MSc Research Proposal

SCHOOL OF MINING ENGINEERING

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Title of Research:	Comparison of Uniform Conditioning on two hypothetical distributions
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1. Introduction

This project will investigate localised uniform conditioning (LUC), and determine under what conditions it is suitable as an estimation method for calculating mineral resources. Uniform Conditioning (UC) is a widely used but often poorly understood non-linear estimation technique (Neufeld, 2005). LUC is application of UC, where the UC results are presented as a localised grade model rather than as a grade tonnage curve representing a large volume. The intention of this project is to describe UC and LUC in an understandable manner, discuss approaches for how to practically apply the technique and how to deal with localising the estimate, and finally to determine under what circumstances it is a suitable approach.

UC, a non-linear estimation approach, seeks to resolve some of the shortfall of linear estimation (e.g. conditional bias seen in ordinary kriging small blocks) by considering the distribution of grades at different supports (mineable block sizes). Linear estimation techniques do not consider the change of support model, which can potentially result in unrealistic grade-tonnage estimations particularly at very high or very low grades cut-offs.

A local average grade of a large block ("panel") is estimated first, and then a grade distribution for a set of small blocks (smallest mining units or "SMUs") is conditional to the panel estimate. This achieved through using a Gausian change of support model based on known distribution of sample grades. A series of proportions above cut-off are then calculated, which honour the known distribution of SMU grades within a panel. To give the results of LUC, SMU grades are then be localised within each panel, for a spatially located grade result.

UC estimates a recoverable resource above multiple cut-off grades. The definition of a recoverable resource is the proportion of an in-situ mineral resource, which is recoverable due to some constraint (i.e. technology, cut-off grade). In the case of UC, the constraint is cut-off grade. Once a UC estimate is localised, then it becomes a resource as the constraint is removed.

Considering two 'simulated realities', one normal distribution and another highly skewed log-normal distribution, a comparison will be made of how well uniform conditioning fares in these two extreme cases. This will include a comparison of grade-tonnage estimates for UC panels and consideration of how close the LUC estimates are to "reality" will be made. Depending on the underlying distribution of the data, UC may produce a more favourable result. This paper seeks to understand what types of underlying distributions are more effective for UC.

2. Research objectives

The objective of this research is to consider and describe UC and LUC and, based on examples of specific underlying statistical distributions, determine conditions where this approach is most favourable.

3. Literature review

UC is described fairly well in literature, written in both French and English. Matheron (1974) is the first reference UC, after which the technique was first fully described by Remacre (1984) in his PhD thesis. Both of these works are in French.

The first English publications on UC were by Armstrong and Matheron (1986) and Rivoirard (1990), who discuss UC in their papers on disjunctive kriging (DK). Many principles relating to the two methodologies are the same (e.g. use of the discrete Gaussian change of support model).

Vann and Guibal (1998) as well as Vann et al (2000) present summaries of several non-linear estimation techniques, and explain advantages of adopting UC and other non-linear techniques over linear estimation techniques. The information presented summarises UC as being a variation of Bi-Gaussian DK, with an advantage that UC performs better over DK in non-stationary environments. The authors suggest UC is heavily dependent on a well performing panel estimate and the discrete Gaussian change of support model is robust.

Humphreys (1998) provides case study in uniform conditioning at Wandoo deposit, which describes his approach and various tests carried out to determine if it is applicable to use the Discrete Gaussian model on the data.

In the early 2000’s, the Centre for Computational Geostatistics (CCG) at the University of Alberta undertook a research program into UC, and Neufeld (2005) produced a guidebook and non-commercially available GSLib software programs. The research sought to consolidate knowledge and present an easy to understand procedure on the subject. Neufeld and Deutsch (2005) also discuss the method further.

4. Hypothesis

This research intends to compare the performance of UC in the presence of normal and log normal data

5. Key questions to be answered

The key question to be investigated in this research is under which conditions this uniform conditioning is most suitable for estimating recoverable resources. These questions will be answered through reviewing literature and comparative examples.

Blindly applying any geostatsitical methodology to a deposit can lead to erroneous results, which may produce estimates which have significantly more or significantly less mineral abundance than there actually is. The danger of inaccurately estimating grades and tons, can lead to gross errors in mining or possibly erroneous valuation of mining projects.

UC is, like any geostatistical method, makes assumptions about the underlying distribution and grade continuity, and thus may perform more favourably depending on the underlying distributions.. The aim of this research is to prove which deposits (based on their underlying distributions) are suitable for using UC to calculate recoverable resources, or whether UC is robust enough to suit a range of underlying grade distributions.

6. Methodology

6.1 Dataset

The project will consider two grade distribution/variability scenarios, one skewed log normal distribution with the variance described by a high nugget and how short range grade continuity; and a second normal distribution with a low nugget and good continuity. The log normal distribution will be positively skewed and the normal distribution will be symmetrical. The log normal distribution's covariance is slightly larger, as there is a wider spread of values. These unconditionally simulated distributions are modelled on typical grade distributions that one might see in a sedimentary hosted gold deposit and a porphyry copper deposit respectively.

The example data will be generated from a sub-sample of the simulated realization for each of the two distributions. This simulation will be generated on a tightly spaced point data grid and will represent the true grade of the simulated deposit.

Each simulation will be re-sampled with pseudo drillholes on a grid, which will replicate an approximate exploration drilling programme. These pseudo drillholes will form the sample dataset to be used in the worked UC examples, while the simulation itself will represent reality for the basis of comparison.

6.2. Process outline

Normal scores

A statistical and geostatistical analysis will be carried out, in order to understand the underlying distribution and spatial characteristics of the data. The data [Z(x)] are transformed to a Gaussian distribution (normal scores) of the data [Y(x)].

Testing for bi-Gaussianity

It can be demonstrates that the madogram/variogram ratio of the Gaussian transformed data confirms whether the transformed data are bi-Gaussian, and therefore can be used for UC. The ratios of different indicators show whether the raw data are best considered as a Mosaic or Diffusion phenomenon. Mosaic models are not compatible with UC, whilst diffusion models are. Based on this, such test will be run to check for the correlation of indicator residuals. The results of this test will determine if a Gaussian approach (for UC) is suitable (Rivoirard (1994), Humphreys (1998)).

Change of support

A Gaussian anamophosis change of support model is used. Hermite polynomials are fitted to the Y(x) distribution. A set of equations described by are used to convert the point anamophosis (Y(x) distribution) to varying supports, which are the SMU support and panel support (Rivoirard (1994)). The change of support co-efficient, namely "r" for SMU support, "R" for panel support, are calculated from theoretical block variances based on the size of the blocks and the distribution of samples within those blocks. These samples are inputs into Rivoirard's equations, and which determines the change of support. ultimately guide the change of support. Alternative methods of calculating this change of support co-efficient will also be investigated.

The panel grade is known (a robust panel estimate is a requirement of UC), which is then used to solve the above equations. Using the ratio of R vs r, a distribution of the individual grades within the panel is calculated using the change of support model.

Uniform conditioning

UC will then be applied to the sample data, based on the calculated change of support model. The resultant estimate is a set of SMU grades for each panel. The location of these grades within the panel is unknown at this stage.

Localisation

The uniform conditioned data will be localised. The localisation of SMU's with each panel will be based on a lowest to highest grade rank order, calculated from ordinary kriged estimate of the SMUs. The grades from the ordinary kriged SMU model are not used, only the location of (or rather, rank order of) within the panel are used to determine the spatial of the UC grades.

Comparison

Several comparisons will be made and the results presented, to test the effectiveness of the UC and the LUC for the log-normal distribution and for the normal distribution:

- Deposit and individual panel mean grade evaluations, to compare the average panel grades versus the simulated ("real) grade for deposit and each panel.
- Grade-tonnage comparison to compare the UC calculated grade-tonnage at multiple cut-offs, versus the "real" grade-tonnage results from the simulated model.
- A grade-tonnage comparison of the UC versus "real" data, for the deposit.
- Comparison of UC estimate using kriged panel grades versus UC estimate using on mean simulated panel grades.
- LUC rank order versus "real" rank order comparison.
- Comparison of LUC grades versus "real" simulated grades.

6.3 Software

At the time of this project, UC has only been implemented in a single commercial software package, namely Geovariance's Istatis. In 2013 CAE Mining entered into collaboration with Geovariance, and as such uniform conditioning is scheduled to be released in Studio 3 in late 2014.

For this project, the UC work flow will be carried out using a combination of CCG's UC software and CAE Studio 3. Parts of the process are well defined within the GSLib software framework (i.e. determining dispersion variance and running the UC) whereas other parts are not (i.e. converting the uniform conditioned grade-tonnage distributions to individual panel grades and localising these). New software tools will need to be developed to complete sections of these activities, which will form part of the scope of the project.

7. Outline of chapters

The envisaged outline of chapters is as follows:

1. Introduction
2. Theory of Uniform Conditioning
   - 2.1 Linear estimation techniques
   - 2.2 Non-linear estimation techniques
   - 2.3 Change of support
   - 2.4 Uniform conditioning procedure
   - 2.5 Localised uniform conditioning
3. Approach
   - 3.1 Generating simulated data
   - 3.2 Sampling simulations
   - 3.3 Exploratory data analysis
   - 3.4 Normal scores
   - 3.5 Variography
   - 3.6 Panel estimation
   - 3.7 Bi-Gaussianity
   - 3.8 Uniform Conditioning
   - 3.9 Localisation
4. Results

4.1 Model comparison

4.2 Localisation rankings

4.3 Local grade-tonnage comparison

5. Discussion

6. References

8. Facilities required

No special facilities are required for carrying out this project. Commercial software (CAE Datamine) may be required, and licences will be provided by Anglo American (MinRED).

9. Time schedule

At the time of submitting revisions to this proposal, the technical work for the project had been completed (see Figure 1). Currently further literature is being reviewed and the project written up. The project is currently progressing quickly, as approximately 50 hours per week can be spent on the project, until 10th August. Thereafter, approximately 10 hours per week are available for project work.

Week starting	31-Mar	07-Apr	14-Apr	21-Apr	28-Apr	05-May	12-May	19-May	26-May	02-Jun	09-Jun	16-Jun	23-Jun	30-Jun
Reading / refrences	■	■	■	■	■									
Develop proposal	■	■	■	■	■	■	■	■						
Simulations						■	■	■	■					
Panel Krig									■	■				
UC and LUC											■	■		
Grade tonnage												■	■	
Write : Theory & Lit review													■	■
Write : Approach														
Write : Results														
Write : Discussion														
Write : Intro														
Review and Corrections														

Week starting	07-Jul	14-Jul	21-Jul	28-Jul	04-Aug	11-Aug	18-Aug	25-Aug	01-Sep	08-Sep	15-Sep	22-Sep	29-Sep	06-Oct	13-Oct	20-Oct	27-Oct	03-Nov	10-Nov	17-Nov	24-Nov	01-Dec
Reading / refrences	■	■	■	■	■	■	■	■	■													
Develop proposal																						
Simulations																						
Panel Krig																						
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Write : Theory & Lit review																						
Write : Approach	■	■																				
Write : Results		■																				
Write : Discussion			■	■																		
Write : Intro			■	■																		
Review and Corrections					■	■	■	■	■													

Figure 1 Gantt chart showing work plan

It is anticipated that this research will be completed by December 2014.

10. Budget

The project will be funded by the author.

11.Intellectual property

There are no intellectual property right required with this project. All data will be generated from simulations of known data distributions, and information pertaining to the work flow is based on published literature.

12. Publications/presentations

Currently there are no intentions for publication of this work.

13. References

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