Optimisation grade control procedures at the open pit mines:

GEOSTATISTICAL APPROACH

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Grade control
A large Copper open pit mine in Chile has lost **US$134 million** over a **10-year** period because of suboptimal grade control procedures based on the blast holes sampling.

It was estimated by the difference between actually used blast hole sampling protocol and its optimized version.

(P. Carrasco: WCSB1, Denmark 2003)
Grade control at open pit mines

Grade control variable:

Sampling grid:

Sample quality:

Cost of the lost/gained metals

Grade control costs
Grade control at open pit mines

Grade control variable:

- Sampling grid:
- Sample quality:

Cost of the lost/gained metals

Grade control costs
Nugget Effect and Estimation Error

\[ \gamma(h) \]

Variogram

Nugget Effect

Sill

h
Nugget effect is a geostatistical term defining "an apparent discontinuity in the experimental variogram near the origin caused by measurement errors or by nested structures that have ranges smaller than the sampling interval, or both."

Nugget Effect and Estimation Error

CASE 1: Uranium ISL operation
Nugget Effect and Estimation Error

CASE 1: Uranium ISL operation

Reference data

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel. Nug. 0%</td>
<td>Rel. Nug. 11%</td>
<td>Rel. Nug. 24%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rel. Nug. 40%</td>
</tr>
</tbody>
</table>

Nugget Effect and Estimation Error
Nugget Effect and Estimation Error

CASE 1: Uranium ISL operation

Reference data
Case 1
Case 2
Case 3

Exhaustive data set
50 x 50m grid

Rel. Nug. 0%
Rel. Nug. 11%
Rel. Nug. 24%
Rel. Nug. 40%
Nugget Effect and Estimation Error

CASE 2: Uranium project

Avr. relative error: 0.75

Avr. relative error: 0.58
**Nugget Effect and Estimation Error**

Nugget effect is a geostatistical term defining

“an apparent discontinuity in the experimental variogram near the origin caused by measurement errors or by nested structures that have ranges smaller than the sampling interval, or both”

Grade control at open pit mines

Grade control variable:

Sampling grid:

Sample quality:

Cost of the lost/gained metals

Grade control costs
Sample quality

\[ CV = \sqrt{\frac{2}{N} \sum_{i=1}^{N} \left( \frac{(a_i - b_i)^2}{(a_i + b_i)^2} \right)} \]

The average coefficient of variation (CV%) is suggested to be used as the universal measure of relative precision error.

- **Pitard, F.** 2004: Pers. Communication
- **Stanley, C.R. and Lawie, D.** 2007: Average relative error in geochemical determinations: clarification, calculation and a plea for consistency: *Exploration and Mining Geology*, 16(3-4): 265-274

CV% can be calculated using AMZ_QAQC.xls file which is explained in (Abzalov, M.Z. 2008, 2011) and available on your request.
Grade control at open pit mines

Grade control variable:

Sampling grid:

Sample quality:

Cost of the lost/gained metals

Grade control costs
Pair-wise Variogram

\[ \gamma_{PWR}(h) = \frac{1}{2N} \sum_{i=1}^{N} \frac{[Z(x_i) - Z(x_i + h)]^2}{[Z(x_i) + Z(x_i + h)]^2} \]

\[ \gamma_{PWR}(0) = \frac{2}{N} \sum_{i=1}^{N} \frac{[Z(x_i) - Z(x_i + 0)]^2}{[Z(x_i) + Z(x_i + 0)]^2} \]

(Nugget Effect of \( \gamma_{PWR} \))
Sampling grid vs. Sample quality

\[
CV = \sqrt{\frac{2}{N} \sum_{i=1}^{N} \left( \frac{(a_i - b_i)^2}{(a_i + b_i)^2} \right)}
\]

\[
CV^2 = \sigma^2_{RSV} = \frac{2}{N} \sum_{i=1}^{N} \left( \frac{(a_i - b_i)^2}{(a_i + b_i)^2} \right) \quad \text{(Relative Sampling Variance)}
\]

\[
\gamma_{PWR} (0) = \frac{2}{N} \sum_{i=1}^{N} \frac{[Z(x_i) - Z(x_i + 0)]^2}{[Z(x_i) + Z(x_i + 0)]^2} \quad \text{(Nugget Effect)}
\]

Sampling grid vs. Sample quality

Contribution of the Sampling Errors and Geology to the Nugget Effect

\[ \sigma_{\text{Geol}}^2 = \gamma_{\text{PWR}}(0) - CV_{\text{Field Duplicates}}^2 \]

\[ CV_{\text{Field Duplicates}}^2 \]

\[ \gamma_{\text{PWR}}(0) \]

\[ \gamma(h) \]

Geological Factors

Sampling Error

Nugget Effect

Sampling grid vs. Sample quality

Case 2: Bauxite project

Contribution of the Sampling Errors and Geology to the Nugget Effect

Sampling grid vs. Sample quality

Case 2: Bauxite project
Contribution of the Sampling Errors and Geology to the Nugget Effect

Geological Factor constitutes 13% of nugget effect of LOI

Sampling grid vs. Sample quality

Case 2: Bauxite project

Contribution of the Sampling Errors and Geology to the Nugget Effect

Error decreased from 24% to 15%

(1) by reducing drill spacing from 20x20m to 12.5 x 12.5m;
(2) by optimising sampling procedures and decreasing sampling error
Sampling grid vs. Sample quality

Case 3: Yandi Open Pit

Abzalov et al., 2010: Optimisation of the grade control procedures at the Yandi iron-ore mine, Western Australia: geostatistical approach, Applied Earth Science Journal, v.119, No.3, p.132-142
Sampling grid vs. Sample quality

Case 3: Yandi Open Pit

Abzalov et al., 2010: Optimisation of the grade control procedures at the Yandi iron-ore mine, Western Australia: geostatistical approach, Applied Earth Science Journal, v.119, No.3, p.132-142
Sampling grid vs. Sample quality

Case 3: Yandi Open Pit

Contribution of the Sampling Errors and Geology to the Nugget Effect

Geological Factor constitutes 52% of nugget effect of $\text{Al}_2\text{O}_3$

Grade control at open pit mines

Grade control variable:
- Sampling grid
- Sample quality

Cost of the lost/gained metals

Grade control costs
Economics: OPEX *vs.* Cost of Lost/Gained metal

Cut off by VALUABLE component (e.g. Au, Ni, Fe)
Correlation: 0.43
Ore to waste: 11%
Waste to Ore: 11%

Correlation: 0.95
Ore to waste: 3%
Waste to Ore: 3%

Economics: OPEX vs. Cost of Lost/Gained metal

Case 1
Mean 1 = 7.9
Mean 2 = 7.9
CV% = 21%

Case 2
Mean 1 = 7.9
Mean 2 = 7.9
CV% = 6.7%
Economics: OPEX vs. Cost of Lost/Gained metal

( Case 1 ) Nugget effect is caused by poor samples repeatability (i.e. large precision error)
Economics: OPEX vs. Cost of Lost/Gained metal

( Case 2 ) Nugget effect is caused by geological factors (i.e. geological variability at the short distances)
In the current study Z was generated using Conditional Simulation technique.

Equigrobale realisations of SGS method

Economics: OPEX vs. Cost of Lost/Gained metal

Case 3: Yandi Open Pit

(a) Explanation (cut offs on $\text{Al}_2\text{O}_3\%$)

(b) 1$^{\text{st}}$ option (BH: 5 x 5m)

(c) 2$^{\text{nd}}$ option (RC drilling: 25x25m)

Explanation
(cut offs on $\text{Al}_2\text{O}_3\%$)

1$^{\text{st}}$ option (BH: 5 x 5m)

2$^{\text{nd}}$ option (RC drilling: 25x25m)

2.7% of SMU size ORE blocks are misclassified as WASTE

4.1% of SMU size ORE blocks are misclassified as WASTE

Abzalov et al., 2010: Optimisation of the grade control procedures at the Yandi iron-ore mine, Western Australia: geostatistical approach, Applied Earth Science Journal, v.119, No.3, p.132-142
CASE 4: Bauxite operation

Grid 20 x 20m
- 1.3% misclassified blocks
- Contain 80,775t bauxite
- Which cost $2.8M
- 5318 drill holes which cost $3.03M

Grid 50 x 50m
- 2.3% misclassified blocks
- Contain 139,725t bauxite
- Which cost $4.9M
- 664 drill holes which cost $0.38M

Grid 100 x 100m
- 2.7% misclassified blocks
- Contain 161,145t Bauxite
- Which cost $5.6M
- 222 drill holes which cost $0.13M
Summary and Conclusions

- Efficiency of Grade control depends on sampling grid and samples quality. Right balance between them can be find by estimating contributions of 'Geological factors (discontinuity)' and 'Sampling errors' to 'Nugget Effect' of the Pair-Wise Relative Variogram \( \gamma_{\text{PWR}}(0) \).

- The proposed approach is as follows:

\[
\sigma_{\text{Geol}}^2 = \gamma_{\text{PWR}}(0) - CV_{\text{Field Duplicates}}^2
\]

- Optimisation of the grade control procedures requires estimation costs of the lost/recovered metals which are deduced from the Z vs. Z* diagrams.
Next Step...

MINING PROJECT DASHBOARD

STANDARDEISED SET of ‘GAUGES’
Thank you

Questions ?

Comments ?

Suggestions ?
CASE 2: Bauxite project – South America

Field (coarse) duplicates:

- CV = 20.7%
- No of sample duplicates = 1868

Pulp duplicates:

- CV = 13.5%
- No of sample duplicates = 472
\[ CV\% = 100\% \times \sqrt{2} \frac{|a - b|}{(a + b)} = 100\% \times \frac{\sigma}{m} \]

\[ CV = \frac{\sigma}{m} = \frac{\sqrt{\sum_{i=1}^{n} (x_i - \frac{\sum_{i=1}^{n} x_i}{N})^2}}{\sum_{i=1}^{n} x_i} \quad m = \frac{\sum_{i=1}^{n} x_i}{n} \]

\[ \sigma^2 = \frac{(a - \frac{a + b}{2})^2 + (b - \frac{a + b}{2})^2}{2 - 1} = \frac{(2a - a - b)^2 + (2b - a - b)^2}{2} = \frac{(a - b)^2 + (b - a)^2}{4} = \frac{(a - b)^2}{2} \]

Standard Deviation = \(\sqrt{\sigma^2} = \frac{|a - b|}{\sqrt{2}}\)  \hspace{1cm} Mean = \(\frac{(a + b)}{2}\)

\[ CV = \frac{\sigma}{m} = \frac{\sqrt{2}}{(a + b)} = \sqrt{2} \frac{|a - b|}{(a + b)} \]
\[ \sigma_{\text{Total}}^2 = \sigma_{\text{Sampling Protocol}}^2 + \sigma_{\text{Practical Implement.}}^2 + \sigma_{\text{Instrument}}^2 \]

Another errors \( \sum \sigma_i^2 \)

It includes: Extraction Error
Preparation Error
Delimitation Error

\[ \sum \sigma_i^2 = \sigma_{\text{Field Duplicates}}^2 - \sigma_{\text{FSE}}^2 \]

FSE ( \( \sigma_{\text{FSE}}^2 = \frac{K \cdot d_N}{M_S} \) )

P.Gy’s Safety Line

0.0595cm

0.0074cm

0.3cm