Mine Closure Risk Modelling- A Continuous Improvement Approach

David Laurence
School of Mining Engineering
University of New South Wales
NSW 2052, Australia

Abstract
The Closure Risk model was developed as a new tool to aid decision makers in the complex area of mine closure. It uses a simple analytical technique that allows the decision maker to simplify what is often a complex mine closure process into more easily managed sub components. This systematic approach ensures that critical factors in the closure process are not overlooked. It also allows the most important issues to be highlighted. The model can also be used to produce quantitative estimates of risk by weighting and prioritising the issues to produce the Closure Risk Factor (C_{RF}).

Field trials at several mine sites in the Northern Territory of Australia in 2001 tested the model. The trials confirmed that the model has significant potential as a tool for decision-makers to assess in a structured, systematic manner, the major closure risks at individual mine sites. The risks include not only environmental impacts but safety and health, community, legal, financial, technical and other issues. The trials confirmed the value of a team-based approach and the inputs of key staff including environmental, production, mine planning, and community liaison personnel as well as mine management. Although the usefulness of the qualitative component of the model was established, it was found that, due to the influence of subjectivity, the utility of the prototype model to determine quantitative risk was of limited value. Using a continuous improvement approach, improvements to the model were sought.

A refined model, incorporating the Australian Standard 4360 definition of risk, was developed and tested against the data obtained in the field trial. This model, while maintaining the qualitative strengths of the original, allows more accurate absolute and relative quantitative scores to be calculated. This in turn facilitates comparisons between the issues at a single site as well as between different mines.

INTRODUCTION

The Closure Risk model was developed as a new tool to aid decision makers in the complex area of mine closure. It uses a simple analytical technique that allows the decision maker to simplify what is often a complex mine closure process into more easily managed sub components. This systematic approach ensures that critical factors in the closure process are not overlooked. It also allows the most important issues to be highlighted (Laurence, 2001).

The model can also be used to produce quantitative estimates of risk by weighting and prioritising the issues to produce the Closure Risk Factor (C_{RF}). A comparison of closure risk factors from various sites will be particularly useful for the larger company with a stable of sites to allow appropriate resources to be dedicated to those sites with the highest risks. Correspondingly, a government department regulating numerous sites will find the tool useful in applying its limited resources for the best outcome. The technique will assist industry and government personnel to achieve the optimum closure outcome in the knowledge that all factors, and not just environmental factors, have been adequately considered.

This paper describes the results of field trials at several mines in the Northern Territory of Australia in which the model was tested. As a result of the trials, an improved version of the model was developed.

METHODOLOGY

Mine closure questionnaires were distributed to five mines in the Northern Territory of Australia as follows:

- Mine A – major alumina producer, employing over 1000 personnel. Responses from eight managerial personnel received.
- Mine B – major zinc and lead producer, two responses.
- Mine C – medium scale open cut gold mine, three responses.
- Mine D – medium scale open cut gold mine, one response
- Mine E – small-scale industrial minerals producer, one response

The manager of each mine was requested to engage key personnel to complete the survey including:

- the mine manager (or resident manager or general manager)
- the environmental manager (and environmental personnel)
- the technical services manager (or mine planning engineer)
- the community liaison coordinator
- other key personnel including mill manager, financial controller, and/or production superintendent.

By capturing the views from this broad cross section of senior staff it would ensure that as many of the major issues are captured as possible.

The participants were required to rate on a scale of 0 for no importance to 10 for major importance:

1. The relative importance of the following major mine closure issues at their site:
   - Environment
   - Safety and health
   - Community/public
   - Final Land use
   - Technical
   - Legal/financial
   - Other

2. They then were required to list and rate each of the sub-issues within those broad areas.

3. Using the formula, $C_{RF} = \Sigma (R_E + R_{SH} + R_C + R_{LU} + R_{LF} + R_T)$, the Closure Risk Factor was calculated for each response.

RESULTS

The results from each of the mines are shown in Table 1.

Table 1: Mine Closure Risk Factors from Mines Participating in Field Trial

MINE	RESPON.	ENVIRO	SAFETY	END USE	COMM.	LEG/FIN	TECH.	OTHER	TOTAL
Mine A	Ops man.	2200	1810	600	688	400	200		5898
	Proj man	3430	3500	2024	1960	2163	1841		14918
	Resid man	3330	2540	2430	1000	2700	2160		14160
	Man - A	3320	1900	490	2540	475	250		8975
	Man - B	3159	3240	2443	3231	1650	1208	1520	16451
	Man - C	2970	1960	600	3300	0	0		8830
	Man - D	2450	2620	2548	2940	1715	2058	500	14831
	Man - E	3400	1000	800	2540	1900	2032		11672
	Average	**3032**	**2321**	**1492**	**2275**	**1375**	**1219**	**1010**	**12724**
Mine B	Enviro	2840	2640	990	2352	1980	2640		13442
	OHS	2970	2640	700	2940	1470	500		11220
	Average	**2905**	**2640**	**845**	**2646**	**1725**	**1570**		**12331**
Mine C	Gen Man	3400	4000	1230	2360	3400	4000		18390
	SME	1880	1360	1134	1235	1600	2412		9621
	Prod super	3100	3260	1326	200	944	2200		11030
	Average	**2793**	**2873**	**1230**	**1265**	**1981**	**2871**		**13014**
Mine D	**Enviro**	**2862**	**2450**	**1600**	**924**	**1435**	**1505**	**2960**	**13736**
Mine E	**Manager**	**3900**	**2540**	**2540**	**500**	**2163**	**3250**	**854**	**15747**

DISCUSSION OF RESULTS

Mine A

The results from the eight respondents from Mine A show good consistency on the environmental issues, but variable results thereafter. The main closure risks at the mine are tailings, water management, final land use and impact on indigenous landowners and the local community. This is reflected in the risk scores with Environment "leading" by a long margin, followed by Safety and Community, and the remaining issues. The overall Closure Risk Factor varied from 5898 to 16451 with a mean of 12724. However, when this quantitative estimate is compared with the qualitative evaluation, it is evident that a mismatch has occurred. Under the original classification (Laurence, 2001), this would place the mine as an extreme mine closure risk with a variation from high to extreme. When the mine is objectively analysed, it is not considered an extreme risk, and should realistically be classified as a high risk.

Mine B

The responses here were remarkably consistent in all areas except the Technical issues. Environment was considered the biggest risk followed by the equally weighted Community and Safety issues. The major concerns identified by the team were tailings and waste dump rehabilitation, public access, the use of a realistic closure plan and employee entitlements. Again, the mean score of 12331 placed the mine in the extreme risk category under the original classification. The appropriate classification is probably high risk.

Mine C

The three responses varied significantly for this mine in all of the broad closure issues except for the final land use. Unlike other mines, safety and health issues were considered the most significant, followed closely by technical and environmental issues. This in itself is significant, as it confirms that mine closure is multi-factorial and one cannot assume that environmental issues are the only issues requiring focus from senior management. The major issues were considered to be the adequacy of funds to cover closure, employee entitlements, open voids, and acid drainage. The average C_{RF} score of 13014 is considered excessive and again, the mine should be considered as having a high closure risk.

Mine D

"Other" or communication issues scored the highest followed by environment and safety. Internal and external communication, unsafe open pits, stakeholder requirements, and capping of tailings and waste rock dumps rated highly. Again, at 13736, the classification would be extreme whereas a moderate to high rating would be more appropriate.

Mine E

This is a small mine, with few major or complex environmental or other issues in its closure planning. Ensuring the area is safe for tourists or fossickers once the mine has closed is the major issue followed by dismantling the infrastructure and stabilising the pit walls. Environmental issues dominate, followed by technical, end use and safety issues. The score of 15747 is not realistic and reflects a very comprehensive response from the manager who rated most issues in the highest categories. A more appropriate rating is considered to be minor-moderate.

ANALYSIS OF RESULTS

The field trials illustrated that useful results are achievable particularly when used to brainstorm the qualitative broad closure issues and individual risks on a mine site. As one of the managers stated, *"I held a workshop with my managers today who all filled in the questionnaire independently. We then discussed and allocated the important issues. (It is) a good searching questionnaire."* Using this form of the model however, allows too much of a subjective bias which heavily influences the quantitative results. This makes comparing different mines and even the same mines with different respondents difficult. These drawbacks can be overcome though by ensuring that the same facilitator is used at each mine. Each manager can still complete his or her individual responses but these should then be smoothed in a facilitated group session. Agreement or consensus should then be reached on the various broad issues, and the weightings.

COMMENTS FROM MANAGERS

Mine A

- *"It is important to ensure that an operating company has both the intention and financial capability to complete closure obligations. An agreed closure plan and the demonstrated capability to meet the plan are important in the absence of clear intent/capability a closure bond or trust account may be required."*

Mine B

- *"Issues with closure are two fold. Traditionally companies do not devote adequate time or technical expertise to developing properly constructed closure plans and then implementing them. Also, regulatory agencies are not developing/encouraging novel approaches to mine closure and the future direction of legislation in this area does not indicate that they are likely to."*

Mine C

- *"My view has been to make/leave the bare minimum behind so that half-baked heritage issues don't come back to haunt the industry in 40 years time. I guess I liked the Shay Gap closure, which left behind only one small plaque to show where it had been."*

Mine E

- *"Companies and individuals can now be held responsible for environmental damage. Whether the DME or government have the resolve or the resources to chase is another matter. DMEs are reluctant to take responsibility for mine sites because of the costs of recovery. Many sites are on caretaker status and the damage has been done."*

AN IMPROVED MODEL

The science of risk management continues to evolve. Australian Standard (4360) defines risk as *"the chance of something happening that will have an impact on objectives"*. It is measured in terms of the probability of an event occurring and the consequence of that event, or Risk = Probability x Consequence.

One of the more important tools for quantifying risk in mining is the Workplace Risk and Control or WRAC technique. The method requires a team of key personnel to generate a number of possible hazards or events with a process, or piece of equipment and quantifying the likelihood or probability and the consequence of that event occurring. The team will usually consist of mine site personnel familiar with the process/equipment as well as external participants including a facilitator. Quantification of the risk allows a decision maker to prioritise the risks and decide to eliminate control or tolerate the risks. The risks are calculated in a risk matrix such as shown in Figure 1.

	CONSEQUENCES				
LIKELIHOOD	Very Low **1**	Minor **2**	Moderate **3**	Major **4**	Catastrophic **5**
A (Almost Certain)	**15** *(Significant)*	**10** *(Significant)*	**6** *(High)*	**3** *(High)*	**1** *(High)*
B (Likely)	**19** *(Moderate)*	**14** *(Significant)*	**9** *(Significant)*	**5** *(High)*	**2** *(High)*
C (Moderate)	**22** *(Low)*	**18** *(Moderate)*	**13** *(Significant)*	**8** *(High)*	**4** *(High)*
D (Unlikely)	**24** *(Low)*	**21** *(Low)*	**17** *(Moderate)*	**12** *(Significant)*	**7** *(High)*
E (Rare)	**25** *(Low)*	**23** *(Low)*	**20** *(Moderate)*	**16** *(Significant)*	**11** *(Significant)*

Figure 1 – Calculation of risk using the risk matrix (after Thompson 1999)

The power of the earlier version of the closure risk model is that it enabled the risks from the various broad closure issues to be compared and combined to enable an overall Closure Risk Factor for a particular mine site to be estimated.

This refined model retains this power and incorporates the probability and consequence of each singular event or risk to be quantified. The refined model results in a more accurate:

- quantification of each risk,
- comparison of the broad closure issues
- estimation of the overall Closure Risk Factor ($\boldsymbol{C_{RF}}$)

The refined model differs from the original model in the following ways:

- the terminology of "primary risk", "secondary risk" and "tertiary risk" are replaced by "broad closure issue", "sub-issues" and "event" respectively
- weightings have been removed
- the probability and consequence of each risk have been introduced.

Unlike the typical WRAC matrix in which the highest probability and consequences are usually allocated the smallest numbers, in the refined model, the higher the probability or consequence, the higher the number. In other words if an event has a probability of 10, then, unless timely intervention occurs, the event would certainly occur. If a probability of 1, then it is unlikely to occur. If the consequence of an event is 10, then the outcome could be catastrophic in the form of a multiple fatality, a major environmental incident, major equipment damage, a major loss to the business, or a ruined community standing. If a consequence of 1 there is an insignificant chance of injury, or a health implication, environmental damage or ongoing liability to the business. The modified risk matrix is illustrated in Figure 2.

Probability	**10 (certain)**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1 (rare)**
Consequence										
10 (catastrophic)	100	90	80	70	60	50	40	30	20	10
9	90	81	72	63	54	45	36	27	18	9
8	80	72	64	56	48	40	32	24	16	8
7	70	63	56	49	42	35	28	21	14	7
6	60	54	48	42	36	30	24	18	12	6
5	50	45	40	35	30	25	20	15	10	5
4	40	36	32	28	24	20	16	12	8	4
3	30	27	24	21	18	15	12	9	6	3
2	20	18	16	14	12	10	8	6	4	2
1 (insignificant)	10	9	8	7	6	5	4	3	2	1

Figure 2 – Mine Closure Risk Assessment Matrix

An example of the refined model is shown in Table 2.

Table 2: The Refined Closure Risk Model

CALCULATION OF CLOSURE RISK - URANIUM MINE, NORTHERN TERRITORY						
			P	Q	QUANTITATIVE	
BROAD CLOSURE ISSUE	**SUB-ISSUE**	**EVENT**	**prob**	**conseq**	**RISK**	**SUBTOTALS**
ENVIRONMENT	WATER	DOWNSTREAM - POTABLE	8	10	80	
		RADIATION/HEAVY MET.	8	9	72	
		SEDIMENTATION	8	3	24	
	AIR	DUST (RADIOACTIVE)	9	9	81	
	LAND SYSTEMS	AESTHETICS - WORLD HER.	10	10	100	
		INFRASTR. - BUILD., EQUIP	9	3	27	
		REVEG. - TROPICAL	8	6	48	
		FAUNA REESTABLISHMENT	7	4	28	
		VOIDS	9	7	63	
	WASTES	DUMPS - RESHAPING	8	8	64	
		TAILS	9	9	81	
		HAZARDOUS	7	7	49	
		DOMESTIC	6	3	18	
						735
SAFETY/HEALTH	UNSAFE OPENINGS	OPEN PITS	8	8	64	
		TRENCHES/COSTEANS	5	5	25	
	INFRASTRUCTURE	BUILDINGS/EQUIP	9	3	27	
	SECURITY	SABOTAGE THREAT	4	9	36	
	AIR	GAS (RADON)	9	7	63	
						215
LAND USE	HIGH VALUE	WORLD HERITAGE	10	10	100	
						100
COMMUNITY/SOCIAL	EMPLOYEES	ENTITLEMENTS	9	6	54	
		RETRAINING, RELOCATION	2	2	4	
	UNIONS	HEALTH ISSUES	6	7	42	
	LANDOWNERS	INDIGENOUS HOSTILITY	10	10	100	
	COMMUNITY IMPACT	LOCAL	9	9	81	
		REGIONAL	9	7	63	
		NATIONAL	9	6	54	
		INTERNATIONAL	9	5	45	
						443
LEGAL/FINANCIAL	GOVERNMENT	RETAIN TITLE	9	6	54	
		SECURITY	9	8	72	
	CREDITORS	EMPLOYEES	7	7	49	
		CONTRACTORS	7	5	35	
		BUSINESSES	7	4	28	
		GOVERNMENT	7	3	21	
	PROVISIONING FOR REHAB	EXPENSIVE REHABILIT.	9	10	90	
	ADVERSE PUBLICITY	PROTESTS, CORPORATE PR	8	8	64	
						413
TECHNICAL	CLOSURE PLAN	COMPLEX	8	7	56	
	REHAB PROGRESS	GOOD PROGRESS	5	3	15	
	CLOSURE TEAM	MANAGEMENT	4	4	16	
		ENVIRONMENT, PLANNING	4	6	24	
	RESERVES/RESOURCE	EXHAUSTED	7	3	21	
						76
CLOSURE RISK FACTOR						**1982**

This closure risk factor of 1982 for this example compares with the original model score of 11597 (Laurence, 2001). This particular mine should be classified as a very high to extreme risk due to the numerous significant environmental, community, legal and other issues. The mine is surrounded by a world heritage listed national park, there is considerable indigenous and general community opposition to the mine and the commodity is uranium, the word itself generating considerable emotions in Australia and elsewhere.

In a similar manner, the closure risk factors for Mines A to E were recalculated as illustrated in Table 3. Using these examples as a basis, it is possible to amend the original classification of risk as illustrated in Table 4.

Table 3 – Comparison of Models and the Closure Risk Factor

MINE	ORIGINAL CRF	NEW CRF	NEW CLASSIFICATION
URANIUM MINE	11597	1982	EXTREME
A	12724	1040	HIGH
B	12331	708	MODERATE
C	13014	1368	HIGH
D	13736	1315	HIGH
E	15747	470	MINOR

Table 4: Relationship between CRF and complexity of mine closure

C_{RF}	Closure Risk Rating	Typical Characteristics	Examples
> 2000	Extreme	Environmentally and socially sensitive locations; subjected to past, extensive environmental abuse;	OK Tedi, Grasberg or other large scale open cut mines in Pacific, Indonesia, using riverine or deep sea tailings disposal
1500 – 2000	Very high	Proximity to extremely sensitive areas eg world heritage; long established mining towns; sensitive commodities such as uranium, asbestos;	Arnhem land uranium mines; Butte; Broken Hill; Wittenoom blue asbestos;
1000 – 1500	High	Large surface mines in proximity to settled areas; mines in developing countries; gold or other mines with acid mine drainage potential; any mines where mine is only employer in local community;	Hunter Valley strip mines; Pine Creek geosyncline gold mines; Zambian copperbelt;
500 – 1000	Moderate	Underground coal mines with pillar extraction; hard rock mines using caving methods; suspect crown pillars; gold mines in remote, semi-arid regions;	Lake Macquarie underground coal mines; Northparkes block cave mine;
< 500	Minor	Alluvial strip mines using chemical-free gravity treatment; underground coal mines with first workings only; clay quarry near regional centre – to be used as landfill or other purpose on closure; small extractive operations;	New England sapphire mines; Sand extraction in any capital or regional city;

In a similar manner to environmental and OHS risk management, individual closure risks can also be classified or prioritised. It can be seen that, in the case study listed above, the highest risks and their score are:

- environment - aesthetics due to the mine being surrounded by a world heritage national park (100)
- land use – need to rehabilitate to the standards of the surrounding environmentally sensitive wetlands (100)
- community – hostility to both operation and closure of mine by indigenous landowners (100)
- financial – adequate provisioning for the cost of rehabilitating to these standards (90)

CONCLUSIONS

This paper described the results of field trials using the Closure Risk Factor (***C_{RF}***), which was empirically derived in earlier research. The trials confirmed that the model has significant potential as a tool for decision-makers to assess the major closure risks at individual mine sites in a structured, systematic manner. Although the usefulness of the qualitative component of the model was established, it was found that, due to the influence of subjectivity, the use of the model to determine quantitative risk was of limited value.

A refined model, incorporating a standard definition of risk as being the product of probability and consequence, was developed and tested against the data obtained in the field trial. This model, while maintaining the qualitative strengths of the original, allows more accurate absolute and relative quantitative risks to be calculated. This in turn facilitates comparisons between the issues at a single site as well as between different mines. A team-based approach is essential to ensure all the risks are incorporated and the use of an external facilitator, as is standard in risk assessments, will assist in reducing subjective bias.

RECOMMENDATIONS

As with all models, the more this improved mine closure model is "road tested" the more valid and reliable it will become. Therefore the next stage of the research will involve testing the model at more mine sites throughout Australia and internationally, in a mix of commodities, mining methods, and scale and scope of operations.

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