Tricks to Creating a Resource Block Model

St John’s, Newfoundland and Labrador
November 4, 2015
Agenda

→ Domain Selection
→ Top Cut (Grade Capping)
→ Compositing
→ Specific Gravity
→ Variograms
→ Block Size
→ Search Ellipse
→ Nearest Neighbour
→ Inverse Distance
→ Ordinary Kriging
→ Validation
→ Resource Classification
→ Indicator Kriging
Fundamentals

GI – GO
Garbage In – Garbage Out
Black Box
Domain Selection

A domain is a spatial entity with common geological or geostatistical attributes.
Domain Selection

- Most domains are selected based on geological or grades
  - Or a combination of both

- The definition of the boundaries between geological domains can be problematic due to several factors, including
  - Defining geological domains relies on the geologist’s interpretation
  - Sample information is limited and therefore interpreted boundaries have a degree of uncertainty

- Domains have either a “hard boundary” or “soft boundary”
Domain Selection

Hard boundary

→ Most common domain selection used by geologists
→ Based strictly on geological or geochemical constrains
  ▪ All material inside Quartz Porphyry unit
  ▪ All material contained within the “shear zone”
  ▪ All material on the 2.5 g/t grade shell
→ It is easy for the human eye to “see” the boundary and make the estimation process easier
  ▪ The samples are either inside the boundary or outside the boundary
Domain Selection

Hard boundary

- Solids or wireframes tend to have unrealistic shapes
  - not geologically realistic
  - particularly with grade shells due to “snapping” to the drillhole
Domain Selection

What do you do here?

Folding

Faulting

WSP
Domain Selection

What do you do here?

Pinch and Swell

Variable Dip
Domain Selection

Soft boundaries

- A soft boundary has a gradational zone between two adjacent domains, making it difficult to identify the exact boundary
  - Porphyry deposits
  - Disseminated sulphides
  - Stringer or stockwork deposits
  - Transition from oxide to sulphide

- The estimation process using soft boundaries is complex
Domain Selection

Soft boundaries

→ Estimate the overlap with the data from both Domains A and B
Domain Selection

Soft boundaries

- Estimate Domain A using data from Domain A, then estimate Domain B using data from Domains A and B
- Estimation of B might have a different capping strategy, variogram, and search ellipse
- Estimate using data with X metres of the boundary
Top Cut and Bottom Cut (Grade Capping)

→ Fix all errors in the data
→ Do not blindly follow the advice in statistics books
→ Do not blindly use all data; follow local customs
→ Consider probability plots
There are three “schools” of thought on this process:

1. Conduct capping analysis on the raw data (before composites)
2. Conduct capping analysis on the composited data
3. No capping to be completed

Which is correct?
Top Cut and Bottom Cut (Grade Capping)

**Bottom cut**

→ Should be done with very large data sets that have a large population which would be deemed as “background”

→ Removing bottom cut results in the data shifting left
Top Cut and Bottom Cut (Grade Capping)

**Probability plots**

→ Useful to identify populations and consider outlier treatment

→ Updated program
  - Fits arbitrary number of populations with lines (fitted non-parametric model) or mixture model
  - Normal or lognormal
  - Iterative optimization with least squares objective function
  - Provides population adjusted values for upper tail
  - Plots metal at risk for upper tail values
Top Cut and Bottom Cut (Grade Capping)

Some probability plots
→ Fitted non-parametric – lines
→ Mixture model – curved where distributions overlap
Top Cut and Bottom Cut (Grade Capping)

Parrish Analysis (Decile Analysis)

→ Paper in the Mining Engineering Journal (April 1997)

→ Arrange the sample data into decile grouping (10%)
  - If the top decile (90-100) has 40% or more of the metal content, than capping may be required
  - If the top decile (90-100) has more than twice the metal content of the next decile (80-90), than capping may be required
  - If the top percentile (99-100) has more than 10% of the metal content, than capping maybe required

→ Before any capping, review the spatial distribution of the samples
  - Might be a high-grade sub-domain
### Top Cut and Bottom Cut (Grade Capping)

#### Example of a Parrish Analysis

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Sample Compositing

- Procedure of combining adjacent values into longer down-hole intervals
- These are usually weighted by length, and possibly by specific gravity and core recovery
Sample Compositing

- Compositing leads to one of the following results
  - Orebody intersections
  - Lithological or metallurgical composites
  - Regular length composites
  - Bench composites or section composites
  - High-grade composites
  - Minimum length and grade composites

- Each of these types of composite are produced for different purposes and in different situations

- Regular length or bench composites are common in geostatistical analysis
  - Geostatistical software assumes the data represent the same volume
  - The length should be small enough to permit resolution of the final simulated grid spacing
  - The length shall respect domain contacts
Sample Compositing

Factors to consider

- Mean sample length
- Median sample length
- Potential block size
- Potential mining width or height

- Composites should not be shorter than the median sample length
- Composites should be 1/3 to 1/2 the block size
- Composites should be 1/3 to 1/2 the mining width
- Most geostatisticians like longer composites (regardless of the geology)
Sample Compositing

Compositing procedure

→ Top of hole
→ Top of interval
→ Bottom of interval
→ Bench
→ Watch for “tails”
  ▪ A small interval remaining after the composites are completed
  ▪ Tend to be at the end of the interval
→ How to deal with tails
  ▪ Ignore
  ▪ Include
  ▪ “Backstitch”
Specific Gravity

The ratio between the density of a material and the density of water
Specific Gravity

→ In the metric system, specific gravity (SG) and density are the same value

→ In the imperial system, SG and density are different values

→ Not to be confused with tonnage factor

→ Could be one of the more important numbers in a resource estimation

→ Global SG

→ Linear equation

→ Polynomial equation

→ There is a temperature correction
  - The SG of water is 1 at 4°C

foam: 0.03 g
wood: 0.7 g
lead: 11.35 g
Specific Gravity

Polynomial equation based on measured values
Specific Gravity

Why is SG so important in a resource model?

➤ Assume a block model with 10 x 10 x 10 m blocks
➤ Each block has a volume of 1,000 m³
➤ Tonnage of the block is volume x SG
➤ SG = 2.75, then the tonnage is 2,750 t
➤ SG = 2.76, then the tonnage is 2,760 t
➤ Just added 10 tonnes per block by changing the SG by 0.01
Variograms

The empirical variogram provides a description of how the data is related (correlated) with distance.
Variograms

Components to make a variogram

→ Azimuth: the horizontal direction the variogram searches
→ Plunge: the vertical direction the variogram searches
→ Lag: the distance between samples
→ Maximum distance: how far out to search
→ Spread: the cone angle to search
→ Spread limit: the maximum radius of the spread
Variograms

Components of a variogram

→ Nugget: no spatial correlation from a the geological microstructures and measurement errors

→ Sill: is the variance

→ Range: is the distance at which the variogram reaches the sill
Variograms

No spatial correlation; should be a small component of the overall variance.

Commonly encountered variogram shape.

Similar to spherical but rises more steeply and reaches the sill asymptotically.

Implies short scale continuity; parabolic behaviour at the origin, instead of linear.

For periodic variables.

For periodic variables, when the period is not regular.

Variogram models include:
- Nugget Effect Variogram Model
- Spherical Variogram Model
- Exponential Variogram Model
- Gaussian Variogram Model
- Hole Effect Variogram Model
- Damped Hole Effect Variogram Model
Variograms

To improve the variogram

→ Increase lag distance
→ Change rotation direction
→ Open or narrow spread
→ Allow overlap
→ Hide “pairs” less than 50, 100, 1000
Variograms
Variograms

0 \rightarrow 120 (30)
Variograms

0 → 120 (30)
Variograms

Ensure a positive definite model by

- Picking a single (lowest) isotropic nugget effect
- Choosing the same number of variogram structures for all directions based on most complex direction
- Ensuring that the same sill parameter is used for all variogram structures in all directions
- Allowing a different range parameter in each direction
- Modeling a zonal anisotropy by setting a very large range parameter in one or more of the principal directions
- Rotation direction of the variogram may not match geology

The responsibility is yours, but most software helps

Variogram modeling is one of the most important steps in the geostatistical study, however, do not spend days on it
Block Size
Block Size Selection

Some factors to consider

→ The sample interval of the data; there's not a lot of point in being smaller than that

→ What is the scale of your problem? If this is part of an exploration exercise and the model is really large, then you can safely and justifiably lose temporal resolution

→ How much time have you got? Small samples means more compute time, more statistics, more fiddling with details

→ 1/3 to 1/2 sample spacing is typical

→ Smallest mining unit

→ Blocks do not have to be cubes (2 x 2 x 2) or (5 x 5 x 2)

→ Sub-block or sub-cell
  ▪ Be careful of the sub-block routine

→ Smaller blocks does not mean more accuracy
  ▪ A block grade is the average of the estimation at the discretization points
Search Ellipse
Search Ellipse

Creation of search ellipse

➔ The dimension of the ellipse should be generated from variogram model
➔ Based on the ratio of the Major / Semi-major / Minor Axis
➔ Rotation angle should mimic the geology
Search Ellipse

Search ellipse

Different search ellipse rotations would be required as the mineralization geometry changes (Dynamic Anisotropy)
Nearest Neighbour
Nearest Neighbour

Provides the best global estimate

→ Should not be used in a resource statement (if possible)

→ Estimates the grade of the block from the closest data point
  - Uses a single sample point
  - Does not take into account the distance from the sample
  - Does not take into account the relative direction of the sample
Inverse Distance
Inverse Distance

Used for early estimations and validation

→ Can use several samples in the estimation
→ The distance of the sample is the weighting factor
→ Relative direction is not accounted for in the estimation (Surpac might be different in this case)
→ The variance is not accounted for in the estimation
→ A power of 2 is the most common
  ▪ Power of 3 is acceptable
→ Increasing power makes the estimate “like” a nearest neighbour estimate

\[ W(d) = \frac{1}{d^p} \]
Kriging
Ordinary Kriging

Context

→ The goal is to compute a best estimate at an un-sampled location
→ Considers the data as differences from their mean values
→ Statistical inference and a decision of stationarity provides the required information
→ Weights could be positive or negative, depending on relationship between unsampled location and data
→ Considering quadratic or higher order terms increases inference and does not lead to improved estimates
→ Co-variances are calculated from the variogram model
Ordinary Kriging

Kriging will be similar to other estimation methods

→ If the data locations are fairly dense and uniformly distributed throughout the study area, fairly good estimates regardless will be obtained, regardless of interpolation algorithm

→ If the data locations fall in a few clusters with large gaps in between, unreliable estimates will be obtained, regardless of interpolation algorithm

→ Almost all interpolation algorithms will underestimate the highs and overestimate the lows; this is inherent to averaging and if an interpolation algorithm did not average, it would not consider it reasonable
Ordinary Kriging

Some advantages of kriging

→ Helps to compensate for the effects of data clustering, assigning individual points within a cluster less weight than isolated data points (or, treating clusters more like single points)

→ Gives estimate of estimation error (kriging variance), along with estimate of the variable, $Z$, itself (but error map is basically a scaled version of a map of distance to nearest data point, so not that unique)

→ Availability of estimation error provides basis for stochastic simulation of possible realizations of $Z(u)$
Ordinary Kriging

Parameters to adjust during estimation runs

- Minimum number of samples
  - Too low will use only a single sample
  - Too high might not find enough data points to complete the estimate

- Maximum number of samples
  - Too low
  - Too high results in an over-smoothed estimate

- Maximum number per drillhole
  - Too low results in a single sample per hole and not enough samples to satisfy the minimum number of samples criteria
  - Too high results in the entire holes being used in the estimate
Ordinary Kriging

$KE = \frac{BV - KV}{BV}$

A number between 0 and 1
Ordinary Kriging
Ordinary Kriging

Estimation strategies

→ 3 or 4 estimation passes
→ On each estimation pass the search ellipse is increased and the min/max criteria is adjusted
→ There is not perfect fit
  - Pass 1
    - Smallest search ellipse (50% to 65% of variogram range)
    - Min samples 4 to 5
    - Max samples 15 to 20
    - Max / hole 2 or 3
  - Pass 2
    - Search ellipse (70% to 85% of variogram range)
    - Min samples 3 to 5
    - Max samples 15 to 20
    - Max / hole 2 or 3
  - Pass 3
    - Full search ellipse (100% of variogram range)
    - Min samples 2 to 5
    - Max samples 15 to 20
    - Max / hole 2 or 3
  - Pass 4
    - Large search ellipse (125% to 200% of variogram range)
    - Min samples 2 or 3
    - Max samples 15 to 20
    - Max / hole 2 or 3
Block Model Validation

WHY CHECK?
Block Model Validation

Resource model integrity

→ Field procedures
  - Starting from scratch”; checking related to
    - sampling
    - collar locations
    - topographic
    - down-the-hole surveys
    - drilling methods
    - sample collection and preparation
    - assaying, and sample quality control
    - quality assurance program

→ Data handling and processing
Block Model Validation

Resource model validation

→ Geological model validation
  ▪ Cross-check between solid and block model proportions

→ Statistical validation
  ▪ Statistical data (mean and variances) between dataset and block model
  ▪ Swath plots – grade trends analysis between declustered composite grades and block model grades
  ▪ Contact analysis – grade behaviour near contact zones

→ Graphical validation
  ▪ Grade-tonnage curve
  ▪ Cross-sectional view, looking for spilling grades
Block Model Validation

Resource model validation
→ Statistical validation – comparison between dataset and block model
Block Model Validation

Resource Model Validation

→ Statistical validation – swath plots
Block Model Validation

Resource model validation

→ Statistical validation – contact analysis
Block Model Validation
Block Model Validation
Resource Classification

Exploration Results

Mineral Resources          Ore Reserves

- Inferred
- Indicated ↔ Probable
- Measured ↔ Proved

Increasing level of geological knowledge and confidence

Consideration of mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors

(the “modifying factors”)
Historical Approaches

- Expert assessment of geological continuity
- Distance from a sample(s)
- Sample density in the vicinity of a block
- Geometric configuration of data available to estimate a block
- Kriging variance or relative kriging variance
Geometric Measures

→ Geometric measures such as drillhole spacing, drillhole density, and closeness to the nearest drillhole are direct measures of the amount of data available.

![Diagram showing drillhole spacing and density](image)

- **Drillhole Spacing**
  - Parameters: L₁ and L₂
  - Units: meters
  - Formula:
    \[ d = \frac{10000}{L_1 \cdot L_2} \]

- **Drillhole Density**
  - Parameter: d
  - Units: number/(100x100m²)
  - Formula:
    \[ \left( \frac{L_1 + L_2}{2} \right) = \sqrt{\frac{10000}{d}} \]

- **Radius from Drillhole**
  - Parameter: r
  - Units: meters
  - Formula:
    \[ L_1^2 + L_2^2 = (2r)^2 \]
    \[ r = \sqrt{\frac{L_1^2 + L_2^2}{4}} \]

→ They are related.
Calculating Geometric Measures

→ Calculate the density of data per unit volume
→ Choice of thresholds depend on
  - Industry-standard practice in the country and geologic province
  - Experience from similar deposit types
  - Calibration with uncertainty quantified by geostatistical calculations
  - Expert judgement of the Competent or Qualified Person

\[ d = \frac{10000 \cdot n}{\pi \cdot r_s^2} \]
\[ L = \sqrt{\frac{10000}{d}} \]
Uncertainty

- Geometric methods for classification are understandable, but do not give an actual measure of uncertainty or risk.
- Professionals in ore reserve estimation increasingly want to quantify the uncertainty / risk in their estimates.
Classification of Resources and Reserves

→ Three aspects of probabilistic classification
  1. Volume
  2. Measure of “+/-” uncertainty
  3. Probability to be within the “+/-” measure of uncertainty

→ Format for uncertainty reporting is clear and understandable, e.g.:
  ▪ Monthly production volumes where the true grade will be within 15% of the predicted grade 90% of the time are defined as measured
  ▪ Quarterly production volumes where the true grade will be within 15% of the predicted grade 90% of the time are defined as indicated

→ Drillhole density and other geometric measures are understandable, but do not really tell us the uncertainty or risk associated with a prediction

→ There are no established rules or guidelines to decide on these three parameters; that remains in the hands of the Qualified Person
Example of Probabilistic Classification

- Note the limited number of drillholes
- A reference histogram and variogram are used
- The probability to be within +/-50% of the estimated grade could be used for classification
More Drilling and a Change in Modeling

→ More drillholes (190 vs. 21 before)

→ Different decision of stationarity

→ New calculation of probabilities

→ The probability to be in interval has mostly increased, but 16% of the probabilities are lower!
Indicator Kriging
Indicator Kriging

→ A variogram is needed for each threshold
  ▪ More difficult inference problem, however, there is great flexibility

→ Too few – insufficient resolution of the estimated distributions

→ Too many – insufficient data in the neighbourhood for reliable estimates

→ Conventional practice – consider 7 to 12 thresholds considering
  ▪ Regular spaced (probability) quantiles of the global distribution, say the nine deciles \( (z_{0.1}, z_{0.2}, \ldots z_{0.9}) \) plus a high value \( z_{0.95} \)
  ▪ Resolution where needed – may need less in the low grades
  ▪ Consider the economic cutoff
  ▪ Consider inflection points on the probability plot
Indicator Kriging

→ Standardize all points and models to a unit variance $p(1-p)$

→ Model the variograms with smoothly changing parameters for a consistent description
  - Common origin → imparts consistency
  - Reduced order relations in IK/SIS
  - Allows straightforward interpolation of models for new cutoffs
In this case
- Nugget is larger for the first and last cutoff
- *Medium* range exponential model with consistently increasing range, contribution, and anisotropy
- *Long* range spherical model with decreasing range, decreasing contribution, and increasing anisotropy
Conclusion