

Integration of ‘safe closure’ into the selection of a new tailings storage facility

James Penman ^{a,*}, Jonothan Sanders ^a

^a Klohn Crippen Berger, Australia

Abstract

The Global Industry Standard on Tailings Management (GISTM) requires demonstration that all feasible sites, technologies and strategies for tailings management have been considered for a new tailings storage facility (TSF) with the goal of selecting an alternative that minimises risks to people and the environment throughout the tailings facility life cycle. To meet this goal, a new TSF will be required to demonstrate ‘safe closure’, which the GISTM defines as not posing ongoing material risks to people or the environment.

At a concept study stage, it can be difficult to determine what is likely to constitute a ‘material’ risk at closure; however, a robust risk assessment of credible failure modes should be able to factor in variabilities and uncertainties which could become material over the facility life cycle. Importantly, a robust risk assessment at the concept stage allows for a risk-informed design to be implemented in subsequent study stages.

This paper presents a synthesis of the authors’ experience in applying risk assessment at the concept design stage and how the outcomes can be integrated into a multi-criteria alternatives assessment framework for selecting a preferred tailings management alternative consistent with the International Council on Mining & Metals (ICMM) Tailings Management: Good Practice Guide.

Keywords: *tailings, risk assessment, safe closure, GISTM, multi-criteria alternatives assessment*

1 Introduction

The Global Industry Standard on Tailings Management (GISTM) published in August 2020 is the product of the Global Tailings Review commissioned after the catastrophic failure of the tailings facility at the Córrego do Feijão iron ore mine near Brumadinho, Brazil. The GISTM “requires Operators to take responsibility and prioritise the safety of tailings facilities, through all phases of a facility’s life cycle, including closure and post-closure” (Global Tailings Review 2020a). The tailings facility at Córrego do Feijão was itself entering into the closure phase at the time of its failure and the subsequent deaths of over 270 people.

Within the GISTM are several requirements that relate to closure of a tailings facility. For example, Requirement 5.2 requires development of “a robust design that considers the technical, social, environmental and local economic context, the tailings facility Consequence Classification, site conditions, water management, mine plant operations, tailings operational and construction issues, and that demonstrates the feasibility of safe closure of the tailings facility. The design should be reviewed and updated as performance and site data become available and in response to material changes to the tailings facility or its performance”. To meet this requirement, a new facility design should therefore consider the feasibility of achieving safe closure from as early as practicable in the design process.

Under Requirement 3.2 for new tailings storage facilities (TSFs), the GISTM also requires the use of a multi-criteria alternatives analysis (MAA) which is typically initiated at the concept design phase of a project. Therefore, the successful integration of closure considerations into the MAA process presents a key

* Corresponding author. Email address: jpenman@klohn.com

opportunity to account for safe closure from the concept design phase for a new TSF. This paper presents an assessment of the MAA process effectiveness in considering safe closure for a new tailings facility.

2 Background

2.1 Industry guidance

The GISTM defines a tailings facility as being in safe closure where it is “a closed tailings facility that does not pose ongoing material risks to people or the environment which has been confirmed by an ITRB [independent tailings review board] or senior independent technical reviewer and signed off by the Accountable Executive”.

The GISTM further defines 'material' to mean “important enough to merit attention or having an effective influence or bearing on the determination in question. For the Standard, the criteria for what is material will be defined by the operator, subject to the provisions of local regulations, and evaluated as part of any audit or external independent assessment that may be conducted on implementation”.

With respect to tailings closure, the accompanying Towards Zero Harm compendium (Global Tailings Review 2020b) states that “good practice tailings closure development and design starts during the initial stages of the mine development programme, when decisions are made about site selection and tailings management”. To achieve this, a three-stage process is recommended which consists of:

- developing closure criteria
- identifying alternative technologies
- community engagement.

It is likely no coincidence that this process is closely aligned with the recommended approach for carrying out an MAA for a new TSF which is discussed further in this paper.

This sentiment is echoed in the International Council on Mining & Metals Tailings Management: Good Practice Guide (ICMM 2021), which recommends “the closure plan and objectives should be considered in the MMA conducted during the Project Conception phase of the tailings facility and should be a key consideration in the facility design and location, and in the technology decisions of the facility”.

2.2 Overview of the multi-criteria alternatives analysis process

For identifying a new TSF, the MAA process can be used to comparatively evaluate a set of potential alternatives (analogous to options for a new TSF) which are combinations of tailings technologies (e.g. thickening, filtration, classification, etc.) and facility locations (e.g. surface TSFs, mine void backfilling, etc.).

The MAA process is typically centred around a ledger comprising a set of objectives (or desirable attributes) which the ideal solution should be able to attain. Following the Government of Canada (2025) Guidelines for the Assessment of Alternatives for Mine Waste Disposal, the development of objectives for the ledger is typically grouped into three accounts:

1. Technical considerations – focusing on characterising and comparing the engineered elements of each alternative.
2. Environmental considerations – focusing on characterising positive and negative impacts to the environment surrounding each alternative.
3. Socio (or socio-economic) considerations – focusing on each alternative’s positive and negative impacts to local/ regional/national land users or other impacted stakeholders.

For each objective, one or more measurement criteria must be defined that can be used to gauge the attainment of a given objective. A focus on quantitative measurement criteria is preferred to mitigate against bias in the decision-making process; however, the use of qualitative measurement criteria is often required.

Design work is undertaken to characterise each alternative and generate inputs to the measurement of objective attainment. Each objective should be assigned a weighting by project stakeholders to reflect the relative importance to the success of the project.

For each *objective*, measurement criteria representing a scoring range (typically a six-point best-to-worst [6-to-1] scale is used) must be defined to allow for assessment of how well an alternative attains the relevant objective. The scoring and weighting are used to generate an overall score for each alternative within each account and in total. These scores are used to assess and rank alternatives to assist in selection of the preferred tailings management solution, as illustrated in Figure 1.

Objective		Scoring Criteria (Low to High)						Alternative Score			MAA Score								
Objective Description	Objective Weighting	1	2	3	4	5	6	Alt. 1	Alt. 2	Alt. 3	Alt. 1	Alt. 2	Alt. 3						
Account 1 - Technical		Qualitative or quantitative description developed based on characterisation of Alternatives																	
Minimise/Maximise...	5													3	4	5	15	20	25
Minimise/Maximise...	7													4	2	4	28	14	28
Minimise/Maximise...	8													1	3	5	8	24	40
Account 2 – Environmental																			
Minimise/Maximise...	3													5	4	3	15	12	9
Minimise/Maximise...	6													1	2	4	6	12	24
Minimise/Maximise...	2													3	2	1	6	4	2
Account 3 – Social																			
Minimise/Maximise...	9													4	3	3	36	27	27
Minimise/Maximise...	10							2	3	4	20	30	40						
Total MAA Score											134	143	195						
Rank											3	2	1						

$$Total\ MAA\ Score = \sum (Objective\ Weighting \times Alternative\ Score)$$

Figure 1 Illustrative example of a multi-criteria alternatives analysis (MMA) ledger

Project economics can be included as a separate account with its own objectives during this step or simply presented as a total estimated cost for each alternative. In the authors' experience, performing the MAA first, based only on technical, environmental and social considerations, and then introducing the cost estimate afterwards is a good approach to reduce biasing the discussions towards the lowest-cost alternative.

The process outlined above can theoretically be carried out with limited interaction between the MAA facilitator and the client; however, the importance of stakeholder engagement cannot be understated in developing a site-specific, credible and useful MAA. The stakeholder group should be as diverse as practicable to ensure relevant viewpoints covering all design criteria, accounts and objectives are well represented. Figure 2 highlights the key structured stakeholder engagement and decision approach used to progress the MAA. This approach aims to build consensus among key stakeholders and to support defensible, risk-based decision-making for a preferred tailings management solution.

Further detail on a general approach to carrying out an MAA for a new TSF and with specific consideration for TSF closure solutions is presented in Penman & Casey (2023) and Sanders et al. (2019), respectively.

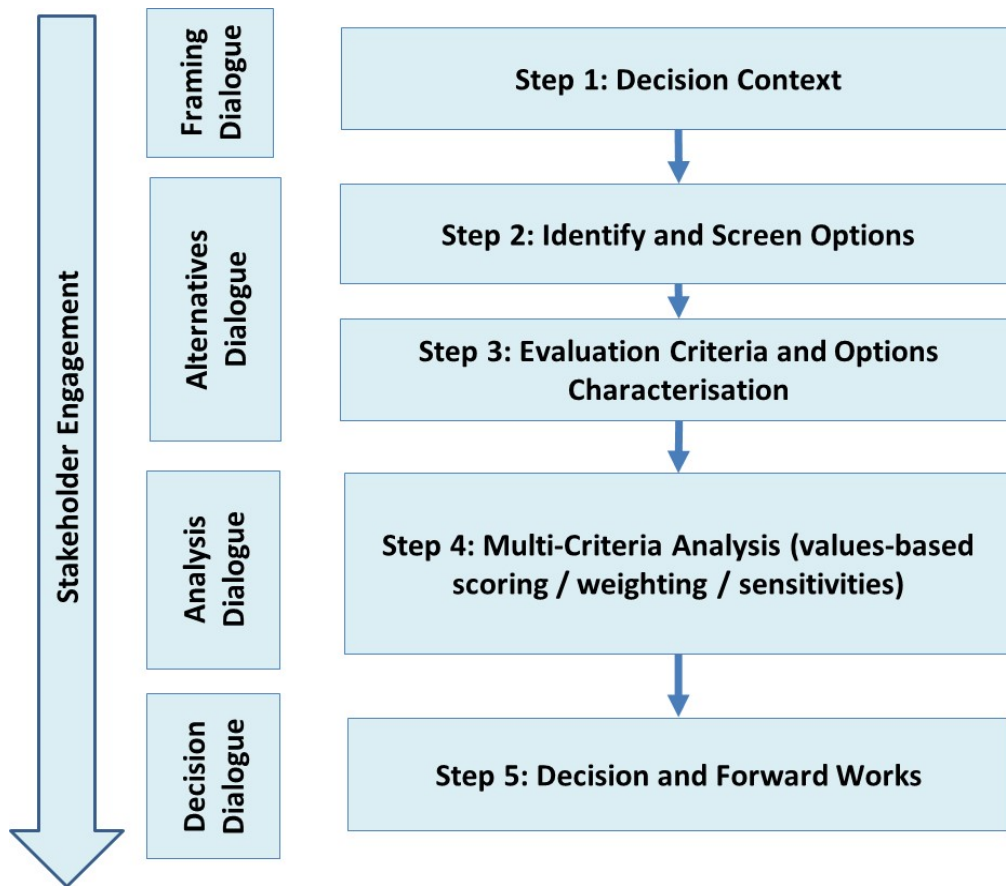


Figure 2 Example of a structured decision assessment process to support the multi-criteria alternatives analysis

3 Closed facility failure modes

For a new TSF option to effectively address safe closure considerations, the selection process should consider the potential failure modes of a closed facility. These failure modes should be reflected, either explicitly or implicitly, in the MAA framework. Ideally, these failure modes would be informed by several closure planning elements including the knowledge base, closure vision/future land use, design basis and risk assessment. However, for most new TSF projects there will be limited potential for a meaningful risk assessment process to be carried out.

In this context, it may be appropriate to consider broad key strategic objectives that support safe and responsible TSF closure based on general focus areas. Utilising these objectives and strategic value drivers, potential evaluation criteria, indicators and success criteria can be developed for closure-focused solutions. Table 1 summarises potential criteria that may be used to inform the MAA ledger for a new TSF, which is discussed further in Section 4. Of particular usefulness are the identified material risks which support development of appropriate objectives.

Table 1 Example safe closure objective indicators and supporting completion criteria used to inform a multi-criteria alternatives analysis ledger

Technical focus	Attribute/performance indicator	Material risks ¹	Material risk critical controls	Example design criteria	Completion criteria reference ²	Example completion criteria to demonstrate 'safe closure' ³
Physical-geotechnical	Tailings runout/flowability	Static- and seismic-induced liquefaction of foundations or embankments Internal erosion	Site selection Embankments designed to industry-standard criteria	Peak undrained FOS > 1.5 Post-liquefaction FOS > 1.1 or deformations that might occur because of liquefaction must meet acceptable criteria	ANCOLD, CDA, ICOLD, etc. Professional judgment by EoR and ITRB	The landforms are performing in accordance with the final approved detailed designed intent and are physically stable, considering: Potential for flow failure beyond the immediate bounds of the facility cannot travel and impact people, property or protected environmental/cultural values Phreatic levels within the impounded tailings not increasing above agreed trigger levels No reduction in strength parameters over time No internal erosion that leads to a material impact
Physical-hyrotechnical	Flood routing and drainage	Overtopping of impoundment facility leading to loss of containment Erosion of embankment toe	Surface water routing design (ditches, spillways, etc.) Long-term settlement considered in drainage design	PMF for drainage channels	ANCOLD, CDA, ICOLD, etc.	Flood routing meets design criteria and functions as intended Cover, cover slopes and drainage prevent permanent ponding of water on the surface
	Landform erosion	Erosion and landform evolution	Final landform configuration/drainage plan and cover material selection	200-year peak precipitation event for embankment slopes	ANCOLD, CDA, ICOLD, etc. Professional judgment by EoR and ITRB Analogue sites Field trials	No erosion resulting in material impact including loss of containment (for example, gully depths < 2 m). Long-term maximum erosion rates from the final landform are ≤ 10 t/ha/yr and long-term average rates are of ≤ 5 t/ha/yr

Technical focus	Attribute/performance indicator	Material risks ¹	Material risk critical controls	Example design criteria	Completion criteria reference ²	Example completion criteria to demonstrate 'safe closure' ³
Source-pathway-receptors	Groundwater flow and quality	Material impact to groundwater users Material impact to environmental values including groundwater-dependent ecosystems	Site selection Geochemistry source control Cover design	Agreed groundwater/wetland levels and groundwater quality criteria at defined downgradient receptors	Environmental permit Established water quality guidelines	Analytes of concern below background levels or ANZECC guideline levels Groundwater recharge less than the drawdown rate in deposit
	Surface water flow and quality	Material impact to downstream surface water users	Site selection Geochemistry source control Closure cover design	Agreed surface water quality criteria at discharge location	Environmental permit Established water quality guidelines	Spillway discharge and run-off water quality within levels to be determined via studies Surface water flows as per closure strategy without permanent ponding in conveyance structures or within infiltration basins
Land use/social	Inability to achieve agreed PMLU	Long-term maintenance of landform	Final landform design Growth medium sources and quality Revegetation strategy to support PMLU	Determined through technical studies	Analogue sites Field trials	No long-term material maintenance required Agreed stakeholder PMLU achieved

EoR = Engineer of Record; FOS = Factor of Safety; PMF = probable maximum flood; ANZECC = Australian and New Zealand Environment and Conservation Council; PMLU = post-mining land use. Notes: ¹ Materials risks summarised, however, requires formal risk assessment to determine potential failure modes and level of materiality; ² Reference may include baseline, analogue, industry practice, professional judgment. The basis for the criteria should be stated; ³ Expected duration to assess performance against is defined in the closure monitoring and maintenance plan.

4 Integrating 'safe closure' into a new tailings storage facility option selection

4.1 General approach

Safe closure does not necessarily equal responsible closure or guarantee dam declassification/relinquishment and does not guarantee complete risk transfer in the event of a future failure. Rather, safe closure should demonstrate that no credible failure mode/scenario with material risk to people or the environment exists, and illustrate the effort made to achieve As Low as Reasonably Practicable and reduce the overall residual risk of the asset. Ongoing residual risk is expected long-term; however, there should be no material risks remaining.

For early-stage projects it may be impractical to identify and quantify all facility-specific material risks when considering options for a new TSF; however, it is possible to give due weight to choosing an alternative that mitigates potential risks using the MAA process. In the authors' experience, integrating safe closure concepts can be achieved through ensuring that the agreed set of MAA framework objectives include some consideration of relevant material risks.

Rather than explicitly addressing the failure mode (which may be impractical to do with limited design completed), failure mode material risks can be addressed through considering fundamental risk factors and potential mitigations. Using this approach, it is likely that some objectives will be able to implicitly consider the potential impact for multiple material risks, further supporting a positive outcome.

In the case of physical failure modes, this could include risk factors such as known weak foundation geology, total stress imposed on foundations or external catchment size. Examples of this being applied in previous MAA frameworks include objectives to minimise:

- exposure to significant foundations defects (e.g. known faults)
- overall landform height
- an external catchment area that cannot be diverted.

In the case of source-pathway-receptor failure modes, this could include risk factors such as the potential for acid-metalliferous drainage and downstream interception, or proximity to sensitive receptors. Examples of this being applied in previous MAA frameworks include objectives to:

- minimise the tailings oxidation potential
- maximise the potential to capture fugitive discharge (seepage, sediment)
- maximise the distance from sensitive aquatic receptors.

In the case of post-mining land use failure modes, this could include risk factors such as the potential for loss of local populations (that could re-use the land) or the ability to support rehabilitation. Examples of this being applied in previous MAA frameworks include objectives to minimise the:

- loss of high-value land
- impact on environmental flows in downstream rivers
- run-off water quality and sediment risks.

4.2 Case studies

Table 2 presents the outcomes from five case studies used to support assessing the MAA process effectiveness in considering safe closure. The case studies cover a range of physio-graphic settings, commodity types and project life cycle stages.

Table 2 Summary of case studies for multi-criteria alternatives analysis application

	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5
Location	Australia	United States	Australia	Tanzania	Australia
Commodity	Iron ore	Copper	Lithium	Gold	Copper
Project stage	Operating	Proposed	Proposed	Operating	Proposed
Target tailings capacity	200+ Mt	450+ Mt	100+ Mt	40+ Mt	300+ Mt
Locations considered	4	3	5	8	4
Alternatives considered	5	11	9	16	10
Outcome with all objectives considered:					
Total number of objectives	17	19	21	30	21
Average objective weighting ¹	6.6	6.1	6.6	6.5	7.1
Top-ranked alternative (all objectives considered)	Thickened slurry tailings. Backfill of open pit at Location 1	Filtered tailings. Valley-Fill TSF at Location 1	Filtered tailings. Valley-Fill TSF at Location 4	Thickened slurry tailings. Backfill of open pit at Location 8	Filtered tailings. Valley-Fill TSF at Location 2
Outcome with only 'safe closure' linked objectives considered:					
Total number of objectives	5 (29%)	8 (42%)	7 (33%)	8 (26%)	7 (33%)
Average objective weighting ¹	6.8	6.4	6.6	7.2	8.0
Top-ranked alternative (safe closure objectives only)	Filtered slurry tailings. Backfill of open pit void at Location 1	Filtered tailings. Valley-Fill TSF at Location 1	Filtered tailings. Valley-Fill TSF at Location 4	Filtered tailings. Open pit backfill at Location 8	Filtered tailings. Valley-Fill TSF at Location 1

¹ The MAA process involves stakeholders assigning a weighting (from 1 [very low] to 10 [very high]) of 'importance' to the overall success of the project for each criteria.

In general, the top-ranked alternatives intuitively meet general expectations for a TSF that could achieve a ‘safe closure’ state, i.e. below ground storage and/or ‘dry’ tailings placement. The outcomes of the case studies summarised above indicate the following:

1. The objectives that can be directly linked to considering safe closure make up a significant portion of the total objectives ranging from 26 to 42% but do not represent the majority of objectives, which were dominated by objectives related to facility construction and operation.
2. In almost all cases (four out of five), the stakeholders assessed that attaining the closure-linked objectives was generally more important (as determined from average weighting) than meeting the full set of objectives. This result shows that stakeholders in general are supportive of considering safe closure when selecting a new TSF.

In most cases (three out of five), the top ranked alternative when considering all the objectives was also the top-ranked alternative when considering the safe closure-linked objectives only; noting that where the outcome differed, the storage solution (i.e. backfilling an open pit void) inherently presents lower material risks for safe closure. This result shows that the MAA process is effective at identifying alternatives that are more likely to support achieving safe closure.

Notwithstanding the apparent effectiveness of the MAA framework in identifying solutions supporting safe closure, in most cases (four out of five) the top-ranked alternative was not selected as the preferred Alternative. Instead, the selected preferred alternative in these cases used a thickened slurry tailings with further processing in some cases, e.g. hydrocyclone classification. This outcome was primarily driven by the assessed capital and operating costs for filtration which – in the stakeholders’ opinion – were not offset by the assessed closure cost savings and mitigation of material risks. This result indicates that the cost-benefit equation for filtered tailings versus thickened tailings during the closure and post-closure phases requires further support. The true costs of closure are often missed or devalued during early project stages, thus a focus on long-term residual risk is a priority.

5 Conclusion

The multi-criteria alternatives analysis (MAA) framework is assessed to be effective at identifying new tailings storage facility options that are more likely to support safe closure relative to other options. This result is achieved through ensuring that the objectives used to develop the MAA framework have linkages to material risks associated with closure failure modes.

Although the MAA framework is considered effective at addressing safe closure, there remains an industry bias against options with high capital and operating costs, even if they are likely to present the lowest closure risk profile. Uncertainty at the project conception stage in projecting closure costs associated with effectively addressing material risks for an alternative with a potentially higher risk profile further hinders the preferred option selection process.

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