata for probability:

- 100 - 999 / 10,000 PYR
- 10 - 99 / 10,000 PYR
- 1.0 - 9.9 / 10,000 PYR
- 0.10 - 0.99 / 10,000 PYR
- 0.010 - 0.099 / 10,000 PYR

The qualitative matrix is displayed in Figure 2 and Figure 3.

Figure 2 also gives the results of a risk assessment you might expect to see after consideration of the occupational health hazards in an underground coal mine. This type of approach is useful for rapid initial "walk-through" assessments. It does require familiarity with the relevant hazard-disease combinations and good judgement in order to estimate the risk assessment codes (RAC).

Figure 3 gives the results of a risk assessment you might expect to see after consideration of the occupational health hazards in metalliferous mines, and minerals processing plants.

It is important to stress that the estimated risk assessment codes (RAC) in Figure 2 and Figure 3 take into account common controls already present in the industry. For example the probability of silicosis in underground metalliferous mining would be much higher without the widespread use of dust suppression, ventilation and cabin enclosure. The consequences (disease severity) of silicosis would also be worse without these controls and without the use of regular health surveillance to detect silicosis at an early stage.

Figure 4 shows the semi-quantitative matrix. Figure 4 also gives the results of a risk assessment using attributable risks I have calculated from published peer-reviewed international journal articles [4-52]. This gives an insight into the relative importance of some of the classic hazard-disease combinations in mining and minerals processing. By it's very nature it is retrospective and overestimates the risk of diseases occurring in the industry today. For example:

1. The risk of lung cancer in nickel refineries has declined with improving hygiene.
2. Improvements in underground ventilation and dust suppression will have reduced the risk of silicosis, lung cancer and coal workers pneumoconiosis.

3. The risk of lung cancer in copper smelters has probably declined with improving hygiene and less commercial collection of arsenic.
4. The risk of nasal cancer in nickel refineries has declined substantially with improving hygiene.

Nevertheless, Figure 4 indicates how severe the risks are if control measures are neglected. The range of risk assessment codes (RAC) relate to the range of attributable risks calculated from studies reporting statistically significantly elevated risks. I have included for comparison the risk assessment codes for current fatal work injuries and lost time injuries in the Australian mining industry [53-55].

Although "Typical Risk Acceptability Criteria" have been included in Figures 2 - 4, these should only be used as a very rough guide. It is important to reduce risks to as low a level as is reasonably practicable. It is also important to make all practicable efforts to achieve exposures below the relevant threshold limit values (TLVs).

Figure 2. Qualitative Hazard Risk Assessment Matrix and Estimated Risk Assessment Codes for Occupational Health Hazards in Underground Coal Mining

Probability		Consequences: Death	Permanent Major Disability	Permanent Minor disability	Temporary Disability
	Frequent	1	3	7	13
	Probable	2	5	9	16
	Occasional	4	6	11	18
	Remote	8	10	14	19
	Improbable	12	15	17	20

Where:

Frequent	is likely to occur frequently
Probable	is likely to occur several times in the life of the facility
Occasional	is likely to occur sometime in the life of the facility
Remote	is unlikely, but possible to occur sometime in the life of the facility
Improbable	is so unlikely that it can be assumed that it may never occur

Risk Assessment Code Results

RAC	Hazard - Disease Combination
5	Manual handling - severe musculoskeletal disorders
5	Whole body vibration - severe neck / back disorders
6	Coal dust - chronic obstructive pulmonary disease
7	Manual handling - mild musculoskeletal disorders
7	Whole body vibration - mild neck / back disorders
7	Noise - noise induced hearing loss, tinnitus
11	Coal dust - simple coal workers pneumoconiosis
12	Coal dust - progressive massive fibrosis
13	Heat and humidity - heat exhaustion, heat cramps
13	Uncontrolled work load - occupational stress
13	Irritants - irritant dermatitis
14	Crystalline silica - silicosis

Typical Risk Acceptability Criteria

RAC 1 to 5 inclusive	Unacceptable - risk must be reduced
RAC 6 to 9 inclusive	Undesirable - all practicable controls must be used - documented acceptance of residual risk
RAC 10 to 17 inclusive	Acceptable with documented acceptance of residual risk
RAC 18 to 20 inclusive	Acceptable

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Figure 3. Qualitative Hazard Risk Assessment Matrix and Estimated Risk Assessment Codes for Occupational Health Hazards in Metalliferous Mining and in Minerals Processing.

Probability		Consequences: Death	Permanent Major Disability	Permanent Minor disability	Temporary Disability
	Frequent	1	3	7	13
	Probable	2	5	9	16
	Occasional	4	6	11	18
	Remote	8	10	14	19
	Improbable	12	15	17	20

Where:

Frequent	is likely to occur frequently
Probable	is likely to occur several times in the life of the facility
Occasional	is likely to occur sometime in the life of the facility
Remote	is unlikely, but possible to occur sometime in the life of the facility
Improbable	is so unlikely that it can be assumed that it may never occur

Risk Assessment Code Results

RAC	Hazard - Disease Combination
4	Electricity - fatal electric shock
4	Radon, crystalline silica, arsenic, +/- diesel in underground mining - lung cancer
4	Arsenic in copper smelters - lung cancer
4	Nickel compounds in nickel refineries - lung cancer
5	Aluminium smelter potroom work - occupational asthma
5	Manual handling - severe musculoskeletal disorders
5	Whole body vibration - severe neck / back disorders
7	Manual handling - mild musculoskeletal disorders
7	Whole body vibration - mild neck / back disorders
7	Noise - noise induced hearing loss, tinnitus
8	Heat and humidity in underground mining - heat stroke
8	Cyanide - fatal toxicity
8	Confined space - toxicity, oxygen deficiency, fire, explosion, drowning, or heat stroke
8	Asbestos - mesothelioma
8	Welding fumes and gases - pneumonia, chemical pneumonitis
8	Ammonia refrigerant spill - fatal pulmonary oedema
8	Sulphur dioxide in smelters - fatal exacerbation of asthma
8	Hydrofluoric acid vapour inhalation - fatal pulmonary oedema
9	Vibration from jackhammers / rock drills - vibration white finger, carpal tunnel syndrome
9	Hydrofluoric acid spill - chemical burns
10	Welding fumes and gases - occupational asthma, chronic bronchitis
11	Crystalline silica dust in underground mining - silicosis
12	Cooling towers - legionnaires disease
12	Xanthate reagent mixing - acute or chronic carbon disulphide toxicity

13	Heat and humidity in underground mining - heat exhaustion, heat cramps, miliaria rubra
13	Uncontrolled work load - occupational stress
13	Irritants - irritant dermatitis
13	Sulphur dioxide in smelters - exacerbation of asthma, irritant effects
14	Infra red in smelters - cataracts
16	Welding fume - metal fume fever
18	Lead dust and fumes in lead smelters - symptomatic lead poisoning
18	Xanthate reagent mixing - acute mild carbon disulphide toxicity

Typical Risk Acceptability Criteria

RAC 1 to 5 inclusive	Unacceptable - risk must be reduced
RAC 6 to 9 inclusive	Undesirable - all practicable controls must be used - documented acceptance of residual risk
RAC 10 to 17 inclusive	Acceptable with documented acceptance of residual risk
RAC 18 to 20 inclusive	Acceptable

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Figure 4. Semi-Quantitative Hazard Risk Assessment Matrix and Risk Assessment Codes for Occupational Health Hazards in Mining and Minerals Processing. The Relevant Exposures Occurred in Previous Decades. These Are Historic Rather Than Current Risks.

Attributable Risk		**Consequences** Death	Permanent Major Disability	Permanent Minor disability	Temporary Disability
	100 - 999 / 10,000 PYR	1	3	7	13
	10 - 99 / 10,000 PYR	2	5	9	16
	1.0 - 9.9 / 10,000 PYR	4	6	11	18
	0.10 - 0.99 / 10,000 PYR	8	10	14	19
	0.010 - 0.099 / 10,000 PYR	12	15	17	20

Risk Assessment Code Results

Range	Median	Hazard - Disease Combination
2 to 2	2	Nickel compounds in nickel refineries - lung cancer
4 to 2	2	Radon, crystalline silica, arsenic, +/- diesel, in underground metalliferous mines - lung cancer
4 to 2	4	Arsenic in copper smelters - lung cancer
4 to 2	4	Crystalline silica dust in underground metalliferous mines - fatal silicosis
4 to 2	4	Nickel compounds in nickel refineries - nasal sinus cancer
4 to 4	4	Coal dust in underground coal mines - fatal coal workers pneumoconiosis
8 to 4	4	Fatal work injury in the Australian mining industry 1996/97, 1997/98, 1998/99
7 to 7	7	Lost-time injury in the Australian mining industry 1996/97, 1997/98, 1998/99
9 to 7	7	Crystalline silica dust in underground metalliferous mines - silicosis (total incident cases)
9 to 7	7	Noise in underground and surface mining - noise induced hearing loss
8 to 8	8	Heat and humidity in South African deep underground mines - heat stroke
9 to 7	9	Coal dust in underground coal mines - coal workers pneumoconiosis (total incident cases)
9 to 7	9	Hand held rock drilling - vibration white finger
9 to 9	9	Coal dust in surface coal mines - coal workers pneumoconiosis (total incident cases)
13 to 13	13	Heat and humidity in deep underground metalliferous mines - heat exhaustion

Typical Risk Acceptability Criteria

RAC 1 to 5 inclusive	Unacceptable - risk must be reduced
RAC 6 to 9 inclusive	Undesirable - all practicable controls must be used - with documented acceptance of residual risk
RAC 10 to 17 inclusive	Acceptable with documented acceptance of residual risk
RAC 18 to 20 inclusive	Acceptable

Accurate and Current Risk Assessments for Occupational Health Hazards

The qualitative matrix assessments convey useful information about the risk of current exposures and are useful in rapid walk-through surveys. However they rely on estimate and judgement.

The semi-quantitative matrix assessments of Figure 4 draw on real data from epidemiological studies and should be more accurate than those reliant on estimate and judgement. However they are of limited value in assessing the risks of occupational diseases occurring as a result of current day exposures, because they reflect the frequencies of diseases occurring in response to exposures in previous decades.

In order to perform more accurate risk assessments of current exposures it may prove useful to:

- Obtain representative measurements of the current exposures
- Obtain information on the relevant exposure-response relationships from the literature
- Determine from these two sets of information, the attributable risks likely to result from the current exposure levels
- Apply the attributable risks and the appropriate disease consequences to the semi-quantitative hazard risk assessment matrix.

I intend to undertake further work on this methodology soon.

Summary

The qualitative matrix is useful for ranking current occupational health risks. The methodology relies on knowledge of the relevant hazard-disease combinations and good judgement. The semi-quantitative matrix is useful for ranking historic occupational health risks. It may also be of use in future work to more accurately define the risks associated with current exposures.

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