The Application of Second-Generation Stope Optimisation Tools in Underground Cut-Off Grade Analysis

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Abstract

This paper introduces a new stope optimisation tool and demonstrates how it can be applied in the strategic planning of an underground mining operation.

The tool is used to generate inventories for a series of cut-off grades. The resulting scenarios are then scheduled for various production rates to produce the familiar NPV vs tonnage relationships. The optimum size and configuration of the underground mining operation can then be determined.

Introduction

Facilities for determining the optimum ore envelope for open-pit mining operations have been available for many years in the form of the Whittle ***Four-D*** and ***Four-X*** software packages. These packages use the Lerchs-Grossmann 3D Graph Theory algorithm, as described in Lerchs and Grossmann (1965).

In the case of underground mining operations, however, the situation is not quite straightforward. To date, no underground equivalent to the Lerchs-Grossmann algorithm has been published and underground equivalents to the Whittle products are yet to be released.

Floating Stope

Alford (1995) describes the Floating Stope technique, which seeks to determine, for each ore block above a nominated cut-off grade, whether the block can be included in a stope that meets a nominated head grade. This is achieved by floating a stope shape of the minimum stope dimensions around each qualifying ore block to locate the stope position of the highest grade, as illustrated in Figure 1.

The floating operation results in the generation of two envelopes:

(i) the "inner" envelope – the union of all the best grade stope shapes, and

(ii) the "outer" envelope – the union of all possible stope positions.

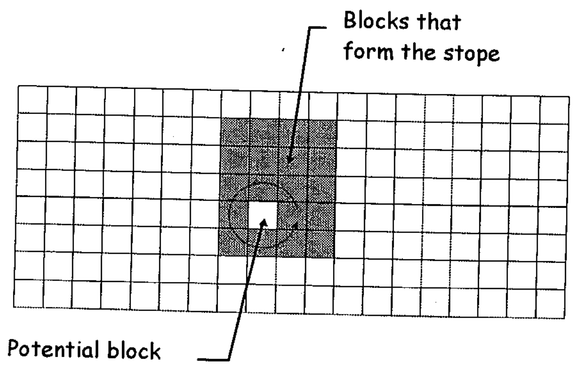

Figure 1: Modelling the Stope in the Block Model

Alford states that the final stope design should take practical design considerations into account and be as close as possible to the "inner" envelope whilst remaining within the "outer" envelope.

The technique is not capable of producing an extraction sequence. Furthermore, it suffers from the limitation that, although two (or more) overlapping best stopes may be economic individually, their union may not be since the stopes may share high-grade blocks[1]. The consequence of this is that even the "inner" envelope may not always bound the optimum stope configuration. This has a potentially deleterious effect on the results produced for all ore bodies and is of particular concern in narrow, banded ore bodies.

The Floating Stope technique is available commercially in the form of DATAMINE's ***Floating Stope Optimiser*** and Earthworks' ***Ore Finder*** packages.

New Developments

In recognition of the limitations of the existing products, Snowden has been researching and developing new underground stope optimisation techniques. This research is based on ideas that were developed within CSIRO Exploration and Mining and reported by Thomas (1996). The aim of the research has been to produce a technique that is capable of deriving the optimum stope configuration and extraction sequence subject to the following criteria:

1. The resource model is provided as a three-dimensional fixed block model (as is required by the Whittle products). The dimensions of the blocks in each direction may be different, but all blocks must be the same size.
2. The objective of the optimisation is to define practical stope shapes and extraction sequences that maximise the net present value (NPV) of the operation.
3. Each stope must be of a minimum specified dimension, defined by the height, width, length and dip angle.
4. The effects of overlapping stopes must be factored into the optimisation process.
5. Subject to the requirements of the mining method, it may be necessary to ensure that the stopes fall on specified levels.

The first product from this research has now been released as ***Snowden STOPESIZOR***.

SNOWDEN
STOPESIZOR

Figure 2: Snowden STOPESIZOR Logo

[1] A similar problem causes the Moving Cone technique to produce sub-optimal open-pit limits.

Capabilities of the New Product

The key features of ***Snowden STOPESIZOR*** are summarised below:

1. The resource model can be supplied in Whittle ***Four-D*** or ***Four-X*** format, or simply as a list of blocks and associated grades and relative densities.
2. The elements, processing methods, revenues, costs and adjustment factors can be specified in Whittle ***Four-D*** or ***Four-X*** parameter files.
3. A series of minimum three-dimensional stope sizes can be specified, each with their own individual cost parameters (or cut-off grades).
4. Dip angle constraints can be included.
5. Where required, the stopes can be constrained to be based on particular levels. In such cases, the average grade and tonnage for each stope size on each level can also be reported.
6. Minimum pillar widths can be specified.
7. Output is in the form of a configuration and sequence of stopes that is very close to the optimum for the specified design criteria. The results can be:
   (i) exported to other mine planning software packages (Datamine, Surpac, Vulcan, Gemcom, etc),
   (ii) saved in comma-separated value format for importing into spreadsheets (e.g. Excel), or
   (iii) saved in VRML format to facilitate 3D viewing and rotation.

Comparison with Existing Products

Within the constraints of the design parameters that can be accepted, the stope outlines and extraction sequence produced by ***Snowden STOPESIZOR*** will be very close to the optimum that maximises the NPV of the operation. As with the Whittle ***Four-D/X*** "best" cases, the extraction sequence produced is an "ideal" extraction sequence, which places few constraints on access requirements, and could rarely be used as the basis for a practical mining operation. However, it does provide an upper bound on the NPV that could be achieved using the specified combination of stope sizes.

Practical NPV-based Economic Optimisation

As for the strategic planning of open-cut mines using Whittle ***Four-D/X***, in order to obtain a realistic estimate of the NPV, it is necessary to make certain assumptions about the mining method and associated development and production rates. Once these decisions have been made, the reserve identified by the stope optimisation software can be scheduled and an estimate of the practically achievable NPV can be produced for a range of scenarios.

Typical Case Study

The application of ***Snowden STOPESIZOR*** is best illustrated by way of a case study.

In this case study, the geometry of the ore-body lends itself to an open stoping operation. Access will be gained via a decline, the development of which is to lead the stoping operation by a minimum of 6 months. Mining will proceed from the top down. The interlevel spacing will be 45m.

The following stoping methods and sizes are to be used:

- 22.5m x 22.5m x 45.0m open stoping
- 22.5m x 15.0m x 45.0m uphole retreat stoping
- 22.5m x 7.5m x 15.0m cut-and-fill stoping

The maximum decline and production advance rate is to be 50 vertical metres per year.

Snowden STOPESIZOR can be used to generate inventories for a range of cut-off grades for each stope size. All blocks identified by the optimiser will be processed as ore, regardless of the grade of the individual blocks. (The grade of the final stope is the critical consideration here.)

The stope inventories identified at each cut-off grade between 2.0g/t and 4.5g/t at 0.5g/t intervals are illustrated in Figures 3 to 8. The shading from dark to light indicates the extraction sequence that will maximise the NPV of the operation.

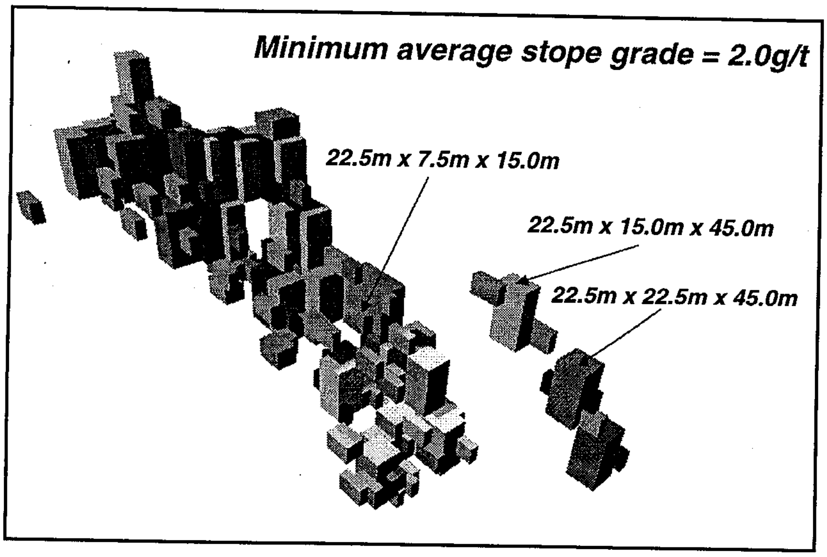

Figure 3: Stope Outlines at 2.0g/t Cut-off With the Various Specified Stope Sizes Indicated

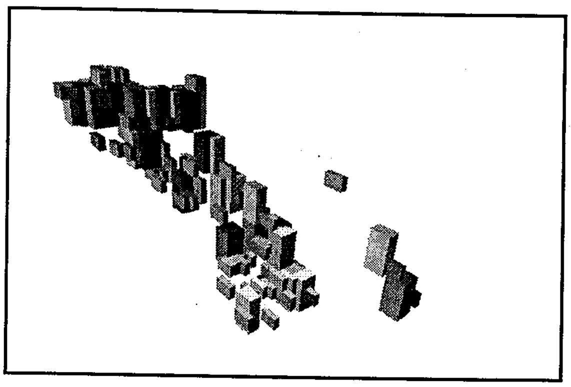

Figure 4: Stope Outlines at 2.5g/t Cut-off

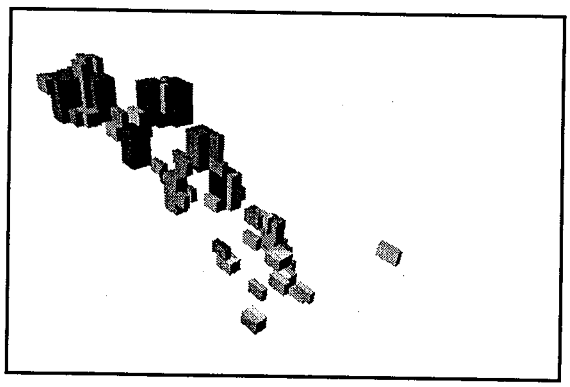

Figure 6: Stope Outlines at 3.5g/t Cut-off

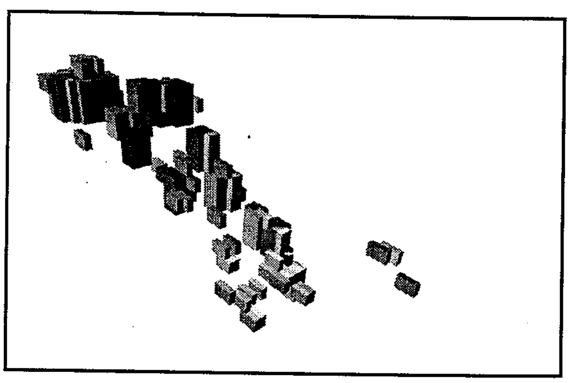

Figure 5: Stope Outlines at 3.0g/t Cut-off

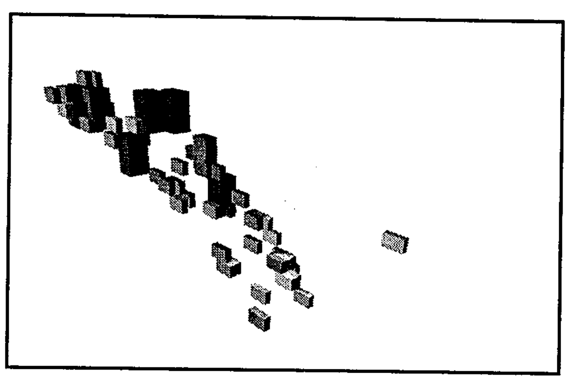

Figure 7: Stope Outlines at 4.0g/t Cut-off

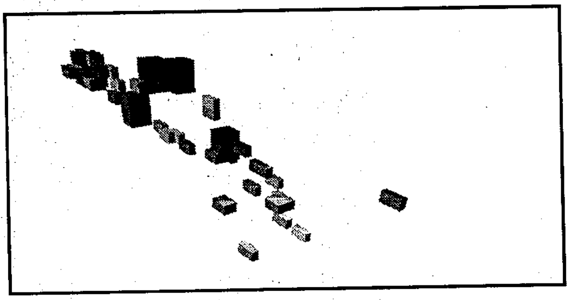

Figure 8: Stope Outlines at 4.5g/t Cut-off

These stope inventories can then be used to generate a grade-tonnage curve for the overall underground reserve. This is shown in Figure 9.

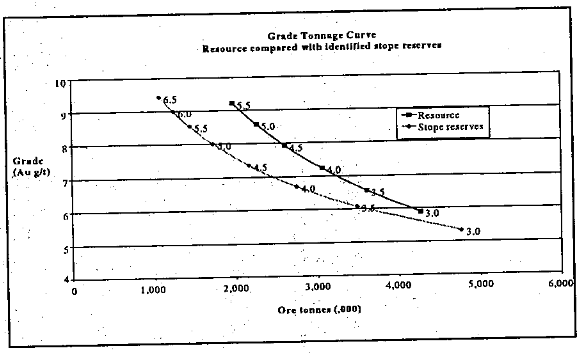

Figure 9: Grade-Tonnage Curves for the Resource and Identified Stope Reserves

Finally, suitable production rates can be selected and the operation can be scheduled. The NPV of the operation at each cut-off grade can then be determined. A typical graph of results is shown in Figure 10.

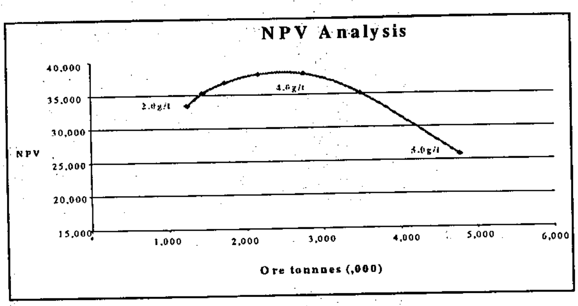

Figure 10: Graph of NPV vs Tonnage of Stope Reserves (for a particular production rate[2])

The optimum size and cut-off grade for the underground mining operation can then be determined.

Interaction with Whittle Four-D/X

Once the optimum size and configuration of the underground operation has been determined, the underground processing facilities[3] in ***Four-D/X*** can then be used to determine the optimum size of the open pit. The blocks identified by the stope optimiser should be allocated rock types to distinguish them from those blocks that are only to be mined in the open pit. Line types 30 and 31 should then be used to specify the associated underground processing methods and costs. The value assigned by ***Four-D/X*** to each potential underground block will be the difference[4] between the open pit and underground revenues for those blocks.

It is also possible that the stope optimiser will determine that no part of the resource can be mined economically using underground methods. In such cases, the underground processing options in ***Four-D/X*** should not be used at all.

Other Potential Applications

Other potential applications of ***Snowden STOPESIZOR*** include:

- Generating reserve grade-tonnage curves for a range of stope geometries.
- Determining the optimum stope size and inter-level spacing.
- Testing a range of production/cut-off grade scenarios without the need to go through tedious stope designs for each cut-off grade.

[2] Higher production rates could be expected to push the graph of NPV vs tonnage up and to the right, subject to the ability of the resource to sustain those higher rates.

[3] The underground processing facilities are described on p.325 of the Four-X Reference Manual of November 1998.

[4] The method used to determine block values is outlined on p.343 of the Four-X Reference Manual of November 1998.

- Producing graphs of NPV versus tonnage in order to determine the optimum production rate for an underground mining operation.
- Quantifying the risk associated with the reserve by quickly testing a range of resource simulations.
- Identifying the optimum stope outline as the first step to detailed stope and ring design.
- Quickly converting resources into underground reserves, particularly for scoping studies and pre-feasibility studies.
- Identifying the optimum open pit/underground cut-over point for a range of underground stope geometries and cut-off grades.

Future Developments

The research and development of ***Snowden STOPESIZOR*** is being directed towards generating even more practical stope outlines and extraction sequences. Future developments include:

- placing and sequencing the stopes to minimise the amount of sterilisation,
- optimising the size and location of pillars, and
- connecting the optimiser to ***Snowden MAXIMISOR***, Snowden's advanced conditional simulation toolkit. This will facilitate the generation of stope designs and sequences that minimise the risk of grade variations.

Conclusion

This paper has demonstrated how ***Snowden STOPESIZOR***, a second-generation stope optimisation tool, can be used to quickly[5] assess the potential of an underground resource. By using the same concepts that are widely applied within the open pit strategic mine planning arena, it is now possible to determine the optimum size and configuration of an underground mining operation. In this sense, the new tool can be considered to be the underground equivalent to Whittle ***Four-D/X***.

Acknowledgements

The authors would like to thank their colleagues at Snowden Mining Industry Consultants for their assistance in preparing this paper.

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[5] All the results and analyses required for this paper were completed in less than 2 days.