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A structured decision-making framework for block cave design at Oyu Tolgoi mine

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Abstract

The Hugo North deposit features a staged macroblock and multi-lift block cave design. The upper lift is currently in production, while the lower lift remains at the study stage. As a part of the study, numerous design trade-offs are being considered. Given the distinctive shape, extent of the orebody, geological structures, relative location to the previous lift, and economic factors, there are significant complexities and requirements to satisfy various criteria when making these decisions.

To produce sound and visible decisions on the trade-offs, a decision assessment process has been introduced and implemented, namely the multi-criteria analysis (MCA). The MCA methodology is a systematic and transparent approach, enabling measured comparisons between options within the decision-making process. Relatively similar concepts were used in the previous lift study. This paper focuses on the MCA framework, guidelines and application to several decisions throughout the study work at the Oyu Tolgoi mine.

Keywords: *multi-criteria, block caving, mine design*

1 Introduction

Oyu Tolgoi mine is located in the southern Gobi region of Mongolia (AMC Consultants & Turquoise Hill Resources Ltd 2020). It hosts one of the world's largest high-grade copper deposits. Hugo Dummet or Hugo deposit is the largest orebody and is divided into Hugo North and Hugo South. Hugo North extends horizontally to around 1.8 km. The extraction of the Hugo North orebody uses the block cave mining method with macroblocks and a multi-lift sequence. The first lift, known as the upper lift or Lift 1, is currently in development and production ramp-up, aiming to reach its peak production rate. Given the extent of the Hugo North orebody, ongoing studies are assessing design trade-offs and implementation considerations.

Conceptual arrangements for developing the Hugo North and South deposits are shown in Figure 1. Access to the mining area is anticipated to be via a decline system with internal ventilation shafts or raises to provide ventilation. Ore would be crushed and then conveyed to the surface via a conveyor system that ties into the existing incline. The designed production rate is comparable to the existing lift.

At concept generation, rapid screening tools such as the Pugh matrix (Pugh 1991; Burge 2009) were used to eliminate clearly inferior options. However, the method's reliance on a single baseline and uniform treatment of criteria limits its ability to express discipline-specific weighting and to test weight sensitivity. To produce transparent, evidence-based comparisons across materially different concepts, the study adopts an MCA framework. MCA keeps raw performance profiling separate from scoring, applies descriptor-anchored 1–5 scales, assigns section and item weights, and aggregates via a simple, auditable pathway. The numerical values presented in this paper are for illustrative purposes only.

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This paper outlines the MCA workflow and scoring guide and demonstrates their trade-offs application, showing an auditable pathway from evidence to decision. The MCA approach can be adopted and tailored to other projects/assessments as required.

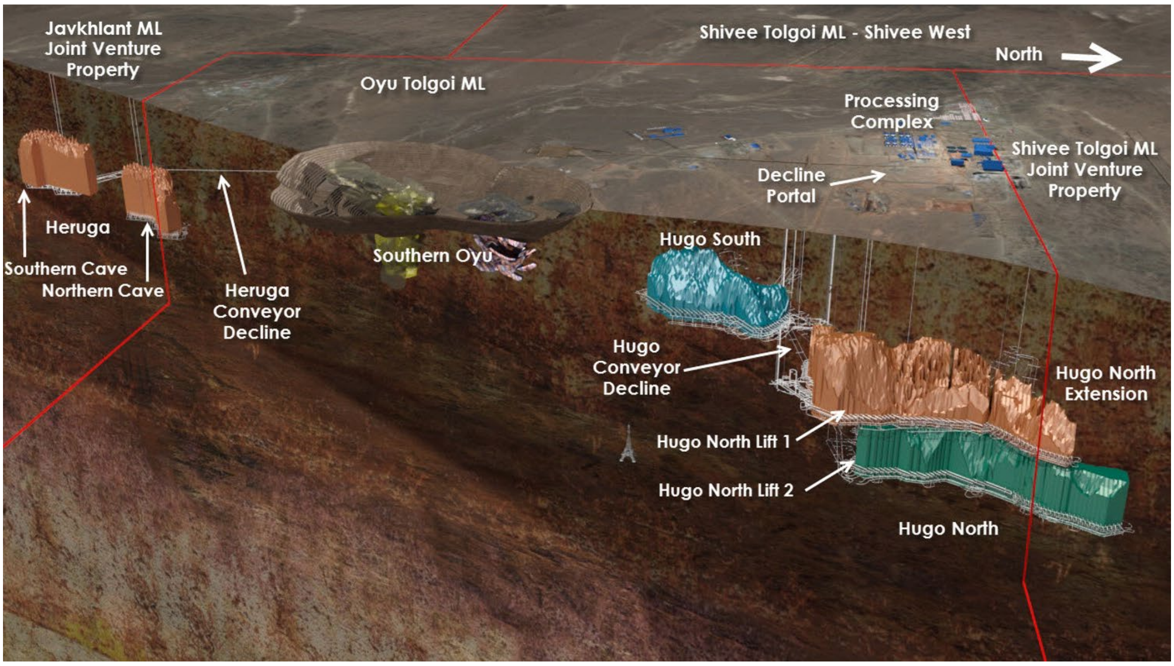

Figure 1 Conceptual arrangements for developing Hugo North and South deposits

2 Multi-criteria analysis workflow

The fundamentals of the MCA workflow include problem definition, construction of options, sets of criteria, performance measurement, scoring, weighting, aggregation, sensitivity analysis and decision-making. These steps may vary depending on the needs of the analysis.

During the adoption of MCA in the Oyu Tolgoi mine study process, several options or designs were evaluated using the workflow shown in Figure 2. In most cases, option development occurs after the listing of the sets of criteria. To yield better, more thorough alternatives, the interaction between option development and criteria is critically considered. Once the appraisal of the options is completed through scoring, weighting and aggregation, the possibility of further refining the existing options can be explored and then reassessed.

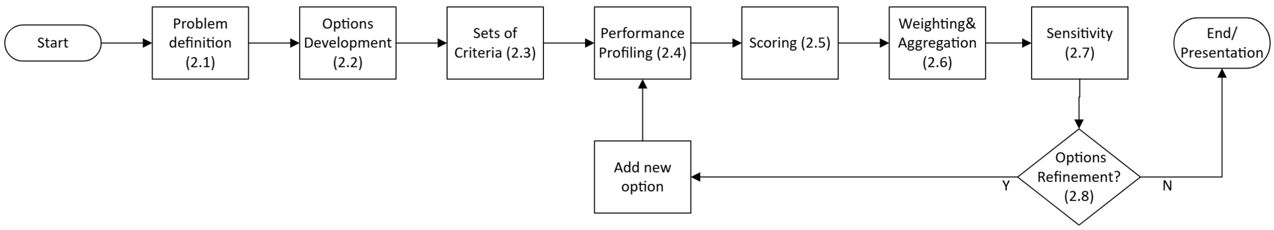

Figure 2 Multi-criteria analysis workflow in Oyu Tolgoi mine study process

2.1 Problem definition

Problem definition is the initial stage of the MCA work, in which an issue or subject is selected for detailed analysis. Part of the definition process is also to determine the respective user/expertise related to the subject of interest, such as the geoscience team for ground stability or disturbance, the mine planner/design for schedule and placement, and the business analyst for financial and operational considerations. This can be in the form of a team or individuals appointed to represent each group based on their competencies or experience level.

In addition, it is necessary to define the purpose of the analysis. As outlined in Dean (2022), in adherence to the mining study space, the common objective can be:

- to rank options, by sorting the options in a preferential order
- to sort the options by acceptability
- to describe the purpose, to point out the formal and systematic assessment of key features of several options and their consequences.

2.2 Options development

This phase allows the construction of materially different alternatives that span feasible design philosophies. A value-focused thinking approach is applied, whereby option generation is guided by project objectives rather than predefined or incremental design variations (Keeney 1992; 1996; Parnell 2007).

In practice, this involves first defining key objectives (e.g. maximise recoverable value, maintain caveability and geotechnical stability and ensure operability) and then systematically generating options to explore trade-offs between these objectives.

For example, in the drive orientation study, options were developed progressively, starting from single tunnel orientation cases and expanding to dual tunnel and multiple tunnel orientation configurations (Figure 3). These alternatives were designed to test trade-offs between ore recovery and geotechnical performance. This ensures that the option set captures meaningful trade-offs between competing objectives rather than minor variations of a single concept.

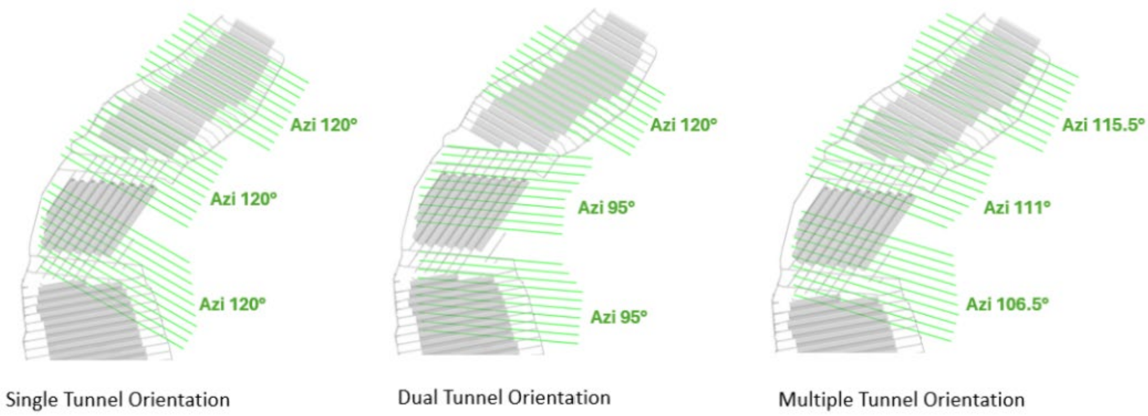

Figure 3 Drive orientation options showing azimuth alignment across three blocks

Another example is finding the most suitable underground primary crushing solution available in the market. The objective is to ensure that the selected crusher technology aligns with the ore characteristics and overall mine design criteria. The study assesses eight options of crusher technology (Worley 2026). These options were assessed based on load–haul–dump (LHD) haulage, meaning that LHD units will feed the run of mine ore.

2.3 Criteria definition

Criteria act as a balanced measure across relevant factors for all options. Reference criteria generally used in Oyu Tolgoi mine MCA are listed in Section 3. Multiple disciplines may need to be considered in a project. Each discipline will list the criteria that are deemed critical to the project, evaluate the list internally and then provide the primary list for that discipline. Once all disciplines had completed their lists, a group of analysts, experts and decision-makers from each discipline gathered to finalise the criteria relevant to the project objectives. During the assessment of production drive or tunnel orientation options in the Oyu Tolgoi study, the mine design, production scheduling and geoscience disciplines, and stakeholders, take part in finalising the specific measurable indicators that should be included in the MCA process.

2.4 Performance profiling

Performance profiling supports the expected performance of each option–criterion pair. Inputs may include:

- modelling outputs (e.g. numerical modelling, scheduling models)
- caveability indices and geotechnical datasets
- monitoring data and operational history
- engineering quantities and spatial metrics
- expert judgement where data are limited.

All option performance data are consolidated to create a single evidence base that feeds into the scoring step. This structure is consistent with recommended MCA practice to keep raw performance and scoring separate.

2.5 Scoring

Performance information is translated into normalised, unitless ratings on a bounded 1–5 scale. Each criterion is scored against a descriptor-anchored rubric, and every rating includes a brief evidence note linked to the performance profile. Separating evidence from rating enables like-for-like comparisons across the selected criteria for the decision and preserves a clear audit trail. Illustrative scoring examples are provided in Section 4.

2.6 Weighting and aggregation

Criterion weights represent relative importance and are set before aggregation with a brief rationale. At the study stage, weights are commonly elicited via discipline-specific workshops and direct expert assignment, normalised so that section and item weight each sum to 1, and overlaps are removed to avoid double-counting. Robustness is checked with simple weight-sensitivity bands. For later stages requiring a more formal basis, structured elicitation such as Analytic Hierarchy Process, AHP (Saaty 1990, 2003, 2008) may be used.

Aggregation computes the weighted scores to produce an overall performance for each option. Weighted scores are transparently calculated based on the scoring and weighting steps. The process maintains a clear audit trail from the underlying data to the score and then to the total. This produces the initial ranking or classification of options according to their weighted performance.

Details of the weighting/aggregation method and a brief worked example are provided in Section 4.2.

2.7 Sensitivity analysis

Sensitivity analysis tests the robustness of results to uncertainty in weights and, where appropriate, scores. Weights can be varied to reflect different stakeholder perspectives; critical scores can be stress-tested under plausible bounds; and criteria of influence (those most affecting rank stability) are identified to guide any follow-up analysis. Sensitivity analysis is essential for understanding model behaviour and informing refinement (Dean 2022).

As an example, sensitivity analysis was applied to the drive orientation assessment by varying the section-level weights in the MCA to adjust the relative influence of Business, Technical and Operational criteria. These weight sweeps tested how different stakeholder priorities affect the aggregated scores and demonstrated that the overall ranking remained stable across the plausible weighting ranges, indicating that the assessment is not overly sensitive to reasonable changes in section priorities.

2.8 Options refinement

Options refinement is an optional step used when MCA results and sensitivity highlight clear improvement opportunities. Its purpose is to adjust an option (or create a targeted variant) to address the criteria of influence while respecting study constraints and interfaces. Any refined option records the change intent and scope, preserves the evidence → rating → weighting → aggregation trail and then re-enters the MCA cycle for like-for-like reassessment using the same scoring guide and weight set.

3 Common criteria for block/panel cave mining studies

Block and panel caving trade-offs are multi-disciplinary and require a clear, auditable structure for comparison. Figure 4 groups the criteria typically used in caving studies and Table 1 lists example indicators and measurement bases commonly applied when defining and scoring each criterion. The final criteria set and descriptor anchors are tailored to each decision and recorded in the scoring guide for that study.

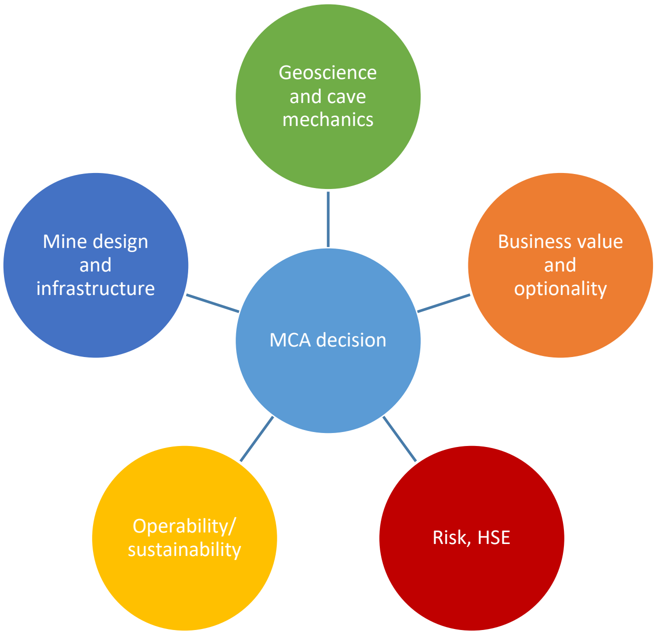

Figure 4 Generic criteria for Oyu Tolgoi mine studies

Table 1 Generic criteria groups and example indicators

Group	Example indicators/measurement basis
Geomechanics and cave mechanics	Undercut (UC) face to σ_{Hmax}
	UC faces major structures
	Cave-front length
	UC drive length
	Tunnels to σ_{Hmax}
	Pillar geometry
	Caveability-hydraulic radius (HR)
	Geological (hydrology, structural, lithology and alteration)
	Resource model
	Strength/rock mass quality in which the blocks are located
	Stress environment (in virgin stress, abutments of upper caves, etc.)

Group	Example indicators/measurement basis
	Seismicity – on footprint, regional
	Stability – footprint performance
	Initiation point and sequence
	Cave propagation
	Subsidence affecting surface infrastructure and other interactions (utilities, areas, etc.)
Mine design and infrastructure	Block layout relative to orebody geometry
	UC and drawbell strategy
	Integration with materials handling
	Permanent access (shafts, declines)
	Life of block access (rim drives)
	Infrastructure for mining block/on footprint (crusher and ore handling; rim tripping, ore passes, loadhouses)
	Infrastructure off footprint (mass excavation, power, ventilation, service excavations)
	Sufficiency of inter-block pillars sizes for stability purposes
	UC length/duration
	UC initiation and direction
	Block height – ability to recover with high columns
Operational/sustainability	Time to first ore
	Ramp-up rate
	LHD tram complexity
	Rim-to-rim XD lengths
	Maintainability
	Production capacity/productivity
	Development requirements (active areas/development metres, mobile fleet)
Business value and optionality	Discounted metal
	In situ metal
	Expansion optionality under XD-length boundaries
Risk, health, safety, and environment (HSE)	Construction/operating risk
	Seismic hazard context
	Subsidence stand-off
	Ventilation interactions

4 Scoring, weighting and aggregation

4.1 Scoring

As described earlier in the MCA workflow (Section 2.5), scoring is determined on a 1–5 scale where 1 refers to the lowest and 5 refers to the highest performer. The scoring matrix may consist of both quantitative and qualitative criteria, depending on the assessment scope and the discipline-specific parameters involved.

To enhance consistency and minimise subjectivity, criteria should be specified as measurable indicators and, where practicable, scored against quantitative anchors. This supports repeatable, like-for-like assessment across options (Dean 2022).

4.1.1 Concession-based scoring

There are two approaches to scoring and weighting: agreement and pairwise comparison. Representatives from each discipline provide scores and weights to the criteria in their field of expertise. The scores and weights are then evaluated together in a larger group to agree on a concession of the final score for all criteria for concession-based scoring. Table 2 is an example of the criteria and scoring used for the Oyu Tolgoi study.

Table 2 Example of geotechnical scoring matrix used in an multi-criteria analysis for footprint tunnel orientation case

No.	Criterion	Unit	Weight (%)	(5) High	(4) High–medium	(3) medium	(2) Medium–low	(1) Low
1	Undercut (UC) face orientation to σ_{Hmax}	°	15	>60	45–60	30–45	20–30	<20
2	UC face orientation to major structures	°	15	>60	45–60	30–45	20–30	<20
3	Tunnel orientation to major structures	°	15	>60	45–60	30–45	20–30	<20
4	Drive orientation to orebody/acute corner	°	15	90	80–90	70–80	60–70	<60
5	Cave front length	m	5	<300	300–350	350–400	400–500	>500
6	Active UC drive length	m	15	300	300–350	350–400	400–500 or <200	>500 or <150
7	Tunnel orientation to σ_{Hmax}	°	5	>20	20–40	40–60	60–80	>80
8	Pillar geometry		15	Rectangular	Trapezium with a similar area	Trapezium with different areas	Near-triangle trapezium geometry	Irregular geometry

4.1.2 Pairwise comparison matrix

The next approach uses a pairwise comparison matrix to assign relative priorities to criteria, converting qualitative judgements into quantitative scores. Ratings follow Saaty's fundamental 1–9 scale (1 = equal, 3 = moderate, 5 = strong, 7 = very strong, 9 = extreme; and reciprocals indicate the opposite preference), as shown in Table 3 (Saaty 2008).

Table 3 Fundamental scale of absolute numbers (Saaty 2008)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
1.1–1.9	When activities are very close, a decimal is added to 1 to show their difference as appropriate	A better alternative to assign the small decimals is to compare two close activities with other widely contrasting ones, slightly favouring the larger one over the smaller one when using the 1–9 values
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A logical assumption
Measurements from ratio scales		When it is desired to use such numbers in physical applications; alternatively, judgement is often used to estimate the ratios of such magnitudes

In the matrix, the diagonal is fixed at 1 and the lower-triangular entries are automatically populated as reciprocals of the corresponding upper-triangular values. For example, in Table 4, discounted metal copper (disc. metal Cu) has the same importance as in situ Cu metal, so a rating of 1 is entered. Conversely, the disc. metal Cu is considered more important than material access constraints, reflected by a rating of 5.

Table 4 Pairwise comparison between criteria

Criteria	Disc. metal Cu	In situ metal Cu	Material access constraints	Footprint expansion	Pillar recovery potential
Disc. metal Cu	1	1	5	5	5
In situ metal Cu	1	1	5	5	5
Material access constraints	1/5	1/5	1	1	1
Footprint expansion	1/5	1/5	1	1	1
Pillar recovery potential	1/5	1/5	1	1	1

Reciprocal scoring occurs when comparing the relative priorities between material access constraints and disc. metal Cu, or between footprint expansion and in situ metal Cu.

4.2 Weighting and aggregation

4.2.1 Simple additive weighting

The study applies simple additive weighting (SAW) to combine criteria into a single score. Each section (e.g. Business, Technical, Operational) is given a section weight and each criterion within a section is given an item weight. Section weights sum to 1 and item weights within each section also sum to 1. Options are scored on a 1–5 rubric (5 = better). As shown in Figure 5, item scores are summed to derive a section contribution and section contributions then combine to obtain the total SAW score.

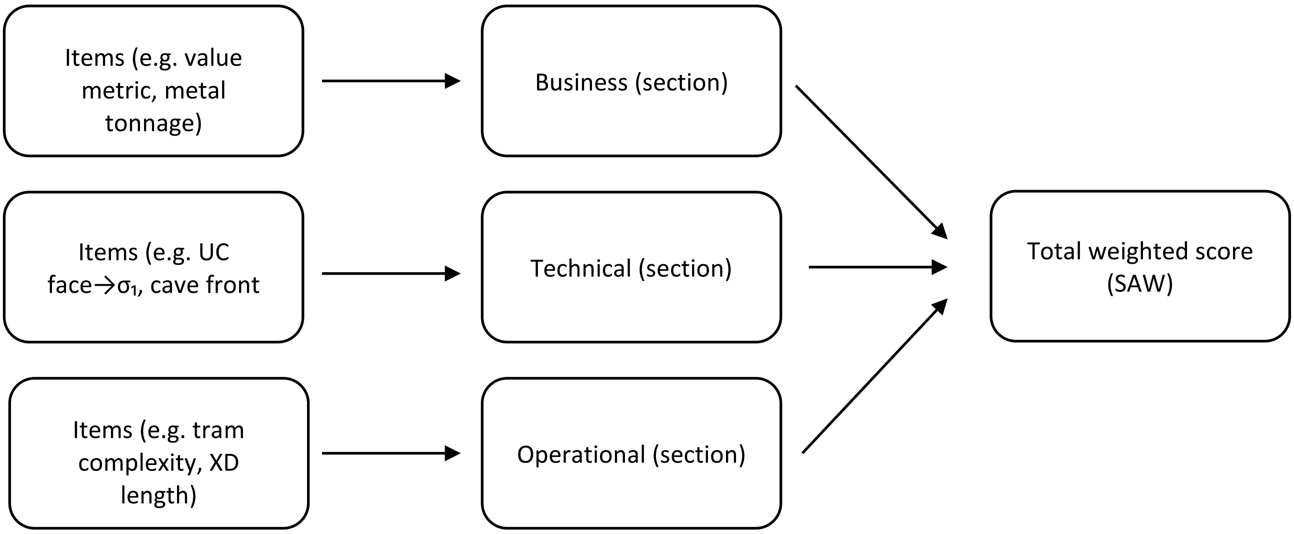

Figure 5 Evidence-to-decision path (item scores → section contribution → total simple additive weighting [SAW] score)

The total score uses a weighted sum formula:

$$S_{\text{total}} = \sum_{\text{sections}} \left(w_{\text{section}} \times \sum_{\text{criteria in section}} (w_i \times s_i) \right) \quad (1)$$

where $s_i \in [1,5]$ and all section weights and the criterion weights each sum to 1.

The weighted scoring table (Table 5) is an example to show the calculation path (illustrative figures only).

The section weighting adopted for the example in this paper is 40% Business, 40% Technical and 20% Operational. This distribution reflects the intent of an order-of-magnitude study stage, where the primary objective is to differentiate between materially distinct concepts at a strategic level. At this stage, value potential and technical feasibility are the dominant decision drivers, while operational considerations are incorporated at a level consistent with the available design definition.

It is important to note that the 40/40/20 weighting is presented for illustrative purposes only to demonstrate the aggregation approach within the MCA framework. In practice, section and item weightings are case specific and evolve with study maturity, reflecting the level of design definition and decision requirements. In later study stages (e.g. PFS/FS), operational considerations typically carry greater influence, as constructability, execution risk and system integration become more clearly defined.

Table 5 Weighted scoring example

Section 1 – Business (section weight: 40%)				
Item	**Criterion**	**Item weight**	**Rating**	**Item-weighted score**
1.1	Disc. Cu metal	30%	3	0.90
1.2	In situ Cu metal	30%	3	0.90
1.3	Material access constraints	20%	3	0.60
1.4	Footprint expansion	10%	4	0.40
1.5	Pillar recovery potential	10%	4	0.40
Item-weighted sum				**3.20**
Section weighted score				**1.28**
Section 2 – Technical (section weight: 40%)				
Item	**Criterion**	**Item weight**	**Rating**	**Item-weighted score**
2.1	Undercut (UC) face orientation to σ_{Hmax}	15%	3	0.45
2.2	UC face orientation to major structures	15%	3	0.45
2.3	Tunnels orientation to major structures	15%	3	0.45
2.4	Drive orientation to orebody	15%	4	0.60
2.5	Cave front length	5%	4	0.20
2.6	UC drive length	15%	3	0.45
2.7	Tunnels orientation to σ_{Hmax}	5%	3	0.15
2.8	Pillar geometry	15%	4	0.60
Item-weighted sum				**3.35**
Section-weighted score				**1.34**
Section 3 – Operational (section weight: 20%)				
Item	**Criterion**	**Item weight**	**Rating**	**Item-weighted score**
3.1	LHD tram complexity	50%	3	1.50
3.2	XD length	50%	2	1.00
Item-weighted sum				**2.50**
Section-weighted score				**0.50**
Total score				**3.12**

Step 1: business (40%)

- Item weights: 30%, 30%, 20%, 10%, 10%
- Illustrative ratings: 3, 3, 3, 4, 4
- Item-weighted sum: 0.30 × 3 + 0.30 × 3 + 0.20 × 3 + 0.10 × 4 + 0.10 × 4 → 3.20
- Section contribution: 0.40 × 3.20 → 1.28

Step 2: technical (40%)

- Item weights: 15%, 15%, 15%, 15%, 5%, 15%, 5%, 15%
- Illustrative ratings: 3, 3, 3, 4, 4, 3, 3, 4
- Item-weighted sum: 0.15(3 + 3 + 3 + 4) + 0.05 × 4 + 0.15 × 3 + 0.05 × 3 + 0.15 × 4 → 3.35
- Section contribution: 0.40 × 3.350 → 1.34

Step 3: operational (20%)

- Item weights: 50%, 50%
- Illustrative ratings: 3, 2
- Item-weighted sum: 0.5 × 3 + 0.5 × 2 → 2.50
- Section contribution: 0.20 × 2.500 → 0.50

Total (illustrative): 1.28 + 1.34 + 0.50 = 3.12

4.2.2 Pairwise normalised weights

Once the scoring process is done in the pairwise comparison (Section 4.1.2), the next process it to calculate the weight of each criterion as shown in Table 6 for row weights and normalised weights columns.

Table 6 Pairwise weights

Criteria	Disc. metal Cu	In situ Cu metal	Material access constraints	Footprint expansion	Pillar recovery potential	Weights	Normalised weights
Disc. metal Cu	1	1	5	5	5	1.92	0.38
In situ Cu metal	1	1	5	5	5	1.92	0.38
Material access constraints	0.2	0.2	1	1	1	0.38	0.08
Footprint expansion	0.2	0.2	1	1	1	0.38	0.08
Pillar recovery potential	0.2	0.2	1	1	1	0.38	0.08
Column sum	2.6	2.6	13	13	13	5.00	1.00

The following formula is used for the calculation:

$$Column\ 'n'\ sum\ = \left(\chi_{(nmin,n)} + \chi_{(nmin+1,n)} + \cdots + \chi_{(nmax-1,n)} + \chi_{(nmax,n)}\right) \quad (2)$$

where:

n = criteria (1, 2, 3, 4, 5). Eq: 1 ≈ disc. metal Cu, 2 ≈ in situ Cu metal, 3 ≈ material access constraints, and so forth.

n_1 = nmin

n_5 = nmax

$\chi_{n,n}$ = pairwise rating.

Then

Column ‘1’ sum disc. metal = 1 + 1 + 0.2 + 0.2 + 0.2 = 2.6

Column ‘3’ sum in situ Cu metal = 5 + 5 + 1 + 1 + 1 = 13

Column ‘5’ sum in situ Cu metal = 5 + 5 + 1 + 1 + 1 = 13

$$Weight\ row\ 'n' = Wn = (x_{n,nmin} * column\ \ 'nmin'sum + \ x_{n,nmin+1} * column\ \ 'nmin + 1'\ sum + \cdots + \ x_{n,nmax} * column\ \ 'nmax'sum$$

For example:

Weight row ‘1’ = W_1 = 1*2.6 + 1*2.6+ 5*13 + 5*13 + 5*13 = 1.92

Weight row ‘3’ = W_3 = 0.2*2.6 + 0.2*2.6 + 1*13 + 1*13 + 1*13 = 0.38

Weight row ‘5’ = W_5 =0.2*2.6 + 0.2*2.6 + 1*13 + 1*13 + 1*13 = 0.38

$$Normalised\ Weights\ Row\ 'n' = \frac{W_n}{\sum_{nmin}^{nmax} W_n} \quad (3)$$

For example:

Normalised weights row ‘1’ = W_1 / (W_1 + W_2 + W_3 + W_4 + W_5) = 1.92/ (1.92 + 1.92 + 0.38 + 0.38 + 0.38) = 0.38

Normalised weights row ‘3’ = W_3 / (W_1 + W_2 + W_3 + W_4 + W_5) = 0.38/ (1.92 + 1.92 + 0.38 + 0.38 + 0.38) = 0.08

Normalised weights row ‘5’ = W_5 / (W_1 + W_2 + W_3 + W_4 + W_5) = 0.38/ (1.92 + 1.92 + 0.38 + 0.38 + 0.38) = 0.08

Once all the pairwise comparison matrices for the criteria are appraised as shown in Figure 6, the next step is to follow the aggregation procedure.

5 Multi-criteria analysis implementation in Oyu Tolgoi studies

The Oyu Tolgoi studies applied a consistent MCA framework across two concept-stage decisions: drive orientation across blocks and access decline tie-ins to the existing materials handling system. Each study defined the decision scope, established materially different alternatives, compiled a structured performance profile and applied descriptor-anchored scoring. An audit-traced aggregation method and targeted sensitivity review supported clear traceability and helped identify criteria with meaningful influence on option rankings and follow-on work.

The drive orientation study (Sta Ana 2025) compared a single consistent azimuth with several hybrid and progressive configurations across business, technical and operational criteria. The performance profile covered the projected metal value, alignment of the undercut face and tunnels to the principal stress and major structures, drive orientation relative to orebody geometry and the resulting cave front and undercut drive lengths, rim-to-rim distances and interface pillar geometry. Operational aspects such as LHD tram complexity and overall haul route efficiency were also assessed to establish the relative feasibility and performance of each configuration.

The access decline tie-in assessment (Sta Ana 2026) evaluated numerous design concepts and options for the conveyor tie-in to the existing materials handling system across business, operational, safety, electrical/services and geotechnical criteria. Key considerations included development cost and duration, excavation effort and complexity, waste rock handling efficiency, access conditions and mechanical integration requirements such as tie-in complexity, shutdown exposure and effects on materials handling availability. Safety, ventilation performance, electrical interface impacts and ground condition and support demands were also assessed to establish overall feasibility and implementation risk.

Across both studies, scoring used descriptor-anchored 1–5 rubrics supported by brief evidence notes, and the aggregation method preserved a clear trail from inputs to section summaries and overall totals. The sensitivity review varied plausible assumptions to identify the criteria of influence and to target the options refinement before re-entering the MCA cycle.

6 Conclusion

The MCA framework is well suited to the Oyu Tolgoi studies. By structuring performance profiles prior to scoring and weighting, applying descriptor-anchored 1–5 scales and aggregating results using SAW, the framework provides a transparent, repeatable and auditable path from evidence to decision. The structure accommodates all relevant disciplines: geoscience and cave mechanics, mine design and infrastructure, operations, business value and optionality and risk/HSE, within a single model, enabling like-for-like comparison of materially different concepts and preserving traceability from inputs to overall rankings or sorting options.

On this basis, MCA provides an evidence-based and defensible foundation for down-selection at study gates and is recommended for ongoing use across trade-offs and comparable block/panel caving design decisions.

Please note that this paper contains estimates and forward-looking statements within the meaning of applicable securities laws. These statements are based on publicly available information, operational observations, assumptions and interpretations available at the time of writing. Actual outcomes may differ due to operational, geotechnical, market, regulatory and other factors.

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