Empirical mill throughput modelling and linear programming
Phu Kham Copper-Gold Operation, Laos
Warning: this presentation contains coarse metallurgical language and frequent strong maths
Geology and mine background

- PanAust's Phu Kham Copper-Gold Operation is an open-pit copper and gold mine in northern Laos
- The mineralisation occurs in altered volcaniclastics, skarns and stockworks that represent the distal expression of a conventional porphyry copper-gold system (Tate, 2005)

Fresh mineralised rocks

3 cm
Volcaniclastic

10 cm
Diorite

4 cm
Skarn
The problem and the solution

The problem

• The predicted SAG mill throughput was 20% higher than achieved throughput

The solution

• An empirical throughput formula

The extra value

• The optimal feed blend to achieve maximum throughput can be determined from the empirical formula
Throughput and rock strength are related at Phu Kham.

Rock strength has been determined by point load index (PLI) tests.

Validated the PLI data, found 80% of the data was invalid.

Invalid data resulted in low PLI values in the block model, therefore high throughput.
Point load index data
Empirical throughput model

Formula

\[ \sum_{i=1}^{n} C_i \omega_i = T \]

Variables

- \( C_i \) – Causal factor, which is the proportion of fresh diorite, skarn and volcaniclastic
- \( \omega_i \) – Constant (to be determined)
- \( T \) – SAG mill throughput in tonnes per hour
Solving the constants

Express formula as matrices

\[ A \cdot B = C \]

Variables

- \( A \) – square matrix of the proportions of fresh diorite, volcaniclastics and skarn in the SAG mill feed
- \( B \) – vector of unknown constants
- \( C \) – vector of actual throughput measurements
Rearrange to solve unknowns

**Matrices**

\[
A^{-1} A = A A^{-1} = I
\]

\[
A^{-1} A B = A^{-1} C
\]

\[
I B = A^{-1} C
\]

\[
B = A^{-1} C
\]

**Variables**

- The inverted matrix \( A^{-1} \) multiplied by \( A \) is non-singular if the product is equal to the identity matrix \( I \)

- Any matrix multiplied by the identity matrix is equal to itself

- So, matrix \( A \) must be non-singular for this to work (can check by ensuring the determinant is non-zero)
Solve

See paper for details

\[
\begin{bmatrix}
0.28 & 0.60 & 0.12 \\
0.34 & 0.53 & 0.13 \\
0.34 & 0.55 & 0.11
\end{bmatrix}
\begin{bmatrix}
\omega_1 \\
\omega_2 \\
\omega_3
\end{bmatrix}
= 
\begin{bmatrix}
2314 \\
1995 \\
1964
\end{bmatrix}
\]

\[
\begin{bmatrix}
\omega_1 \\
\omega_2 \\
\omega_3
\end{bmatrix}
= 
\begin{bmatrix}
-10.995 & 0.444 & 11.552 \\
6.151 & -8.982 & 3.831 \\
3.532 & 42.799 & -45.331
\end{bmatrix}
\begin{bmatrix}
2314 \\
1995 \\
1964
\end{bmatrix}
= 
\begin{bmatrix}
-1869.05 \\
3835.33 \\
4540.22
\end{bmatrix}
\]
Result

- Predicted November throughput: 2405 tph
- Actual November throughput: 2371 tph
- Predicted December throughput: 2190 tph
- Actual December throughput: 2220 tph
Linear Programming

\[
\begin{align*}
\text{max } T: & \quad \sum_{i=1}^{n} C_i \omega_i = T \\
\sum_{i=1}^{n} C_i & = 1 \\
\sum_{i=1}^{n} C_i \omega_i & \leq 2500 \\
\sum_{i=1}^{n} C_i \omega_i & > 1500 \\
C_{\text{diorite}} & > 0 \\
C_{\text{skarn}} & = 0.1
\end{align*}
\]

- The objective function being optimised (T – tph)
- The equality constraint (mill receives 100% feed)
- Upper limit, the SAG mill is volume constrained at 2500 tph
- Lower limit determined from single source feed into the SAG mill
- Must feed some diorite
- The skarn feed is 10 per cent (based on production history)
Linear Programming

- Two important facts:
  1. The maximum throughput of 2500 tph can be achieved
  2. The ideal blend of fresh ore is 25% diorite and 65% volcaniclastic when feeding 10% skarn

\[
\begin{align*}
\text{max}\{-1869x + 3835y + 4540z \mid x + y + z &= 1 \land -1869x + 3835y + 4540z \\
&\leq 2500 \land -1869x + 3835y + 4540z \\
&> 1500 \land x > 0 \land z = 0.1\} \\
= &\ 2500 \text{ tph at } (x, y, z) \\
\approx &\ (0.246, 0.654, 0.1)
\end{align*}
\]
Conclusion

• The study identified a practical solution to predict the SAG mill throughput in the immediate future using available data

• The method is self learning and incorporates the sum and interactions of controlling factors without needing to know all the factors prior to modelling

• The method uses the SAG mill as the analytical instrument

• The predictions rely on accurate weathering and lithology models, which are constantly being updated by the mine geologists

• The empirical throughput equation is suitable to be used for Linear Programming to determine the optimal feed blend to achieve maximum SAG mill throughput