Ore Reserve Assessment

Chairman: Mr A. WEISS
Rapporteur: Dr D. G. KRIGE

Papers:

Statistical valuation of diamondiferous deposits by H. S. Sichel
Geostatistical ore reserve estimation by M. David and R. A. Blais
A model of Bougainville Copper's Panguna orebody by M. R. L. Blackwell

The Chairman and several of the contributors stressed that the three papers presented at the session covered broadly three approaches to the problem of ore reserve assessment, that is, the formal mathematical-statistical, the geostatistical and the at least partly pragmatic and more orthodox, as represented by the authors Sichel, David and Blackwell, respectively. These approaches were also linked by some participants, but with more disagreement, to the 'South African', 'French' and 'American' schools, respectively.

The contributors to the paper by Prof. H. S. Sichel were unanimous in their praise of its excellence from both the statistical and practical points of view. Professor J. E. Kerrich said that the development of the suggested family of distributions based on the mixing of a number of known distributions was new to statistical literature and worthy of incorporation in future text books on mathematical statistics.

A number of contributors said that on the practical side the paper was accepted as a milestone in the literature of statistics and was the first of its kind on the valuation of diamondiferous gravels. Drs R. P. King and F. P. Agterberg and Prof. A. Journel raised the question concerning the level of correlation between stone density and size, to which the author replied that within small geographical areas there was no significant correlation, and that for large areas there was only a slight negative correlation of less than 0,1. This was due to the mode of transportation and deposition of the diamonds which resulted in general in the larger stones occurring closer to the mouth of the Orange River.

A question by Dr D. M. Hawkins related to the frequency of occurrence of very small diamonds. Dr Sichel replied that no micro-diamonds of diameter smaller than 1,7 mm had been found, again because of the mode of deposition.

Dr Agterberg referred to the possibility of linking the statistical model more closely with geological factors of location; the parameters of any mixing distribution could then be expressed as functions of location. The author, however, thought that the model which had been developed had proved to be satisfactory in practical applications to beach mining over distances of 50 miles of diamondiferous gravels.

In presenting his paper Prof. David gave a brief summary of the paper and enlarged on the practical applications to which the paper referred. In reply to a question by Marion Watson on follow-up studies and following on details given by A. C. Royle of a geostatistical analysis conducted on similar lines, Prof. David explained that subsequent grab-sampling of mined ore compared well with the original geostatistical predictions. To a question by D. M. Hawkins on procedures applicable in the case of lognormally-distributed data where reasonable variograms could be obtained only after logarithmic transformation of the basic observations, the author replied that originally this problem had been dealt with on the basis of 'kriging' of the logarithms of values and then transforming the results back to naturals. More recently, however, the alternative approach based on the 'proportional effect' as mentioned in the paper, had been preferred. (Details of the approach, as provided by Prof. David, are added as an annexure to this report.)

Discussion of, and questions on, Mr Blackwell's paper covered many detailed practical aspects of the valuation techniques used. Apart from these questions and others on matters of principle, it was suggested by Prof. C. Huijbrechts that benefits would have accrued from the application of geostatistical methods in substitution of the somewhat arbitrary weighted moving averages, the 'shrinking' of variances and the subdivision of the orebody into zones. Such an approach would have ensured the most efficient evaluation of the individual ore blocks, including the elimination of bias errors in the various grade categories.

Dr Hawkins suggested an alternative weighting system* which had been applied successfully to coal propositions, and which would enable value contouring to be effected directly from the borehole results and not via block values.

From the author's side it was stressed that although more advanced techniques might have improved the estimates, practical considerations dictated the use of techniques which could be easily understood by all the parties involved in the Bougainville project, including various non-mining interests.

*McGillivray, R. B., Hawkins, D. M. and Berzak, M. (1969): The computer mapping and assessment of borehole sampling data for stable minerals, particularly as applied to coal mining. *J. S.Afr. Inst. Min. Metall.* vol. 59, pp. 250-265.

Annexure

Notes on the Proportional Effect in Geostatistics by M. David

Suppose that we have 50 holes in a mine and that each variogram exhibits a transition structure (finite plateau reached after a finite range) with a constant range 'a'.

Remembering that the sill of a variogram is equal to the variance of the samples used to compute it, say $s^2(o/i)$, where o means the sample and i the subset (hole) of the deposit where the variogram has been computed, we may write each variogram

$$\gamma_i(h) = s^2(o/i)\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3}\right]$$

However all these variograms are theoretically deduced from a unique one, computed on the whole deposit. This can be written

$$\gamma(h) = \sigma^2(o/D)\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3}\right]$$

Now in an intrinsic process $s^2(o/i)$ is only a function of the size of the subset i. Thus, all the holes should exhibit the same variogram; thus when the case was discussed previously (as Deposit A in the paper), the process was not intrinsic.

However, a certain type of non-intrinsic process can be studied with the same theory. This is when there exists a linear relationship between the mean and the standard deviation of the samples.

Considering the whole deposit, we may write:

$$\sigma^2(o/D) = Am_0^2$$

For a subset i, we will have:

$$s^2(o/i) = Am_i^2 \quad \text{and } A = \frac{\sigma^2(o/D)}{m_0^2}$$

If we write $\sigma^2(o/D) = \sigma_0^2$ we may rewrite $\gamma_i(h)$

$$\gamma_i(h) = s^2(o/i)\left(\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3}\right) = \frac{m_i^2}{m_0^2}\left[\sigma_0^2\left(\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3}\right)\right]$$

Remarks

1. To be absolutely correct, we should introduce expected values and distinguish between the true values and their estimators. This would take us too far.
2. The main interest of the model is that the value of the sill appears only as a multiplicative factor in geostatistical computations. Thus all variograms can have a standard sill value of s and then the individual results can be remultiplied wherever necessary by

$$\frac{m_1^2}{m_0^2}\sigma_0^2$$

3. When the logs of the assay values exhibit intrinsic features, this model applies and avoids transformation to logs; this is due to the fact that the logarithmic variance is approximately a relative variance. If the assay values are lognormally distributed, then the following equation holds:

if ε_0^2 is the variance of the natural values;

σ^2 is the variance of the log of the values;

m_0 is the average of the natural values;

$$\varepsilon^2 = m^2(e^{\sigma^2} - 1)$$

$$\varepsilon^2 \simeq m^2(1 + \sigma^2 - 1)$$

$$\varepsilon^2 \simeq m^2\sigma^2$$

$$\sigma^2 \simeq \frac{\varepsilon^2}{m^2}$$