An Evolutionary Solution for Coal Reserves Modelling and Production Scheduling

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Introduction

- Coal deposits consisting of multiple layers commonly require a lot of time and effort to produce a representative geological model that will allow accurate estimation of reserves and provide a solid basis for effective mine planning.
- The transition from such a 3D geological model of stratigraphy to an effective Run-Of-Mine model that can be used to calculate reserves is a critical part of this process.
- Approaches to achieve this transition range from one-dimensional mineable coal compositing of drillhole data to more effective three-dimensional aggregation of mineable coal seams based on an appropriate stratigraphic geological model.

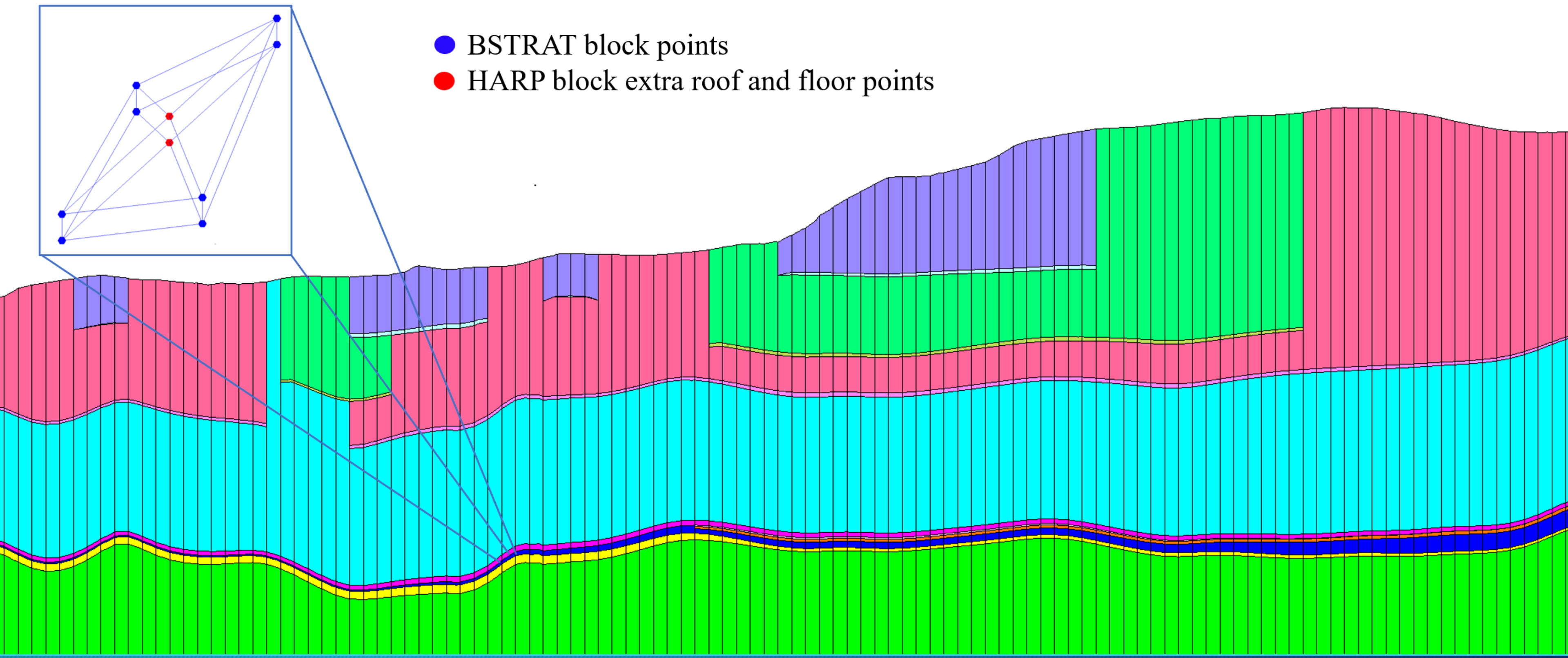
A Complete Solution

- The procedure discussed covers all aspects of generating a coal reserves model starting with a correlated drillhole database.
- Two closely interacting software solutions are presented that provide all necessary functionality to develop a coal reserves model and proceed with the scheduling of the produced reserves.
- Maptek Vulcan and particularly the Integrated Stratigraphic Modeller provides all the necessary functionality to produce a coal resource model using drillhole, topographical and tectonic data.
- Maptek Evolution allows for the development of the coal reserve model and production scheduling.

Maptek Vulcan, Integrated Stratigraphic Modelling and the HARP Model

- Vulcan integrates one of the most complete Integrated Stratigraphic Modelling modules (ISM) providing a variety of modelling methods to develop stratigraphic, structural and grade/quality grid models using an automated modelling process.
- A unique stratigraphic block model structure, the HARP (Horizon Adaptive Rectangular Prism) model, gives further flexibility and capabilities in stratigraphic reserves modelling.
- HARP's non-rectangular block models easily handle reverse faults and very thin horizons, that can be reserved against complex 3D solid shapes such as pit cutbacks and mining blocks.
- A single file contains all the structural, quality, faulting and associated data.

Horizon Adaptive Rectangular Prism Model



Development of a Stratigraphic Model Using ISM

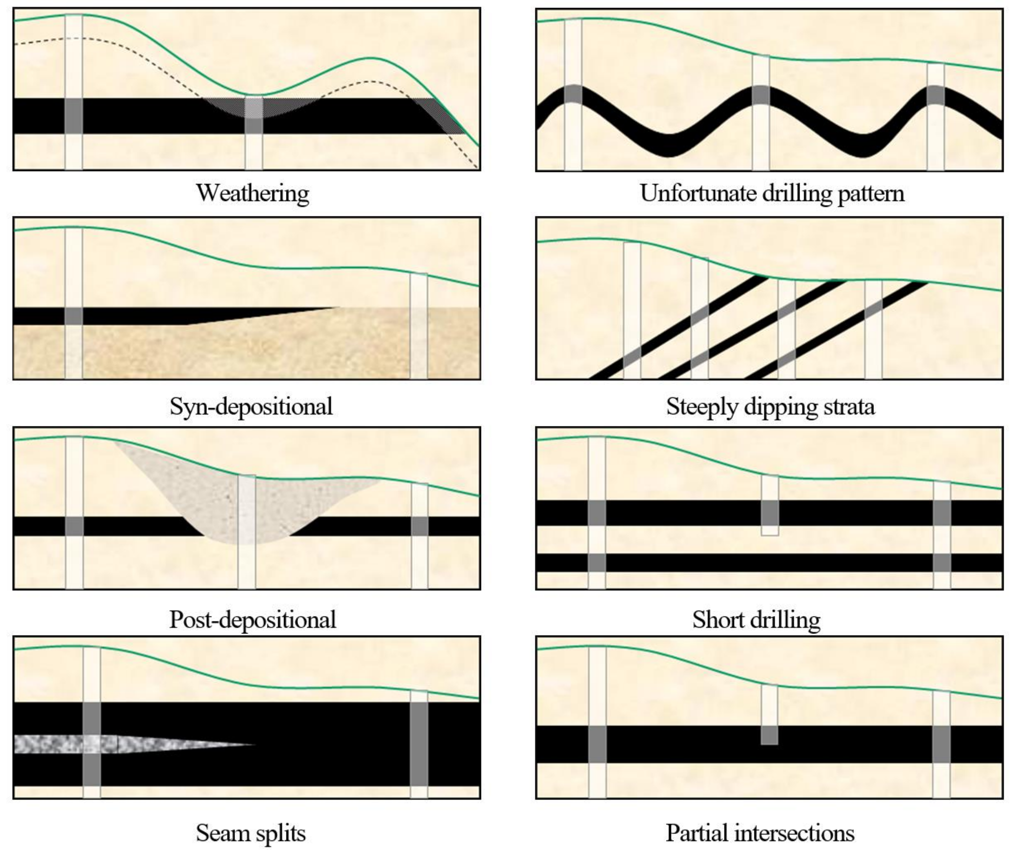
1. ***Database Validation***: the first step in the process is to validate the drillhole database in Vulcan and ensure all data entries are legitimate.
2. ***Drillhole Data Interpolation (FixDHD)***: FixDHD is an option of ISM used to interpolate missing stratigraphic horizons in drillhole data to improve stratigraphic modelling.
3. ***Stratigraphy Structural Modelling***: at this stage, the fixed stratigraphic information of the database is used to model structurally the roof and floor (upper and lower boundaries) of all horizons of interest as well as structural thickness, cropping and horizontal extents (masking).

Development of a Stratigraphic Model Using ISM

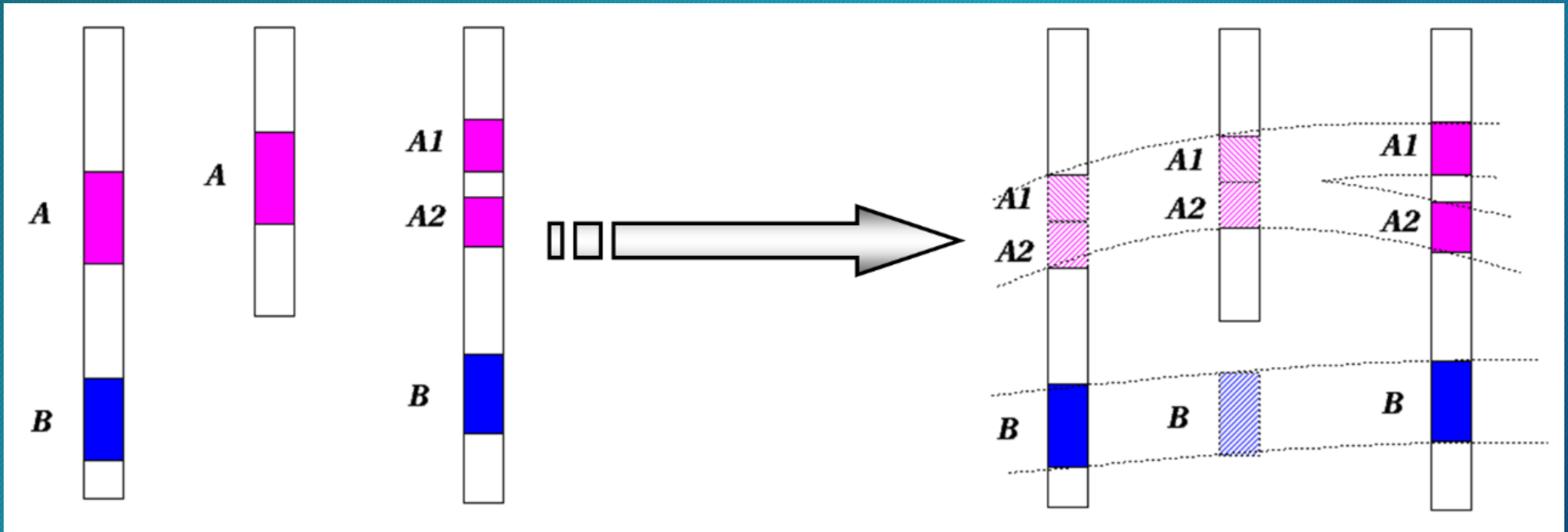
- ***Compositing and Modelling of Qualities***: at this step ISM produces a composite for any specific interval down a hole.
- ***HARP Model Generation***: a HARP model represents an entire Integrated Stratigraphic Model in a single block model file.
- ***Run-Of-Mine (ROM) Model Generation***: ISM simulates the manner in which material is extracted from a stratigraphic deposit and constructs the ROM model from the geological model using the minimum parting thickness, minimum mining thickness and minimum product to waste ratio.

Drillhole Stratigraphic Data Validation and Interpolation

- Typically, data for coal resource modelling is collected in the form of drillholes in which the positions of horizons of interest are logged.
- Rarely, however, are the data so perfectly collected so as to provide information about all of the horizons to be modelled in every hole.



Fixing Stratigraphy with FixDHD



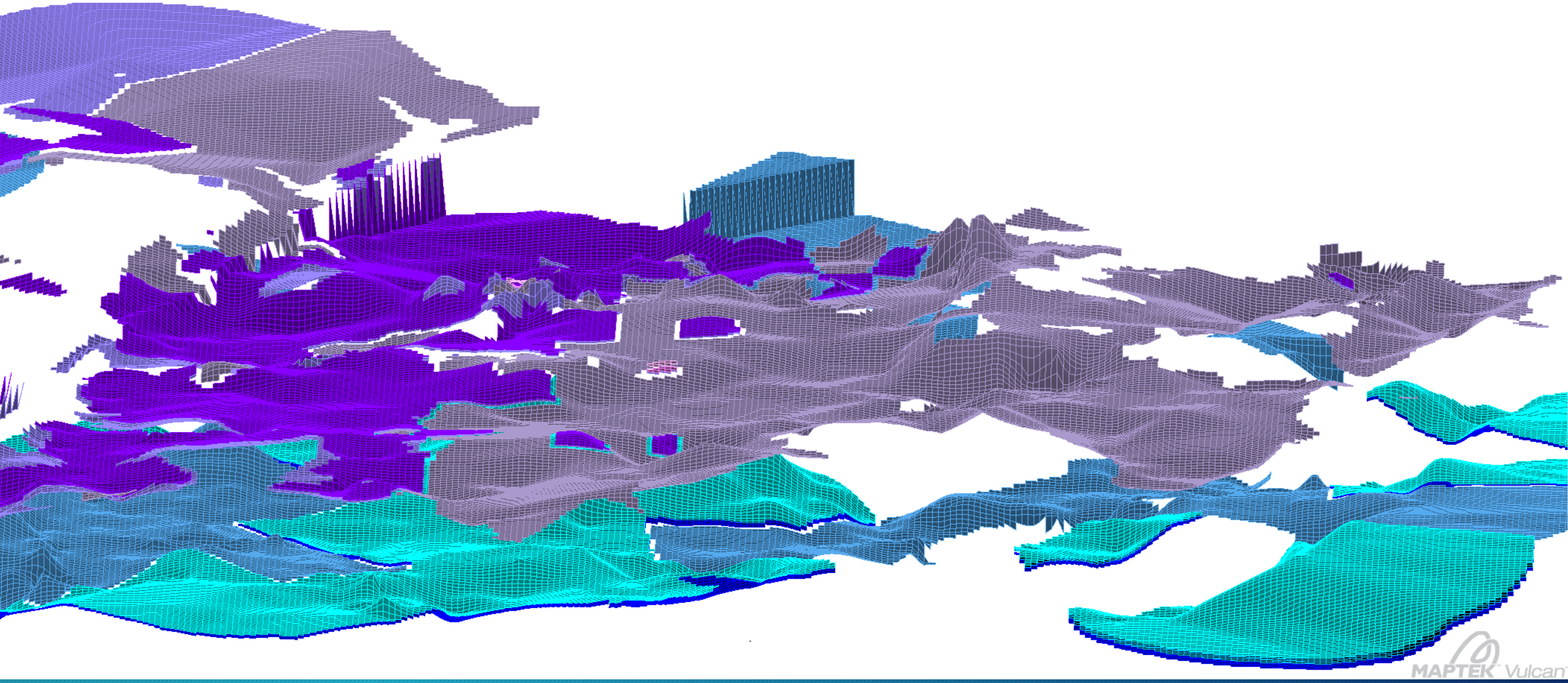
- Problems are resolved using various techniques provided by the FixDHD option of the ISM.
- FixDHD will attempt to fill in these gaps using statistical modelling techniques to determine the missing or unavailable data from the known data, and to manipulate the available data to meet the required criteria for modelling.

Structural Modelling

There are three main methods of creating a structural model in ISM:

- ***Stacking***: creates all horizon models based upon one selected structural surface that becomes a reference for creating the rest of the grids in the model by adding and subtracting thicknesses and midburdens from the reference surface.
- ***Structural Surfaces***: models individual roof and floor surfaces for each horizon using the available modelling algorithms.
- ***Hybrid***: is an enhanced Stacking method with the ability to include additional design CAD data for any roof, floor or thickness interval for any horizon adding extra control.

Structural Modelling



Compositing and Quality Modelling

- In addition to the structural models of the seams, it is necessary to model various coal quality parameters such as ash content, sulfur, insitu moisture, calorific value and density.
- As the original analyses on the drillholes do not necessarily follow the correlated and fixed stratigraphy after the application of FixDHD, it is necessary to composite these values to receive a single value for each parameter per correlated seam before modelling the parameter in two dimensions as a grid model.
- ISM generates files with all the composite values - one file per seam and uses the information in these files to model quality parameters per seam, commonly using the inverse distance weighting method.

HARP Model Development

- Traditional block models, including stratigraphic block models in Vulcan use cuboid blocks formed with right angles that cannot adequately represent roof and floor structures.
- A HARP model block contains 5 points in the roof of the block and 5 points in the block floor allowing vertex angles to fluctuate, which allows the block to conform to structure roof and floor grids.
- HARP models accurately resolve horizons down to a few centimetres of thickness.
- All structural and quality grid models are combined to form a single block model using the geometry of the HARP that allows it to match exactly the shape of the structural grids.
- All quality grid models become block model variables and their node values are transferred to the corresponding blocks.
- The produced HARP model becomes a complete database of coal resources for the project.

Run-Of-Mine Modelling with Maptek Evolution

- With the latest version, Maptek Evolution integrates a new coal seam aggregation (transformation) module that takes an in-situ model and produces practical run-of-mine reserves within a flexible, yet automated, step-based workflow system.
- The coal transformation module is designed to take the reserved insitu solids from a mine planning package and calculate step by step coal qualities and quantities for each stage of the mining and beneficiation process.
- The result of these calculations is the construction of a Coal Reserves Model.
- It uses a ‘pipeline’ calculation process that applies a series of pre-built or custom scripted transforms in order to perform these calculations.

Importing of the Stratigraphic Model

In our example, Maptek Evolution received the stratigraphic model of a coal deposit through a number of solid triangulations - each solid having a unique ‘address’ in the pit based on the following levels:

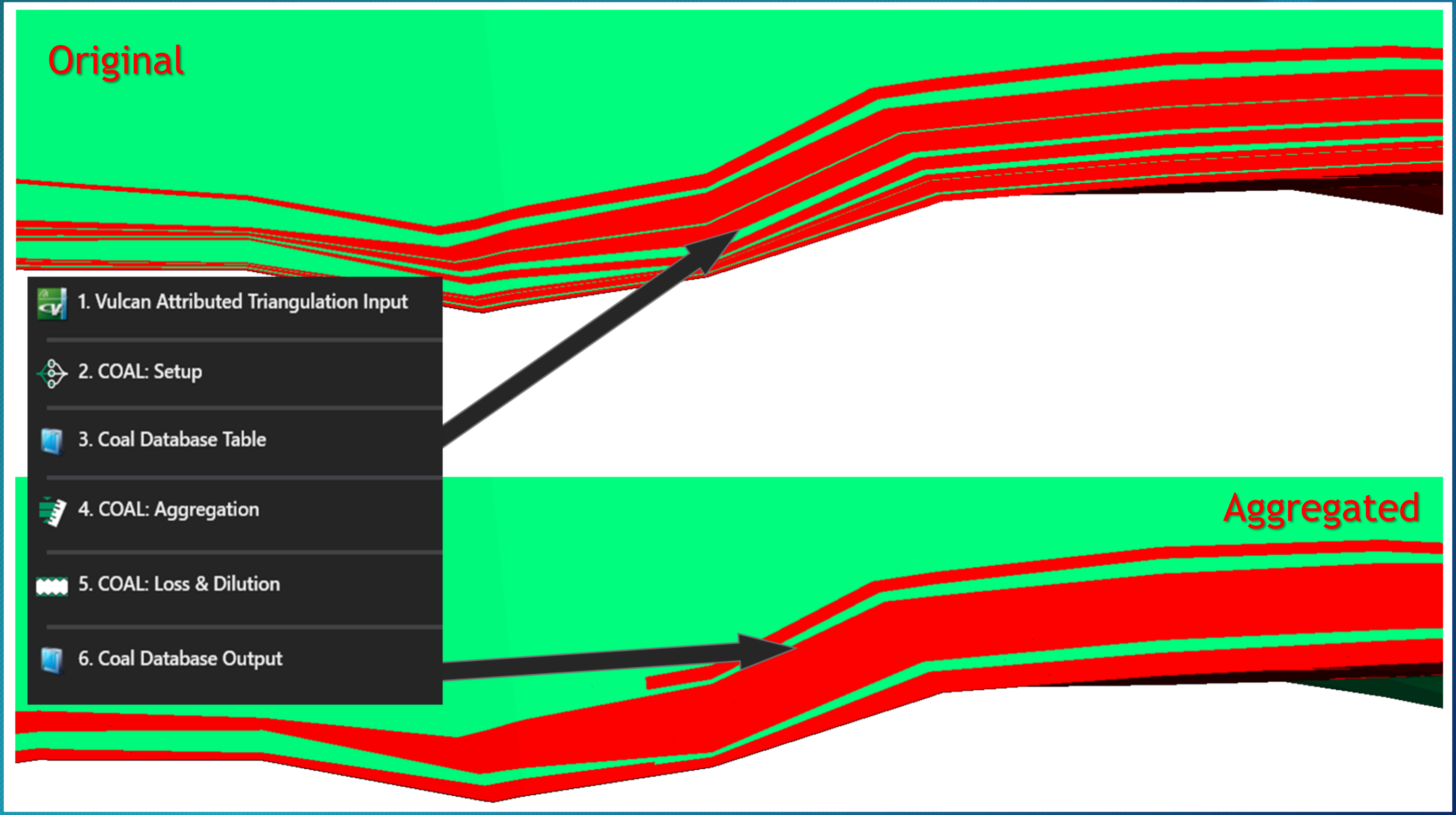
- Pit – individual pit code
- Strip – strip number or code
- Block – block number or code in a strip
- Seam – seam code the block belongs to
- Material – type of material (e.g. coal, overburden, midburden)

These solid models were created in Maptek Vulcan and assigned a number of attributes related to structural and quality resource parameters.

Development of the Coal Aggregation Process

- During the process of coal reserves model development in Maptek Evolution, the user can formulate a customised procedure of coal aggregation to convert the coal resources associated with the imported solids to coal reserves using the available coal database transformation options.
- A transform is a self-contained calculation that transforms incoming data, and then passes the result to the next transform.
- Available transforms include ***wasting***, ***aggregation*** and ***loss & dilution***.

Example of Coal Reserve Model in Maptek Evolution



Coal Production Schedulling with Maptek Evolution

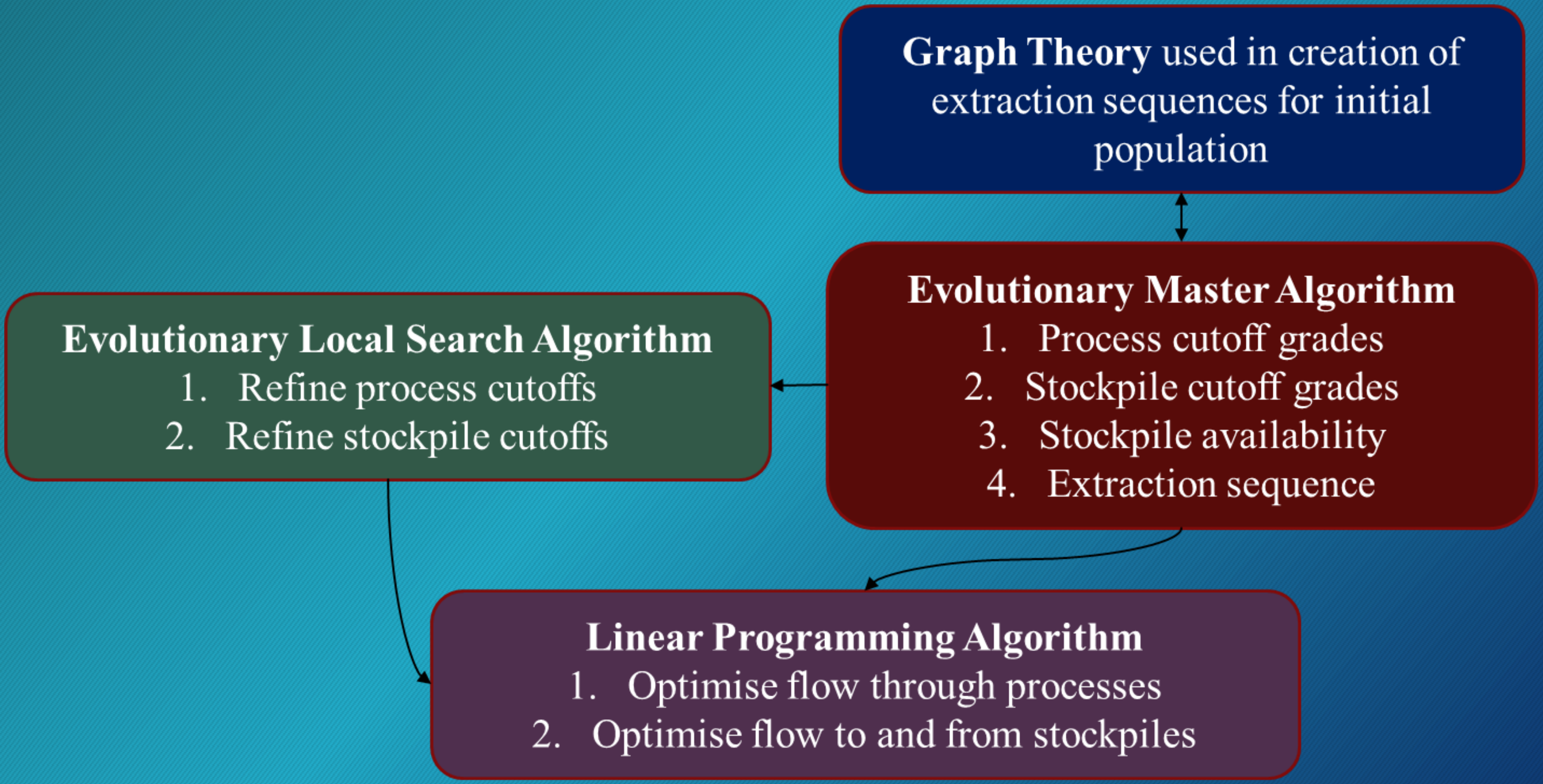
- Evolution consists of two main modules, *Strategy* and *Origin*.
- Strategy is a high-level scheduling solution focusing on value maximisation through the use of cutoff grade optimisation but allows for detailed constraint modelling as well (including blending).
- Origin is a tactical level scheduling system which allows the user to develop detailed mining schedules ready for medium term planning.
- The scheduling and optimisation functionality is cloud-based – the reserve model and schedule setup are transmitted to a cloud facility for processing.
- The scheduling solutions found are transmitted back to the user for further analysis and approval.

Scheduling Based on Evolutionary Algorithms

The main steps of scheduling operation are as follows:

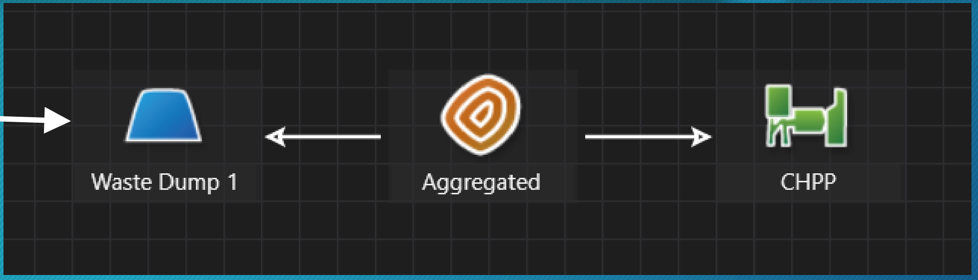
- Creation of the initial population including a geometrically correct extraction sequence. (Graph Theory)
- Calculation of the fitness of each individual and ranking of the population based on fitness. (Master and Local Search Evolutionary Algorithms)
- Iteration through successive generations by generating an offspring population where each child competes with the parents for the privilege to progress to the next generation. (Master Evolutionary Algorithm)
- The master algorithm calls on the secondary local search algorithm to boost the best individual found so far, by manipulating the threads through cut-off grade space whilst keeping the extraction sequence static. The improved individual is then sent back to the master where it replaces or upgrades its old self (analogue to exploring the local neighbourhood). (Local Search Evolutionary Algorithm)
- Steps 2 to 4 are repeated until no improvement is registered, in other words when the population loses diversity and converges on a single high fitness value.

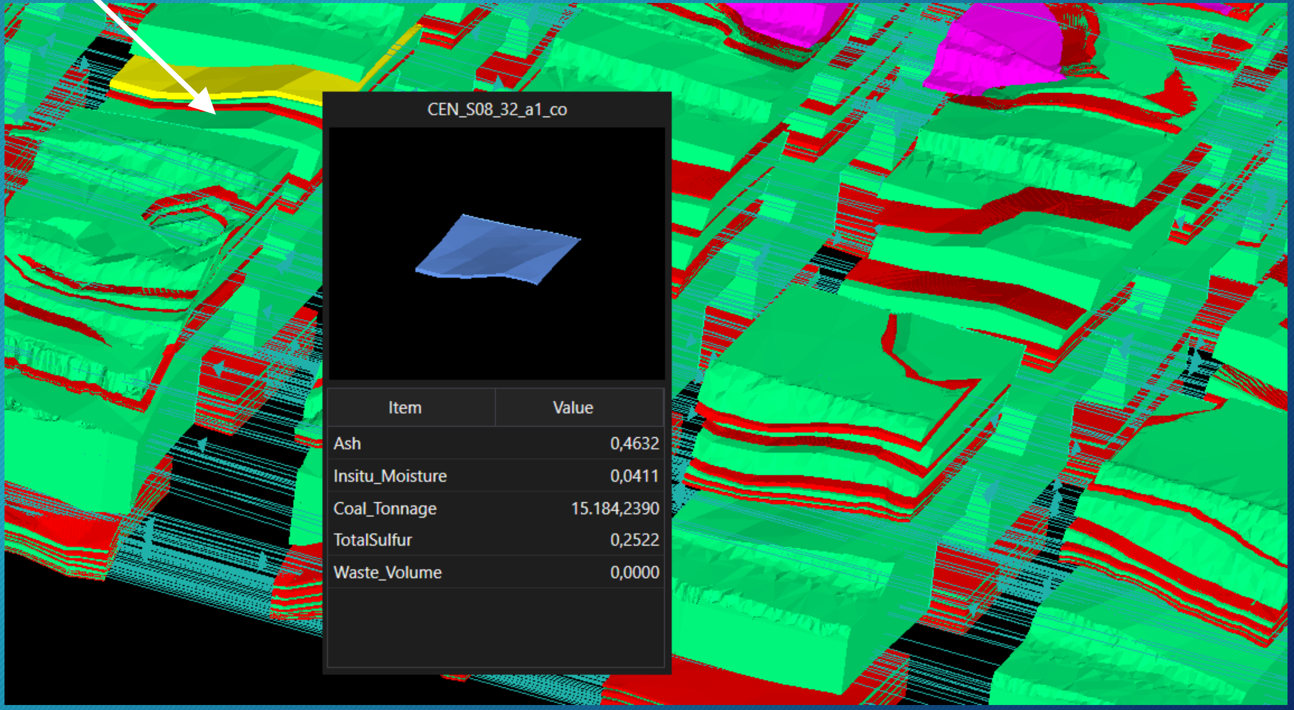
Scheduling Engine Components



Schedule Setup

- Flowchart
- Dependencies
- Calendar
- Objectives
- Constraints





Schedule Setup

- The ***flowchart*** is used to select and define the reserve source models, number of mills, stockpiles and waste dumps to be used in the schedule, highlighting the relationship between them by indicating the direction of material flow.
- ***Dependencies*** are mining sequence controls that define the feasible sequence of extraction and provide the ability to allocate specific equipment for each sequence.
- The ***calendar*** is used to define the number and length of periods in the schedule that can have different lengths, capacities, and utilisation.
- Material ***objectives*** are used to control the waste variance tolerance for each period of the schedule - the waste tolerance controls how hard the scheduler must work on each period to achieve the movement target. A higher percentage number will generate a lower fitness, whereas a lower percentage variance will result in the scheduler refining the result based on a higher fitness value.
- Evolution provides a number of ways to constrain the produced schedule, including ***constraints*** such as sink rate and stage sink rate, stage availability, stage bench turnover, waste area and stockpile availability, waste area dependency and required tonnage, accumulations (stage, model, global, global process and process), and global and process blend.

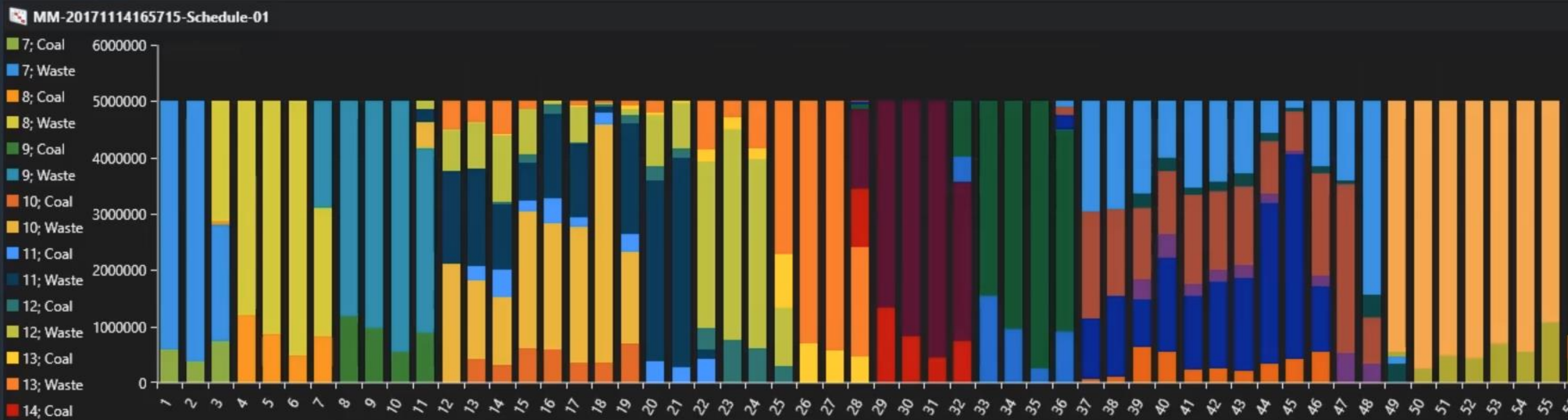
Example Schedule Calendar

Calendar | Start Date 17-Ιουλ-2018 | Split Into

Ore Definition

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10
Calendar										
Start Date	17-Ιουλ-2018	17-Ιουλ-2019	17-Ιουλ-2020	17-Ιουλ-2021	17-Ιουλ-2022	17-Ιουλ-2023	17-Ιουλ-2024	17-Ιουλ-2025	17-Ιουλ-2026	17-Ιουλ-2027
End Date	16-Ιουλ-2019	16-Ιουλ-2020	16-Ιουλ-2021	16-Ιουλ-2022	16-Ιουλ-2023	16-Ιουλ-2024	16-Ιουλ-2025	16-Ιουλ-2026	16-Ιουλ-2027	16-Ιουλ-2028
Days	365	366	365	365	365	366	365	365	365	366
Hours	8,760	8,784	8,760	8,760	8,760	8,784	8,760	8,760	8,760	8,784
Targets										
End of Period Target	Accumulation	Accumulation	Accumulation	Accumulation	Accumulation	Accumulation	Accumulation	Accumulation	Accumulation	Accumulation
Parcel Item Target	Tonnage	Tonnage	Tonnage	Tonnage	Tonnage	Tonnage	Tonnage	Tonnage	Tonnage	Tonnage
Target Value	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000
Total Mill Capacity (tonnes)	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Total Digger Available Hours	5,606.40	5,621.76	5,606.40	5,606.40	5,606.40	5,621.76	5,606.40	5,606.40	5,606.40	5,621.76
Total Max Digger Production (tonnes)	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168
Total Min Digger Production (tonnes)	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168
Digger 1										
Delay Hours	0	0	0	0	0	0	0	0	0	0
Utilisation (%)	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%
Availability (%)	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%
Unit Count	1	1	1	1	1	1	1	1	1	1
Available Hours	5,606	5,622	5,606	5,606	5,606	5,622	5,606	5,606	5,606	5,622
Max Production (tonnes)	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168
Min Production (tonnes)	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168	10,091,520	10,091,520	10,091,520	10,119,168
Mill 1										
Capacity (tonne)	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Ore Definition	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa	parcel.Name="Coa

Example of Coal Production Schedule



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7	Coal	592,093	380,903	743,645																	
	Waste	4,407,907	4,619,097	2,072,573																	
7 Total		**5,000,000**	**5,000,000**	**2,816,218**																	
8	Coal			57,906	1,213,561	875,298	487,330	823,118													
	Waste			2,125,876	3,786,439	4,124,702	4,512,670	2,284,460													
8 Total				**2,183,782**	**5,000,000**	**5,000,000**	**5,000,000**	**3,107,578**													
9	Coal								1,191,530	967,380	558,270	877,398									
	Waste							1,892,422	3,808,470	4,032,620	4,441,730	3,289,723									
9 Total								**1,892,422**	**5,000,000**	**5,000,000**	**5,000,000**	**4,167,121**									
10	Coal												16	431,306	326,743	619,294	583,921	369,369	349,457	695,522	
	Waste											466,743	2,117,340	1,385,790	1,186,096	2,427,908	2,242,525	2,388,169	4,234,705	1,634,945	
10 Total												**466,743**	**2,117,356**	**1,817,097**	**1,512,839**	**3,047,202**	**2,826,445**	**2,757,538**	**4,584,162**	**2,330,467**	
11	Coal												13	244,882	485,519	177,109	454,189	180,503	201,681	317,474	3

Conclusions

- Development of a sound coal resource model should be based on maximum usage of available sampling data, while converting the resource model to a reserve should be based on proper application of mining factors.
- Maptek Vulcan and its Integrated Stratigraphic Modelling module provide all necessary functionality to build an in-situ model of coal resources from drillhole data.
- Maptek Evolution takes the in-situ model and produces practical run-of-mine reserves in a flexible, yet automated, step-based workflow system which allows users to define relevant parameters.

Thank you for your attention!