Blasor—Blended Iron Ore Mine Planning Optimisation at Yandi, Western Australia

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Abstract A new mine planning optimisation software tool called Blasor has been developed and implemented at BHP Billiton's Yandi Joint Venture operation in the Pilbara. Blasor is specifically configured for designing and optimising the long-term pit development plan for the multi-pit blended-ore operation at Yandi. It is used for optimal design of the ultimate pits and the mining phases contained within those pits. In designing the mining phases, Blasor ensures that all market tonnage, grade and impurity constraints are observed whilst maximising the nett discounted cash flow (DCF) of the joint venture operation.

Introduction

In undertaking a life-of-mine development plan for multi-pit blended-ore mining operations, the mine planner is faced with difficult decisions regarding both the extent of ultimate pits and the design and precedence of the mining phases in each pit. Various commercially available optimisation tools are capable of determining optimal extraction sequences for existing blended-ore pit phase designs—for example NPV

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Scheduler, Minemax, ECS Maximiser and Whittle Consulting—but planners are usually forced to rely on a mixture of common sense heuristics and personal experience to design the ultimate pit boundary and the mining phase polygons, e.g. Dincer and Peters (2001) and Noronha and Gripp (2001). A typical pit and mining phase design procedure will require the planner to make arbitrary judgments on in-ground block value—an assumed cut-off grade decision—and then apply a Lerchs-Grossmann algorithm to obtain approximate pit and phase boundaries. These types of approaches become far less tractable when dealing with large multi-pit operations. AQ1

The result is that the design of mining phases in blended-ore operations depends largely upon the expertise and experience of the particular mine planner rather than being an objective and repeatable procedure. Once the ultimate pits and mining phases are put in place the flexibility and value attributable to a mining operation over its lifetime is in many ways constrained—no matter what sophistication is applied in optimising panel extraction sequences, the consequences of suboptimal mining phase design can never be overcome.

The mine planning optimisation group within BHP Billiton Technology has developed a mine planning optimisation software tool called Blasor. The concept of Blasor is to use an optimal extraction sequence to design the ultimate pits and mining phases, not the other way around as is the typical approach.

Blasor is specifically designed to optimise the life-of-mine pit development plan for the eleven pits constituting the Yandi Joint Venture operation. It provides Yandi mine planners with a strategic planning tool that can be used throughout the mine life to reconfigure pit development plans as market conditions change. It also enables the operation to rapidly, accurately and optimally value different future market scenarios and/or expansion options using forward pit development plans that are sympathetic to those scenarios and options.

In this paper, we describe the concept and structure of Blasor. The structure of the optimisation problem and the types of constraints applied are outlined before the major design steps are discussed in more detail.

Blasor Implementation

Blasor has been developed as a PC based (Windows 2000 or XP) integrated stand-alone software package that has the following input/output features:

- Block models are supplied as flat ASCII files.
- Optimisation parameters are entered by the planner through a purpose-built graphical user interface.
- Intermediate data, including all block attributes calculated or assigned by Blasor, can be rapidly viewed in a dedicated 3D visualisation tool.
- Schedule output data, including full tonnage movement and financials, is reported via a number of specialised databases automatically generated by Blasor. A 2D graphical display tool is also provided within the Blasor interface for rapid display of the schedule data on an area and pit-wise basis.

Optimisation Parameters and Setup

Blasor's ultimate objectives are to determine the boundaries of the ultimate pits and the best phase designs for those pits so as to maximise the DCF over the life of the operation. In doing so, Blasor uses the commercially available CPLEX mixed-integer linear programming (MILP) optimisation engine from ILOG Inc to determine the optimal extraction sequence contingent upon a number of constraints being strictly observed.

The parameters Blasor uses to constrain the optimisation of the multi-pit development plans are:

- the constraints imposed by practical mining—respecting maximum slopes and mining rates;
- capacity of the downstream supply chain infrastructure; and
- market tonnage, blended ore quality and grade constraints.

A complete list of the constraints applied in the optimisation is given in Table 1. Other limits to the optimisation model of the real operation are:

- Initial stockpiles are allowed (one for each area). No strategic stockpiling capability is allowed throughout the mine life. Blasor attempts to find an extraction sequence that avoids stockpiling between years.
- No material in the pits is designated as waste a priori—the optimiser makes the decision as to how to best blend the material extracted from the pits to make marketable ore. Only blended ore that meets all market grade and quality constraints can have a positive revenue attributed to its extraction.

Table 1 Constraints applied in optimisation

Constraint class	Constraint
Mining	Maximum slope angles enforced at the selective mining unit block size level
	Maximum mining rate for the operation, each mining area and each pit (variable per annum)
	Earliest start year for pits
	Smooth mining constraint—large jumps in operation mining rate can only occur after a prescribed duration of near constant mining rate
	Maximum sinking rate (benches/year)
Transport	Maximum conveying rate for multiple transport paths (variable per annum)
Crushing and screening	Maximum crusher capacity for mining areas and pits (variable per annum)
Market	Target tonnages for fines and lump product individually (variable per annum)
	Maximum and minimum per cent Fe for fines and lump product (variable per annum)
	Maximum and minimum % SiO2, % Al2O3, % P, % Mn and % S for fines and lump product (variable per annum)

- Mining and transport costs are attributed to each block—according to their position in the pit different blocks will have different mining and transport costs.
- All material in the pits is allocated a bin number. Material may be assigned to bins on the basis of any combination of grade and impurity dimensions.
- Within each bin of an AGG (an 'AGG' is an aggregation of blocks), the material is assumed to be of homogeneous quality. The optimiser may extract any proportion of an AGG in any year, contingent on other constraints being obeyed.
- The extraction precedence of each AGG is determined by the extraction precedence of its constituent blocks. No part of any AGG may be extracted before all its precedent AGGs have been totally extracted. The rules of precedence are simply that if a block lies above another block (precisely if its centroid lies within the 'cone' transcribed by the maximum slope line for the underlying block), then the overlying block must be extracted before the underlying block.
- Prices for both fines and lump material may be specified to change from year to year.
- All net cash flows are discounted at an appropriate rate.
- The optimisation objective is to find an extraction sequence that obeys all constraints explicitly and results in a maximum nett discounted cash flow.
- The optimisation is global, over the full life-of-mine.

Blasor Optimisation Procedure

The Blasor optimisation procedure is summarised in Fig. 1, illustrating the major steps:

- aggregation of blocks including binning,
- calculation of optimal extraction sequence and ultimate pit limits,
- mining phase design, and
- valuation of the optimal panel extraction sequence.

In the following section, we describe each step of this procedure in more detail.

Aggregation

For the large block models encountered at Yandi (containing >100 000 blocks), it is necessary to aggregate blocks before they can be tractably scheduled using any linear programming approach. To provide the optimiser with valuable selectivity, binning is used to allow blocks of similar quality to be extracted together by the optimiser. A common method used to aggregate blocks is to re-block the model into a larger block size—this is not the method used in Blasor. The aggregation method used is a proprietary fuzzy clustering algorithm that has the following characteristics, where the term 'AGG' is used to refer to an individual aggregation:

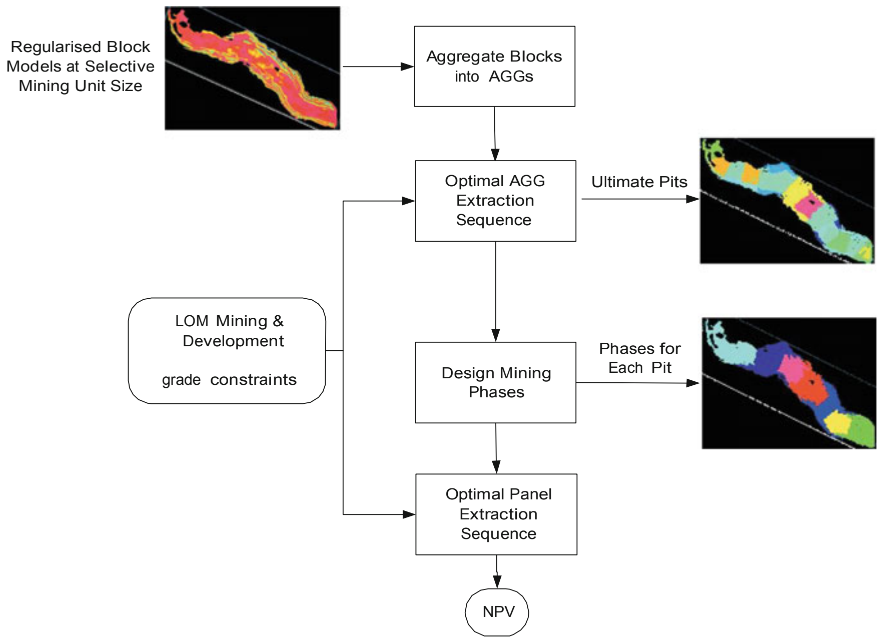

Fig. 1 Blasor pit development optimisation procedure

- blocks that are spatially connected and with similar properties are predisposed to belong to the same AGG, and
- the AGG boundaries respect the maximum slope constraints encoded in the selective mining unit block models.

The user may choose to present Blasor with block models that are already cut back to some nominal 'ultimate pit' surface or to allow Blasor to aggregate a larger volume. Each AGG in the larger volume would be presented to the optimiser as a candidate for extraction over the life-of-mine.

After this step, each pit is described by a set of AGGs. Each AGG contains material which is classified in bins. Each bin is allowed to be extracted independently of other bins in the same AGG. A set of AGG precedence rules is also created. These rules, represented as a set of arcs, force the optimiser to extract material in a valid order.

AGG Extraction Optimisation

This is the vital step in the Blasor design process whereby an optimal AGG extraction sequence is calculated and the blocks in each pit are assigned a period of extraction. The scheduled entities are bins within each AGG and the final AGG extraction sequence will obey all mining, slope precedence, processing and market constraints. The typical size of this optimisation problem for Yandi is:

- 1000 AGGs in total from 11 pits, each AGG containing five bins; and
- 20 time periods over the life-of-mine.

A problem of this size will take between six and ten hours to converge within a 0.5% bound of optimality using the CPLEX MILP engine running on a powerful laptop computer. This optimisation also provides an estimate of the AGG extraction sequence life-of-mine discounted cash flow, which can be used as a benchmark for the DCF of the panel extraction schedule (see below) in assessing the practical optimality of the mining phase design step.

Mining Phase Design

The mining phase design is performed individually on each pit in the operation. The design procedure uses a proprietary algorithm, which uses the 'period of extraction' block attribute to prioritise the phases within each pit. Some user input is required to assist the algorithm in designing mineable phases—so-called 'rat-holing' can be controlled or overcome through the judicious selection of phase design parameters. Because this step cannot be completely automated, a tool is provided which allows the planner to make practical modifications to the automatically generated mining phases. The interface that allows manual modification of phase designs in Blasor is shown in Fig. 2.

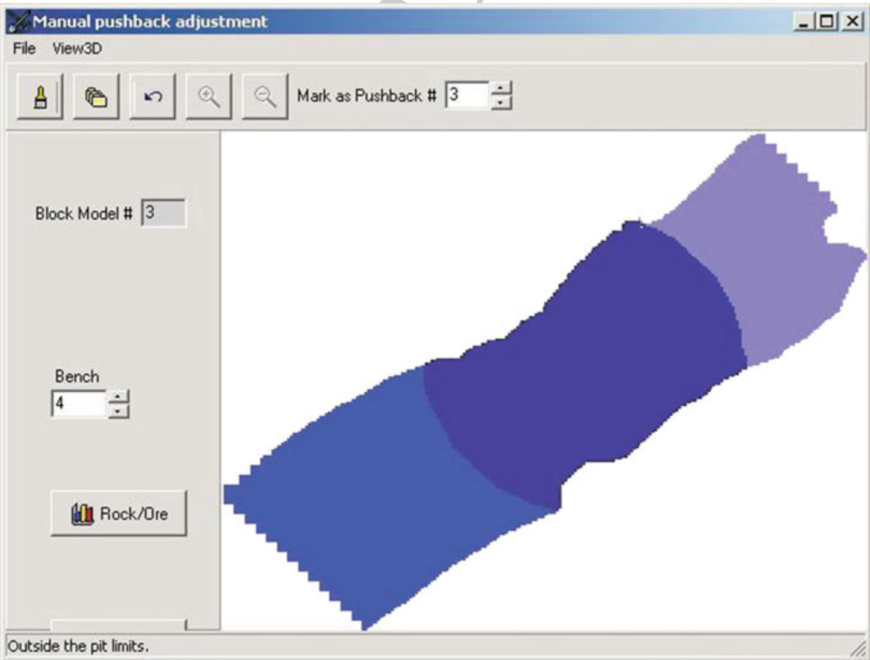

Fig. 2 Interface for the manual phase adjustment tool in blasor

Panel Extraction Optimisation

Having designed the mining phases for each pit, the planner then uses Blasor to generate the panel attributes (where a 'panel' is the intersection of a mining phase and a bench). Panels are represented in the same way as AGGs—via tonnes of all attributes in each bin. The optimal panel extraction sequence is calculated in the same way as for the AGG extraction sequence and uses the same mining, processing and marketing constraints. The final optimal sequence provides the user with a direct estimate of the DCF over the life-of-mine. For the Yandi operation, the optimal panel extraction sequence DCF is usually very close to the optimal AGG extraction sequence DCF, showing that the Blasor phase design process is efficient at preserving the value of the mining operation despite the inevitable compromises that must be made in constructing mineable phases.

The panel extraction optimisation process requires a similar processing time as the AGG extraction sequence optimisation, the final result being an attribution of period of extraction for each block in each pit. An example of the block extraction sequence, illustrated as a colour-coded period of extraction section through the centre line of a single pit, is shown in Fig. 3.

Conclusion

Blasor provides an efficient and integrated long-term pit development planning and evaluation tool for the Yandi Joint Venture operation. It enables mine planners to design ultimate pits and mining phases that are based upon a globally optimal multi-pit life-of-mine extraction sequence and then to generate an optimal panel extraction sequence from which the practically realisible maximum DCF for the operation can be reliably estimated.

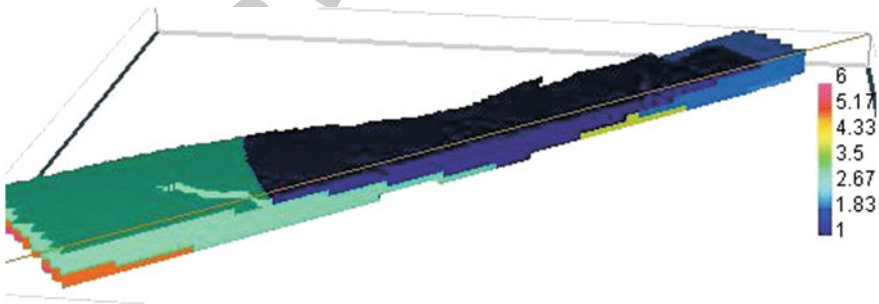

Fig. 3 Optimal period of extraction according to blasor panel schedule

References

Dincer T, Peters B (2001) Blending optimum pit mining sequences. In: Proceedings fourth biennial conference: strategic mine planning 2001, pp 43–53 (Melbourne, The Australasian Institute of Mining and Metallurgy)

Noronha RA, Gripp, AH (2001) Ultimate pit selection and design in iron ore. In: Proceedings fourth biennial conference: strategic mine planning 2001, pp 133–136 (Melbourne, The Australasian Institute of Mining and Metallurgy)

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