The design of hazard risk assessment matrices for ranking occupational health risks and their application in mining and minerals processing

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Two hazard risk assessment matrices for the ranking of occupational health risks are described. The qualitative matrix uses qualitative measures of probability and consequence to determine risk assessment codes for hazard–disease combinations. A walk-through survey of an underground metalliferous mine and concentrator is used to demonstrate how the qualitative matrix can be applied to determine priorities for the control of occupational health hazards. The semi-quantitative matrix uses attributable risk as a quantitative measure of probability and uses qualitative measures of consequence. A practical application of this matrix is the determination of occupational health priorities using existing epidemiological studies. Calculated attributable risks from epidemiological studies of hazard–disease combinations in mining and minerals processing are used as examples. These historic response data do not reflect the risks associated with current exposures. A method using current exposure data, known exposure–response relationships and the semi-quantitative matrix is proposed for more accurate and current risk rankings.

Key words: Disease; hazard; health; matrix; minerals processing; mining; occupational; risk; risk assessment; smelter.

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Introduction

The risk of a hazard is determined by the probability that it will result in an undesired event and the consequences that such an event would have. This relationship can be described by the equation:

$$\text{risk} = \text{probability} \times \text{consequence}$$

Risk assessment matrices have been used for many years in industry and by the US military to rank different risks in order of importance. This allows priorities to be set for the implementation of control measures. The two variables, probability and consequence, may be classified by qualitative terms or quantitative values.

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]:

- $f > 10^{-1}$

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

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 such as:

- Cost > £10^6
- £10^6 > Cost > £10^5
- £10^5 > Cost > £10^4
- Cost < £10^4

Figure 1 is an example of a hazard risk assessment matrix using qualitative measures of probability and consequence. The numbers represent rank order of risk and come from a hazard risk assessment matrix in the US Military Standard: System Safety Programme Requirements (MIL-STD-882C) [1].This is a source document on which many hazard risk assessment matrices have been based [2,3]. 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

These are only guidelines and it is important to remember to take all steps to reduce risks to as low a level as is reasonably practicable.

Figure 1. Typical qualitative hazard risk assessment matrix.

	Consequences			
Probability	*Catastrophic*	*Critical*	*Marginal*	*Negligible*
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

Two points have occurred to me recently:

1. That a hazard risk assessment matrix, which uses qualitative terms for probability, may be useful to rank occupational health risks after walk-through surveys.
2. That a hazard risk assessment matrix which uses attributable risk as a quantitative measure of probability may be a useful tool to determine occupational health priorities from existing epidemiological studies.

This paper describes the construction of two such matrices and gives examples of their use in mining and minerals processing.

Method

The two hazard risk assessment matrices can be referred to as qualitative and semi-quantitative. The first uses qualitative measures of both probability and consequence. The second uses attributable risk as a quantitative measure of probability, while using qualitative measures of consequence.

Both matrices classify consequence using the following terms:

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

In the qualitative matrix, probability is expressed qualitatively using the conventional categories of:

- 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

In the semi-quantitative matrix, probability is expressed quantitatively using attributable risk. The following strata are used (PYR = person-years):

- 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

Figure 2 shows the qualitative matrix and Figure 3 shows the semi-quantitative matrix. The risk assessment code positions are taken directly from MIL-STD-882C [1].

Figure 2. Qualitative hazard risk assessment matrix for occupational health hazards.

	Consequences			
Probability	*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

Figure 3. Semi-quantitative hazard risk assessment matrix for occupational health hazards.

	Consequences			
Attributable risk (PYR)	*Death*	*Permanent major disability*	*Permanent minor disability*	*Temporary disability*
100–999/10 000	1	3	7	13
10–99/10 000	2	5	9	16
1.0–9.9/10 000	4	6	11	18
0.10–0.99/10 000	8	10	14	19
0.010–0.099/10 000	12	15	17	20

To demonstrate the use of these matrices:

1. A walk-through survey of an underground mine and concentrator (a surface plant that removes waste material from ore to deliver a 'concentrate' product, which is then sent to a smelter or refinery for further purification to produce metal) was applied to the qualitative matrix. The walk-through survey is based on my experience of walk-throughs at several operations and has not therefore been derived from a single real site. Risk assessment codes were determined for several hazard–disease combinations. For comparative purposes, a risk assessment code for traumatic fatal injury was included.
2. An occupational health risk assessment of mining and minerals processing was undertaken using attributable risks calculated from peer-reviewed journal articles. The semi-quantitative matrix was used to determine the risk assessment codes for each hazard–disease combination. Where retrospective cohort studies were used to calculate attributable risks, person-years of observation were used as the denominator. Where cross-sectional studies were used to calculate attributable risks, the person-years denominators were approximated by multiplying mean or median years of exposure by numbers of employees. Risk assessment codes for each hazard–disease combination were determined using studies reporting significantly elevated risks and providing enough data to calculate attributable risks. The range and median of the risk assessment codes for each hazard–disease combination were determined. For comparative purposes, the risk assessment codes for current fatal work injuries and lost time injuries in the Australian mining industry were included.

Table 1. Walk-through risk assessment code (RAC) results for an underground metalliferous mine and concentrator

RAC	*Hazard–disease combination*
2	Trauma—fatal injury
4	Electricity—fatal electric shock
4	Radon, crystalline silica, arsenic, ± diesel exhaust, in underground mining—lung cancer
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 in place—mesothelioma
8	Welding fumes and gases—pneumonia, chemical pneumonitis
8	Ammonia refrigerant spill—fatal pulmonary oedema
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	Irritants—irritant dermatitis
16	Welding fumes—metal fume fever
18	Xanthate reagent mixing—acute mild carbon disulphide toxicity

Results

Table 1 gives the results of the walk-through occupational health risk assessment of an underground mine and concentrator. It is important to stress that the estimated risk assessment codes in Table 1 take into account the mitigation of controls already commonly in use. For example, the probability of silicosis in underground

Table 2. Risk assessment code results for mining and minerals processing using historic attributable risks calculated from epidemiological studies

References	*AR range*	*AR median*	*RAC range*	*RAC median*	*Hazard–disease combination*
4,5	10.8–93.6	52.2	2–2	2	Nickel compounds in nickel refineries—lung cancer
6–20	2.60–42.8	12.3	4–2	2	Radon, crystalline silica, arsenic, ± diesel exhaust, in underground metalliferous mines—lung cancer
21–24	4.36–11.6	7.90	4–2	4	Arsenic in copper smelters—lung cancer
6,7,11,12,25–28	1.45–33.4	7.75	4–2	4	Crystalline silica dust in underground metalliferous mines—fatal silicosis
4,5,29	2.42–39.1	2.85	4–2	4	Nickel compounds in nickel refineries—nasal sinus cancer
30	6.42–6.42	6.42	4–4	4	Coal dust in underground coal mines—fatal coal workers' pneumoconiosis
31–33	0.91–3.17	1.83	8–4	4	Fatal work injury in the Australian mining industry 1996/7, 1997/8, 1998/9
31–33	243–368	308	7–7	7	Lost-time injury in the Australian mining industry 1996/7, 1997/8, 1998/9
11,14,26,34	81.6–197	159	9–7	7	Crystalline silica dust in underground metalliferous mines—silicosis (total incident cases)
35–39	61.7–400	138	9–7	7	Noise in underground and surface mining—noise induced hearing loss
40	0.56–0.56	0.56	8–8	8	Heat and humidity in South African deep underground mines—heat stroke
41–46	18.8–172	51.6	9–7	9	Coal dust in underground coal mines—coal workers' pneumoconiosis (total incident cases)
47–51	31.8–385	84.3	9–7	9	Hand held rock drilling—vibration white finger
52–54	22.6–38.7	23.4	9–9	9	Coal dust in surface coal mines—coal workers' pneumoconiosis (total incident cases)
55	942–942	942	13–13	13	Heat and humidity in deep underground metalliferous mines—heat exhaustion

AR = attributable risk (cases/10 000 person-years); RAC = risk assessment code.

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.

Table 2 gives the results of the occupational health risk assessment of mining and minerals processing undertaken using attributable risks calculated from published peer-reviewed journal articles.

Discussion

The qualitative hazard risk assessment matrix could be a widely used tool for walk-through occupational health risk assessments. Clearly, knowledge of hazards and the occupational diseases they can cause is required for sound estimates of risk using the matrix. Control measures can be applied in an iterative fashion until the risk has been reduced to an acceptable residual. This is an established principle of risk management [3].

The semi-quantitative hazard risk assessment matrix allows comparison of the occupational health risks presented by several different hazards within an industry using data from epidemiological studies.

The results in Table 2 give an insight into the relative importance of some of the classic hazard–disease combinations in mining and minerals processing. By its very nature, this analysis is retrospective and overestimates the risk of occupational diseases occurring in the industry today. For example:

1. The risk of lung cancer in nickel refineries has declined substantially with improving hygiene.
2. Improvements in underground ventilation and dust suppression will have substantially 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 may have been eliminated with improving hygiene.

Nevertheless, Table 2 indicates how severe the risks are if control measures are neglected.

An advantage of using hazard risk assessment matrices is that the managers of large organizations are becoming familiar with their use in safety. Their application to occupational health risks may facilitate better understanding and implementation of controls.

It is possible that another type of analysis could be undertaken, using the semi-quantitative hazard risk assessment matrix, which might deliver accurate and current occupational health risk assessments. This would involve, for a given hazard–disease combination:

- Obtaining representative measurements of the current exposure

- Obtaining information on the relevant exposure–response relationship from the literature
- Determining the likely response, in terms of the attributable risk, to the current exposure level, using these two sets of information
- Applying the attributable risk and the appropriate disease consequence to the semi-quantitative hazard risk assessment matrix

This may further aid the setting of priorities for exposure control, especially in industries where exposures to several hazards exceed the relevant threshold limit values. I intend to undertake further work on this methodology soon.

Summary

The qualitative matrix is useful for ranking occupational health risks after walk-through surveys. The methodology requires knowledge of the relevant hazards and the occupational diseases they can cause. The semi-quantitative matrix is useful for ranking historic occupational health risks using existing epidemiological data. It may also be of use in future work to more accurately define the risks associated with current exposures.

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