PRACTICAL PROBLEMS IN THE ESTIMATION OF RECOVERABLE RESERVES WHEN USING SIMULATION OR BLOCK KRIGING TECHNIQUES.

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ABSTRACT

The main problems associated with the estimation of recoverable reserves are addressed via the following objectives common to the early feasibility stage of a mining project:

i) Realistic tonnage-grade estimates for life-of-mine financial estimates.
ii) Detailed estimates, as far as practically possible, of the in situ distribution of SMU block grades for mine planning purposes, using simulation or kriging techniques.

It is shown via a 3D simulated ore body and a series of estimates based on a limited set of data from this ore body, that neither simulation nor a limited kriging search routine provides the answer to the problem of minimising the overall effect of misclassification.

A practical approach is proposed based on block kriging with an adequate search routine so as to eliminate conditional biases, followed by practical adjustments so as to minimize the effects of misclassification and to optimise the total profit. The limiting conditions for the application of this approach are discussed.

1. GENERAL BACKGROUND.

The estimation of recoverable reserves in the case of mining selectively to a cut-off has received much attention in recent years. The two main objectives involved are:

i) Realistic global tonnage-grade estimates for life-of-mine production and feasibility analyses based on selectively mining to a scale dictated by the planned SMU blocks. Where the data permits of a reasonable estimate of the spatial structure(s) of the grade data, such global tonnage-grade estimates can be produced via various techniques without necessarily attempting the specific valuation of individual SMU ore blocks. These techniques will not be discussed in this paper; and
ii) A detailed pattern of the grade distribution throughout the ore body preferably on a (SMU) block by block basis, for use in the mining plan. The objective is to provide a guide to the mine planners for planning the selection of blocks in the two main categories above and below the cut-off respectively.

The second objective presents serious practical problems where the data grid is such that estimates of individual ore blocks will, unavoidably, have wide confidence limits and will either be smoothed or will be subject to serious conditional biases dependent on the technique used and the basis on which it is used. The consequences are that a significant number of blocks actually above cut-off could be classified at this early stage as below cut-off and could be bypassed in the early mine planning. Similarly, blocks actually below cut-off could be classified as above cut-off and be included in the program for mining. The extent to which such misclassifications will be carried through to the selective mining stage, and thus affect the actual selection of blocks, will depend on the details and scheduling of the development, mining and sampling plans to be implemented.

The initial guidance provided by the valuations at the feasibility stage must, unavoidably, have some effect on the eventual efficiency of the selective mining process. Therefore, it is essential that all biases are eliminated in these early block valuations and that misclassifications are kept at a minimum.

2. THE SIMULATION OPTION

Simulation techniques have, in recent years been and is currently used on a wide front in the mining environment, mainly because it can provide, at the exploration stage, an indication of the broad pattern of the grade variations likely to be encountered through the ore body. Furthermore, such a simulation

requires basically only a realistic model of the spatial structure of the data and the coordinates and grades for the exploration data already available for the conditioning of the simulation. However, such a simulation provides only one of an infinite number of possible versions of the grade pattern and this will be evident if repeated simulations are done using the same data. A series of simulations can, thus, provide a useful measure of the overall uncertainty in the grade pattern and if these are incorporated in a corresponding series of mine plans and their financial outcomes, a clear indication of the overall risk involved in the project can guide management in critical decisions. However, when any single simulation is used to predict the grades for individual SMU blocks and this is used for a specific mine plan, the outcome could be misleading; this is the aspect to be covered in this paper.

The net effects of using simulation for this purpose were analysed using the Turning Band method (ISATIS, software by Geovariances, France) to simulate a 3D lognormal ore body with 13824 point values spaced 5m apart, with a mean grade of 1, a variance of 1.7 and an anisotropical spatial structure with the nugget at 0.7, ranges of 19 to 35m, and the net sill at 1.0. From these values a set of 216 (6x6x6) values was drawn to represent data available at the exploration stage. The complete grid of point values was also used with a proper search routine to provide kriged grades for a set of 1728 SMU blocks (measuring 10x10x10m); these showed a negligible average error variance and were accepted as the 'actual' follow-up SMU block grades. The set of 216 values was, in turn, used with a search routine of 15 to 56 values, to simulate a grid of 48x48x48(110592) point values. This was regarded as a 'proper' search routine to use. Within each of the 1728 SMU block outlines the 64 point values as simulated were averaged to provide the simulation estimates for these blocks at the exploration stage.

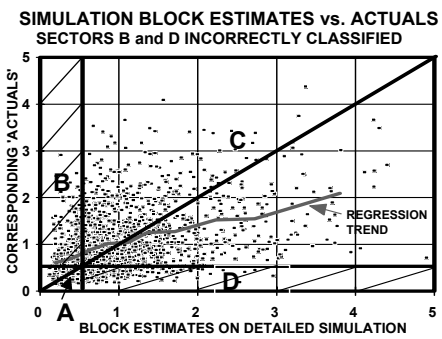

Fig. 1 showing correlation of simulation estimates with proper search vs. 'actuals'

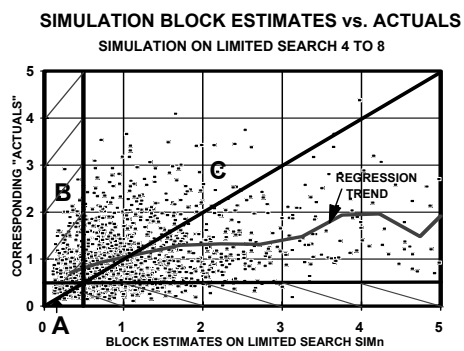

Fig. 2 showing correlation of simulation estimates with limited search vs. 'actuals'

Fig. 1 shows the correlation of these simulation block estimates on the X-axis vs. the 'actual' follow-up grades on the Y-axis. With a cut-off at 0.5 this figure also shows the pairs of estimates and follow-up 'actual' grades in the 4 categories of:

Correctly classified: Sector A – below cut-off
Sector C – above cut-off
Misclassified : Sector B – estimates below, actuals above cut-off
Sector D – estimates above, actuals below cut-off

Sectors B and D thus provide a measure of the overall efficiency of these exploration estimates in guiding mine management in the early planning of the selective mining operations. In this case the misclassified blocks cover 28.1% of the total.

Sector D generally warrants a more critical analysis than Sector B, as any block selected here for mining but which, when more data become available at the mining stage, will be below cut-off, will, in fact, produce a financial loss. Once mined such a block cannot be reclassified and remined so as to cancel the loss.

Blocks in Sector B, estimated as below cut-off and left unmined for this reason can, in specific cases still be mined at a later stage should the final data indicate a grade above cut-off. However, this will only be possible if the early decision is reversible and will, therefore not be practical, for example, in open cast operations where a block cannot be left unmined in isolation in between others which have to be mined at that stage. In underground stoping operations such a selection could well be reversible.

The extent to which blocks misclassified in Sectors D and B on the basis of these exploration estimates, will, in practice, be selected for mining or be discarded respectively, will depend on the mining technique, and the schedule of development, detailed sampling and production and can vary between 0% (with all selections done on final data) to 100%(with all selections done on the exploration estimates).

Apart from the effect of the misclassifications at the exploration stage on actual selection decisions, there will, unavoidably, be some negative effect on the development planning of underground operations, or on the planning of the sequence of open cast operations and of the pit outline.

The need for misclassifications at the exploration stage to be kept at a minimum is, therefore obvious.

3. FLEXIBILITY IN SIMULATION ESTIMATION

Given the set of exploration data, and the accepted spatial structure, any given conditional simulation program provides input flexibility essentially only in respect of variations in the grid of simulated points and in the selection of the search parameters for the kriging routine used in the program. In order to test for the effect of a variation in the search routine used, a second simulation was done on the same set of 216 selected exploration data using a limited search routine of between 4 and 8 point values. The correlation results for this case are shown in Fig. 2 and a summary comparison with the first case in the first half of Table 1.

TABLE 1 showing comparison of results for 4 techniques

ESTIMATION TECHNIQUES	Simulation		Kriging	
	proper search	limited search	limited search	proper search
Correlation Coefficient with actuals	0.460	0.388	0.455	0.543
Error Variance of Estimates	0.571	0.971	0.817	0.330
Slope of regression-acts/ests	0.403	0.255	0.313	0.806
Global Bias %	1.0%	10.6%	0.7%	0.1%
%Blocks Misclassified: Sector B	15.8%	17.6%	31.4%	1.9%
Sector D	12.3%	11.5%	9.7%	21.1%
Total	28.1%	29.1%	28.5%	23.0%
Relative Profit as % of maxm with all selections on final SMUs grades:				
As expected on estimates	103.0%	122.8%	105.3%	95.1%
Corresponding actuals	85.9%	83.0%	83.2%	94.7%
do. with adapted cut-off in D	------	------	------	98.4%

This table compares the levels of the correlation coefficients, average error variances of the estimates, inherent conditional biases, global biases in the estimates, and percentages of blocks misclassified; also an indication of the relative profits to be realised if all final selections are done on the basis of the exploration estimates. These relative profits are shown as percentages of the maximum relative profit to be earned with all selections performed on the final 'actual' data. It is measured by:

Relative profit =(blocks mined)*(average grade mined above cut-off, less cut-off grade)

Table 1 and Figures 1 and 2 show that:

i) A limited search routine yields significantly poorer results than an adequate one and can introduce a serious global bias.

ii) Both sets of simulation estimates show:
- low correlation levels,
- high error variances,
- serious conditional biases,
- high levels of misclassifications,
- badly misleading estimates of relative profits from blocks estimated above cut-off and low levels of actual relative profits from these blocks.