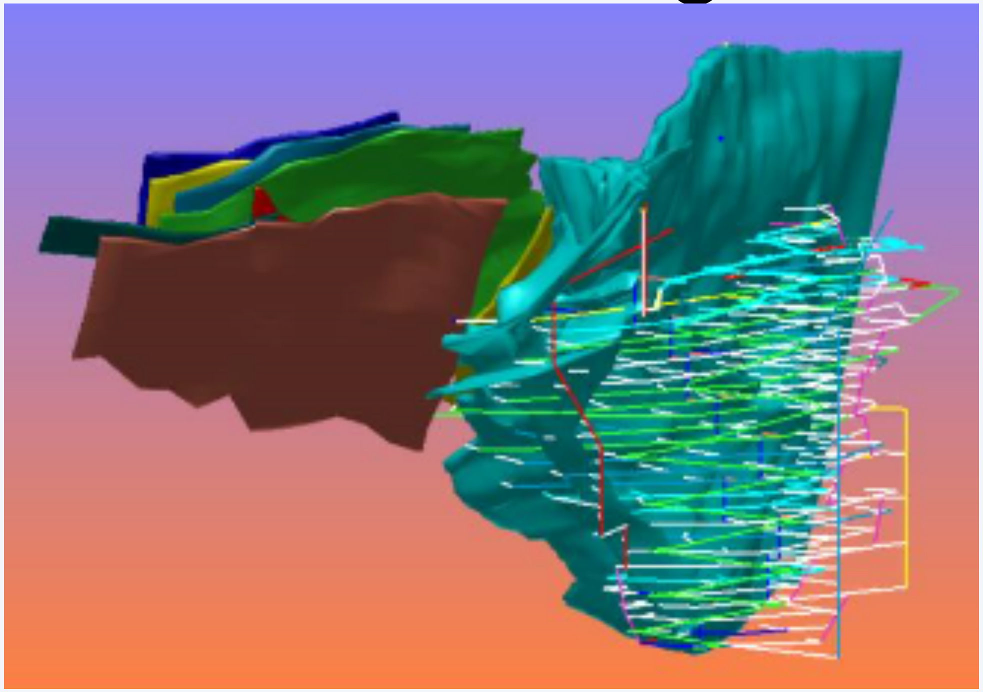
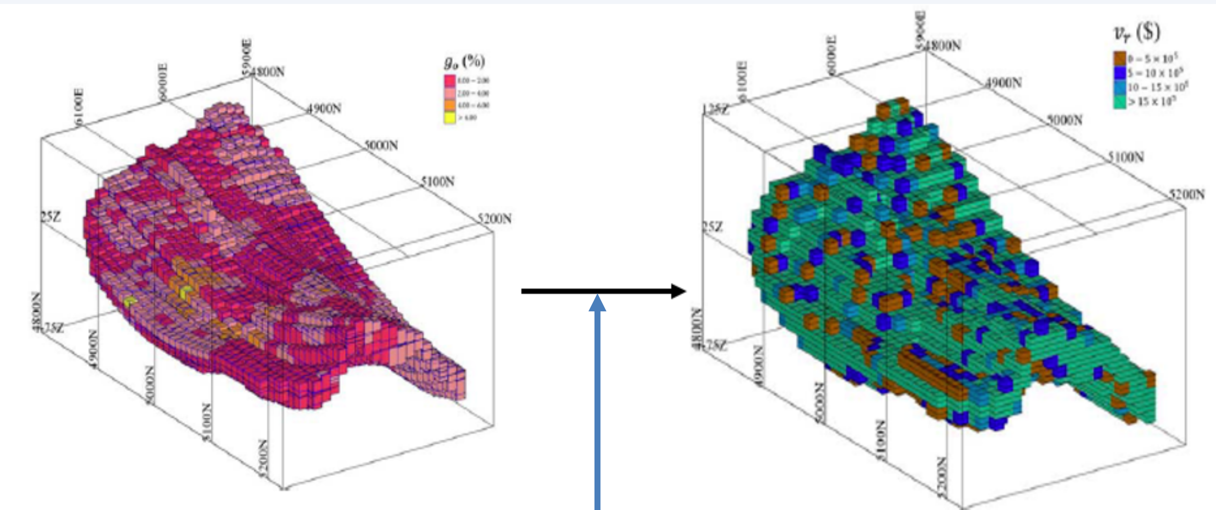
An Algorithm for Stope Boundary Optimisation for Underground Mines



Sihe Nhleko 15 January 2018

Conversion of Geological block model to economic block model



Geological block model

Economic block model

- Exploration
- SAMREC
- Geological block model: grade values (ore/waste)

Selection of a mining method
(Sub-level stoping)

- Block economic value (value to be realised if a block is mined);
- Any block has a potential of being included in the stope layout;
- Maximise the net present value (NPV) of the orebody;

$$v_r = \left[\left(p - r_r\right) \times g_r \times y - \left(e_r + c_r\right)\right] \times t_r$$

v_r	block economic value ($) for block *r;*
p	metal price ($/oz);
r_r	refining cost of block *r* ($/t);
g_r	grade of block *r* (g/t);
y	recovery from block *r* (%);
e_r	mining cost for block *r* ($/t);
c_r	processing cost of block *r* ($/t);
t_r	tonnage of block *r* (t).

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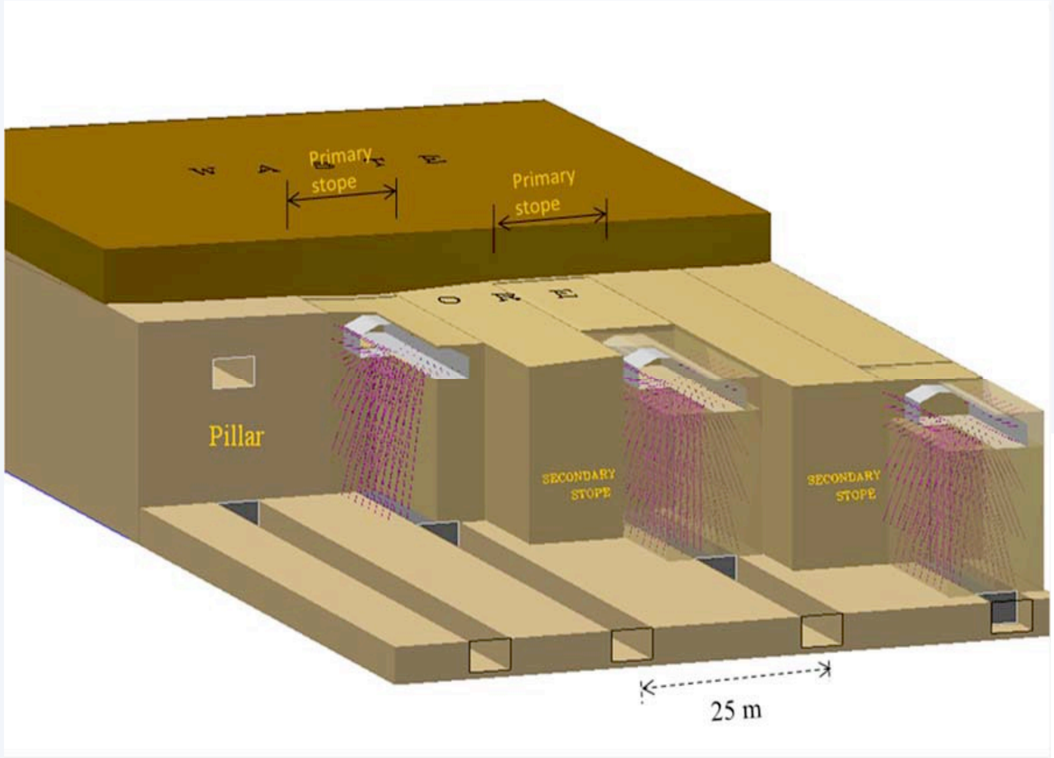
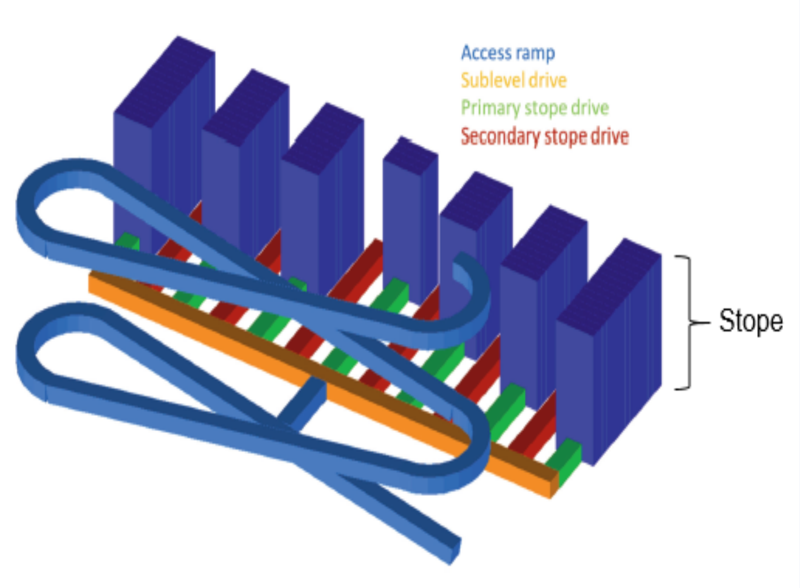
Mining method



Mining constraints:

- Stope size (minimum & maximum);
- Level position;
- Pillar positions;
- Non-overlapping stopes;



- **Stope**: an underground production area where ore is extracted from the surrounding rock mass using underground mining methods;

- A stope comprises of a certain number of the individual economic blocks

Example

-20	10	30	40	15	-25
a	*b*	*c*	*d*	*e*	*f*

Step 1 : Block *a* is negative and algorithm stops the block from further proceedings.

Step 2 : Feasible neighbourhoods for block *b* is evaluated and MVN is selected as follows.

(i)	-20	10	30	⇨ Neighbourhood Value : -20+10+30=20
(ii)	10	30	40	⇨ Neighbourhood Value: 10+30+40=80

Blocks *c* and *d* are flagged and neighbourhood (ii) is selected as the MVN for block *b*

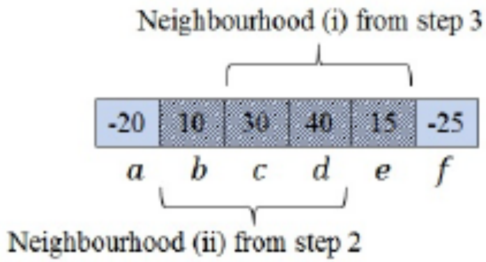
Step 3: Blocks, *c* and *d* are flagged already. Thus, feasible neighbourhoods of block *e* is evaluated and MVN is selected as follows.

(i)	30	40	15	⇨ Neighbourhood Value: 30+40+15=85
(ii)	40	15	-25	⇨ Neighbourhood Value: 40+15-25=30

Block *e* is flagged and neighbourhood (i) is selected as the MVN for block *e*.

Step 4 : Block *f* is negative. Thus, the algorithm stops them from proceeding further.

Step 5 : Final stope layout consists of blocks which are hatched as follows.

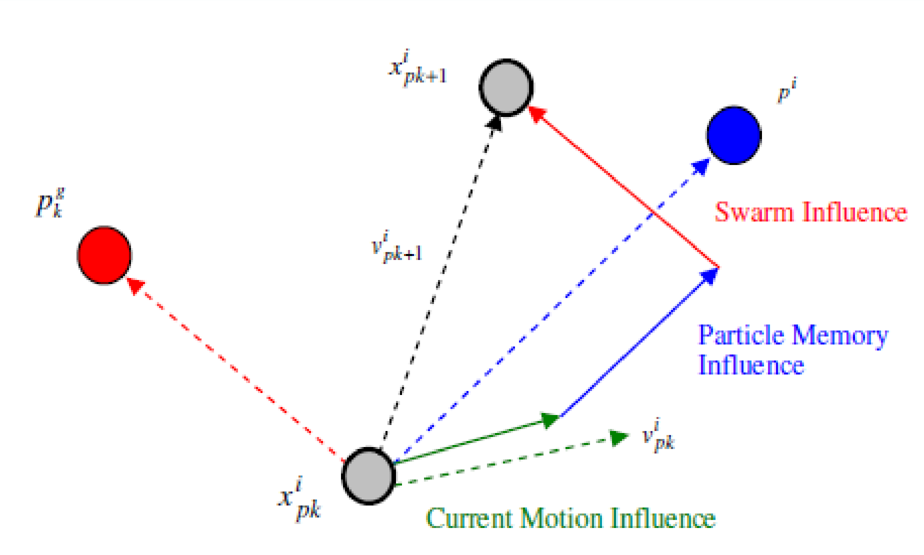


- Three blocks is defined as the minimum stope size;
- Two MVNs, which comprise blocks *b, c, d* and *e*;
- Selecting either of the neighbourhoods may result in violation of the minimum stope width constraint;
- If neighbourhood (i) is selected from step 2, mining of block *b* may be impossible because it is a single block;
- Similarly, mining of block *e* may be impossible, if neighbourhood (ii) is selected from step;
- Thus, the algorithm does not yield a practical mining solution

Development of the '*combinatorial*' algorithm

PSO

- Each particle modifies its position according to:
  - its current position
  - its current velocity
  - the distance between its current position and *pbest*
  - the distance between its current position and *gbest*



$$\vec{x}_{i,t} = \vec{x}_{i,t-1} + \vec{\vartheta}_{i,t}$$

$$\vec{\vartheta}_{i,t} = \omega\vec{\vartheta}_{i,t-1} + c_1\vec{r}_1.(\vec{p}_{i,t-1} - \vec{x}_{i,t-1}) + c_2\vec{r}_2.(\vec{g}_{t-1} - \vec{x}_{i,t-1})$$

- It can solve the optimisation problem in 3D
- Optimise NPV in long-term (*gbest*)
- Optimise profit in short-term (*pbest*)

Source: Pinto *et al* (2011)

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Dynamic Programming

$$P_{ijo} = M_{i,j} + Max\{P_{i+r,j-1}\}$$

Where:

P_{ijo} the profit achieved by mining through the block I row “i” of drawpoint “j” and starting at any level of drawpoint “o”;

$M_{i,j}$ the cumulative net value of blocks, given by, $M_{ij} = \sum m_{qj}$ $q = 1\ to\ i$ where m_{qj} represents the economic value of a block in row q and column j;

r the range indicating adjacent blocks.

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Problem statement

- To address the generation of optimum stope layout in 3D;
- Combination of Dynamic Programming and Particle Swarm Optimisation algorithms is the most appropriate to determine the optimum stope layout;
- *"Can a 'combinatorial' algorithm be developed to guarantee an optimal underground mining stope boundary solution in 3D space given the physical and geological mining constraints?"*

Particle Swarm Optimisation Algorithm	**Dynamic Programming**
• If particle = stope = stope of high value will be selected (gbest); • Trace of other mineable stopes; • PSO behaviour when particle size changes; • Should a hypothetical stope layout be developed and floated in the orebody; • What is *pbest* or *gbest*?	• Keep trace of blocks to be mined.

Combinatorial algorithm

- Varying stopes;
- 3D;
- Optimum stope layout.

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