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Using decision science to build trust in mine closure decisions

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Abstract

In today's changing social and environmental landscape, society requires organizations to shift to an ever-evolving world of 'tell me what you are doing', through to 'show me what impact you are having', and now to 'involve me in your work'. With public trust in mining at an all-time low globally (Dhawan 2023), decision transparency involving competing objectives and unavoidable trade-offs can help build trust with interest groups, titleholders, and regulators in mine closure decisions. For years, the multiple accounts analysis decision science tool has been widely adopted for tailings site management (ECCC 2016) and closure objective trade-off evaluation. Mine closure professionals may not be fully aware of how a broader decision science approach may be used to provide clarity and confidence for the complex decision-making required in mine closures.

Decision science offers a structured approach to integrate and weigh multiple perspectives on objectives, risks, trade-offs, and preferences, that supports efficient mine closure planning. Breaking complex decisions down using logical frameworks with a structured and transparent approach helps people gain a common understanding, so that they can identify and discuss objectives. It exposes options across competing objectives at the core of difficult decisions. In contrast to other approaches such as gut feel and 'we've always done it this way', it addresses multiple objective trade-offs directly. It is a conceptually intuitive and easily applied approach. An intentional shift to structured, logical thinking provides confidence and clarity resulting in higher efficiency projects, cost savings, and a significant reduction in re-work.

A decision science approach includes: (1) front end facilitation to frame the decision or decision series, (2) assessment of the project objectives including potentially conflicting desires of internal or external interest groups, (3) divergent creative thinking to identify new alternatives that better fulfill the prioritized objectives, (4) qualitative and quantitative analysis to assess and contrast alternatives based on how well they fulfill desired objectives, (5) threat identification and uncertainty management aspects that will flow into the project management and execution phase of the closure.

A healthy decision culture, where teams and decision-makers foster a culture of inquiry instead of advocacy allows people embrace creative conflict and curiosity around differing values and objective trade-offs. This results in a shared understanding, identifies superior alternatives, reduces risk, and accelerates project development. Our industry can benefit from adopting a decision science approach to the many important, complex decisions we all face, as we work to increase efficiency, reduce cost, and build trust in mine closure decisions.

Keywords: *decision science, decision quality, decision analysis, structured decision making, project management, engagement*

1 Introduction

Decision science is a field of research and practice that focuses on decision making. The field consists of theories, frameworks, and tools for informing decisions (Kleindorfer 1993; Keeney 1982; Howard 1966) that has been well developed over the last half a century; however, terminology and definitions have not been standardized. The original term used to describe the field was 'Decision Analysis'. We use the term 'decision science', but other terms refer to the same field (Decision Quality, Structured Decision Making, Decision Support, Integrated Decision Management, Decision Intelligence). The key attribute of a decision science approach is that it has a qualitative objective assessment and framing phase (decision framing), and a qualitative and/or quantitative assessment phase prior to implementation (decision evaluation). While these tools and processes are conceptually intuitive, they are rarely applied with rigour because of individual cognitive biases and mental short-cuts and organizational factors. This approach is similar and complementary to approaches used in continuous improvement, change management, and risk analysis.

To be clear, the decision science approach does not make decisions for you, it provides a structured approach to support decisions. It is not a calculation. It does not replace critical thinking, professional knowledge/input, or usurp decision-making authority. It is used to provide clarity and confidence that the chosen decision paths are valid, reliable, and offer the best opportunity to achieve required objectives in the most efficient and value additive/preserving manner possible. Decision science provides a structured approach to decision making and strategy formulation as outlined in Figure 1.

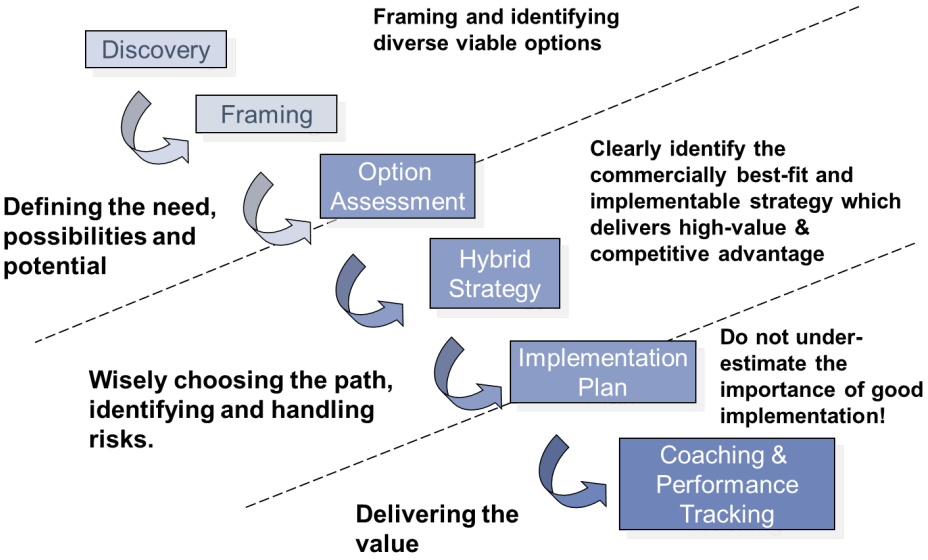


Figure 1 Phased approach to decision science/support (adapted from Haskett & Leach, 2009)

Within this phased approach, decision science provides principles for defining a good decision *at the time it is made*. A decision science approach is not a 'checkbox' or 'cookbook', where you step sequentially and linearly through the process. Rather, a decision science approach should be a support model that is scalable and adaptable to the organizational culture. People should not be overly anchored on the decision process itself. The objective is to help people come to a confident, quality decision, and to help people create coherent strategies within which quality decision may be made. It should not force people to follow a detailed process or to take away choices from decision-makers. A decision process needs to be driven by the support decision-makers want on a decision problem. It must deal with the material elements, on a timeline which provides validity and reliability to inform the decision problem. The process is generally sequential. It can be iterative and can be visualized as an interconnected ecosystem of tools which support an overall goal of a quality decision.

Tip: Adhere to the principles of the approach, use decision tools as needed, but always keep in mind that materiality matters. Don't use a scalpel if an axe will do. Don't use an axe if a scalpel creates value.

Decision science approaches have been widely adopted in the energy, pharmaceutical, and high-tech sectors to inform investment decisions of billions of dollars (Neal 2010). The energy sector, as with mining, is a high-risk, high-uncertainty, and capital-intensive business. In mine closure, we face similar challenges as energy sector. We need to be good stewards of capital, as well as incorporate multiple objectives for project decisions. A decision science approach provides solutions. Through the following sections, our intent is to increase awareness and adoption of a decision science approach in mining. While it is impossible to provide a full field-guide on the topic, we encourage the reader to explore decision science via the numerous citations. While we discuss application of the concepts to decisions and decision sets, recognize that the decision science/support process also applies to the Project Management and Risk Management fields.

2 Overview of decision-centered effort

When applying a phased approach as outlined in Figure 1, there are a few high-level steps that are taken. The overriding concept is that all work done within a project is either work to inform a decision or work to implement a decision. Work unrelated to a decision has a very high probability of having no value. Effort needs to be 'decision-centric'.

A decision-centric approach to projects and strategy development involves a structured approach to the strategy or decision problem being faced. Taking a very high-level approach, the following are generally considered to be the basic steps to carry out decision support in any industry. Note that the process is scalable. While there is a general order, the amount of effort in each step will vary.

Step 1 – Understand the Context of the project, including what is within and outside of scope, the business setting, and identify the internal and external interest groups.

Step 2 – Identify the objectives the project needs to achieve as well as the objectives that would be desirable to achieve. For each objective identify what needs to be achieved to enable it. This is incredibly important yet seldom considered outside of a coherent decision support process. Having a broad understanding of the minimum acceptable objective fulfillment across the range of project interested/affected groups is essential. Not all project objectives will be equal, and some will conflict with other objectives. This will be where Objective preference and trade-off discussions come to the fore.

Step 3 – Identify the material decisions to be made during the project. While 'material' is a fuzzy term and we know that materiality of specific decisions will change as the project progresses, it is important to start out with the decisions that would change the overall direction or flavour of the project. To help you sort out what matters, ask three questions. If any are in the affirmative, the decision is treated as material.

a. Does this decision make a difference to the overall project?
b. Does this decision have to be made now?
c. Does the decision we make now eliminate options, capabilities, or competitive advantage later?

Step 4 – Itemize the potential solution paths for each material decision.

Step 5 – Identify the potential solution pathways through your series of decisions. Even a relatively small number of decisions with a relatively small number of solutions can be overwhelming if not handled 'objectively'. Five decisions with five solutions each creates 3125 potential combinations: an infeasible situation for any hope of efficient solution and would lead to analysis paralysis. One should identify coherent feasible pathways through the potential solutions that achieve different 'Flavors' (combinations of prioritized project objectives). For example, prioritizing cost saving will create one set of decision solutions, prioritizing

ease of permitting or fastest closure would create two other pathways. These objective prioritized pathways are called 'Themes'.

Step 6 – Assess each theme **Qualitatively**, examining the pros/cons, consequences, trade-offs, and the conditions that would have to exist to make a particular theme the absolute best and worst choice. This allows you to produce preferred options without the contamination of numerical anchoring or 'construction' bias.

Construction Bias: A bias that narrows the 'allowable' ideas based on a strongly desired decision choice. This bias usually originates from the piecing together of individual uncertainty events, usually by people who 'just know what is going to happen' and used to invalidly support a solution.

Step 7- Concentrating on the best qualitative solutions, perform standard **Quantitative** assessment (as per company / corporate requirements). Always be willing to incorporate excellent solution discoveries from unused themes, creating a 'Hybrid' theme.

Step 8 – Assure Objective fulfilment as the implementation plan is created.

3 Complexity of mine closure decisions

Mine closure projects are different from typical mine planning and operating projects because there is usually no foreseeable revenue. Mine closure investments support acceptance and approval of mining by government, local communities, and the broader society (license to operate). License to operate a mine, develop a new mine or expand an existing mine can lead to very large economic returns, but obtaining license to operate is complex and multi-dimensional, and as a result, contributes to the complexity of mine closure decisions. An added complexity is that closure practitioners are required to apply current values on a landscape defined by past values, which were often determined by more narrow economic objectives.

Why are mine closure decisions so complex on today's social, environmental, and cultural landscape? Consider these issues: (ICMM 2019):

- Has our engagement with external interest groups on post-closure land use been sufficient to allow meaningful feedback to be included in closure plan?
- Is our physical, environmental, social/socioeconomic, and regulatory knowledge base sufficient to develop a closure plan?
- Does our assessment of risks and opportunities adequately capture the categories of risk that are important to the mining company and Communities of Interest?
- Does our closure plan, inclusive of external input, align with our corporate values?(Davies 2023)

These types of decisions require careful planning, collaboration with interest groups, titleholders and regulators. They require cross-functional earth science, social science, and engineering teams They must also include traditional knowledge holders to integrate economic, environmental, social, and cultural objectives into decision making for closure. Process knowledge and facilitation skill can help groups listen, understand, and integrate different perspectives.

The organizational setting adds further complexity (McNamee 2008; Skinner 2001) because:

1. The decision problem is often not well defined.
2. Decision may be delegated to the extent they require cooperation of multiple decision makers.
3. The complexity of decision sets requires cross-functional teams who may not fully understand, trust, or agree with information developed by other teams or members outside the organization.

Even after a decision is made, implementation may be an issue due to a lack of resources, a lack of understanding, recycling of poorly communicated decisions, or lack of implementation team commitment

due to a flawed/failed decision process. The concentration of decision-making within a small group of people, who may be time constrained, distant from the decision work, and therefore more susceptible to cognitive biases, and mental short-cuts (see below for examples and further detail) clutters the process. While your organization may or may not face such complexities, being aware of these added challenges is beneficial as it can enable you to spot and minimize their threat to decision quality.

Mine closure decisions typically involve a mix of high organizational and analytical complexity combined with high levels of uncertainty. As such, involving the right people and including the right content to inform a decision from the start of a project is essential (Figure 2).

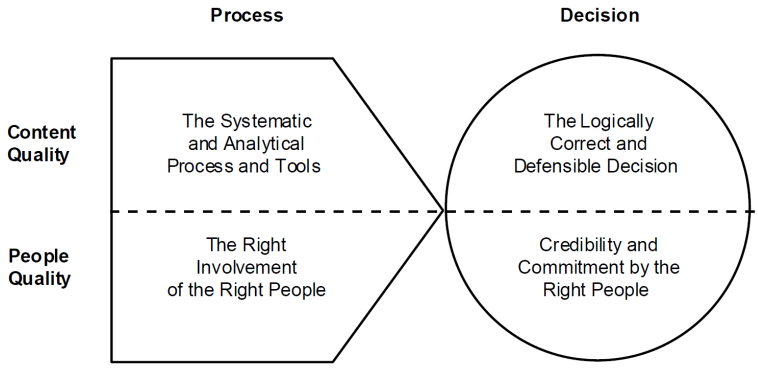


Figure 2 When facing a decision considering both the content quality and people both contribute to making an informed decision (McNamee 2008)

Almost always you will be dealing with a series of decisions. Complexity increases with the number of decisions, especially when the decisions are partially or fully dependent, or when uncertainties may be correlated. The decision pathway chosen will tend to support a particular key objective such as low cost, easiest to do, or least risk. Competing objectives become more apparent when people assess differences in decision pathways as opposed to decisions held in isolation. We must remember that the project outcome is the result of many decisions. That complexity is amplified by a plethora of threats and uncertainties (internal and external) within each decision path. Identifying and prioritizing material threats and uncertainties is important. Decision-focused assessment helps to manage uncertainty and inform decision-makers of the probability and consequences of making a regrettable choice. Assessing the value of reducing different uncertainties is valuable exercise.

In closure project planning and execution, we are faced with many issues, threats, and opportunities. Adopting a decision science approach in conjunction with the application of closure planning stage gates (i.e., gather information, select best option, project definition, decommissioning and handover, post closure management) enables organizations to take a more agile and informed approach. Increasing transparency in decision-making applied as part of closure stage gate governance will also help Communities of Interest reach a common understanding and acceptance of a coherent project plan, ultimately reducing completion time.

4 Managing the complexity and risks of mine closure decisions

Gregory (2002) notes a structured approach using modern decision approaches that embraces risk, uncertainty, and probabilities helps inform/enable decision-makers to explore and identify risks and risk tolerance. Only then are they able to make valid and reliable judgments concerning acceptable levels of risk and precaution, and along with line teams, find creative ways to manage residual risk during implementation.

Given that most mine closure projects lack a revenue stream, three elements to rise to the top of concern: cost, efficiency, and risk management. Cost and efficiency tend to be ongoing efforts across the full project domain, but Risk tends to be associated with discrete elements, issues, or threats. As such, risk identification and handling within a decision framework becomes a valuable output from decision support.

Figure 3 illustrates a typical risk response matrix is shown in Figure 3 in the context of Pain (the penalty suffered when a risk event occurs) and Regret (the probability that a risk event will occur). No single risk avenue needs to be preferred and the option chosen will depend on the prioritized objective set of a particular themed option.

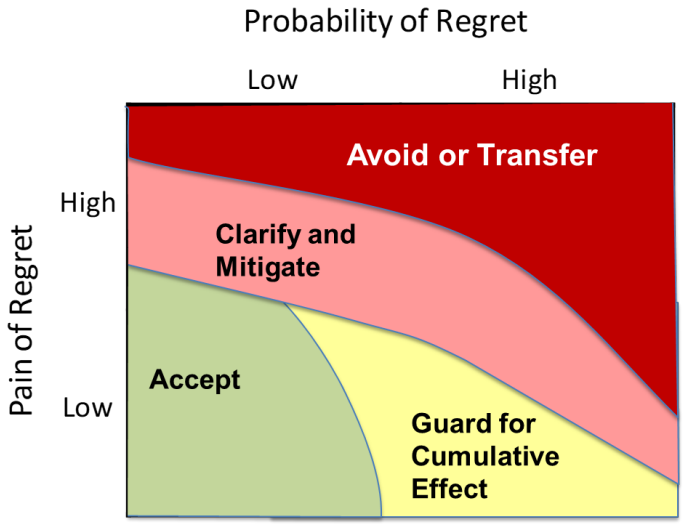


Figure 3 Illustrates common responses to risk management within a context of pain and regret (Haskett 2003)

A decision-centric, objective-based approach to managing project risk decisions uses the four-question approach (Haskett 2021). The four decision-centric questions and the associated decision tools will provide decision-makers with a means to identify, prioritize, and efficiently manage material issues:

1. Does the issue/threat/opportunity make a material difference to a project decision? (Materiality).
2. Can you do anything about it? (Influence) – aspects of Value of Control, Access, and Preservation.
3. Can you afford to do anything about it? (Value) – Value of Information, Value of Control.
4. What if you are wrong? (Confidence) – Threat/penalty asymmetry, Pre-mortem, Root Cause Analysis.

5 Behavioral aspects

Decision science incorporates insights from behavioural science to help us be rational decision-makers. We have two types of thinking for decisions (Kahneman 1982; 2013). Type One is intuitive or automatic. It is quick and operates mostly in our sub-conscious. Type Two is deliberate, reflective, and effortful. It is slower, logical, and requires effort. It is analytical reasoning and has ability override the intuitive Type One. Behavioural science knowledge encourages group-based Type Two thinking reduces bias, and enables better, more reliable project decisions and strategy development.

Corporate environments have always been busy and demanding. Today is no different. It is difficult to override Type One thinking. The effort must be intentional. Valuable ideas are generated from both systems of thinking, but shifting towards Type Two helps avoid the bias of our individual intuition. When faced with a volatile, uncertain, complex, or ambiguous decision landscape, decision science offers a framework to sort and organize decisions to reduce bias, improve options, and gain Community of Interest acceptance. ‘Clarity of decision’ enables us to triage and evaluate cognitive biases and flawed mental shortcuts. Involving decision-makers and decision participants encourages collaboration.

Type One involves generalizations and quickly drawn conclusions. This decision flaw is a primary cause of poor decisions and results in project re-work. A major benefit of a structured decision framework is the likely

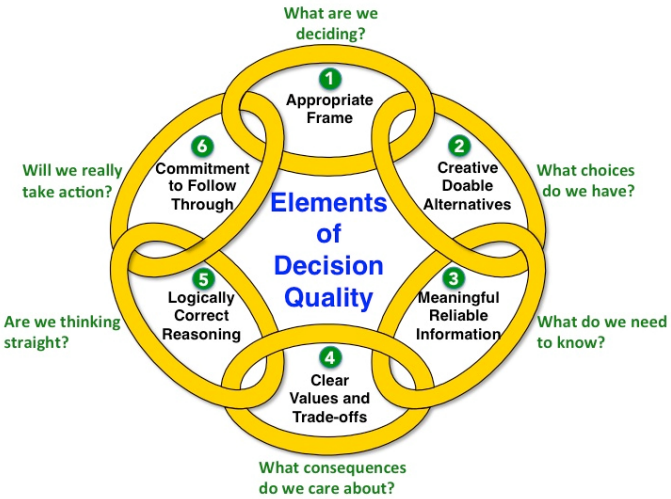
elimination of a significant amount of re-work. The pause to create a decision-centered assessment pays for itself in this aspect alone.

A decision science approach provides a means to separate value judgments from technical judgments, thereby enabling objective trade-off options. This separation helps to simplify judgements and facilitates the participation of all parties to the project, whether they have specific technical expertise or not (Gregory 2023). The process helps people make better, clearer, well-reasoned judgments. Organizations that make transparent decisions and can show a clear prioritization of objectives in a project will build greater trust internally and within the community, thus increasing the likelihood of acceptance by Communities of Interest, regulatory approval, and permitting ease.

6 Decision quality: how to achieve it

We assume by default that a good decision should result in a good outcome, but it's important to recognize that a good decision does not guarantee a good outcome. There is much we do not control in our projects, yet we are obligated to make the best decision possible given our current knowledge. Good decisions increase the likelihood of a good outcome, and even using a few simple tools (Duke 2020) can increase the likelihood of a good outcome. When we put the effort to make and vet a decision, we greatly increase the odds of achieving a desired outcome. We should judge the quality of a decision based on the information available to the decision-makers at the time it was made. In this respect the six elements of decision quality serve as a pathway for a good decision.

In previous sections we have reviewed some of the reasoning behind good decision-making. We will now shift to decision quality and provide a few foundational tools that may be applied immediately to any project. A common model of decision quality is a decision chain with six links (Figure 4). Each link represents an activity in the decision process. Decision quality can be no better than the weakest link. While the specific activity at each link will vary depending on the project and decision being made, the general requirement is consistent. A good decision process needs to be scalable and adapted for the situation at hand. The extent and applicability of a particular decision tool will be dependent on the situation and team/organization culture.



Source: Stanford University Decisions and Ethics Center

Figure 4 Illustration of the decision quality model with six elements of a decision chain and key questions to ask for each link of the decision chain

A decision support model has two parts: decision framing (front end), and decision evaluation (back end). A high-quality front end, including an appropriate frame with creative and doable alternatives, has a strong influence on outcome of the process and therefore of the project. A high-quality evaluation is important but will be of questionable value without good framing as input (Keeney 2020). Good framing helps us see the

material problems to solve and most importantly identifies the important questions we need to ask. Solving the wrong problem provides no value, often resulting in value degradation and rework.

We emphasize that the highest value/lowest effort action you can make to improve the quality of your decisions is to make time for good decision framing. Confidence that your decision is correct is a primary output of decision quality and retains focus on objective fulfillment.

6.1 Decision framing

Decision framing includes the first three elements of a quality decision: appropriate frame, objectives, and creative doable alternatives.

6.1.1 Appropriate frame – establish the scope

Establishing an appropriate frame starts with a discovery phase, where we identify decision context, define the decision problem, gather relevant information, and compile information, data, and insights relevant to the decision at hand. Framing a problem or opportunity as a decision set, recognizing what we are trying to achieve/decide and what we are not trying to decide, will avoid unwarranted assumptions, option-limiting prejudices, and out-of-scope elements (Hammond 1999). Problems and projects are unique. Be flexible. While we are only alluding to a few tools in this document of a few dozen that are available, do not throw every tool you know at every project/decision.

It is generally good to maintain a wide scope. Ask “What are we trying to achieve?”. The more uncertain and ambiguous the project, the more intense the entire decision process will be. In tailings pond water management, a wide scope may include timing, what to do with the water, regional ground water assessment, community and regulatory concerns, and require comprehensive decision modelling work. Reducing scale is appropriate for simpler decisions with lower degrees of uncertainty and ambiguity.

Separate ‘strategic decisions’ (decisions that are important now) from ‘tactical decisions’ (non-material or delayable decisions). While tactical issues will eventually have to be decided, if they aren’t material to the overall ‘flavor’ of the project or must be decided ‘now’, their consideration should be delayed. Understand what has already been decided (e.g., the mine will close, we will develop a plan that we can execute safely, etc.). Complex decisions require framing to identify decision sets needing to be sorted and organized, so that people can prioritize and generate solution pathways. Prioritizing the important decisions removes clutter and eliminates the tactical element distraction. Always work on the decisions that matter most, the material decisions.

6.1.2 Objectives

In defining and structuring a decision problem or it is helpful to clarify what you want to achieve, what values are important and why they are important (Keeney 2020). The closure principles listed by International Committee of Mining and Metals Good Practice Guide (ICMM 2019) may be an appropriate set of elements to articulate as starting-point objectives for framing a closure decision. We often hear “everybody knows what we need to do” but in our experience few teams can express why they need to do a particular activity in a particular way. Providing a common understanding of objectives and objective priorities helps identify and resolve misalignment amongst project team members.

How do you know you have all relevant objectives covered? The best one can do is to be comprehensive and cover all areas of the desired outcome. This can be difficult for technical teams as concentration on their primary focus may obscure other important objectives, especially those of external interest groups. Review your objectives using a tool such as the Objective Influence Model shown in Figure 5.

Centered in the model is the ultimate project intent: to create a coherent and well communicated/accepted strategy/solution to achieve a successful project (using ‘strategy’ as a series of connected decisions and plans that establish or position an entity). The solution is a combination of objectives across several domains.

There are four main Objective 'arenas' in this model.

- **People and Skills** – The appropriate staffing to carry out the closure planning and implementation. Example: Sufficient personnel and expertise to treat the pond water and ensure compliance to at least minimum standards, and project management skill sets to provide appropriate risk and value protection.
- **Factory Efficiency** – The quality and quantity of the product of the project as well as the means to produce it. Example: obtain a water treatment plant to reduce total dissolved solids in outflow to desired level at desired throughput rate.
- **Financial Capability** – The ability of the entity to appropriately fund the project as well as the achieving the resulting benefits (or handling the economic threats). Example: minimize cost, establish long-term debt.
- **Image and Communication** – The 'Social' or external aspects of the project. Level of acceptance, trust, and approval your company has from Communities of Interest, and regulators. Example: End land use of the site and compliance with local community and/or regulatory requirements.

These four arenas exist within the context of Competitive Advantage and the desire to control your own destiny/project. Assess your objectives. Are there any weak or missing arenas?

Three universal characteristics to deal with are Materiality, Access, and Preservation. The objective must matter, the ability to do something about it exists, and it is long-lasting or 'sticky'. Anticipate several objectives in each of the four areas and others to take into account the context considerations.

Figure 5 Illustration of the Haskett Influence Model (Haskett 2021b)

Involve diverse perspectives and recognize external Community of Interest objectives. Cross-functional biological science, earth science, engineering, and project management teams will identify a greater diversity of material objectives than a narrowly focused team. Problem solving tools like asking "why" five times (Ohno 1988) on what is important can be helpful to identify underlying objectives.

So, you now have a collection of objectives. What do you do with them? Sort them into an Objectives Hierarchy (Figure 6). This is a tool that helps clarify fundamental objectives, and sub-objectives so that goals are documented, and there is clarity on what each objective means. We recommend starting at the top, primary objective (e.g., 'Efficient Mine Closure'). The next line will have the objectives that are required to achieve the primary objective. The 3rd level will be the objectives required to enable the 2nd line, and so on. Continue until you arrive at tactical objectives.

Everyone associated with the project should have a common understanding of the project objectives. This reduces conflict, confusion, and possible indecision.

An important project management element to observe in an Objectives Hierarchy are the 'critical objectives'. A critical objective will likely require additional attention. They are not just the ones you feel are the most

important and may not be the ones occurring most frequently. In the hierarchy look for pinch points (where several lower-level objectives enable a single higher-level objective, or where any objective enables several other objectives. Anticipate enablers and pinch-points to cause concern in the project implementation. Even in the simplified hierarchy shown in Figure 6, it is possible to see enablers and pinch points. Select the material and critical objectives in a representative manner from across the hierarchy. Avoid selecting more than two along the same vertical path if possible. You will use these to score the potential decision solutions of the various alternatives you are evaluating.

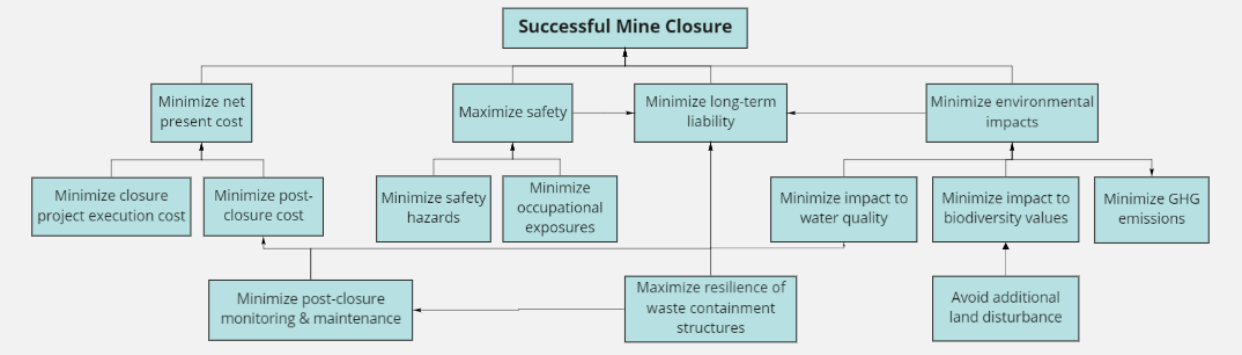


Figure 6 Illustration of a simplified Objectives Hierarchy for a mine closure project

6.1.3 Creative and doable alternatives

Effort spent identifying the best alternative to achieve objectives is a good investment as a decision can only be as good as the best alternative identified (Keeney 2020). Set up your decision set with the possible solutions for each. There are many tools and techniques that encourage identification of creative alternatives. structured brainstorming, scenario planning, game theory, and objective intent exercises are all appropriate given fit to a project. Framing workshops are the standard to facilitate dialogue, especially in cases of diverse perspective, conflicting objectives, and differing priorities. It is important to have experience, neutral facilitation to allow safe, open, and innovative participation. To maximize creativity and divergent thinking, its often best to have people identify prioritized objectives and create alternatives independently, and then share in a group setting. Do not allow the initial solutions or the stronger voices in the room to reduce the quantity or creativity of alternatives identified. If facilitating, be aware of groupthink and other common biases. Stay theme based. For example, what would we choose to do given that cost savings (or safety, or speed of closure, or ease of permitting) reigned supreme? As you work through this process, you may identify new objectives, and, possible adjust your decision frame, as more information and perspectives and input from people is integrated. This process is referred to as value focused thinking (Keeney 2020).

Complexity reducing tip – Evaluate decision options by how they fulfill critical and the most demanding objectives. As with decision pathways, avoid 'getting into the weeds'. Analysis paralysis should be avoided.

Divergent thinking can feel chaotic and messy as people work through the process of defining an appropriate frame and doable alternatives. It is a good idea to warn people ahead of time that this step may feel messy, but clarity will follow. Good facilitation of the process is required to stay on track and out of the weeds. This is followed by a structured convergent thinking processes to sort and prioritize objectives and score the alternative themes for their ability to fulfill objectives. New alternatives, which may be more creative and better able to meet multiple objectives are a frequent by-product of good workshop facilitation. The ultimate solution will usually be of a hybrid theme of alternatives where good individual decision solutions are combined with the best theme, but that usually doesn't happen until after the initial themes have been evaluated.

6.2 Decision (theme) evaluation

Decision evaluation includes three elements of a quality decision (relevant and reliable information, clear values and trade-offs, and sound reasoning). Once themes have been created, we do the qualitative evaluation. We look at how each fulfills our evaluation objectives. The pros and cons and the external conditions that, if existed, would make each individual theme the best or worst choice. Quantitative methods are important, but they should occur after we have progressed qualitative efforts as far as we can. Once numbers show up, thinking becomes anchored. Your creative divergent process is compromised. The focus shifts to incremental improvement of the numbers, which almost always leads to a suboptimal decision.

Using qualitative evaluation methods provides the initial screening for non-numerical objective fulfillment (i.e., social, environmental, and cultural value). One approach to valuing intangibles, is setting minimum acceptable objective fulfillment criteria during decision framing (the point below which the solution would be rejected). Additionally, effective qualitative analysis decreases the amount of quantitative 'churning' needed as the material uncertainties may be identified. Sometimes, the decision path is obvious, and no quantitative assessment is needed apart from that required by the corporate resource allocation system. Remember, decision support is scaled to fit a given decision.

Decision evaluation tools and approaches (Skinner 2001; Leach 2014; Clemen 2014; Hollmann 2016) often focus on economic values (net present value or economic value added). That said, identification of heuristic performance measures can be developed and adapted to enable integration of social, environmental, and cultural values. These in turn can provide qualitative and quantitative measures of value to inform decisions with multiple dimensions of value.

6.2.1 Relevant and reliable information

We need relevant and reliable information as inputs to validate the decision frame and estimate consequences. Good decision science-based decision support identifies the material issues and enables preferential allocation of scarce resource (people, time, capital) to them. Information reduces uncertainty and connects what we can do (alternatives) to what we want (objectives).

The default to seek more data, without assessing if that new information is likely to help us make a decision is a common flawed practice. Tools such as the Value of Information assessment (Clemen 2013, Bratvold *et al* 2009, Leach 2014) can be partnered with a Value of Control assessment (Skinner 2001) to provide an indication of value-adding could occur. Value of Information will help quantify the value of new information for an uncertainty/issue/threat (question #3 from section 4: Is it worth doing anything about?). The assessment helps determine if new information is worth the effort involved focuses attention on what really matters. This saves time and money while allocating scarce resource on what matters most.

Value of information – the value contributed to the project by obtaining new information that is pertinent to a decision uncertainty. We are learning about an uncertainty. *Example: a multi-well drilling program to determine the regional permeability of an aquifer.*

Value of Control – the value contributed to a project by controlling an uncertainty. *Example: establishing a fixed rate contract for installation of multiple groundwater wells.*

Other decision science tools such as decision trees, tornado diagrams, contribution to variance, and stochastic simulation rely on quantification of the range of possible outcomes as inputs to the decision model. These tools quantify underlying threats in a decision model enabling a focus on the most material uncertainties requiring management. Subject matter experts are important as they provide uncertainty estimates for critical inputs and risk outcomes given threat events occur. Characterizing uncertainty and identifying threats is a critical aspect of decision management and contingency planning. Tools such as pre-mortem analysis (described section 6.2.2) can help to identify more creative ways to manage residual risk during implementation, and in turn support better risk management.

6.2.2 Clear values and trade-offs

In decision science, your 'Values' for a decision are the context of what you want to achieve, while an objective is a tactic to achieve an outcome in the context of a value. For example, 'caring for the land' is a value, while 'minimizing environmental degradation' is an objective. Mine closure decisions involve multiple parties with different values. Expect conflicting objectives. Typically, values are givens. You are required to achieve them. Objectives may be prioritized. Fulfilling one may degrade another (i.e., trade-offs are possible).

Multiple Account Analysis is one decision science tool we have used to assess objective trade-offs. There are other tools to support decision-makers, including:

Decision Model – A probabilistic, quantitative model, usually but not necessarily spreadsheet based, that can simulate the project and comparing/testing a series of decisions. It assesses several different alternative pathways based on the themes created during framing.

- Six Thinking Hats (De Bono 1999), where teams evaluate and discuss a decision with six different assigned viewpoints to encourage creative divergent thinking on complex problems.
- Value-Ease Matrix or Difficulty-Importance matrix, where teams graphically plot tasks to help assess and prioritize tasks, actions and projects given materiality and Value of Information .
- Strategy Table, where theme decision pathways are plotted.
- Strategy Tree, a probability tree approach that maps uncertainties to optimal solutions including the probability of using a specific solution, thus reducing work to flesh out low probability outcomes.
- Pre-mortems, an exercise that identify risks by creating a mindset of 5-10 years into the future recognizing the project as an utter failure. Given failure certainty, what were the proximate and causative aspects that created failure?
- Indifference Assessment, establishing under what conditions your decision path would change (Haskett 2023)

These decision science tools sort objective complexity and exposes choices and ramifications between competing objectives, enabling decision-makers to make judgements for the project given the objectives. Discussing different solution priorities, where they are optimal, and their inherent threats provides context, clarity, and confidence. Understanding the decision context contributes greatly to acceptance and communication of the ultimate action plan. Building on the best theme, a hybrid solution is developed that takes advantage of the best elements from the lesser themes. From the beginning, decision-makers and teams should be clear on objective preference. This allows an optimal decision path to be found early.

Today's social and environmentally oriented closure decision climate sees objectives go beyond direct economic cost or benefit. Intangibles such as organization reputation, regulatory assurance, Community of Interest and titleholder trust, are not easily measured or well defined but are often critical enabling or pinch-point objectives. Measuring intangibles to support multiple objective trade-offs between economic objectives and environmental or social values can be developed and used to assess how well a given alternative achieves an objective (Hubbard 2014; Gregory 2012). Objective trade-off in biodiversity conservation as discussed by Hemming (2021) provides further insights on this application.

Mine closure decisions typically affect multiple groups. For example, as we work with Communities of Interest to co-create a long-term, overarching, and site-specific closure vision, we should use a decision science approach that incorporates the values and objectives of all parties. A collaborative outcome is impossible without it. A decision-centric approach enables this to be done efficiently and supportively. Understanding the plan, especially when it involves new technology or alternatives, is enabled by a good process and destroyed by an inept approach.

6.2.3 Sound reasoning

Reasoning for complex decisions goes well beyond simple objective trade-offs. Making difficult or complex decisions requires people to act in the face of uncertainty.

Probabilistic modelling (e.g., 'Monte Carlo' models) translates uncertainty into a source of potential value (Leach 2014). Influence diagrams help to examine the numerous factors and interconnected aspects that contribute to the value of different alternatives. A common misconception of modelling is that it is schedule and cost risk based. Other elements can be incorporated into a decision model including water treatment and flow, tailings pond management, efficient development, and full project economic simulation. A probabilistic model provides better reasoning than a deterministic models. They are not difficult, especially if it starts with an existing deterministic model.

6.3 Commitment to action (implementation)

There is no effective decision without action. Value is created by action. Involving the people responsible for implementing a decision from the beginning builds common understanding of the ultimate feasible solution. Implementation must be considered from the beginning. There should be team members present in framing who have or will have implementation responsibilities. Whenever implementation issues are likely to surface, have implementation people present. The best laid plans are for nought if they cannot be implemented.

7 Build and maintain trust through decision transparency

Decision science clarifies conflicting objectives and unavoidable trade-offs seen in mine closure. When unavoidable trade-offs are transparent to all, we can find solutions and build a trust in mine closure decisions. Complex technical aspects can provide Communities of Interest and titleholders a common understanding, even given non-technical backgrounds, when those aspects are characterized by how they fulfil objectives people care about.

A common understanding enables Communities of Interest to identify differing priorities in context within the decision frame. As we unravel the complexity of mine closure decisions, we can support collaboration between parties to have informed discussions. Engagement and dialogue are particularly helpful when uncertainty and ambiguity are high. Fostering an atmosphere of inquiry, not advocacy, enables dialogue that creates a shared understanding. In turn, integration of Community of Interest preferences is more easily incorporated into the development and execution plan.

An approach that is fair, transparent, and involves the right people from the beginning reduces bias, improves common understanding, and increases positive outcomes. This is particularly important when collaborating with external parties on decisions where objective conflict is present. A dialog process for a decision takes trust on all parties to increase engagement, encourage better collaboration and improve sound reasoning.

Structuring a decision process to combine engagement and decision evaluation has been successfully completed in developing closure plans and aligns with International Committee of Mining and Metals best practice (Hockley 2010; Bainton, 2018). As organizations move forward adopting recommendations from the United Nations Declaration of the Rights of Indigenous Peoples (United Nations 2007), the tools and approaches offered by decision science are a superb fit. Initiating discussions early with intent to co-create a common understanding can help guide an organization-led Impact Assessment and/or an Indigenous-Led Impact Assessment (Nishima-Miller J. 2022). A decision science approach may be started internally before engaging external interests. This allows teams to anticipate, formulate, or mitigate potentially sensitive conflict to preserve the collaborative process.

Sustainability-related closure objectives handled within a decision-centric approach enables rapid integration within the greater closure plan to avoid, minimize, rehabilitate, and offset impact. Management of closure projects within a portfolio is an additional area where decision-transparency can build and maintain trust with Communities of Interest, titleholders and regulators.

8 Summary

Decision Science is more than a process. It is more than a collection of tools. It is a way of approaching complex projects such as mine closure in a way that frames objectives, illuminates opportunities, assesses material threats, and aids implementation and project management. It reduces recycling of work, minimizes the potential for re-work and helps prioritize resources.

Society expects more transparent judgements which integrate multiple dimensions of social, environmental, and cultural value. Decision science provides companies an approach that can be adapted to embrace societies changed expectations which can help build and maintain trust required co-create the future of mining as our world transitions to a low carbon economy.

Good decisions start with good Framing. Embrace uncertainty and use it as a source of value. While making a good, well-supported decision does not guarantee a desirable outcome, it significantly increases your odds.

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