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Risks and cost estimates: the disconnect

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Abstract

Many mine closure plans these days appropriately include a risk assessment. This is often driven by corporate and regulatory pressures to have a risk basis for closure plans. Unfortunately often these risk assessments sit in isolation to the rest of the closure plan and often do not feed into the closure strategy and proposed actions. Importantly, very few are incorporated into the closure cost estimates.

Identifying and quantifying risks is critical to the closure planning process because of the inherent uncertainties associated with closure planning, which is often undertaken many years or even decades before the cessation of mining activities. Therefore, a comprehensive and representative risk assessment which can then form the basis for closure risk costs to be estimated and included as part of the overall closure cost estimate is required.

A proper understanding of the likely closure costs cannot be obtained without understanding the closure risks. These risks are many and varied but can be broadly grouped with respect to costs. The first group comprises those risks associated with uncertainties relating to the planned closure activities, such as quantities and unit rates (termed 'uncertainty risk'). The second group of risk costs is that associated with 'risk events'; that is, things that are not certain to occur but could have a material impact on the closure cost if they occur.

The first group could be addressed by applying a contingency factor to the cost estimate. Percentage contingencies are widely used for project cost estimates in industry as, being simple and easily understood, they have a high level of acceptance. They are, however, a very crude measure of uncertainty and do not directly relate to each specific cost line item.

Percentage contingencies are not appropriate to address the second group — risk events. Unfortunately, all too often the risk costs represented by such events are either ignored or assumed to be covered by a contingency.

A preferable system is to adopt a two-fold approach to cost estimating using range analyses to reflect uncertainties regarding items such as quantities and unit rates as well as a more detailed estimate of the likelihoods/consequences of risk events. Each approach can use either deterministic or probabilistic evaluation techniques with the latter, it is argued, thereby presenting a more robust and defensible cost estimate.

Keywords: *closure risk, risk assessments, risk cost, closure planning, contingency*

1 Introduction

Many mine closure plans these days appropriately include a risk assessment. This is often driven by corporate and regulatory pressures to have a risk basis for closure plans. Unfortunately, these risk assessments often sit in isolation from the rest of the closure plan and do not feed into the closure strategy and proposed actions. Importantly, very few risks are incorporated into the closure cost estimates. The risks appear to be ignored or glibly covered by a contingency cost item.

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Identifying and quantifying risks is critical to the closure planning process because of the inherent uncertainties associated with closure, and planning often occurs many years or even decades before the cessation of mining activities.

2 Closure risk assessments

There are many references to risk-based closure planning, which is now a well-accepted principle in developing a strategy for mine closure. The International Council on Mining and Metals (International Council on Mining and Metals [ICMM] 2019) notes that a key element of mine closure planning is a:

> *'…formal identification and assessment of risks and opportunities throughout iterations of the closure plan...'.*

Historically, mine closure plans either did not evaluate closure risks or only discussed them superficially. Over the past decade risk assessment has become a standard chapter in most closure plans. This has been driven by corporate acknowledgement of the uncertainties associated with mine closure as well regulatory requirements for risk assessment to be included in closure plans.

2.1 Regulatory requirements

Most Australian states require a closure (or rehabilitation) plan to incorporate a formal risk assessment. Such risk assessment requirements are, however, focused on the residual risks associated with the final landform. This is because the long-term liabilities that the landform presents (for example, slope instability, erosion, water management) are appropriately key issues for the state.

There are some subtle differences to these requirements in terms of focus and detail, as shown in Table 1.

Table 1 Risk assessment requirements — Australian states

Jurisdiction	Key focus
New South Wales (NSW Resource Regulator 2021)	'… Risks to achieving rehabilitation … including geophysical and geochemical properties of materials, and the availability of suitable rehabilitation materials…' '… how each identified risk and associated risk controls (refer to definition in the glossary) have been addressed in this rehabilitation management plan...' '… assessment of the effectiveness of risk controls...'
Queensland (Department of Environment and Science 2019)	A progressive rehabilitation and closure plan '… must include a risk assessment identifying the risks of a stable condition for land not being achieved and how the applicant intends to manage or minimise the identified risks…' '… risk evaluation should assist in making decisions, based on the risk analysis, about what risks need to be managed and prioritised. This step involves comparing the level of risk found during the analysis process and using this to determine the need of risk treatment...'
Victoria (Earth Resources Regulation 2020a)	'… an identification and assessment of relevant risks that the rehabilitated land may pose to the environment, to any member of the public or to land, property or infrastructure in the vicinity of the rehabilitated land…'
Western Australia (Department of Mines, Industry Regulation and Safety 2023)	'…A reviewed mine closure plan must include an environmental closure risk assessment that … identifies all the environmental closure risk pathways; evaluates these risks to derive an inherent risk rating, prior to the application of treatments; identifies appropriate risk treatments; re-evaluates the risk pathways to derive a residual risk rating …' '… identify the closure risks and their potential environmental impacts post-mining…'

While the differences may be subtle — is the risk assessment just to focus on the residual risks associated with the final landform, as appears to be the case in Victoria, or is it to also include the risks of actually implementing closure, as appears to be required in New South Wales — the intent of all jurisdictions is to avoid leaving an unacceptable legacy to the state (and therefore the community).

2.2 Corporate requirements

As well as regulatory requirements, most companies require risk assessments as part of the closure planning process. For example:

> *'…Consistent with a risk-based approach, IGO requires a structured risk management process to be undertaken to identify, assess and manage the potential risks associated with closure issues…'* (IGO n.d.).

The main difference between regulatory and corporate requirements is that the latter likely need to address a broader range of issues and risks. A key difference is related to societal or stakeholder risks. These include:

- not meeting stakeholder expectations regarding post-mining land uses and landforms
- unrealistic stakeholder expectations
- inadequate planning for the transition from a mining-dependent local economy to a post-mining economy
- inappropriate management of the employee transition and redundancies
- damage to corporate reputation from a poor approach to closure
- shareholder discontent over inadequate closure provisioning and/or budgeting
- changing regulatory conditions.

A robust closure plan will address a full range of closure risks. This will have an impact on closure cost estimates.

3 Recent closure plans and risk assessments

The author has carried out a high-level review of 29 randomly selected and recent closure plans to establish the quality of risk assessments, identify good and poor practices, and understand how the risk assessments could link to closure costs. The closure plans cover a range of commodities including coal, metals and industrial minerals. Of the 29 plans:

- 10 could be described as at concept stage
- 15 are, to various degrees, related to ongoing operations, but all are more comprehensive than the concept closure plans
- four relate to projects that are in the closure execution phase.

Many of these are rehabilitation and closure plans prepared under Queensland's jurisdiction, chosen because they are readily available and contemporary because of the relatively recent introduction of the *Mineral and Energy Resources (Financial Provisioning) Act 2018* in that state, and because of the quite specific requirements of formal rehabilitation risk assessment. The review indicates that most closure plans contain a risk chapter, although the risks discussed are mostly limited to the evaluation of landform stability. Of the closure plans that discuss closure risks, only 75% contain a formal risk register, with the remainder discussing risk in summary form or in a qualitative manner.

There is a range of complexity of the risk assessments, with the number of risks being an indicator as to their comprehensiveness. The average number of risks identified and assessed is 34, with as many as 158 being identified for one project and only four for another. While the number of risks may be indicative of the complexity of the site, it is more likely that it reflects the level of detail invested in the risk assessment.

It could be argued that perhaps up to 25% of the closure plans that were assessed either did not discuss risk at all or did not have a very comprehensive risk assessment.

For those that contain risk registers, all used a qualitative risk assessment process linked to a risk matrix evaluating likelihood and consequence. Most risk matrices look similar, with most being a 5 x 5 matrix that has five levels of likelihood compared to five levels of consequence. A small number of matrices comprise a 5 x 6 structure, with an additional level of a 'catastrophic' consequence, and one closure plan contains a 4 x 4 matrix. There is a significant variation in the descriptors for consequence categories, to some extent reflecting the risk frameworks of individual companies while others reflect various approaches adopted by different consultants preparing the closure plans.

While the most common risk matrix is 5 x 5, the descriptors of the risk ratings identified by the risk matrix vary markedly, with most reflecting differing risk frameworks of individual companies. Most matrices contain four levels of risk rating (low, medium/moderate, high and extreme), although some have only three (green, orange, red) and some contain six (represented by varying colour shades). Additionally, the thresholds for these risk ratings vary between closure plans. That is, a risk denoted as 'high' in one closure plan may be designated 'low' or 'medium/moderate' in another.

At first glance it might seem that these differences are superficial, but they are considered important. Most readers of closure plans look at the qualitative descriptors of risk without interrogating the details in the risk register and how the risk ratings have been developed. Moreover, the distinction between a medium/moderate risk and high risk is often instinctively related to 'acceptable' and 'not acceptable'. Indeed, the Victorian mining regulator regards a high-risk rating as '… *generally unacceptable* …' and a medium-risk rating as '… *may be acceptable* …' (Earth Resources Regulation 2020b). Similarly, Anglo American (2019) defines:

> *'… residual risk is at an unacceptable level (broadly defined as where residual risk is rated as significant or high) …'.*

Not understanding the distinction between a high- and a medium-rated risk could mislead the reader. It might translate into the following actions, which could have implications for closure costs:

- less emphasis being placed on controls that need to be incorporated into a revised closure plan for risks rated as medium/moderate
- ruling out risk costs for those rated as medium/moderate.

Some closure plans for complex sites have multiple risk registers embedded within appendices. These often relate to detailed assessments of geotechnical or hydrogeological risks. It is not clear how these risk registers were reconciled between each other and the main or consolidated closure risk register. In only one closure plan is it clear that there had been such reconciliation. In another closure plan, different risk matrices have been used for technical studies and the main closure risk register, resulting in potentially different conclusions on risk acceptability (and therefore controls).

In some closure plans the risk register was based on environmental aspects and impacts structure. Such a structure made it very difficult, if not impossible, to understand what actual risk events were being assessed. The author fails to understand how, without describing the risk event, conclusions have been made regarding the respective risk parameters and the resulting risk rating, as well how the identified risk controls produce an acceptable residual risk rating. Although risk registers were not a significant aspect of the reviewed closure plans, the author has seen many risk registers structured around risk issues that result in the registers having multiple hundreds of so-called risks. Upon review, these registers duplicate the same risk event by listing different consequences under different risk issues or aspects. In reality these risk registers can often be reduced to 20 or 30 risk events, albeit with some risk events having multiple consequences.

Despite the drawbacks identified in the review of recent closure plans there are encouraging aspects in some:

- most (although not all) showed the reduction in initial risk due to identified controls and which resulted in the residual risk
- identified controls appear to have been incorporated into the closure plan
- risk assessment was an integral part of the closure strategy.

These positive aspects are an improvement on closure plans prepared in the past that had a 'tick the box' risk chapter included which played no further part in the closure plan development or had identified risk controls that were not incorporated into a revised closure plan. Such improvements are likely due to a maturity of corporate recognition and understanding of risk assessment as well as regulatory drivers, such as those introduced in Queensland in recent years.

4 What are risk costs?

England & Moreci (2012) define contingency as:

> *'… an amount of funds added to the base cost estimate to cover estimate uncertainty and risk exposure…'.*

What they have described as contingency, this paper describes as risk cost. Risk costs are the estimated cost of the risks associated with closure. They can be segregated into two broad groups:

- risks associated with uncertainties relating to the costs of the planned closure activities — the 'estimate uncertainty' described by England & Moreci
- costs associated with risk events — the 'risk exposure' described by England & Moreci.

4.1 Estimate uncertainty

The first group of risk costs applies to any project and relates to the uncertainties around items such as quantities, volumes, materials, unit rates and timing. England & Moreci (2012) further note that estimate uncertainties (or contingencies) are:

> *'…Uncertainties that are inherent in the estimating process …Minor errors and omission that occur when the estimate is put together … not intended to cover major changes in scope…'.*

With mine closure cost estimating, these uncertainties are exacerbated because closure is often many years into the future; the plan may still be at conceptual stage; and there may not be recent examples of the costs or rates for the planned closure activities. Therefore, it would be expected that the greater the uncertainties over these issues, the greater the cost of their associated risks.

Typically, risk costs for this group are estimated either by using a range analysis or by adopting a percentage contingency.

A range analysis models the uncertainty (or risk) of the cost estimate by listing two or more cost estimates for a cost line item, a unit rate or a quantity. The cost ranges can then be used to arrive at a total cost range using deterministic or probabilistic techniques. With the former approach, separate calculations are made for the various ranges, arriving at two or more total costs to provide an indication of the possible outcomes. Probabilistic techniques use a probabilistic distribution of the ranges for selected cost line items, unit rates and quantities, and then create a model using a Monte Carlo simulation. The outcome is a total cost (and sub-totalled costs, if required) reported at selected levels of confidence.

Similarly, uncertainties around the timing and/or duration of activities can be modelled, although this is normally limited to probabilistic approaches and where discounted estimates are needed.

Adopting a percentage contingency is a very common technique used in project management. It is simply a percentage increase over the total base cost estimate to cover the estimating uncertainty. It is a very crude approach but perhaps the construction industry can sometimes be justified in its use because there is a high level of confidence and experience in rates, quantities and timing. However, regarding mine closure cost estimates, a percentage contingency might just be a wild guess. How can one demonstrate that 10%, 20% or 30% etc. is an appropriate amount?

It is the author's opinion that the range analysis approach is a more robust method of modelling cost estimate uncertainty.

4.2 Risk exposure

The second group of risk costs is that associated with risk events: things that are not certain to occur but which could have a material impact on the closure cost if they did occur. They affect the closure cost estimate in two ways:

- the cost to implement risk controls
- residual risks.

As discussed in Section 3 of this paper, a risk register should identify the controls needed to bring closure risks to an acceptable level. It is critical that these controls then be incorporated into a revised closure plan. If they are not, the risk assessment and closure plan are misleading. Critically, the additional cost (including the estimate uncertainty) of those controls needs to be incorporated into the closure cost estimate. It is important therefore that the effectiveness of the controls in reducing the level of risk be rigorously examined to ensure that they do actually reduce risk. For example, a commonly identified risk control is monitoring. It is difficult to see how monitoring on its own can substantially reduce the risk parameters. It is acknowledged that monitoring could reduce the consequence of a risk event if it identifies that there is early detection of a greater likelihood of the risk occurring. In a qualitative risk assessment, however, while the consequence parameter will be reduced, the likelihood parameter should be increased: therefore, the overall risk rating might not change.

Regarding risk controls, it is also important to ensure that they have been incorporated into the closure plan and that their cost of implementation is included in the cost estimate. Costs for risk controls are typically estimated either by using a range analysis or by adopting a percentage contingency, as discussed in the previous section.

The second way that risk events impact closure costs is in the form of residual risks. While controls may have been implemented to reduce risks to either an acceptable level or as low as reasonably practical, the risk events associated with these residual risks could still occur and have an impact on the ultimate closure cost as well as long-term land management, maintenance and monitoring costs.

Costs for residual risk events can only be effectively estimated by adopting a range analysis using deterministic and probabilistic techniques, as described in Section 4.1. The only difference is that the risk event is modelled using a likelihood of occurrence. For the deterministic approach the likelihoods of occurrence are simply multiplied by the costs for each residual risk. A more robust system models the likelihood of occurrence and a probabilistic distribution of the cost if the risk occurred (the consequence cost) using Monte Carlo simulation. The outputs can be reported separately as risk costs as well as a combined total closure cost estimate. Such cost estimates can be as complex or as basic as desired. Even the simplest probabilistic cost model is much more powerful and defensible than applying the percentage contingency approach.

It is argued that a percentage contingency is not an appropriate method to estimate the costs of risk events. Applying an arbitrarily selected contingency percentage bears no relationship to the cost and likelihood of the occurrence of a group of residual risks.

Unfortunately, all too often the costs of residual risks are either ignored or it is somehow assumed that they are covered by the percentage contingency, which was really developed to model only the uncertainty around the base case estimate.

5 Why are risk costs important?

A proper understanding of the likely closure costs cannot be obtained without understanding the closure risks. Identifying and quantifying risks is critical to the closure planning process because of the inherent uncertainties associated with closure planning, which is often undertaken many years or even decades before the cessation of mining activities. This is reflected in various publications such as Anglo American (2019) ('…*Compare the residual risk profile and the associated liability estimate*…') and by the Asia Pacific Economic Cooperation (Asia Pacific Economic Cooperation [APEC] 2018), which states that financial assurances should be '*proportional to remaining risk'.* The importance of risk and uncertainty is also acknowledged in accounting standards for contingent liabilities (IFRS Foundation 2001) as:

> *'…The risks and uncertainties that inevitably surround many events and circumstances shall be taken into account in reaching the best estimate of a provision…'.*

If risk costs are not included in closure cost estimates an unrealistic estimate of the closure cost liability may be developed. Closure plans are based on underlying assumptions which are often not identified (Byrne 2019). The corollary of an assumption is a risk, i.e. if the assumption does not eventuate then a risk exists. Proper acknowledgement of all the risks and their incorporation into the closure cost estimate are essential to provide greater confidence in the closure liability for all stakeholders.

It is not clear that this is universally happening across the industry. There is a likely disconnect between the residual risks identified in closure risk assessments and the parallel estimate of closure costs. This is compounded by the use of percentage contingencies, the drawbacks of which have been described in Section 3 of this paper. The issue is made worse (i.e. the practice is given further credibility) by the common use of percentage contingencies for regulatory bonds and financial provisions which assume that the percentage contingency will not only cover the uncertainty over the estimate, but also the cost of residual risks. It is, however, noted that there is some recognition of the distinction between the two: for example, in British Columbia, Canada, the Ministry of Energy, Mines and Low Carbon Innovation (Ministry of Energy, Mines and Low Carbon Innovation [MEMLI] 2024) uses the regional mine reclamation bond calculator to apply an effective contingency of 15% as an '*uncertainty estimate'.*

The treatment of risk cost in a mine closure cost estimate will also be influenced by its primary objective. That objective will be determined by which of the four types of closure cost estimate is being developed (ICMM 2019; Brock et al. 2019). Different risks might apply to a financial liability (or closure provisions) estimate than those for the life of the asset, sudden closure or regulatory scenarios. The important point is that the treatment of risks cost must be linked to the specific risk register that has been developed for each type of estimate.

A natural argument to the inclusion of risk costs is that the total closure costs will be unreasonably high. If a more rigorous approach which includes risk costs is adopted and results in an increased closure liability, that is a positive outcome. It would then reflect a more representative and accurate closure cost estimate. An increased closure liability may not, however, be an automatic outcome. Addressing line-by-line estimate uncertainty using range analysis could result in the elimination of hidden contingencies and built-in conservatism on rates, quantities and material costs. Applying more thoroughness to modelling risk events could result in a lower overall cost than applying an arbitrary percentage contingency figure. Whatever the outcome, there is greater confidence in the cost estimate and it is more defensible to scrutiny.

6 Approaches and solutions

Why is there an apparent disconnect between risk registers and risk costs? Notwithstanding that some organisations are including risk costs in various closure cost estimates, it is the author's experience that many are not. This could be due to a variety of reasons including:

- k of corporate or management appetite for adding what may be perceived as more costs to an estimate
- there being no requirement to include them (in the case of regulatory financial assurance mechanisms)
- residual risks not being considered significant enough or likely, such that they can be ignored in the estimate
- blind faith that a percentage contingency will cover all potential outcomes
- an assumption that estimate uncertainties and residual risks will reduce or disappear as mine life proceeds.

Many of these reasons are exacerbated by the fact that a lot of people do not know how to incorporate risk cost or consider it too complex a process. There are, however, approaches that can improve the integration of risk costs into closure cost estimates.

6.1 What to include in risk costs

The first step in developing risk costs is to ensure that the closure risk assessments are both comprehensive and representative. The author has observed the inclusion and improvement of closure plan risk assessments in recent years, but considers that further advances could be made to ensure that:

- different risk registers in the closure plan are reconciled
- risk controls are linked to planned closure activities and incorporated into revised closure plans
- risk parameter descriptions and risk matrices are consistent
- there is transparency around the terminology and meaning of risk ratings
- risk registers describe risk events rather than just issues or aspects
- closure plan assumptions are identified and their associated risks are included in the closure risk register
- closure plan optimism is critically questioned.

Risk assessments also need to include the full range of risks associated with closure. This is likely to include a greater range of risks than might, for example, be included in a risk register required by a regulator. The latter may be limited to landform risks whereas companies are likely to have other risks, notably those relating to stakeholder risks. The assessment of such risks may need more detailed review of the potential impacts on mining-dependent communities, contractors and workforces. This might require the adoption of techniques such as those described by Cole et al. (2024) which base risk ratings on various factors including population size, remoteness, vulnerability and resilience, among others.

The remaining question after finalisation of the risk register is what to include, and perhaps what to exclude, in the risk costs. This is likely to be a somewhat subjective decision. One might decide to include all residual risks, even those rated as low or very low. To some extent this might be determined by the number of residual risks and whether including a large number becomes a cumbersome exercise which does not 'shift the dial' of the total closure cost. An alternative might just be to include risks rated as high or above, although one needs to have a good understanding of the risk matrix structure to do this. Another alternative is to include all risks that have material consequences, regardless of their likelihood of occurrence. Whatever choice is

made, the decision must be defensible and should be documented and consistent with documentation that forms the basis of all other aspects of the overall closure cost estimate.

6.2 How to quantify risk costs

Once there is full confidence in the integrity of the closure plan risk register, the estimate uncertainties and residual risks need to be translated into costs. This is less difficult than an initial review may indicate.

Section 4 of this paper discusses techniques and approaches to integrate estimate uncertainty and risk costs into a cost estimate; in particular, the use of range analyses and probabilistic costing. In the author's experience, what appears to complicate things for people is the question of what numbers to put into these techniques.

The answers to these questions lie in the details of the risk register. Even qualitative risk registers have measures of the severity of consequence. These can, with some judgement and experience, be translated into costs, examples of which could include:

- costs of rework for risks of severe erosion or failed revegetation
- water treatment costs for risks related to unacceptable water quality discharges or long-term water management
- earthworks and materials costs for risks associated with a more complex tailings storage facility cover than planned.

Such costs can be obtained from existing projects either on site or similar projects elsewhere. Similarly, other benchmarks may be available through published data at a national or international level. Such benchmark data can also 'circle back' to quantify risk controls that will mitigate unacceptable risks to either eliminate them or reduce them to an acceptable level.

What perhaps is off-putting to some is how to quantify so-called intangible risks, notably social risks. These too can be quantified using a financial measure as a 'common denominator' to compare and relate various social risks. Table 2 provides some examples of mine closure social risks, their consequences and how those consequences could be translated into financial measures.

Table 2 Social risk examples

Risk event	Consequences	Financial measures
Does not meet post-closure expectations of stakeholders	Negative reputation impacts and community outrage	Management time (site and corporate) Credit rating reduction on borrowings Approval delays to other company projects (local or international) Consultant/legal costs
	Rehabilitation rework	Costs for rework
	Failure to relinquish site	Landholding, management and monitoring costs
Unpredicted stakeholder expectations	Ongoing access maintenance	Landholding, management and monitoring costs
	Continuation of community water supply	Water supply/treatment costs

Risk event	Consequences	Financial measures
Loss of community services	Negative reputation impacts and community outrage	As above
	Class action	Management and corporate costs Consultant/legal costs Credit rating reduction on borrowings Settlement costs Approval delays to other company projects (local or international)
	Failure to relinquish site	As above
Deterioration of retained facilities post-handover	Claims for repair and maintenance	Ongoing repair/maintenance costs
	Negative reputation impacts and community outrage	As above

Table 2 lists just some examples of how intangible risks can be quantified. It is acknowledged that a degree of judgement is required to assess the consequence and their measurements in financial terms, but that is the case with all risks. Also with all risks, uncertainty exists regarding the consequences and their severity. These uncertainties are best modelled using range analysis and probabilistic distribution techniques.

The other component of risk events is the likelihood of occurrence. As with consequences, risk event likelihoods are already identified in the risk register. Although these are typically described in qualitative terms such as probable, rare, almost certain, etc., they can be quantified in a percentage likelihood figure. Guidance on this can be variable. One of the better-known relationships between likelihood/probability descriptors and percent likelihood is that developed by Sherman Kent (Kent 1964), which can be approximately described as follows:

- almost certain 93%, give or take about 6%
- probable 75%, give or take about 12%
- chances about even 50%, give or take about 10%
- probably not 30%, give or take about 10%
- almost certainly not 7%, give or take about 5%
- impossibility 0%.

In the author's experience, the above relationships provide a useful guideline but typically some judgement specific to the circumstances will be required, particularly for very low likelihood/high consequence risk events. Other references present different likelihoods to the above descriptors. For example, Bowden et al. (2001) presents a guide to the quantification of likelihood that at first glance seems to be orders of magnitude different to those proposed by Kent (1964). In one table of that reference, 'unlikely' is quantified as 0.001 or 0.1%. This, however, is an annualised probability of occurrence. Over a 10-year risk assessment period the occurrence likelihood is therefore 1%, and over a 100-year risk assessment period the occurrence likelihood is 10%.

This highlights that an important aspect to consider when assessing likelihood is the time frame over which the risk is being assessed. For some risks this might simply be for the predicted duration of closure implementation, and for others it may be over many decades following the mine shutdown. It is also important to recognise the two (or more) primary components of likelihood/probability: the likelihood of the risk event itself and then the likelihoods of the various consequences occurring should that risk event actually happen.

A simple example of a residual risk cost calculation is presented in Table 3. It shows the outcomes for the risk of a water treatment plant being required to treat discharge from a waste rock dump for a period of 30 years. If the risk eventuated it is estimated that the plant would need to be constructed five years after end of rehabilitation and commence treatment in Year 6. The estimated capital cost is AUD 20 M, with a very high estimate of AUD 30 M and a replacement plant required after 15 years of operation. Similar ranges for operational costs are AUD 1 M to AUD 1.3 M per annum. Cost modelling has assumed a real discount rate of 2% to reflect the time value of money over the water treatment period. The risk workshop assessing the closure risks estimated a 25% chance that the water treatment plant will be required.

Table 3 Risk cost example

Risk approach	Scenario	Risk cost
	Total undiscounted cost estimate ignoring the likelihood of occurrence	AUD 70–99 M
	Total discounted cost estimate ignoring the likelihood of occurrence	AUD 53.2–75.2 M
Percentage contingency	Ignore the risk as likelihoods are considered low and hope that the overall closure cost estimate contingency will cover the cost if the risk eventuates (plus every other uncertainty in the overall cost estimate)	AUD 0 M
Deterministic	Simple multiplication of the occurrence likelihood by the total discounted cost	
	Calculation based on the most likely costs (AUD 20 M capex and AUD 1 M/year opex)	AUD 17.5 M
	Calculation based on the very high estimates (AUD 30 M capex and AUD 1.3 M/year opex)	AUD 24.8 M
Probabilistic	Costs modelled probabilistically with Monte Carlo analysis using a probability distribution of input costs based on the cost ranges	
	P50 (i.e. 50% chance that the cost will be exceeded)	AUD 0 M
	P80 (i.e. 20% chance that the cost will be exceeded)	AUD 46.4 M
	P95 (i.e. 5% chance that the cost will be exceeded)	AUD 61.3 M

The example of Table 3 demonstrates the following:

- the contingency approach hides the financial consequences of the risk. There is a real prospect that the percentage contingency adopted for the whole closure cost estimate has already been consumed by the time that the risk event occurs (if it does)
- the deterministic approach at least includes some allowance for the risk event but, if it does occur, there is a significant shortfall in funds to cover the costs
- the probabilistic methodology allows for a more informed approach to the treatment of risk cost. The choice of risk cost can be defined by the risk appetite of the organisation. The company might be happy to accept a 50% chance that there will be no cost and adopt the P50 cost or it might be more conservative and adopt the P80 cost, still accepting that there is 20% chance that cost will be exceeded. The company might be very risk averse and adopt the P95 costs for all risk costs or it might be uncomfortable with the quantum of cost should the risk eventuate and adopt the P95 cost just for that particular risk event. In any event, the company is better informed about risk costs and has a defensible basis for making risk-related decisions.

7 Conclusion

Closure plans contain many assumption and these translate to risks. As a result, risks form an important component of any closure plan. There has been an improvement in the inclusion and description of closure risks within closure plans over recent years. Further work is, however, needed to ensure that they are appropriately identified and that the assigned risk parameters properly assess the severity of the residual risk consequence and its likelihood of occurrence. Additionally, improvements in closure risk registers are needed through the reconciliation of multiple registers used in the closure planning process; greater consistency with risk matrices and terminology; ensuring that risk controls are re-incorporated into an updated closure plan; and describing risk events rather than using an aspects and impacts approach.

Because risks do form an important component of closure plans, they need to be incorporated into closure cost estimates. Risk costs can be segregated into two groups: estimate uncertainty, those risks associated with uncertainties relating to the costs of the planned closure activities; and risk exposure, those costs associated with the residual risk events listed in the risk register.

The estimate of the cost for each group requires judgement and experience as well as benchmarking and application in a structured approach, as does the development of the closure plan itself. Estimate uncertainty could be addressed by applying a percentage contingency to the base cost estimate, although this is a very crude measure of uncertainty and does not directly relate to each specific cost line item. A preferable method to cost both estimate uncertainty and residual risk events is to adopt a combination of range analyses and probabilistic techniques to arrive at a more robust and defensible cost estimate.

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