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What can we learn from the process safety journey to improve our understanding of the closure challenges and cost estimate?

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Abstract

Mine closure projects by their nature are complex as they exist within a broad system that straddles the geophysical, ecological, climatological and societal. The closure cost estimate is derived from a set of assumptions and a knowledge base that evolve over time. Many creeping increases in cost can occur as a result well before execution.

A risk assessment is often completed in early closure planning stages to inform the closure cost estimate. Intangibles or externalities, like reputation, can be recognised and evaluated in non-financial terms. Technical and delivery assumptions can also be measured this way, or through a financial lens. These are critical to inform the closure planning scope, but can remain disconnected from the closure cost estimate only to be factored in at a later time.

The process safety journey has been well documented since the Flixborough incident in 1974. The tangible nature of catastrophic process safety events has helped build a sense of urgency to proving an operation is safe, rather than assuming it is safe. Various quantitative risk assessment tools and techniques are utilised in process safety that have the explicit aim of demonstrating to leaders that the operation is safe, all of the time.

The immediacy of the closure challenge is highly influenced by time. This paper explores tools that are transferrable and adaptable from the process safety and supporting industries to closure risks. A more quantitative approach to understanding the closure challenges and the closure cost estimate can help build a more balanced sense of urgency. With this, scarce resources can be allocated to deliver the right work at the right time.

Keywords: *estimating closure costs, risk, financing, process safety*

1 Introduction

Mine closure projects by their nature are complex as they exist within a broad system that straddles the geophysical, ecological, climatological and societal. It could be said that they involve the enmeshing of engineered, natural and social systems and, as a result, the corresponding risks may be difficult to quantify. Further, the extent of the potentially extreme outcomes, often referred to in statistical and insurance circles as ‘tail’ risk, is not well understood, particularly for conceptual level estimates that may be relied upon for decades.

Given evolving nature of closure, most closure professionals should expect to experience at least one ‘tail’ event in their career. The losses experienced will rarely be seen as tangible. The challenge is that in key instances those risks manifest themselves slowly and can, through an operational lens, go unnoticed. Consequently, the development of a business case for action is highly challenged when compared to operational risks, particularly those where the scenarios could involve fatalities.

The process safety and high hazard industries have experienced events that fundamentally changed attitudes towards operational risk management and safety. For oil and gas, no doubt the Exxon-Valdez (Skinner and Reilly 1989) was an inflection point. For Rio Tinto, the Texas City Refinery explosion in 2005 (Hopkins 2009) further strengthened Rio Tinto’s resolve to lead the mining industry in employee and process safety. This sense of urgency attached to scenarios that may involve fatalities and significant financial losses has seen the take up and acceptance of operational risk tools that are now routinely applied to maintain a focus on the prevention of sudden catastrophic events.

This paper explores tools that are transferrable and adaptable from the process safety and supporting industries to closure risks. A theoretical closure scenario case study is included that demonstrates how these tools can be applied to improve the understanding of the 'tail'. Through this, a sense of urgency can be elevated to support the building of business cases for action today.

2 Process safety incidents and learnings and mine closure

2.1 Process safety lessons

The process safety or major hazard industry has a well-documented loss history since the Flixborough incident in 1974 (Venart 2004), and the many others that have followed (Kerin 2019). The Flixborough disaster as it has become known was the result of catastrophic release of cyclohexane from a chemical plant in Flixborough, England. The ensuing vapour cloud caused significant property damage and loss of life. The casualty figures could have been significantly higher had the incident not occurred on a weekend when the main office area was unoccupied.

Since 1974, process safety events globally have tragically resulted in more than 10,000 fatalities. These events are often a financial disaster representing balance sheet defining moments. To highlight, in the hydrocarbon sector alone, the 100 largest losses recorded from 1974 to 2021 have resulted in more than USD40 Billion in property damage (Marsh Specialty 2022) compounded by other financial impacts outside of the property insurance market such as Combined General Liability and Directors & Offices insurances.

Through investigations, many of these events have been proven to be avoidable had there been a deeper recognition, and understanding, of the operational hazards within their systems.

Hazard identification for design, process safety management for operating systems, mechanical integrity of processing systems and risk communication and emergency planning are all now common practice with the express aim of elevating the awareness of the potential impacts and preventing catastrophic operational incidents.

The tools, systems and processes that have become routine aim to identify and quantify the root causes to do three important things:

- Understand the full range of consequences, particularly across the commissioning and operational phases through both financial and non-financial outcomes;
- Identify the controls required to bring the likelihood to a range that is in line with societal expectations; and
- Establish the systems to challenge and validate the effectiveness of the controls as implemented.

2.2 Mine closure comparison

The 'boiling frog' reference is a nod to Sorites paradox. This paradox describes putting a frog in a pot of water and gradually heating it up with the frog not able to detect the temperature change until it is too late. Mine closure projects can behave in a similar way. There is no real reported history of catastrophic instantaneous losses like the process safety industry. There are, however, examples of cost increases reported to range from 20% to 100% of the initial estimates (Dunow and Talisch 2022). The history of abandoned mines across many jurisdictions and those under active closure execution perhaps provides the most public set of information on cost increases for us to reflect on (Cohen 2022, Finley 2018, Fitzgerald 2022, Sommerville and Ferguson 2022, Murphy 2022). They can be as small as double through to more than 20 times the original cost estimate.

The reasons for the closure cost increases can be seen through the lenses of:

- Evolving understanding of the technical requirements to achieve the acceptable closure outcome;
- Changing nature of, or lack of engagement with stakeholders (including local communities and regulators) to understand their expectations;
- Deferring execution works because financially it made sense at the time.

A conceptual level cost estimate may be relied upon for decades in long life assets. Variations to the assumptions and the knowledge base may creep over time and will be expressed into an updated estimate. As a central cost estimate these may also be risk adjusted. Low probability 'events' or 'changes' to the cost estimate may be completely removed and separately reported as a series of threats (and possibly opportunities) to the stated outcome.

These impacts may be reflected on a balance sheet, but are rarely 'tangible' property. In a closure execution or a post closure scenario, the economic loss is experienced directly by the organisation's cashflow during the years of expenditure.

The insurance industry has and continues to play an important role in all industries, including process safety and mineral resources sectors. Insurance provides a form of financial assurance to an organisation's bottom line and remains an important part of the risk and control framework. The theory of insurance is simple; the collection of premiums from the many to pay for the losses of the few. Many process safety incidents similar to the Flixborough and Texas City Refinery incidents will have been covered by insurance. Connecting closure with insurance is difficult for two primary reasons:

1. Insurance market do not like exposure to risks that manifest themselves slowly; and
2. Closure risks are not well understood by the insurance industry.

The process safety sector now operates with a chronic sense of unease; a culture that has evolved from one that assumed it was safe to one that proves it is safe, on a day to day, shift to shift basis. In comparison, it could be said that the extractive industry still has some way to go to achieve the same level of maturity with respect to closure-related risks.

3 Risk quantification tools

Probabilistic modelling at its core is a statistical and mathematical approach used to analyse uncertainty and variation around an expected outcome (Gelman et al 2013). A Monte Carlo simulation of a model involves generating a large number of random samples from the defined inputs. By aggregating the results, statistical measures such as mean, standard deviation, or percentiles can be calculated to understand the overall behaviour and variability of the system. From these sets of statistics, sensitivities can be identified to assist decision making.

Probabilistic modelling is not new to closure cost estimating. However, its usefulness at the conceptual estimate level has been questioned given the inherent uncertainty. By modifying the approach to consider not just the risks that are associated with the estimate, but overlaying the risks that sit around the estimate, this form of risk quantification can deliver a deeper set of insights for management.

Several risk quantification tools now routinely utilised in the process safety and high hazard sectors have a demonstrated application to closure scenarios. Combined with expert knowledge, they can assist with generating credible inputs to the model. These tools are briefly described below, and their application demonstrated in the theoretical closure scenario case study (see Section 4).

3.1 Maximum foreseeable loss estimates

Many of the incidents captured within the process safety sector will have been covered by insurance. To obtain the insurance, an understanding of the consequence or range of consequences is required from the owner of the asset. This is developed through the generation of a Maximum Foreseeable Loss (MFL) estimate. The MFL estimate is consequence focused. It considers a failure of one or more layers of protection to determine the magnitude of the event and resultant loss estimate.

Conventional risk assessments utilise a maximum reasonable outcome which accounts for a view on the effectiveness of the current control regime as either a financial or non-financial impact (or both). The MFL approach goes one step further by seeking an understanding of the full extent of the impacts by considering a breakdown in the layers of protection. In some cases, the MFL may well equal the assessed maximum reasonable outcome that is captured in an enterprise risk system, but not always.

3.2 Failure mode and effects analysis

A Failure Mode and Effects Analysis (FMEA) is routinely used to assist breaking down systems, processes and scenarios to highlight individual failure modes and evaluate the impact of the individual elements (Stamatis 2003). The Swiss Cheese model, developed by James Reason (Reason 1990), is another useful reference that follows similar principles and talks to a series of imperfect barriers. Both applications require a disciplined and systematic approach of acknowledging where there are assumptions versus objective proof. This is one of the key lessons from process safety.

3.3 Bow tie analysis

The Bow-Tie risk assessment tool is a visual and qualitative methodology used to analyse and communicate risk. It has been shown to be particularly useful for high-consequence events that exist in a complex system through the development of an understanding the causes, consequences, and controls associated with specific hazards and potential incidents (Fiorentini 2021). The Bow-Tie gets its name from its visual structure that highlights the causal pathways, the unwanted event and then the impacts.

3.4 As low as reasonably practicable

Process safety and high hazard industries acknowledge that under or over investment in the mitigation of a risk could occur. As low as reasonably practicable (ALARP), as a principle, means that an organisation can demonstrate through reasoned and supported arguments that there are no other practicable options that could reasonably be adopted to reduce a risk further. Industry guidance on how to demonstrate ALARP is generally based on the UK HSE targets (UK HSE 2001) as the most widely applied. Three zones of tolerance are established for comparison purposes to societal risk tolerance involving fatalities (refer Figure 1 noting that this is informed by fatality frequency curves for general public and community members which is not reproduced here).

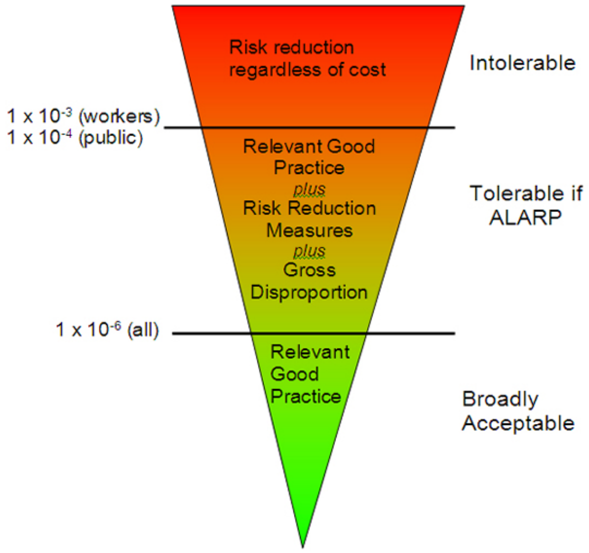


Figure 1 **Risk regions and thresholds (frequency of fatality / year) as per UK HSE 2001**

4 Theoretical closure scenario case study

This section sets out a theoretical closure scenario case study that considers an approach to prepare and report on a closure cost estimate driver review using operational risk tools. An important part of any risk process is to demonstrate how it adds value to decision making. An explanation of how to close the loop with enterprise risk systems is also offered.

4.1 Scenario background

This closure scenario incorporates an amalgam of credible potential closure challenges into a single case study. All details are illustrative in nature and have been exaggerated to highlight influences on financials and any leadership decision making. Any similarities to an existing site, is entirely coincidental.

Mine closure planning is generally developed on a domain-by-domain basis whereby a domain represents a land area to which costs can be allocated. The cost estimate is informed by this as well as considering the necessary studies, closure readiness and preparation, execution, post closure and delivery support requirements and contingency. For demonstration purposes, our case study asset has the following attributes:

- Life of Asset: 2050
- Open pit mining operation with processing facilities
- Located in a remote area that is supported by a small community
- Mining lease under a regulator approved mine management plan including post-closure expectations
- Some contamination from historical activities in the groundwater below the processing facilities
- Current closure strategy is based on relinquishment following 30 years of post closure management
- Agreed final land form is the retention of an open pit, waste dumps and all other areas returned to a vegetation mix that is consistent with surrounding areas
- Operating context is focused on asset and processing stability to meet production demands.

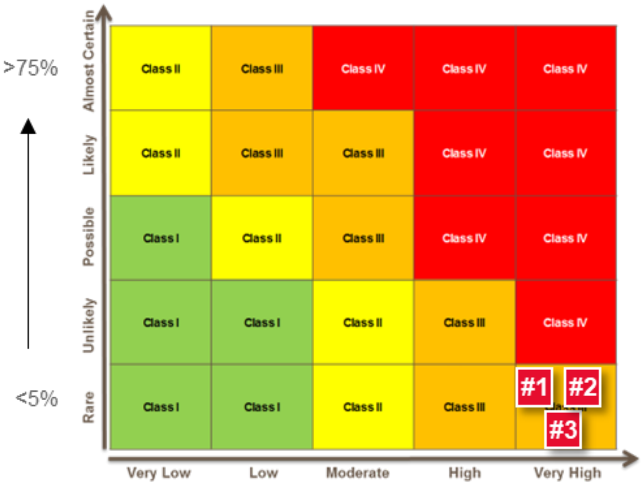
The cost estimate is at a conceptual level and has been estimated at USD 334 Million (M) using a bottom up approach for cost estimating with the costs captured in an agreed work breakdown structure (Table 1).

Table 1 Theoretical case study site closure cost estimate as per work breakdown structure

Facility code	USD M	Description
C000-Pre-closure / Closure Studies	20	All studies and closure readiness
C100-Demolition	50	Removal of all facilities. Disposal of waste material to pit.
C200-Rehabilitation & Revegetation: General	20	Includes areas other than processing plant and pit.
C200- Rehabilitation & Revegetation: Processing Plant	35	Scope covers processing plant area noting some historical contamination (see below)
C200- Rehabilitation & Revegetation: Pits	20	General rehabilitation for pit surrounds noting no backfill requirements
C200- Rehabilitation & Revegetation: Waste dumps	20	Minimal work required based on remote region and climatic influences.
C300-Contaminated groundwater	40	Historical contamination impacting groundwater. Pump and treat system expected to be retained to relinquishment.
C300-Contamination	20	Old site with contamination to be addressed post demolition.
C500-HR	14	Based on workforce and union representation
C600-Communities	5	Small community with alternate economic base assumed
C700-Post Closure	15	Includes post closure monitoring and maintenance
C800-Common distributibles	30	Calculated based on a flat percentage rate of directs (owner's costs).
C900-Contingency	40	Included based on risk profile and allowances

The conceptual closure cost estimate has an accuracy of +/-50%. This is informed by a detailed closure risk assessment conducted using a conventional 5x5 risk matrix method that relies upon a non-economic risk scheme and a context timeframe of the current business planning period (ie, a three to five year time horizon). Three key risks are referenced below and highlighted to management as follows and in Figure 2:

- Risk #1: Contaminated groundwater plume in time may be or become larger and extend off site – evaluation based on environment and community drivers.
- Risk #2: Formation of pit lake at closure may become unacceptable – evaluation based on environmental drivers.
- Risk #3: Climate change may erode the factor of safety of key structure – impact relates to a failure of the structure resulting in damage to the surrounding environment.



	Very Low	Low	Moderate	High	Very High
Almost Certain	Class II	Class III	Class IV	Class IV	Class IV
Likely	Class II	Class III	Class III	Class IV	Class IV
Possible	Class I	Class II	Class III	Class IV	Class IV
Unlikely	Class I	Class I	Class II	Class III	Class IV
Rare	Class I	Class I	Class II	Class III	#1 #2 #3

Figure 2 Risk matrix utilised to support the closure risk assessment and positioning of the three noted risks

4.2 Identifying deviations from acceptance using operational risk tools

The conceptual level closure cot estimate forms the baseline for the risk evaluation. This and the following inputs are factored into the development of a probabilistic model:

- Mine asset closure strategy;
- Closure plan and assumed post closure management plans;
- Domains and established closure criteria;
- Risk register supporting the closure plan and cost estimate;
- Climate change or other longer term projections;
- Stakeholder engagement;
- Status of obligations and commitments; and
- Execution experience and data including progress of progressive rehabilitation (or concurrent reclamation).

The inputs to the model are enhanced by the application of the tools and approaches that are now widely used for operational risks and the lessons from the process safety and high hazard industries. These are briefly introduced in the following sub-sections and their application to a closure scenario demonstrated through reference to the case study asset.

4.2.1 MFL – understanding the possible full extent of the impact

The case study asset has known contamination (Risk #1 above) and as a result there is a costed program of work embedded into the closure cost estimate (USD 40M) as well as an assumption that operational controls continue to focus on containment. The uncertainty is the extent and timing of works required to address the contamination and achieve the closure objective. There is a creeping exposure over a long period given another 30 years of operations plus the closure execution and monitoring period. Developing an understanding of the extent of contamination is a useful way of articulating and managing a 'tail event' that an organisation aims to avoid.

Quantifying the full extent of impacts is the tricky part as there may be tangible and intangible components. The MFL scenario for Risk #1 is estimated at USD 300M based on loss of containment of the plume resulting in the movement of the plume off lease and being detected by a local landholder. The controls in place are human system reliant. The MFL scenario has been quantified based on the following:

- Regaining containment and pumping strategy including expanded pumping network and water management system to address expanded volume throughout operations (acquisition of new land for development of new capacity, extended timeframe of operation – say 50+ years given nature of geology and suspected demographic changes over time to offset the exposure)
- Investigations into sources and remediation across three to five years – a combination of increased costs of operation and/or lower throughput throughout this period
- Compensation for landholder and wider community, and other associated costs including communication program
- Regulatory direction influences including impact on indirects and the accelerated nature of the response requirements
- Fines or penalties.

Precision is not important for these types of calculations, particularly for a conceptual level estimate and where potential future liabilities are involved. What is important are the relativities.

4.2.2 Bow-Tie analysis – breaking the problem down

The scenario relating to Risk #2 is driven firstly by the probability of a pit lake becoming unacceptable and secondly by the range of possible responses. A simplistic version of a Bow-Tie is presented in Figure 3 highlighting the causal pathways, the unwanted event and the range of possible outcomes.

Current controls and mitigation actions can be identified across both the left and right hand sides of the Bow-Tie. For a scenario such as Risk #2, the controls will be a mix of technical, operational and stakeholder management.

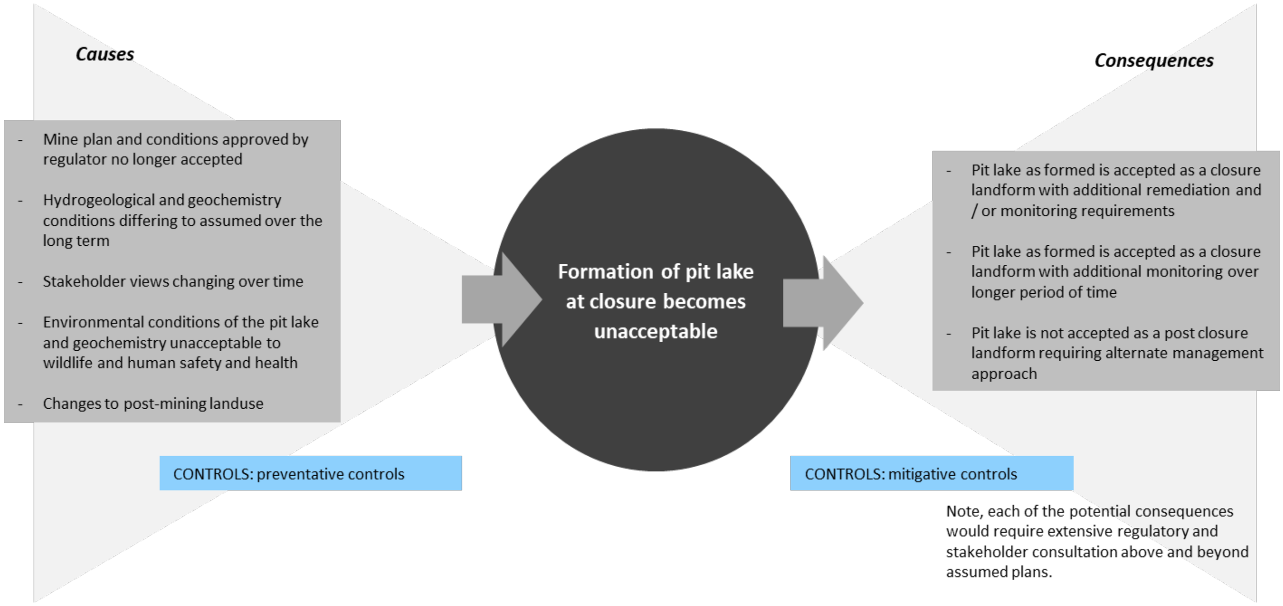


Figure 3 **An example of a simple format to demonstrate the layout and thinking of a Bow-Tie assessment**

The Bow-Tie can be quantified and incorporated in the model as an event orientated scenario across the life of the asset. The MFL approach also assists in establishing ranges for each of the possible responses as per Figure 4 as denoted by:

- Lower – best possible outcome assuming event has occurred;
- Potential base case or most likely outcome; and
- Upper – the MFL.

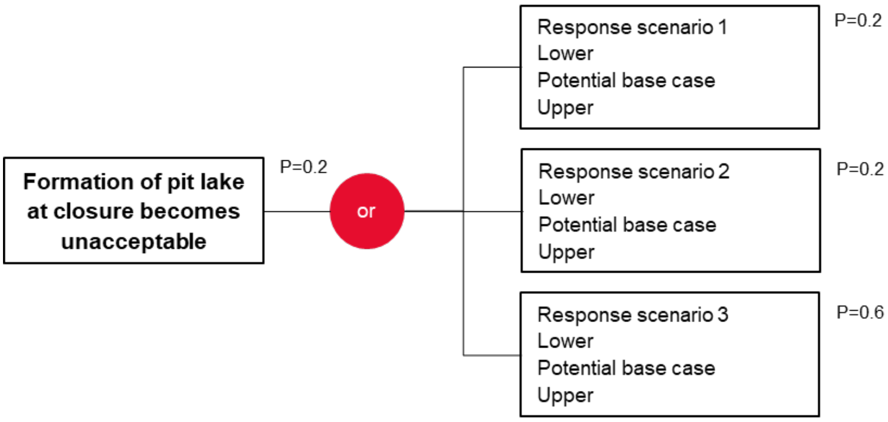


Figure 4 Simplified quantification of the Bow-Tie noting probability (P) of the event occurring with three response scenarios with separate probabilities and cost estimate ranges

4.2.3 ALARP – a test of all due diligence for long term exposures

Risk #3 could be easily dismissed from a narrow quantitative view given the low likelihood (refer Figure 1), particularly where the scenario does not involve fatalities. In the case study, a climate change resilience assessment identified the eroding of a Factor of Safety for a structural feature that is a key deliverable of the closure plan. ALARP can be utilised as test of all due diligence into the future for such risks where there is a long-term exposure.

Most standard risk evaluation schemes allow for a proxy for fatalities when non-fatality scenarios are encountered. For Risk #3, there is an exposure period where the Factor of Safety is eroded under a range of climate change scenarios. This does not mean the event will occur, but it does alter the likelihood evaluation related to the scenario with a FMEA determining that the probability of the event is within the Intolerable region highlighted above, but remains within the Rare region of the risk matrix (refer Figure 1).

If the event occurred, the impacts would be significant with an evaluation of USD 150-250M as a future exposure as determined using the MFL approach. There are three approaches available to address this:

- Option 1 – Install additional engineering reinforcing the structural feature as part of the closure plan with a USD 10M increase to the approved cost estimate: The additional reinforcement would see the Factor of Safety return to a probability which is in the broadly acceptable zone across all climate change scenarios.
- Option 2 – Monitor climate change and install additional reinforcement for the structural feature prior to planned relinquishment: Where climate data indicates the need, the costs for completing the works would be impacted by the need to re-negotiate the relinquishment timeline, re-mobilise a workforce to complete the works (including associated access and accommodation infrastructure) and an extension to post-closure monitoring. A five to ten-fold increase in costs would be the expected exposure based on the need to re-establish supporting infrastructure and the associated support services given the remote location.

- Option 3 – Accept the risk: If the decision is to accept the risk, it needs to be acknowledged that the assumed impacts could vary significantly based on whether the site has been relinquished, and whether the original company retains any control over the activities.

A risk benefit analysis completed using the method outlined in UK HSE (2001) indicates Option 1 or Option 2 would see the structure remain in the ALARP zone and therefore pass the test of due diligence. However, there is a need to communicate the sensitivities within the risk benefit analysis, including:

- Value of preventing an event as a measure of the impact to the case study site and the parent organisation;
- Final likelihood assumed from the installation of the additional reinforcement;
- Uncertainty that relates to the exposure period where the Factor of Safety is eroded; and
- Annual operating costs which are assumed to be nil based on the closure strategy and the targeted relinquishment date.

4.3 Probabilistic modelling – quantifying and explaining the challenge

The cost driver review model has been developed utilising a mix of the examples highlighted in the previous sections across all domains and supporting infrastructure. A Monte-Carlo simulation delivers two key outputs informing strategic direction and resource allocation. These are described in Sections 4.3.1 and 4.3.2.

4.3.1 The curve

The first output is the probability distribution curve (Figure 5). As a risk process, it is critical to understand that this curve presents a hypothetical view of the range of possible futures around the current estimate as a risk overlay rather than a pure cost estimate distribution. The shape of the curve and range of possible outcomes allows several observations to be drawn:

- The uncertainty that exists within and around the estimate is significant as noted by the differential between the 90th and 10th percentiles (approximately USD 280M);
- The potential base case (or P50) is significantly above the current central estimate of USD 326M by about USD 100M;
- The distribution is a multi-modal curve where the tail of the curve is in fact the tail of the tail (see below) highlighting the impact of extreme events on the overall result; and
- The extreme outcome is over twice the current estimate.

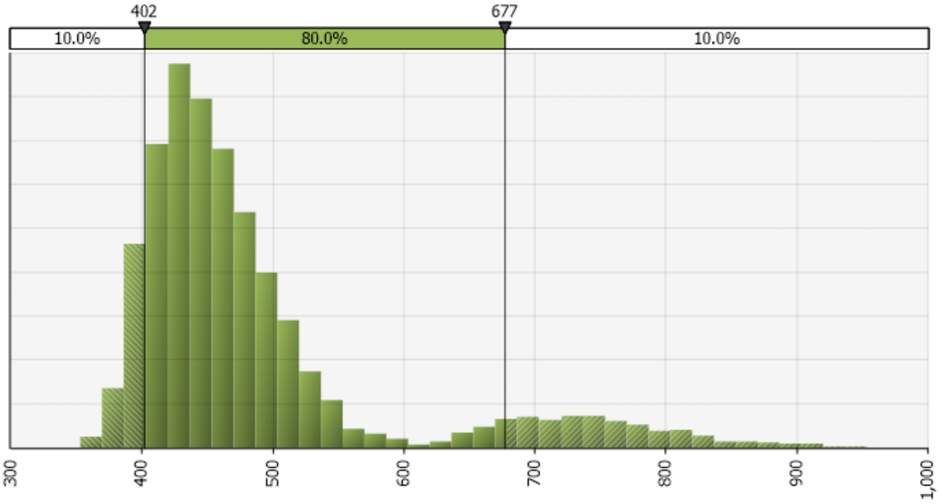


Figure 5 **Probability distribution curve produced from a Monte Carlo simulation of the closure cost driver review**

Most when thinking about statistics will picture the normal bell curve with the tail being the extreme right of the curve. The multi-modal curve in Figure 5 occurs because there are multiple potential paths, and related cost patterns, for the scenario case study asset. Practically speaking, that means the extreme risks that need to be addressed are events that happen in the tail (or extreme right) of the last bump. The key observation in this regard is that, in cost terms, those outcomes can be much further away (that is, higher costs) from the average outcome than a 'mental model' based on the simple bell curve might suggest. The average for the case study is about USD 450M which has an extreme outcome or cost of over USD 900M.

Process safety scenarios measure impacts in dollars and fatalities. As a point of comparison, this distribution provides a clear picture of how significant the end result could be if risks are not managed effectively.

4.3.2 The influencers and prioritisation

The second output is a chart that identifies the key influences and relative importance as measured by their contribution to the variance (Figure 6). Variance is another way of expressing a level of uncertainty. Pictorially, this clearly shows influence on the range of possible outcomes is dominated by Risk #2. This is followed by Risk #1. Risk #3 has a very small contribution.

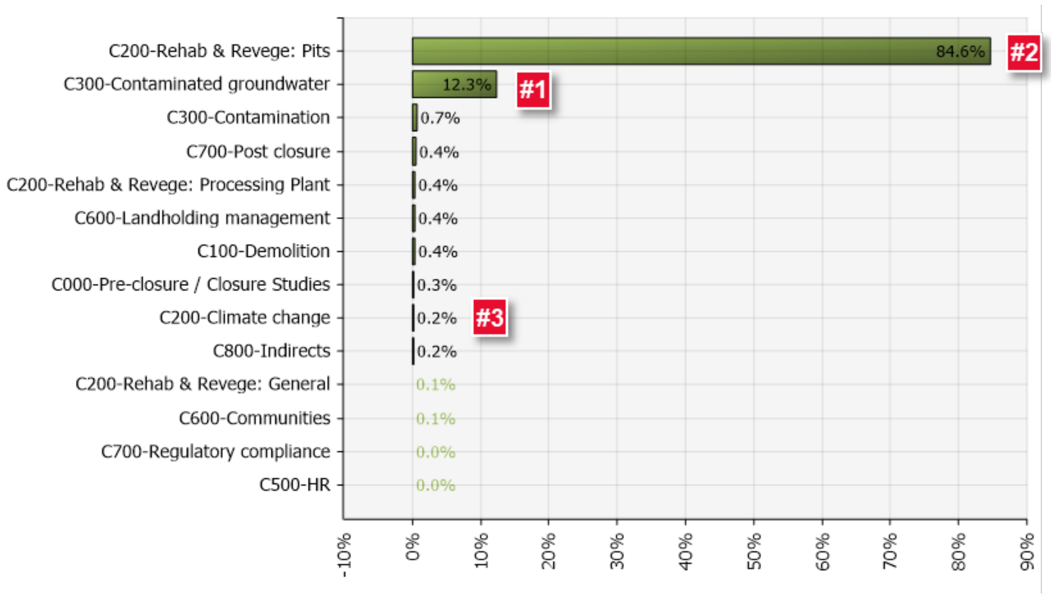


Figure 6 **Closure cost drivers identified by the contribution to the variance with the three highlighted risks from the case study**

With a deeper understanding derived from the application of these tools, questions can be asked regarding what is required to be understood and actioned across the current business planning period versus into the longer term. That is, is the right work being completed at the right time and has the right level of resourcing been allocated to manage (or reduce) the closure risks and costs?

A noted limitation in the model is that each input is treated as independent, and we know that this is not always true. It is therefore critical that any decisions account for potential influence or correlation one driver has on another. For example, the preparatory studies (C000 Pre-closure / closure studies) represent a tiny contribution to variation; but, the influence on the final outcome can be significant if not completed at the right time, not resourced at the right level.

Similarly, the cost allocation associated to communities is modest when compared to other categories within the WBS. Engagement with communities and regulatory stakeholders if not resourced at the right level and progressed continuously as part of operational engagement, may negatively impact the final outcomes (for example landforms, retained infrastructure vegetation), including cost.

Incorporating correlation into the model is not necessary at a conceptual level. The Bow-Ties and MFL components consider this at an individual domain level. However, diagrammatically representing as a combined driver review is an important part of communicating the outcomes. An example extract from the case study is captured in Figure 7. This figure aims to convey the relative influence of the individual drivers on the outcome/s of others. It supports a review of priorities with the relative strength of influence acknowledged by the thickness of the connectors.

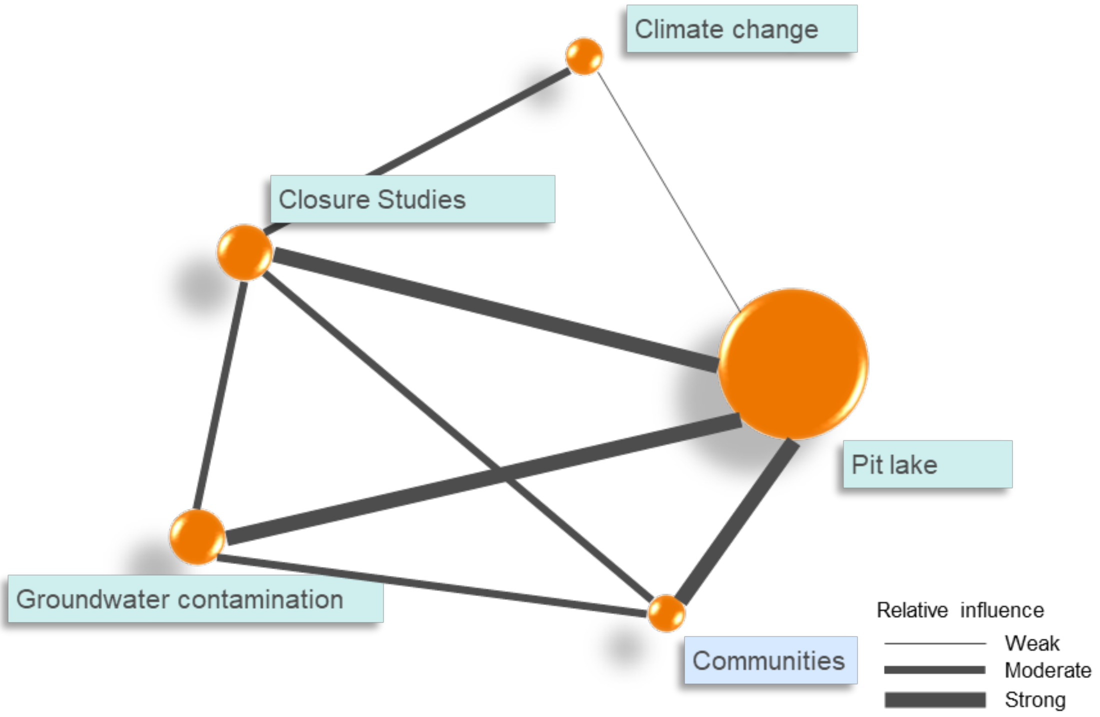


Figure 7 Diagrammatic representation of correlation or influence of the closure cost drivers noting the size of the bubble is representative to the driver's contribution to variance

Armed with the above, the prioritisation of actions for the three risks can now be considered based on a more objective set of inputs:

- Risk #1 – the MFL purely from a consequence perspective highlights the significance of the exposure and supports the prioritisation of actions that focus on ensuring the robustness of the control environment that focuses on prevention.
- Risk #2 – the Bow-Tie points to three possible scenarios including strong link to stakeholders. The level of uncertainty is very significant with short term actions required to address a mixture of technical and stakeholder considerations across the entire time horizon.
- Risk #3 – the time to closure indicates that action can be deferred with subsequent updates to the cost estimate including a review of climate change, say five yearly. If closure was planned for 2025, then the decision timing will be very different, most probably with an emphasis on progressing Option 1.

4.4 Closing the loop

Enterprise risk systems rely upon quality risk information for decision making. The conventional 5x5 risk assessment is, at best, a 'blunt instrument' and may well result in the de-prioritisation of the closure risks when compared to the acute operational challenges that the case study asset faces.

Closure cost estimates have a number of drivers that will be highly dependent upon the asset. The probabilistic modelling enables these to be brought together to provide an overall evaluation of the potential impact. This provides a better understanding of the closure risk as a whole and its component parts. The outcome can be captured within the enterprise risk system at an aggregate level for comparison with other risks at the asset leadership level. The Bow-Ties, FMEAs and resilience assessments provide an objective dataset that also informs the effectiveness of the control environment at an individual driver and overall closure risk levels.

With this enhanced understanding, the company now has a better set of information to support a business case for action. These actions can then be captured with confidence that they are adding value today.

5 Conclusion

What this paper points to is the stark difference between the risks faced by the process safety industry and mine closure projects. Metaphorically, the former is akin to 'sitting on a bomb' and the latter, is the proverbial 'boiling frog'. The sense of urgency relating to managing the process safety risks has become 'business as usual' combined with a culture that focuses on proving it is safe. Assuming it is safe is no longer an option.

Conceptual level closure cost estimates are recognised as being inherently uncertain. This uncertainty has been accepted knowing there are many assumptions that are not necessarily supported by objective proof and, in many cases, the significant time to closure. Developing a sense of urgency which compares to process safety is challenged by the creeping and intangible nature of the technical and stakeholder considerations.

Probabilistic modelling, supported by the operational risk tools that are now routine practice for event-based risks, can provide a more objective and tangible view of the impacts. A clear understanding of the 'tail' in combination with the clarity of the key drivers or influences supports the acknowledgement of a closure risk in the enterprise risk system. In turn, support can be gained from the business cases that provide a more balanced prioritisation of resource allocation.

To conclude, the urgency directed towards closure may not need to be shift to shift, let alone day to day. An earlier understanding of the magnitude of the potential consequences along with regular reviews will help drive the right work at the right time.

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