Addendum

Mineral Reserve Estimation Methods

W.R. Reed

ORE RESERVE MODELING

Ore reserve modeling is the basis for predicting ore grades throughout the ore body using exploration data. The most common method is to use a block model. A block model is a three-dimensional (3-D) model of an area that encompasses an ore body. The block model is composed of individual blocks of a predetermined size. These individual blocks are used to represent areas in the ore body and can contain information on x-y-z coordinates, geology, ore grades, and so forth. The size of the blocks is based on geologic variability. Figure 1 shows an example block model.

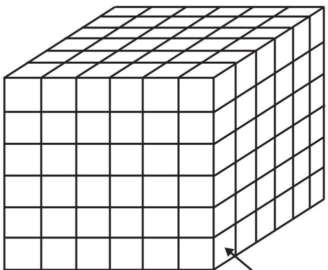

Figure 1 Block model outline example

VARIOGRAMS

Variograms are graphs used in ore reserve estimation to measure spatial continuity among exploration ore-grade data. Graphs generally depict average variability on the y-axis with distance on the x-axis. The following equations are used:

$$\gamma(h) = \text{variogram for distance } h \quad \text{(EQ 1)}$$

$$\gamma(h) = \frac{1}{2N}\Sigma(g_i - g_{i+h})^2 \quad \text{(EQ 2)}$$

where

$i = 1, 2, 3,\ldots N$
h = distance between samples
N = number of pairs
g = grade

Figure 2 shows a typical variogram plot. The x-axis is the distance between the samples with the y-axis showing the variability. Also shown are the nugget effect (1), range (2), and sill (3). These are important points of interpretation of the variogram.

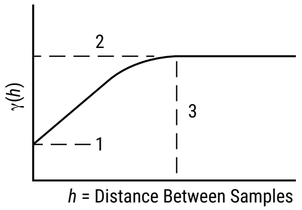

Figure 2 Typical variogram plot, where γh is the variability (y-axis) and h is the distance between samples (x-axis)

- **Nugget effect.** The y-intercept of the variogram plot represents errors from sampling, assaying, and inconsistent mineralization. Low nugget effects are desirable.
- **Range.** The range of influence of the sampling and beyond this distance, there is no correlation among the samples.
- **Sill.** This is the sample variance.

ESTIMATION METHODS

Estimation methods are mathematical methods to calculate ore grades at different points within the ore body using the ore grades measured from exploration data. This exploration data are usually from drill hole data but can also include data from trenching, geochemistry and geophysical surveys, and so forth. Estimation methods include geometric, area averaging, polygonal, and moving-average.

Geometric

The geometric method is a manual method generally accomplished on plan or cross-sectional maps. This method uses a series of maps cutting the ore body into parallel sections. The maps include grade information, geologic information, ore-body mineralization, and so forth. The grades are manually calculated on the maps. This method is seldom used because of the availability of computer methods.

Area Averaging

Area averaging is a simple method that uses the geologic shape of the ore body and averages all the grade information within that shape. This method may also use a series of parallel plan or cross-sectional maps. Ore volumes are computed by calculating the area of the ore on the plan or cross-section map and then multiplying that by the distance between the plan or cross sections. Tonnage is determined using the density of the ore mineralization.

Polygonal

Polygonal methods may also use plan or cross-sectional maps during calculations. Polygonal methods plot a series of grades from sample intersections of the map. Each sample intersection is given a zone of influence. The area for each sample intersection zone of influence is measured. The measured area of influence of each sample intersection is then used as the weight in a weighted average of all samples. This method is also called the *principle of nearest point*. Weighted average is computed as follows:

$$\text{average grade} = \frac{\sum w_i g_i}{\sum w_i} \qquad \text{(EQ 3)}$$

where

w_i = weight of the sample i
g_i = grade of the sample i
$i = 1, 2, 3,\ldots N$
N = number of samples used in calculation

Moving-Average

Moving-average methods use inverse-distance estimation and kriging for calculating ore grades within the ore body. The simplest moving-average method is the weighted average shown in Equation 3.

Inverse-distance. This method is based on the weight of each sample as proportional to the inverse power of the distance from the location of the sample to the location of the estimate. It can be calculated using the following equation:

$$w_i = \frac{d_i^{-p}}{\sum d_i^{-p}} \qquad \text{(EQ 4)}$$

where

w_i = weight for sample *i*
d_i = distance between the sample *i* and the location being estimated
p = weighting power

The weighting power can be any number. Most commonly, $p = 2$, which is called *inverse-distance squared*. Other common powers used are $p = 1$ and $p = 3$. A review of ore-body geostatistical and ore-body mineralization/geology is commonly used to aide in the selection of the power (p).

Kriging. Kriging is a geostatistical method commonly used in ore reserve estimation. In this method, information from variograms is used to establish parameters for kriging. Kriging calculates the grade of an individual block of a block model based on a least squares minimization of error of estimation. It develops weights for the individual samples used for estimating the block grade. The individual samples can be in different 3-D locations. A simple form of the kriging estimator is

$$Z = \sum_{i=1}^{n} \lambda_i x_i \qquad \text{(EQ 5)}$$

where

Z = estimated block grade
λ_i = weighting coefficient developed by kriging
x_i = respective sample
$i = 1, 2, 3, \ldots n$
n = selected number of nearest-neighbor samples used to estimate the block grade

The methods (as there are different variants of kriging) are computationally intensive and are generally calculated using computers.

CONFIDENCE OR CLASSIFICATION OF MINERAL EXISTENCE

Categorization of mineralization existence stems from the distance and how that distance is analyzed, and that an unknown mineral content location exists from a known location based on exploration data. The result of analysis is to rank mineralization with regard to confidence of existence, categorizing by resources and reserves; subcategorizing by inferred, indicated, or measured resources; and by proven and probable for reserves. Many of the internationally recognized standards for resource and reserve classification place actual distance of unknown mineralization to exploration data points as criteria for categorization. For example, a U.S. Geological Survey (USGS) standard (Wood et al. 1976) offers that coal within a 0.4-km (0.25-mi) distance from an exploration data point is satisfactory for measured resources; 0.4–1.2 km (0.25–0.75 mi) is satisfactory for indicated resources; and 1.2–4.8 km (0.75–3 mi) for inferred resources. Because of the variance of standards, the resource and reserve estimation should be done using the applicable classification method for the specific project. See Chapter 9 for more information.

REFERENCES AND ADDITIONAL READING

Darling, P., ed. 2011. *SME Mining Engineering Handbook*, 3rd ed., vol. 1. Englewood, CO: SME.

Hartman, H.L., ed. 1992. *SME Mining Engineering Handbook*, 2nd ed., vol. 1. Littleton, CO: SME.

Hustrulid, W.A., ed. 1982. *Underground Mining Methods Handbook*. Littleton, CO: SME-AIME.

Wood, G.H., Kehn, T.M., Devereux Carter, M., et al. 1976. *Coal Resource Classification System of the U.S. Geological Survey*. Geological Survey Circular 891. Reston, VA: U.S. Geological Survey.