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From provision to decision: using closure costs to drive better business outcomes

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Abstract

Closure cost estimates are commonly developed to support financial provisioning and external reporting. While this function remains essential, a compliance-focused approach can limit the usefulness of closure costs in informing broader business decisions across the life of an asset. As closure liabilities grow in scale and influence, there is an increasing need for closure cost information to actively support risk-based and value-aligned decision-making. This paper explores how closure cost estimates can be repositioned as a decision-support tool to improve risk evaluation, option analysis and strategic trade-offs, rather than being treated as a static liability.

Drawing on practical experience, key themes discussed include the role of governance in shaping estimation methodology and maturity, management of optimism bias, and transparency of uncertainty as critical enablers for improving the credibility and practical value of closure cost estimates, while maintaining consistency across assets. Practical mechanisms to address these challenges are outlined, including a practical framework for embedding closure cost considerations into business planning, with a focus on fit-for-purpose governance, clarity of intent, and alignment between estimated maturity and business needs. By shifting the focus from closure costs as an accounting outcome to closure costs as a decision input, robust, transparent and value-aligned closure outcomes can be supported.

Keywords: mine closure costs, decision-making, governance, risk and uncertainty, closure cost estimating

1 Introduction

Closure cost estimates are a fundamental component of mine closure practice, underpinning financial provisioning, external reporting and regulatory assurance. Accounting standards require that provisions reflect the best estimate of the obligation for current disturbance (at the balance sheet date), accounting for risk and uncertainty, and apply discounting when the time value of money is material (International Accounting Standards Board, IAS 37). As a result, considerable effort is invested in developing auditable, consistent and defensible closure cost estimates. Other closure costs estimates developed by businesses may include:

- closure cost estimate: scenario-specific estimate of all closure expenditures based on the closure strategy, closure plan and study outcomes, including risks, opportunities, cash flow timing and post-closure management requirements
- total projected cost: expected life-of-asset closure cost required to achieve a closure vision and agreed outcomes, assuming the operation continues to its planned end of life; includes the full scope of closure activities, not just legal obligations
- closure and clean-up provision: discounted present value of the closure and clean-up obligations, calculated using controller-set discount rates for financial reporting purposes.

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However, industry guidance increasingly recognises closure as a life of asset process (International Council on Mining and Metals [ICMM] 2019). In this context, closure costs are not only a liability, but a tool to evaluate risk, uncertainty and value trade-offs. Despite this, they are often treated as static outputs, disconnected from the decisions that have the most influence on closure outcomes. Significant closure cost escalations have been realised in mature mining regions (Sanders et al. 2024). For example, closure costs for the Giant Mine in Canada's Northwest Territories were previously reported at just over CAD 1 billion but, have since escalated to more than CAD 4.3 billion (Government of Canada 2022; Minogue 2020).

Similarly, closure costs for Ranger Mine in the Northern Territory in Australia increased from approximately AUD 1 million in 2004 (Energy Resources of Australia [ERA] 2004), to AUD 512 million in 2018 (ERA 2018), and exceeded AUD 2.2 billion in 2023 (ERA 2023). The significance of these examples is not simply the increase in cost, but what it reflects. Closure liabilities evolve as understanding improves, stakeholder expectations change, and long-term risks become clearer. Had these risks been recognised and considered earlier, there may have been opportunities to reduce future liabilities through different operational, design or rehabilitation decisions. This highlights the limitation of treating closure costs solely as reporting outputs. When they are disconnected from business decisions, long-term consequences may not become apparent until options are limited and liabilities are embedded. Closure costs should therefore be used not only to quantify obligations, but also to inform decisions that shape future closure outcomes.

As Sanders et al. (2024) note, the issue is not with current estimating tools, but with the inadequate application of robust closure planning and design. Key decisions, such as mine design, sequencing, rehabilitation strategy and execution models, are frequently made outside formal closure cost governance processes. This disconnect limits visibility of long-term cost and risk implications and can result in short-term decisions that increase closure liability without being explicitly considered at the time.

To address this, closure cost estimates must shift from periodic reporting artefacts to decision-support tools. This requires estimates that are:

- fast to iterate, enabling trend and trajectory tracking
- comparable across options
- explicit in assumptions and risk drivers
- able to incorporate uncertainty and scenario testing, not just base cases
- traceable to source data and assumptions to support assurance and audit
- embedded in operational and planning processes to inform real decisions
- structured to show decision consequences, not just a single value.

2 Governance as an enabler of decision-relevant closure cost estimates

Governance plays a critical role in determining whether closure cost estimates function as decision-support tools or remain limited to compliance purposes. Governance frameworks define the intent of an estimate, establish ownership and accountability, and set expectations for how closure cost information is used in decision-making forums. This is particularly important because closure cost estimates are developed for different purposes, including financial provisioning, life of asset planning and regulatory assurance, and should not be treated as interchangeable (Byrne 2023). Where intended use and governance is weak, closure cost estimates are often developed to meet minimum reporting requirements, with limited challenge to underlying assumptions or consideration of how costs should inform strategic decisions. In contrast, fit for purpose governance clarifies that closure cost estimates serve multiple purposes, including risk evaluation, option analysis and prioritisation, as well as financial reporting.

Key governance elements include:

- clear ownership and accountability
- approval pathways aligned to materiality
- integration with closure studies, core business processes and decision forums.

These mechanisms ensure that changes in estimates are interpreted in context and used to inform decisions. Governance also mitigates optimism bias and anchoring through independent review, structured challenge and documentation of assumptions.

Consistency across cost estimates is equally critical (both across time horizons and across assets). Portfolio-level standards for estimating methodology, cost breakdown structures and assumptions libraries enable meaningful comparison (AACE International 2020). Without this consistency, closure cost estimates may be perceived as subjective or unreliable, reducing their influence on decision-making. For decision-making use, holding assumptions constant and varying only key drivers (e.g. landform design or rehabilitation approach), these tools enable rapid, transparent comparison between options and reduce reliance on bespoke, time-intensive estimates.

A closure cost estimate is decision-useful when it is designed for the decision it informs. Effective estimates are:

- comparable across options
- scenario-based
- transparent in assumptions
- timely to update
- explicit about uncertainty
- traceable to decisions and inputs.

3 Estimate maturity and alignment with decision context

The usefulness of a closure cost estimate is strongly influenced by its maturity relative to the decision it is intended to inform. Estimate maturity reflects the level of definition of scope, assumptions and technical inputs available at the time an estimate is prepared and is a primary driver of the expected reliability of the estimate (AACE International 2020).

Lower-maturity estimates are inherently characterised by higher uncertainty and a wider range of plausible outcomes. As such, they are generally more appropriate for identifying major cost drivers, options screening, trade-off analysis and directional decision-making rather than commitment decisions (Sanders et al. 2024). Conversely, higher-maturity estimates rely on a more detailed technical definition and are more appropriate for supporting approvals, commitments and external reporting.

The ICMM's *Closure Maturity Framework* (ICMM 2019) provides one recognised approach for assessing the current maturity of closure planning and supporting inputs. When applied in conjunction with closure cost estimation, such frameworks can help clarify the level of confidence that is reasonable for a given estimate and decision context.

Misalignment between estimated maturity and decision context is a common source of poor decision outcomes, as it can create false confidence in point estimates and obscure the scale of uncertainty and risk embedded within them (Sanders et al. 2024). This, in turn, increases the likelihood that decisions are made without a full appreciation of their longer-term closure cost and liability implications. This is particularly relevant where estimates of differing maturity are used to compare materially different closure options or justify long-term commitments, as they may imply a level of precision not supported by the available definition (AACE International 2020). Point estimates derived from low-definition inputs may obscure uncertainty and lead decision-makers to over-weight apparent cost differences that are not robust.

Sanders et al. (2024) support aligning estimate maturity with the decision context and recognise that different decisions warrant different levels of maturity definition. High-consequence decisions, such as committing to a closure strategy, execution model or sequencing approach, require higher maturity for key cost drivers, even if full definition across all scope elements is not practical.

Clear articulation of estimated maturity also supports improved communication of uncertainty. Rather than presenting a single number, estimates can be framed as ranges or scenarios appropriate to the decision stage, consistent with the principle that estimate classification is primarily determined by definition maturity rather than estimator effort or tools (AACE International 2020).

For example, a low-definition estimate of long-term water treatment may vary significantly depending on assumptions about treatment duration. In these circumstances, presenting a single-point estimate can obscure the scale of uncertainty and create false confidence in the preferred option. Presenting estimates as ranges or scenarios can provide decision-makers with a more realistic understanding of potential liability exposure. Aligning estimate maturity with decision consequence improves transparency with respect to uncertainty and reduces the risk of long-term business decisions being made on unsupported cost precision.

4 Managing uncertainty, contingency and optimism bias

Uncertainty is inherent in mine closure due to long timeframes, evolving expectations and variable technical conditions (ICMM 2019). How uncertainty and contingency are represented within closure cost estimates materially affects both credibility and decision quality. In many cases, uncertainty is implicitly embedded in a single-point estimate or an aggregated contingency allowance, without a clear explanation of which risks are being covered. This can lead to misunderstanding, with stakeholders interpreting closure costs as fixed or overstated, and reacting negatively when estimates increase as the definition improves (Lovallo & Kahneman 2003).

Explicit articulation of uncertainty and contingency improves transparency and decision quality. Separating a defined base estimate from allowances for uncertainty enables decision-makers to understand the drivers of variability and how they differ between options (International Accounting Standards Board 2026). This approach supports more informed trade-offs by making uncertainty visible rather than hidden.

Closure cost estimates are also vulnerable to optimism bias and anchoring effects. Common examples include reliance on legacy cost benchmarks that no longer reflect current conditions; underestimating indirect, post-closure or long-duration costs such as monitoring, maintenance and caretaker activities, and assumptions that align with best-case regulatory, technical, or execution outcomes. Estimates may also implicitly assume uninterrupted execution, stable regulatory requirements, or timely relinquishment, despite historical evidence to the contrary.

Presenting estimates as ranges or scenarios reduces false precision, helps counter these biases and supports more realistic decision-making by explicitly reflecting uncertainty and downside risk (AACE International 2020; Flyvbjerg 2008). The growing materiality of closure liabilities reinforces the importance of robust closure cost estimation for strategic decision-making. Moody's Ratings (2024) notes that mining industry asset retirement obligations continue to increase and could exceed industry debt levels over the coming decade, highlighting the need for decision-makers to understand and manage long-term closure risks alongside short-term financial outcomes. In this context, improved estimate quality provides greater confidence in future liabilities, reduces uncertainty and supports better-informed capital allocation decisions.

Increases in closure cost estimates are often perceived negatively. However, higher costs frequently reflect improved definition or explicit recognition of previously unaccounted risks (Flyvbjerg 2008). Reframing higher, better-defined closure costs as reduced business and financial risk is therefore critical. This is particularly relevant to senior decision-makers who are balancing short-term financial impacts with long-term risk. Over time, this reframing supports a culture where improving estimate quality is seen as to add value. For example, detailed landform design may increase estimated costs compared to conceptual

allowances. While the liability increases, the improved definition enables better comparison of options and reduces the likelihood of future cost escalation.

5 Applying decision-focused costing across portfolios

Applying decision-focused closure cost approaches across large portfolios presents practical challenges because assets are at different life cycle stages and exhibit varying data quality, closure maturity and decision urgency (ICMM 2019). In this context, consistency remains important, but applying uniform estimation approaches across all assets can reduce the usefulness of closure cost information. Portfolio-level decision-making requires frameworks that support comparability while allowing flexibility for asset-specific context and proportionality, with the level of estimating effort and certainty scaled to the materiality of the asset and the significance of the decision being made (AACE International 2020). Over long asset lives, closure cost estimates also serve as reference points against which future liability movements, strategy changes and investment decisions are assessed. Managing estimate maturity over time is therefore important to maintain continuity, transparency and confidence in how closure risks and costs evolve across the portfolio.

For example, an early-stage development option with limited closure data may require only a screening-level estimate to inform whether alternative layouts or sequencing options should be progressed. In contrast, a mature operating asset approaching a commitment decision on closure execution or rehabilitation strategy may warrant higher estimate maturity for key cost drivers (Sanders et al. 2024). Applying the same estimating expectations to both decisions would either constrain early-stage optionality or delay critical decisions at mature assets.

Achieving consistency across portfolios can also be complicated by legacy assumptions, historical estimating practices and organisational expectations. Existing closure cost estimates are often embedded within planning processes and financial assumptions, making it difficult to incorporate revised methodologies or updated risk information. Structuring estimates to consider a range of closure scenarios and options, rather than a single fixed estimate provides greater flexibility to evaluate new information, test alternatives and understand the implications of changing risks over time However, anchoring effects can make it difficult to introduce new information or revised assumptions, even when justified, and may create a preference for stability over accuracy (Lovallo & Kahneman 2003). This risk is amplified in portfolios where different assets have different estimating practices, leading to inconsistent confidence and comparability (AACE International 2020).

Balancing rigour with practicality requires governance frameworks that define minimum standards while permitting fit-for-purpose approaches at early stages, including the use of ranges and scenario-based estimates when definitions are limited (AACE International 2020). Integrating closure cost information into business planning can also be challenging when organisational incentives are misaligned; sustained leadership endorsement and embedded closure processes are identified as important elements of integrated closure practice (ICMM 2019).

Across large portfolios and long-life assets, maintaining consistency while allowing proportionality and evolving estimate maturity is critical to ensuring closure cost information remains credible, comparable and decision-relevant over time.

6 Designing closure cost estimates for decision-making

Applying decision-focused closure cost approaches requires consistency. Building on Sanders et al. (2024) paper ‘Closing the gap: closure cost estimation trends and pathways to improved maturity’, decision-useful estimates should also be:

- comparable across options (same basis of estimate, same boundaries)
- scenario-structured (options differ by explicit drivers)
- transparent assumptions (what changed and why)

- decision-timely (rapid iteration)
- risk-aware and explicit uncertainty (ranges, key uncertainties, not just a point value)
- traceable (links back to decision, inputs, and governance approvals).

For option analysis, a practical rule is to hold the base estimate methodology constant across scenarios and vary only the defined drivers, then evaluate options using both expected cost deltas and downside exposure for the uncertainties most relevant to the decision. However, this is easier said than done, as Bloemhof & Bothma (2025) highlight, many closure cost drivers are inherently interdependent. For example, changes to landform design influence material movement volumes, which in turn change fleet requirements, water management strategies and indirect costs (due to changes in duration) and contingencies.

Decision-useful cost estimates, therefore, need to capture these interactions, ensuring that changes in one design or operational parameter are appropriately reflected across related costs. Scenario-based and parameter-linked models support this by enabling planners to test the cascading effects of proposed changes, reducing the risk of isolated or misleading cost adjustments and improving the robustness of cost information used to support strategic closure decisions (Bloemhof & Bothma 2025).

Decision-useful cost estimates must therefore be structured to capture and demonstrate these interactions. In practice, this requires parameter-linked estimates, in which changes in a single input are consistently propagated through all dependent cost elements. This means estimates clearly show how key drivers (e.g. landform design, rehabilitation method or sequencing) flow through to:

- quantities (e.g. material movement, areas, volumes)
- productivity and duration
- fleet size and equipment requirements
- indirect and owner's costs (driven by schedule)
- contingency and risk exposure.

Scenario-based and parameter-linked models support this by enabling planners to test the cascading effects of proposed changes, reducing the risk of isolated or misleading cost adjustments and improving the robustness of cost information used to support strategic closure decisions.

7 A framework for decision-driven closure cost integration

To address the limitations of traditional closure cost estimation approaches, this paper proposes the framework for decision-driven closure cost integration (Figure 1). The framework synthesises the key themes discussed throughout this paper and illustrates the shift from a traditional provision-focused approach to one in which closure cost information is integrated into business decision-making.

The framework is built around 5 enabling pillars: governance and accountability, fit-for-purpose estimate maturity, transparency of risk and uncertainty, scenario evaluation, and integration into business processes and decision forums. Together, these pillars support the use of closure costs as a decision-support tool rather than a reporting output.

As shown in Figure 1, traditional approaches typically focus on the development of a singular closure cost estimate for provisioning, reporting and compliance purposes. In contrast, a decision-driven approach uses closure cost information to evaluate alternative pathways, understand cost–risk–value trade-offs and inform planning, design, operational and investment decisions throughout the asset life cycle.

The framework provides a practical structure for embedding closure cost considerations into business processes so that the implications of decisions are understood before liabilities are created. In doing so, it supports improved transparency, more informed decision-making and better long-term closure outcomes.

Framework pillar	Traditional approach	Decision-Driven Closure Cost Integration
Governance and accountability	• Estimate prepared for reporting and compliance purposes	• Estimate developed, maintained and governed to support business decisions.
Estimate frequency and maturity	• One estimate regardless of decision needed. • Primarily considered during closure planning, provisioning and reporting activities.	• Estimate maturity aligned to decision consequence and fit for purpose.
Risk and uncertainty	• Risk and uncertainty embedded within contingency or hidden assumptions.	• Transparent, explicitly quantified and communicated.
Scenario evaluation	• Single case	• Multiple future pathways evaluated through decision forums to understand cost, risk and value trade-offs.
Integration into Business Processes and Decision Forums	• Limited - considered in closure planning	• Embedded throughout the asset life cycle within planning, design, operational and investment decisions.
Decision outcome	• Limited to provision/liability value and reporting.	• Decision-ready information on cost, risk and trade-offs that improves closure outcomes, and supports better-informed decisions

Figure 1 Framework for decision-driven closure cost integration

8 Conclusion

Closure cost estimates are an essential requirement for mine closure, but their value extends beyond financial provisioning when they are governed and applied with decision-making in mind (ICMM 2019). By aligning governance, estimating maturity and transparency of assumptions with the decisions they are intended to support, closure cost estimates can become a powerful tool for improving risk evaluation and strategic trade-offs (AACE International 2020). Under a traditional approach, closure cost estimates are periodically updated, reported as point values and primarily used for financial disclosure. In contrast, a decision-focused approach treats closure costs as dynamic inputs, uses ranges and scenarios to reflect uncertainty and integrates cost insights into planning, design and investment decisions throughout the asset life.

Repositioning closure costs from a static accounting outcome to a dynamic decision input supports more robust, transparent and value-aligned closure outcomes, particularly in complex portfolios where long-term risk management is critical (ICMM 2019). The transition from provision-focused to decision-driven closure costing is likely to require changes to governance frameworks, estimating guidance, business processes and decision forums to ensure closure cost information is routinely considered when evaluating strategic options and making long-term investment decisions.

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References

AACE International 2020, *Cost Estimate Classification System as Applied in Engineering, Procurement and Construction for the Process Industries*, Recommended Practice 18R-97, AACE International, viewed 26 March 2026, https://web.aacei.org/docs/default-source/toc/toc_18r-97.pdf?sfvrsn=4

Bloemhof, R & Bothma, J 2025, 'Navigating uncertainty: towards resilient cost estimation in mine closure', in S Knutsson, AB Fourie & M Tibbett (eds), *Mine Closure 2025: Proceedings of the 18th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, https://doi.org/10.36487/ACG_repo/2515_31

Byrne, G 2023, 'In defensive of NPV', in B Abbasi, J Parshley, AB Fourie & M Tibbett (eds), *Mine Closure 2023: Proceedings of the 16th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 1–8, https://doi.org/10.36487/ACG_repo/2315_083

Energy Resources of Australia 2004, *Annual Report 2004*, viewed 15 June 2026, https://www.energyres.com.au/uploads/Releases/Reports/2004_Annual_Report.pdf

Energy Resources of Australia 2018, *Annual Report 2018*, viewed 15 June 2026, https://www.energyres.com.au/uploads/Releases/Reports/ERA_AR_2018_Final_eBook.pdf

Energy Resources of Australia 2023, *Annual Report 2023*, viewed 15 June 2026, https://www.energyres.com.au/uploads/ERA-Annual-Report-2023_FINAL.pdf

Flyvbjerg, B 2008, 'Curbing optimism bias and strategic misrepresentation in planning: reference class forecasting in practice', *European Planning Studies*, viewed 26 March 2026, https://www.researchgate.net/profile/Bent-Flyvbjerg/publication/233258056_Curbing_Optimism_Bias_and_Strategic_Misrepresentation_in_Planning_Reference_Class_Forecasting_in_Practice/links/0fcfd50c5def1a236d000000/Curbing-Optimism-Bias-and-Strategic-Misrepresentation-in-Planning-Reference-Class-Forecasting-in-Practice.pdf

International Accounting Standards Board 2026, *IAS 37 Provisions, Contingent Liabilities and Contingent Assets*, IFRS Foundation, viewed 26 March 2026, https://www.ifrs.org/issued-standards/list-of-standards/ias-37-provisions-contingent-liabilities-and-contingent-assets/

International Council on Mining and Metals (ICMM) 2019, *Integrated Mine Closure: Good Practice Guide*, 3rd edn, London, viewed 26 March 2026, https://pimcore.icmm.com/website/publications/pdfs/environmental-stewardship/2025/integrated-mine-closure-3rd-edition.pdf?cb=95210

Lovallo, D & Kahneman, D 2003, 'Delusions of success: how optimism undermines executives' decisions', *Harvard Business Review*, viewed 26 March 2026, https://hbr.org/2003/07/delusions-of-success-how-optimism-undermines-executives-decisions

Minogue, S 2020, 'Public hearings into $1B giant mine remediation begin at last', *CBC*, viewed 15 June 2026, https://www.cbc.ca/news/canada/north/public-hearings-giant-mine-begin-1.5432187

Moody's Ratings 2024, *Reclamation Obligations at $78 Billion and Rising, Posing Credit Risk for Miners,* Metals & Mining – Global Sector In-Depth Report.

Sanders, J, Slingerland, N & Murphy, D 2024, 'Closing the gap: closure cost estimation trends and pathways to improved maturity', in AB Fourie, M Tibbett & G Boggs (eds), *Mine Closure 2024: Proceedings of the 17th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 1149–1162, https://doi.org/10.36487/ACG_repo/2415_82