



3DEXPERIENCE®

Whittle 4.7.1 : Pseudoflow & CAPEX Optimisation

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Topics

Pseudoflow

CAPEX Optimization

Lerchs-Grossmann

P-48 copy

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Co. Ltd.

Optimum Design of Open-Pit Mines

Joint C.O.R.S. and O.R.S.A. Conference,
Montreal, May 27-29, 1964

Transactions, C.I.M., Volume LXVIII, 1965; pp. 17-24

ABSTRACT

An open-pit mining operation can be viewed as a process by which the open surface of a mine is continuously developed. The planning of mining programs involves the design of the final shape of this open surface. The approach developed in this paper is based on the following assumptions: 1. the type of material, its mine value and its extraction cost are given at each point; 2. restrictions on the geometry of the pit are given (surface boundaries and maximum allowable wall slopes); 3. the objective is to maximize total profit — total mine value of material extracted minus total extraction cost. Two numerical methods are proposed: A simple linear programming algorithm for the two-dimensional pit (or a single vertical section of a mine), and a more elaborate graph algorithm for the general three-dimensional pit.

Open-Pit Model

Besides pit design, planning may bear on questions such as:

- what market to select;
- what upgrading plants to install;
- what quantities to extract, as a function of time;
- what mining methods to use;
- what transportation facilities to provide.

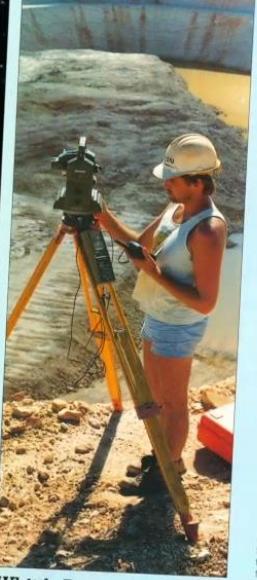
There is an intimate relationship between all the above points, and it is meaningless to consider any one component of planning separately. A mathematical model taking into account all possible alternatives simultaneously would, however, be of formidable size and its solution would be beyond the means of present knowhow. The model proposed in this paper will serve to explore alternatives in pit design, given a real or a hypothetical economical environment (market situation, plant configuration, etc.). This environment is described by the mine value of all ores present and the extraction cost of ores and waste materials. The objective then is to design the contour of a pit so as to maximize the difference between the total mine value of ore extracted and the total extraction cost of ore and waste. The sole restrictions concern the geometry of the pit; the wall slopes of the pit must not exceed certain given angles that may vary with the depth of the pit or with the material.

Introduction

A SURFACE mining program is a complex operation that may extend over many years, and involve huge capital expenditures and risk. Before undertaking such an operation, it must be known what or where there is to be mined (types, grades, quantities and spatial distribution) and how much of the ore should be mined to make the operation profitable.

The reserves of ore and its spatial distribution are estimated by geological interpretation of the information obtained from drill cores. The object of pit de-

Lerchs-Grossmann



THE ULTIMATE IN ECONOMIC PLANNING

Pit optimization is not only practical and quick - it makes design easier and produces more profitable pits.

Whittle Programming, a small Australian company specialising in technical software, has produced two packages which have revolutionised the way in which the mining industry approaches open pit design.

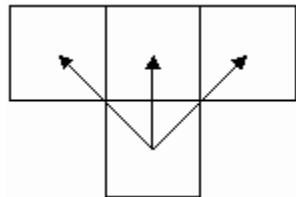
*
Three-D: The Whittle Programming Lerchs-Grossmann Package for Open Pit Optimization provides a moderately priced tool which determines the most profitable way to mine an ore-body for a given set of economic circumstances.
Because the outline it produces is the optimum - and this is on the horizontal part of the value/tonnage curve - small modifications can later be made to suit practical requirements, such as safety berms and haul roads, without significantly affecting the value of the pit.
Written in 1985, **Three-D** is being used successfully in various parts of the world. It is also included in the teaching programs at a number of tertiary institutions in the USA, Canada and Australia.
Since it was found that some users were running **Three-D** repeatedly for differing sets of economic circumstances, Whittle Programming produced a second, highly sophisticated package which provides the facility to do this in a single operation.

*
Four-D: The Whittle Programming Four-Dimensional Open Pit Optimization Package goes far beyond simple optimization. It provides the ultimate in sensitivity analysis by taking into account the fourth dimension — **the economic factors**.
By producing a nested set of optimal pits, typically thirty or forty, **Four-D** allows the swift examination of a range of possibilities under a varying set of economic ratios, with mining schedules and cash flows for each. Thus, in preparing the budget of today, the mine planner can examine the effect of tomorrow's economic possibilities.
Since its release in October 1987, the package has been installed at several sites and is being used by consultants contracting to large mining companies. It provides a valuable tool for economic productivity and sets a new standard in mining technology.
Both in concept and in practical application, it is unique in the world.

Whittle Programming

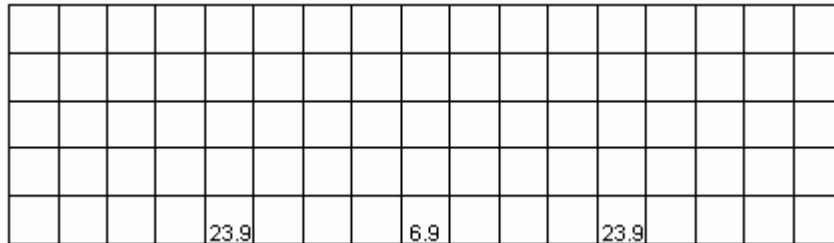
Lerchs-Grossmann

- ▶ The objective of LG in it's simplest form is to
 - ▷ Determine the exact optimal shape for a Open Pit in three dimensions
 - ▷ Using the value of the block and subject to the required pit slopes
 - ▶ The shape
 - ▷ Includes every block that is "worth mining" when waste stripping is taken into account.
 - ▷ Excludes every block that is not "worth mining".
- The method uses the Values of the blocks and slopes, represented by “structure arcs”.



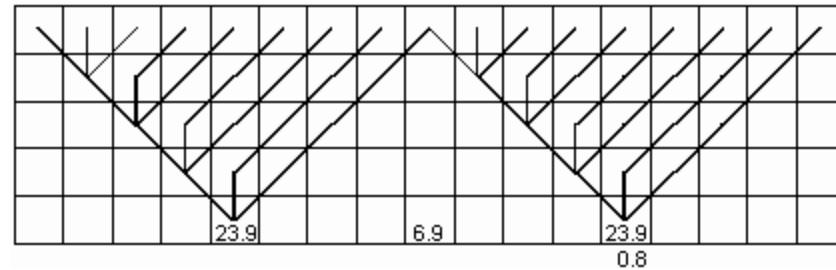
Lerchs-Grossmann

- ▶ This model is 17 blocks long and 5 blocks high.
 - ▶ 3 blocks contain potential ore,
 - ▶ All other blocks are waste and have the value -1.0



Lerchs-Grossmann

- ▶ This is the ultimate Pit Shape for those parameters.



Lerchs-Grossmann

- ▶ The previous problem covers off on a few different mathematical concepts
 - ▷ Set & Graph, and
 - ▷ Maximum Closure of a Set.
- ▶ The same sort of problem can be described like this
- ▶ These same concepts have been extended in the field of *Operational Research* to produce the likes of Pseudoflow as published by Hochbaum in 2008

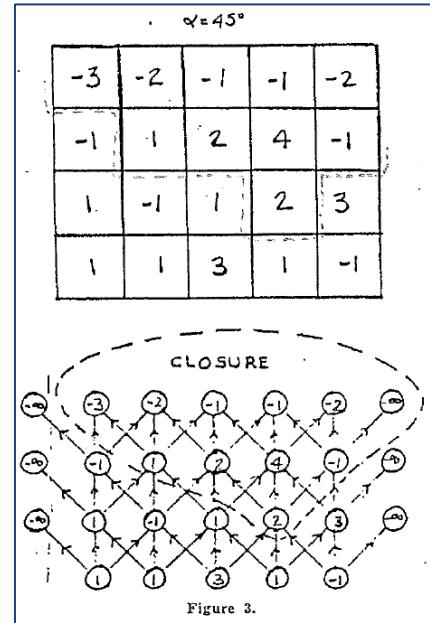
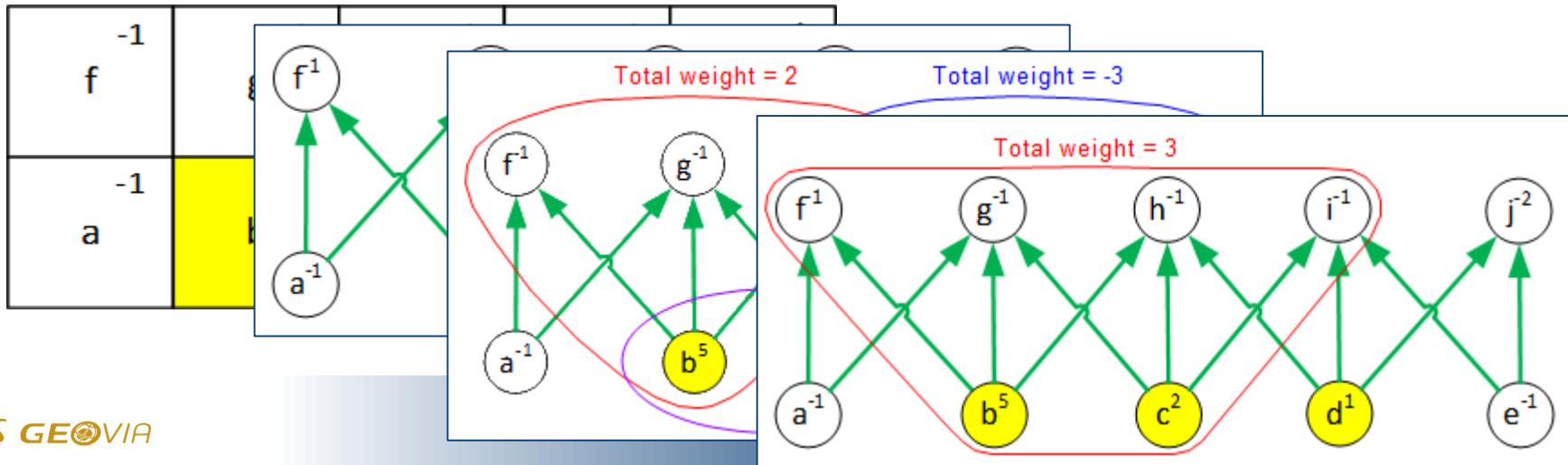


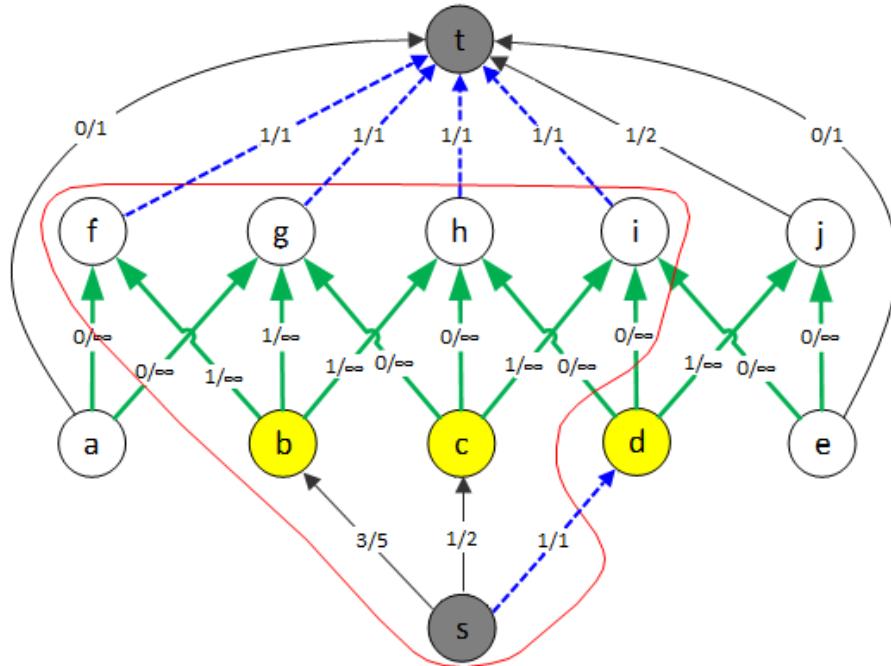
Figure 3.

Pseudoflow

- ▶ The objective of Pseudoflow is to solve the same problem, but research has shown it is more efficient than the other methods
- ▶ The same concepts of *Set & Graph* is used, however instead of solving directly for *Maximum Closure of the Graph*, you solve for a variated version of the graph, a *flow graph* or a *flow network*.

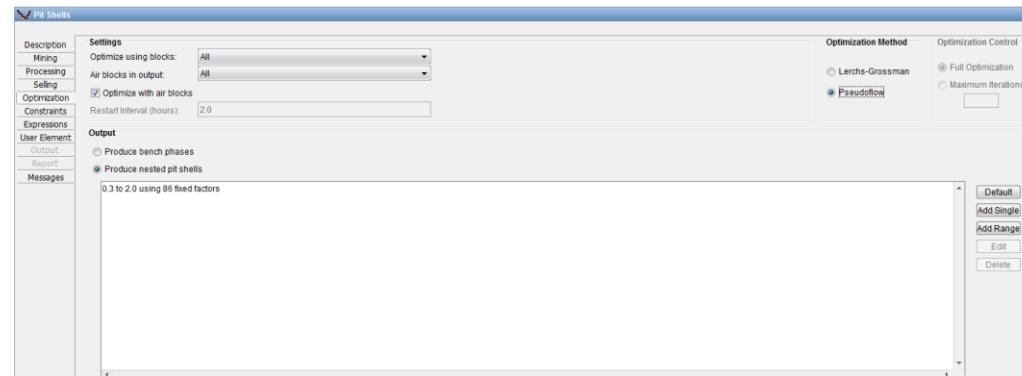


Pseudoflow

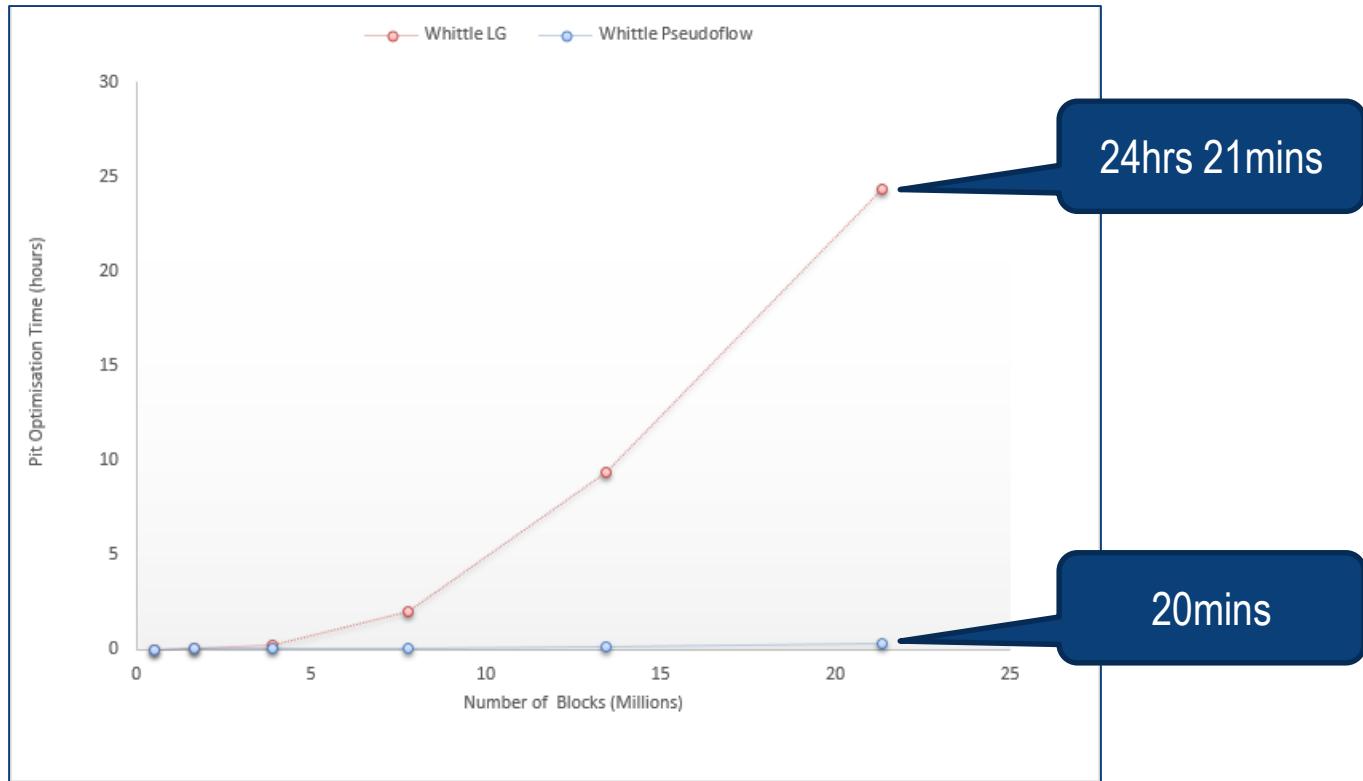


Whittle

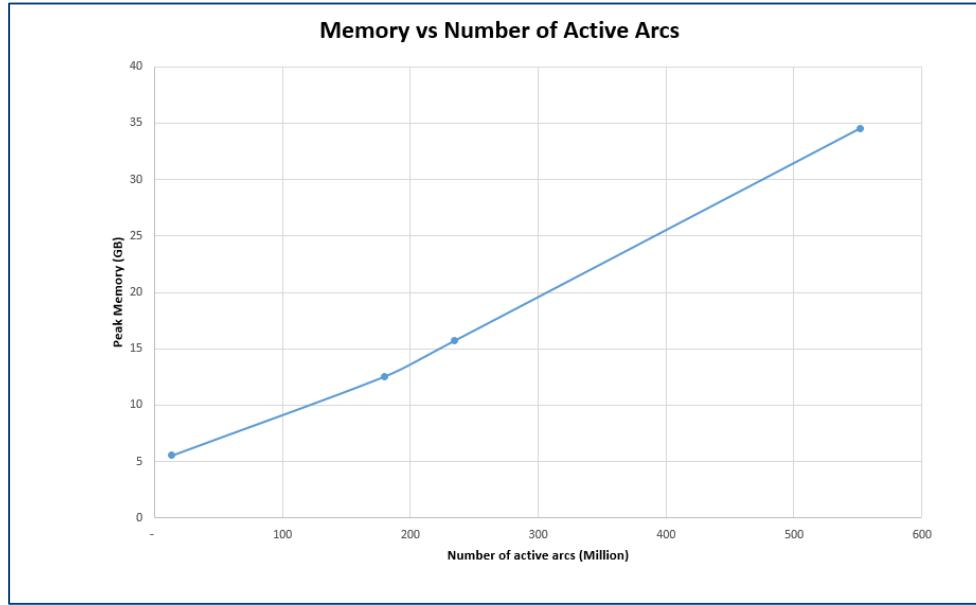
- ▶ Pseudoflow will be available as part of *Whittle Core* and in the *Whittle 4.7.1* release, this is scheduled for 7th July,
- ▶ Only enabled within the *64 bit* version of Whittle,
- ▶ And then, only within the *64 bit* Engine, and
- ▶ From the *Optimization Tab*, the user will need to select Pseudoflow if they wish to use it.



Whittle – Timing Comparison with 9 Revenue Factors

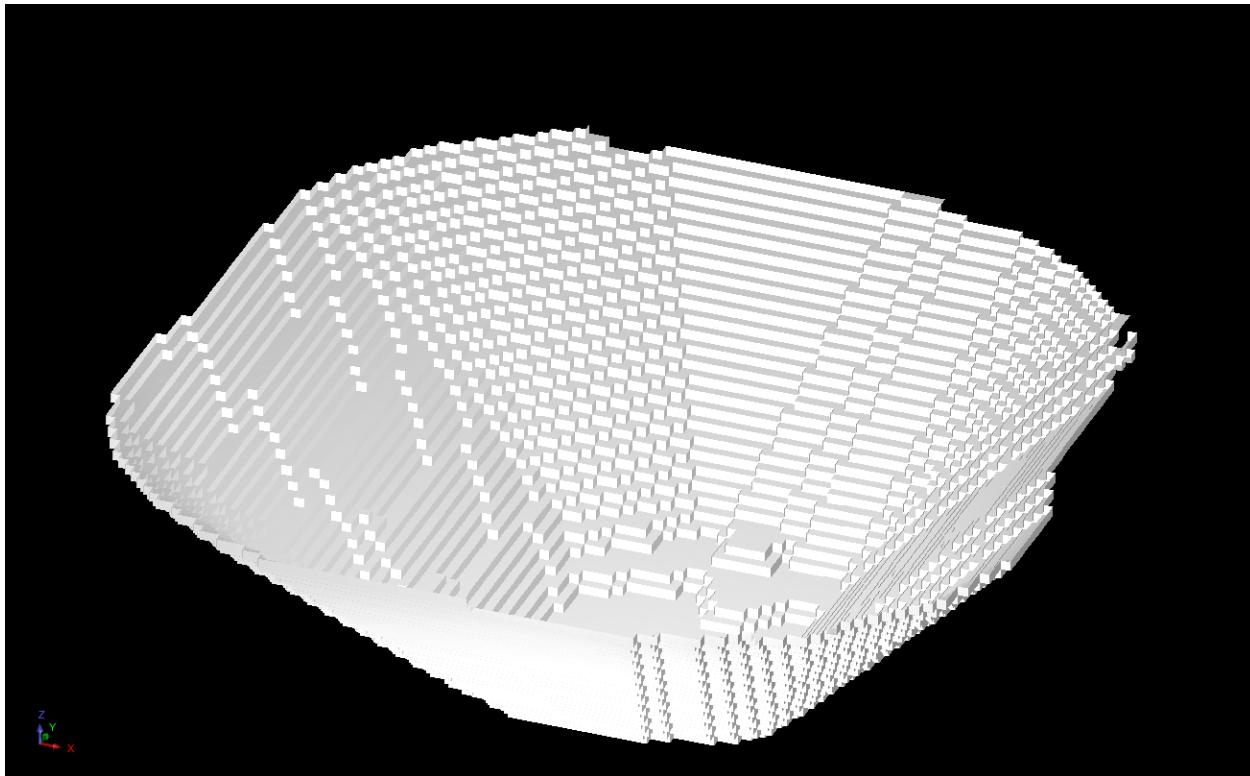


Whittle – Memory Use

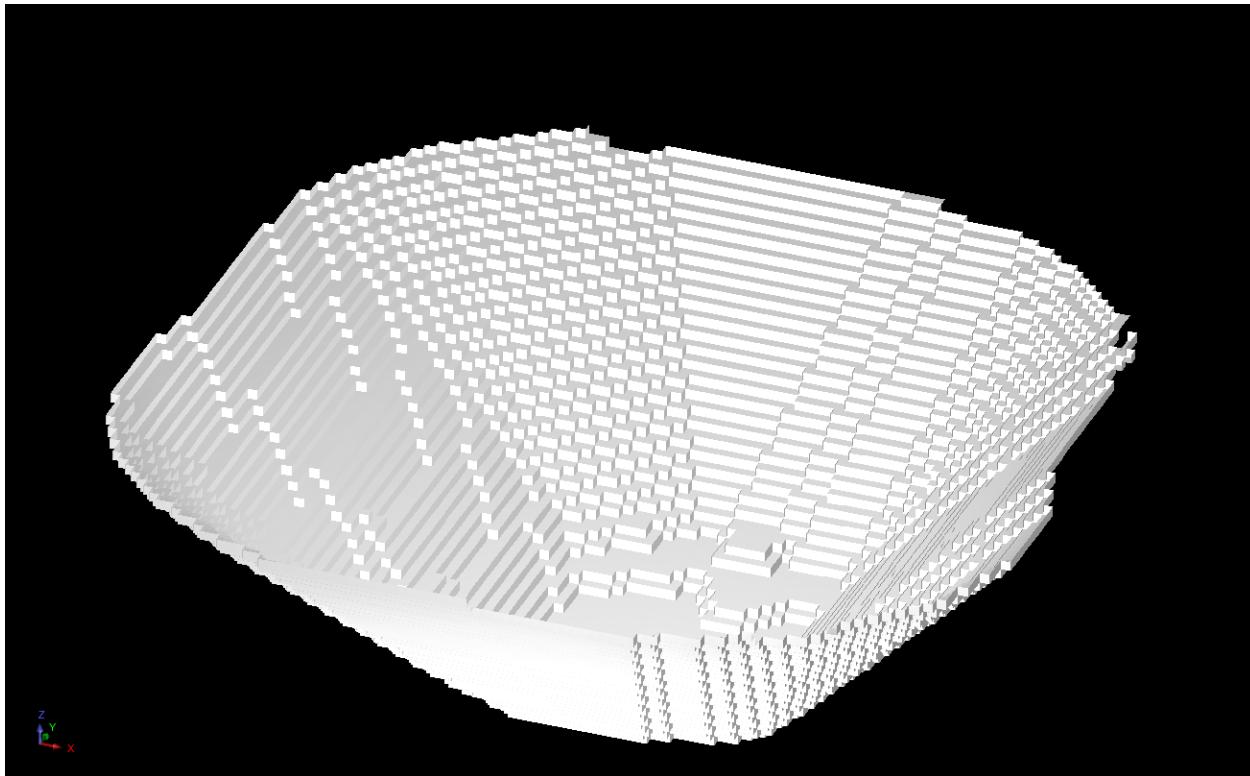


RAM (GB)	8	16	32	48	64
Active Arcs (M)	103	238	509	779	1,049

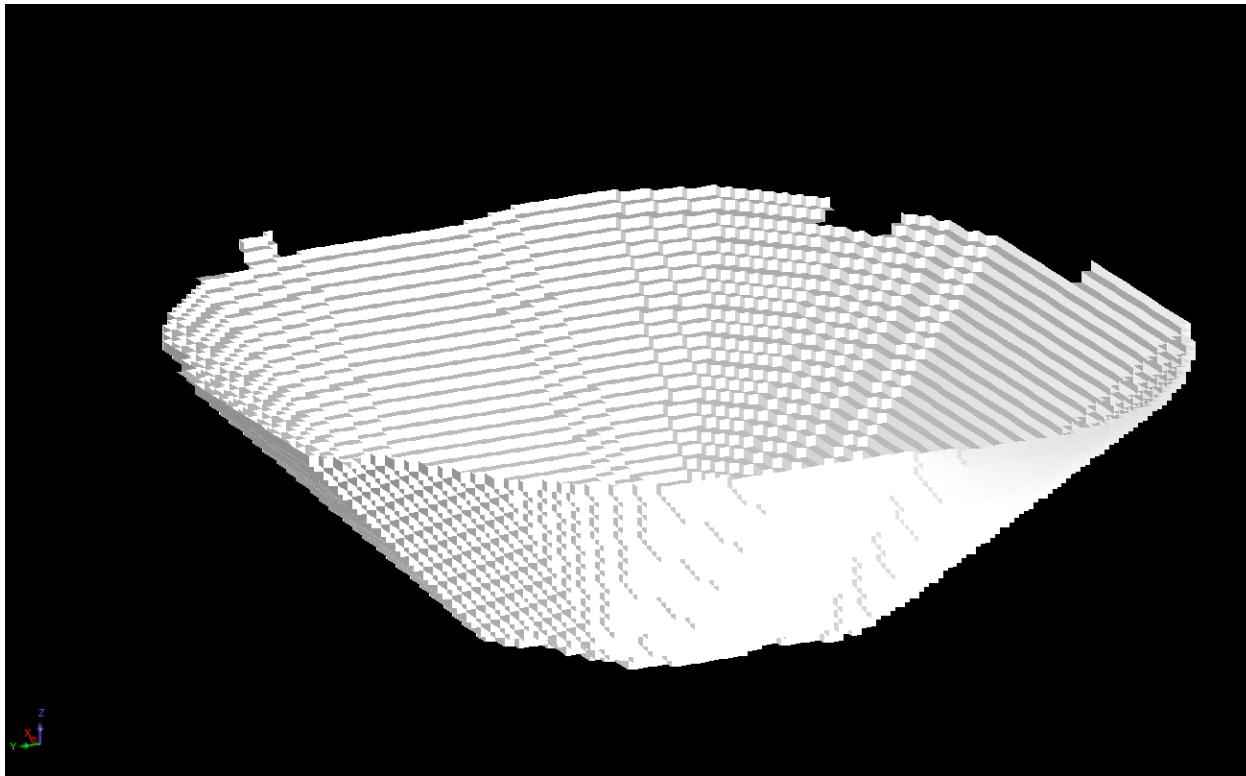
Whittle – Differences in the results: LG Pit 1



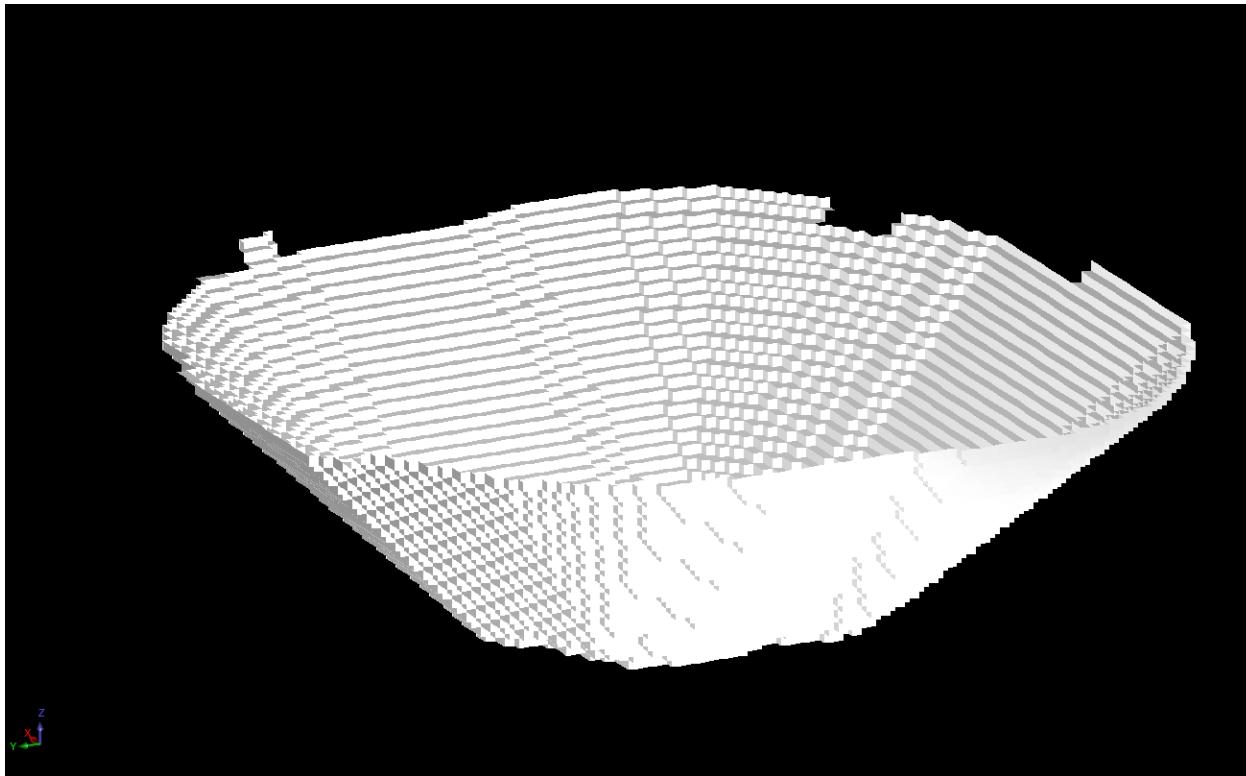
Whittle – Differences in the results: PS Pit 1



Whittle – Differences in the results: LG Pit 2



Whittle – Differences in the results: PS Pit 2



Whittle

Optimization pit summary LG												
Pit	Minimum Rev Ftr	Maximum Rev Ftr	Rock Tonnes	Ore Tonnes	Strip Ratio	Max Bench	Min Bench	AU Units	AU Grade	CU Units	CU Grade	
			x1000	x1000								
1	0.385714	0.385714	93	46	1.03	31	29	36524	0.8	10043	0.22	
2	0.471429											
Optimization pit summary Pseudoflow												
Pit	Minimum Rev Ftr	Maximum Rev Ftr	Rock Tonnes	Ore Tonnes	Strip Ratio	Max Bench	Min Bench	AU Units	AU Grade	CU Units	CU Grade	
			x1000	x1000								
5	0.728571											
6	0.814286	1	0.385714									
7	0	2	0.471429									
8	0.985714	3	0.557143									
9	1.071429	4	0.642857	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	1.157143	5	0.728571	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	1.242857	6	0.814286	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	1.328571	7	0.9	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	1.414286	8	0.985714	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	1	9	1.071429	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		10	1.157143	7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		11	1.242857	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		12	1.328571	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		13	1.414286	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		14	1.5	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
				12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
				13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
				14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

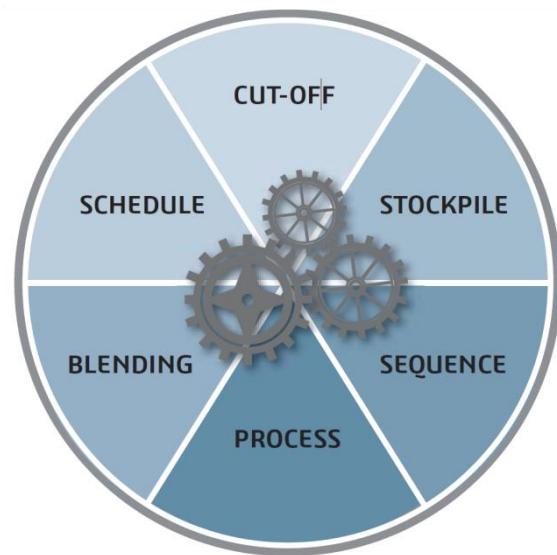
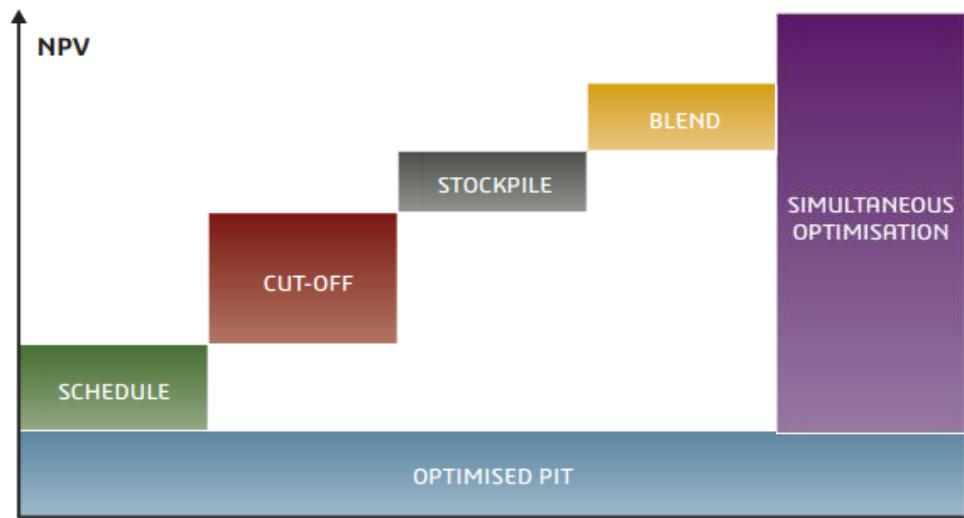
Topics

Pseudoflow

CAPEX Optimization

Simultaneous Optimization – SIMO

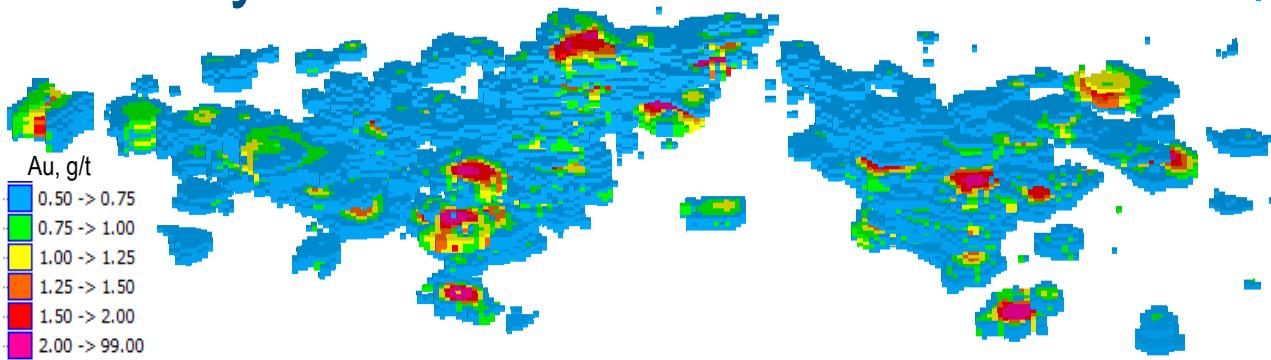
- GEOVIA Whittle Advanced Strategic Scheduling tool
- Optimises inputs simultaneously over life of mine
- Unlocks the hidden NPV



Example 1: Dataset by Minelib

<http://mansci-web.uai.cl/minelib/>

Block size 7.5 x 7.5 x 6
2.14 Mln blocks
Au grade only

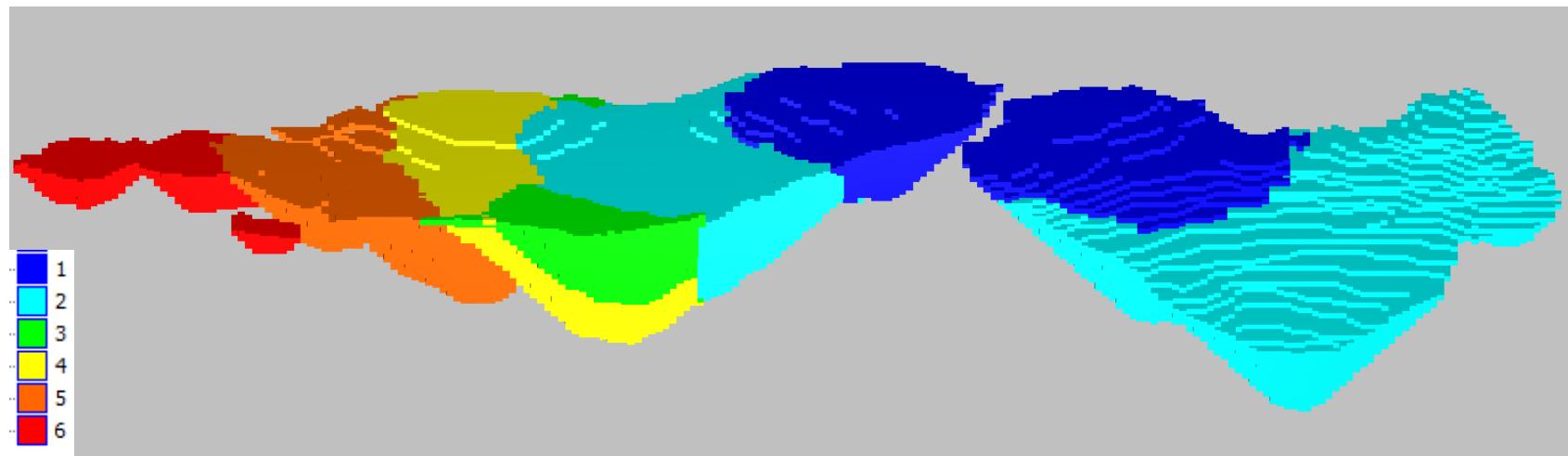


Study Inputs:

Mining cost	\$1.32/t	Slope angle	45 degrees
Processing cost	\$19/t	Mill capacity	3.3 Mt/year
Mining Dilution	5%	Vertical Advance Rate	60 m
Mining Recovery	95%	Disc. Rate	15%
Processing Recovery	90%	Stockpile	
Au price	\$1300/oz	Rehandling Cost	\$0.5/t

Step 1 – Pit Optimisation and Cutback selection

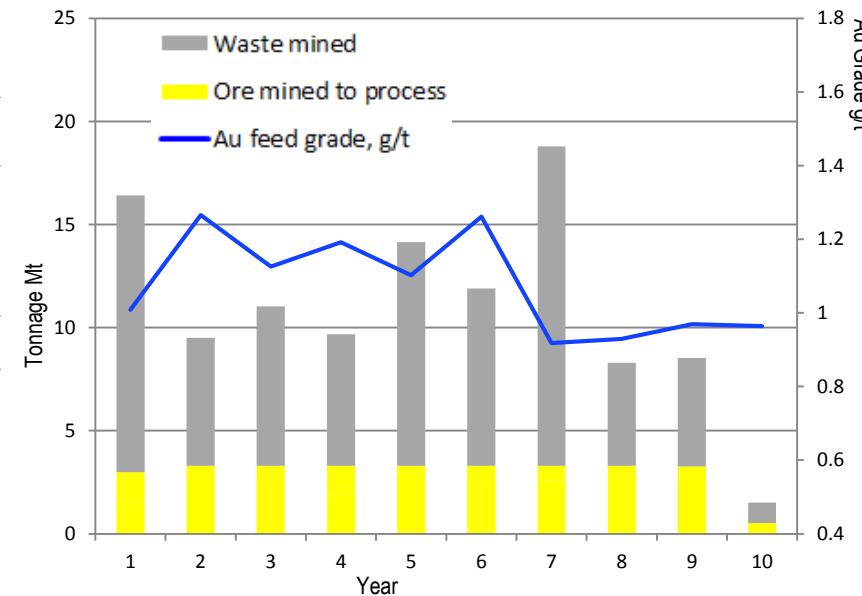
NPV Practical Pushbacks (Mining Width 30m)



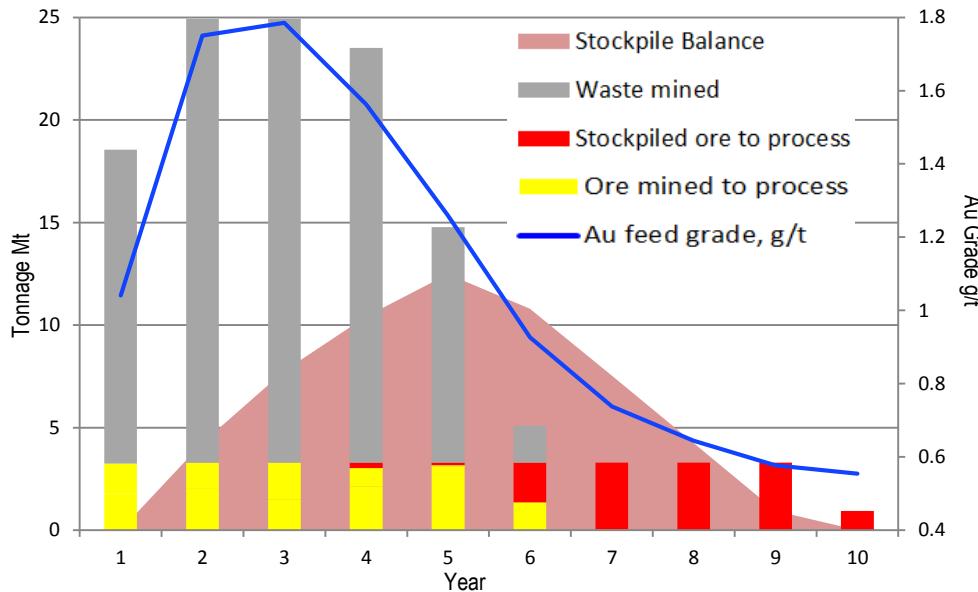
Milawa vs SIMO schedule comparison

Milawa NPV Schedule **NPV \$275M**

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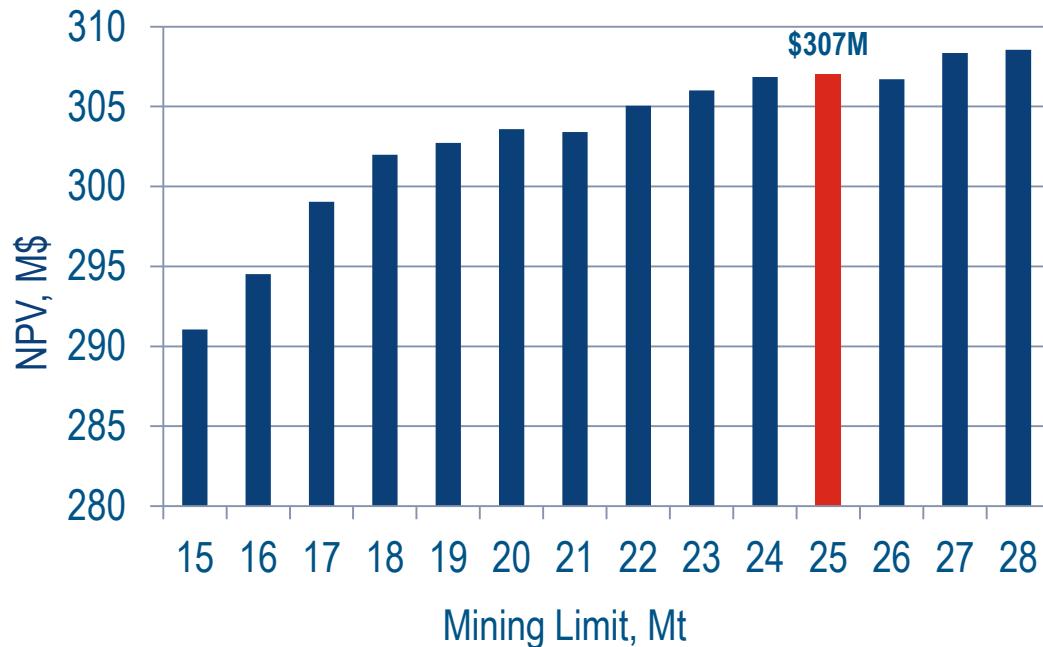


SIMO Schedule **NPV \$307M 12% increase**



Mining Limit Scenario Analysis – Contractor Mining

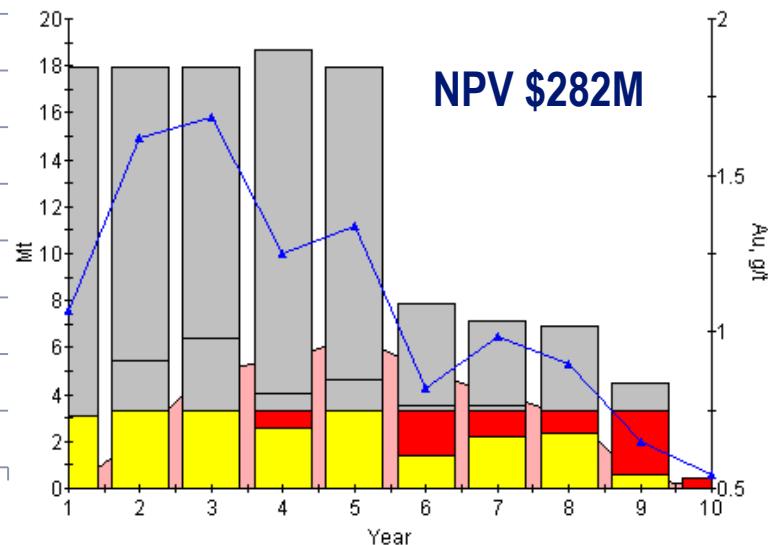
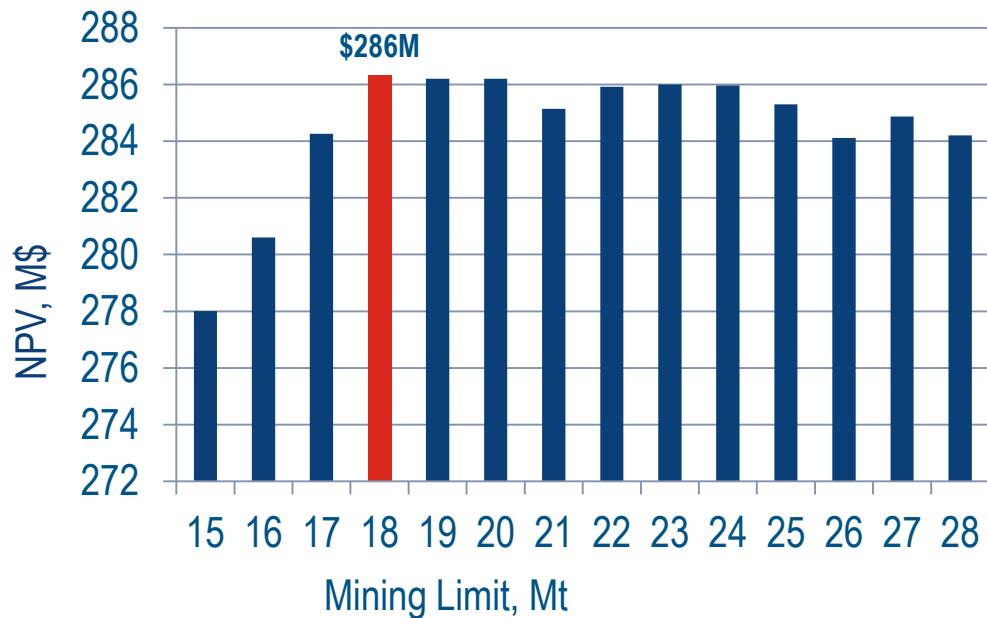
Assume No Capex



- 16Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 17Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 18Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 19Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 20Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 21Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 22Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 23Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 24Mt Mining 3.3Mt Mill
- 7 bins VRA10
- 25Mt Mining 3.3Mt Mill
- 7 bins VRA10

Mining Limit Scenario Analysis – Owner Mining

Assume Capex \$1/t



Mining fleet replacement in Year 6?

Traditional Mining Limit Scenario analysis



- ▶ Multiple Scenarios
- ▶ Iterative
- ▶ Time consuming

Mining Limit – SIMO CAPEX Optimisation

Mining Capex Optimisation setup

The screenshot shows the 'Simultaneous Optimisation : 7 bins VRA10' window. On the left, a vertical menu includes: Description, Selling, Optimization, Blend Bins, Schedule, Stockpiles, Summary, Report, and Messages. The 'Messages' item has a red box around it. In the main area, under 'Run Control', the 'Advanced optimisation controls' radio button is selected. A red box highlights the 'Enable Capex Optimisation' checkbox, which is checked. Below this, under 'CAPEX Optimisation', there is a 'Global Mining Limit' table:

Mining Limit (tonnes)	Additional Capacity (tonnes)	Additional Capacity Costs (\$/tonne)
0	30000000	1 P6/1

A red box highlights the info icon in the 'Additional Capacity Costs' column.

A modal dialog titled 'Period Variation' is open, showing a table with two rows:

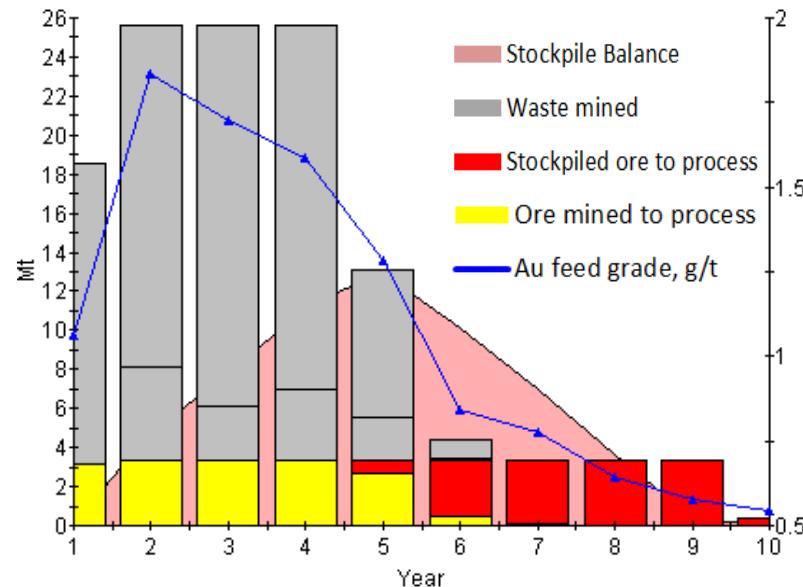
Period	Value
1	1
6	1

Buttons for 'Add', 'Delete', and 'Copy All' are visible on the right, along with 'OK' and 'Cancel' buttons at the bottom.

Mining Limit – SIMO CAPEX Optimisation

Schedule Results

NPV \$285M



Sort : Schedule Report		
Period	New global mining limit	Undiscounted Additional Capacity Cost
1	25,685,200	25,685,200
2	25,685,200	0
3	25,685,200	0
4	25,685,200	0
5	25,685,200	0
6	1,578,060	1,578,060
7	1,578,060	0
8	1,578,060	0
9	1,578,060	0
10	1,578,060	0

Conclusions

CAPEX Optimisation in SIMO

- ▶ Saves time (less Scenarios)
- ▶ Better results – optimal limits for each period
- ▶ Better (practical) schedules – trucks also have value!
- ▶ Applicable at any period of mine life

To consider:

- ▶ Correct cost models are essential
- ▶ Mining limit doesn't include rehandling limit

