Assessing Pillar Geometries in the Witbank and Highveld Coalfields Using Geostatistical Techniques

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Abstract

Research is currently underway, as part of the Coaltech 2020 initiative, to investigate ways of safely and economically extracting pillars in the Witbank and Highveld Coalfields. As a portion of this research, the widespread application of geostatistics is extended to the estimation of coal pillar sizes and their distribution from sample pillar geometries of pillars left as a result of the widespread use of bord and pillar mining methods. Indicator Kriging (IK) is used to identify areas that are mined and those areas that remain as solid (in the form of coal pillars or unmined ground) in the area under consideration. This exercise forms the basis in attempting to simplify the estimation problem of the extent of the pillars, the pillar geometries and thus provide parameters to consider for pillar recovery.

Introduction

South Africa's coal mining industry, which is a little more than a century old, has been based predominantly on the bord and pillar method of mining. In the late 1970's and 1980's longwall mining methods, based mainly on European practice and equipment, were introduced but for a number of reasons, including high capital cost and the geology of the coalfields, they found only limited application. Galvin (1981) gives insight to the economic difficulties that resulted from the introduction of price control in 1950 that ensured that a cheap energy policy was maintained in order to promote economic development. This resulted in an artificially low coal price and this in turn had a detrimental effect on the growth of the coal mining industry. It meant that bord and pillar mining was the only economically viable mining method, and this ensured the further development of underground pillars in favour of technologically advanced mining methods. Selective mining was practised extensively, with only higher grade seams and horizons within seams being extracted to maximise revenue and avoid washing costs. This resulted in overall extraction being as low as 20%.

The Witbank coalfield has been extensively mined for their favourable geology, relative ease of mining and their economic value. However, the tangible reserves have been identified as being less favourable in terms of economic quantity than was expected. This indicates that either new reserves have to be found (such as the Waterberg with its difficult mining parameters and unfavourable geology), or consideration has to be given to fully extracting what remains in the Witbank coalfield area. Considering that partial extraction was practiced over the majority of the coalfield, the remaining amount lies dormant as stability pillars and also provides the potential for complete extraction. These large areas left in the form of pillars may themselves have weakened or caused the overlying strata to weaken. Prevost (1999) suggests that although stricter pollution controls are now in place, the fact that mines and mine owners have become liable for any environmental impact caused by their mines has made industry aware of more efficient mining and processing methods. He further explains that the intense past and present coal mining activity in the Witbank coalfield has caused, as a result closed coal mines, the contamination of water, air and ground, with the worse of these problems caused by relatively shallow, underground, bord and pillar mines.

Methodology

In terms of designing a methodology to conduct pillar extraction techniques, the extent of the workings needs to be estimated. This could take the approach of taking every available underground coal mine in the Witbank area and then counting the number of pillars, or taking a novel approach to this onerous task. In attempting to assess an appropriate novel method for estimating the extent of the remaining reserves, an application using Indicator Kriging (IK) to estimate the extent of abandoned workings in the USA was found (Ovanic & Cawlfield, 1990). Journel (1982) introduced the earliest concepts of Indicator Kriging (IK). Incorporating the Geostatistical techniques brings about the spatial component to this problem.

Indicator Kriging

Indicator Kriging (IK) has been traditionally applied to quantitative data (such as ore grade assays or seam thickness). However, the data obtained from a drilling programme designed to detect unknown or known areas of void and pillar (like bord and pillar mining methods) is less quantitative. To analyse this type of data geostatistically, the qualitative data is transformed into numerical data. IK utilises a binary indicator function to perform the necessary transformations. Clark & Harper (2000) suggest that the approach take the form of specifying some selection criterion (usually a discriminator value in which you are interested). They caution that this should not be confused with an economic cut-off or some critical level, and would probably be something which affects the depositional mechanism of the variable we are measuring. This sort of analysis of estimating the extent of previously mined areas on a regular pattern of bord and pillar mining falls into this category.

The drilling pattern should fall into one of two mutually exclusive classes:

1. Those that indicate mine void (the bords), and

2. Those that do not (the pillars or unmined ground).

The indicator function *I(x)* can be used to code in a binary form the drilling patterns as follows:

$$I(x) = 1, \text{ given all } x \in C$$
$$I(x) = 0, \text{ given all } x \text{ not} \in C$$

Where *C* represents all cases where one drill hole would intersect mine void (bord).

The task, of course, of actually conducting a drilling programme on a regular pattern is expensive and onerous. Computing power does exist for IK semivariograms and Kriging estimates to be produced with any univariate Kriging software. For this paper, the demonstration *ECOSSE* Software supplied with the book *Practical Geostatistics 2000* is used with the indicator values substituted for sample values as input data.

Data Collection

To achieve the goal of estimating the extent of underground reserves using the Indicator Kriging approach as discussed in this paper a relevant sample is needed. It was decided that the best way to achieve this would be to sample mine plan of a defunct operation in the Witbank Coalfield. As these mine plans are at a scale of 1:1,500 feet and extend over a large area, the actual extent of the maps range from 7 metres to 12 metres in length. To narrow the extent of the search, an A3 sample of some of these plans was taken around the main adit of the mine, and these were felt to be representative enough for the approach to test whether IK is a suitable tool to estimate underground mine workings. Mine A was chosen as a suitable sample, shown in Figure 1.

This sample was chosen for its various mining directions and the mixed regular and irregular mining layout. It is a typical bord and pillar type mining operation of the No. 2 Seam in the Witbank Coalfield. It has a depth below surface of approximately 90 metres and is roughly horizontal. The seam thickness and mining height in the area is 3 metres. The mine ceased operation in the late 1960s.

Figure 1. Sample A3 plan of Mine A around the main adit (not to scale)

The sample as shown in Figure 1 was unsuitable for use in Geostatistical analysis, as clear areas of binary coding [1,0] needed to be identified. To this end, it was decided to colour all areas of void black and all areas of unmined ground white. The binary coding took the convention as described above of [1] for intersecting mine void (i.e. black) and [0] for intersecting solid (i.e. white). The result is shown in Figure 2, which represents the area in the Paint application as a Bitmap file.

Data Analysis

For the development of the argument that Geostatistical analyses can be used to estimate the extent of underground workings, a portion of the area under consideration was chosen on which extensive analyses could be done. The portion shown in Figure 3 was decided upon it was not regular in its direction (not north-south or east-west in orientation), has varied pillar and bord width sizes and consists of both regular and irregular mining layouts. This area is approximately 270 metres in the north-south direction and approximately 230 metres in the east-west direction.

Figure 2. Mine A coded for binary coding analysis (not to scale)

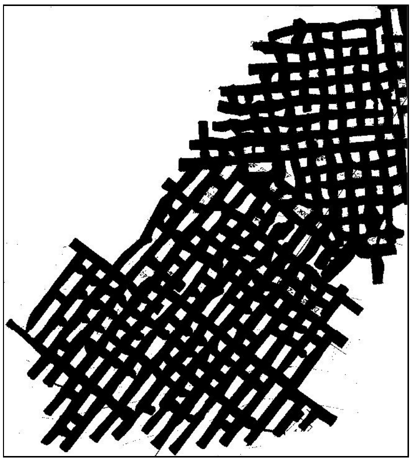

Figure 3. Portion of Mine A used for Geostatistical analyses (not to scale)

A tool, called *Bitmap Decoder* was developed to enable the above map to be decoded into a form that any Geostatistical package would understand so that analyses of the area could be conducted. It enables the image to be read in on a pixel grid spacing of one's choice with the closer the spacing the more detailed the analysis. These images were scanned at 100pixels per inch (roughly 3,94 pixels per millimeter). The above image was thus represents a size of 724 x 648 pixels. An iterative drilling pattern based on this information can thus be designed. It was decided to decode the image in Figure 3 using the *Bitmap Decoder* on a sampling gird spacing of 25 x 25 pixels (starting in both directions from the first pixel), 10 x 10 pixels, 5 x 5 pixels and 2 x 2 pixels.

The 25 x 25 sampling grid proved to be too sparse for any valuable analyses to be conducted and was excluded from any further analyses. The remaining three samples appeared to be adequate for the analyses as they show definite signs of spatial correlation (confirmed by the semivariograms shown later), and the post plots for these are shown in Figures 4, 5 and 6. It is observed that the denser the gird spacing, the more true the pattern of the sample.

Looking closer at the 5 x 5 and the 2 x 2 post plots, little difference in the quality of the sample is given and for the purposes of this paper, the less sampled 10 x 10 and the more detailed 5 x 5 sample will be further analysed..

The corresponding data files were then inputted in the *ECOSSE* programme to produce the following corresponding experimental semivariograms. The input parameters for all three examples specified a search radius of 100 pixels (approximately 4 pillars off the plan) and calculated the experimental semivariograms looking at the main point son the compass (north, east, south, west). So, for example, for the 5 x 5 grid spacing, the interval between the points on the graph was 5, and the number of intervals was 20 to give a search radius of 100 pixels. These experimental semivariograms are shown in Figures 7 and 8.

Models were then fitted to these experimental semivariograms. The Paddington Mix model was chosen to be the most suitable, with the results of fitting the same inputs into both the 10 x 10 and the 5 x 5 experimental semivariograms being the same. They consisted of 2 components with a nugget effect of 0.04. The cycle period was 30, the decay parameter was 100 and the sill for the cycle was 0.03. These fitted models are depicted in Figures 9 and 10.

If we take the 5x 5 scenario further and fit a Paddington Mix model on all possible pairs in all direction, one gets the result shown in Figure 11. What one sees happening is an increase in the damping of the cycles when one goes from 10 x 10 to 5 x 5. Obviously the spherical parameters were refined to achieve this as the cycles started to interfere with one another. What this modelling shows is that if the pillars were exactly the same size and exactly equidistant apart that the cycle parameter would be the same.

Taking the process a step further and conducting Kriging analysis on the 5 x 5 grid gives a probability estimate and also calculates the variance associated with each estimation. This variance provides a measure of reliability with respect to the probability map. In areas where the estimation is relatively high the reliability of the estimated probability is low. Figure 11 shows the Kriging estimate of the area and shows that the area can be roughly reproduced on the 5 x 5 sampling grid.

Figure 12 shows the map of standard errors (variance). This map shows a regular pattern of areas where the highest estimation errors exist. Not surprisingly these areas occur between points on the regular 5 x 5 grid spacing. This map will in the real world identify areas where additional information may be gathered to reduce the uncertainty associated with this analysis.

Conclusion

The work conducted by Ovanic & Cawlfield (1990) an exponential model to fit the experimental semivariogram. What has been shown in this paper is that a better model to fit the experimental semivariogram has been used to better estimate the extent of the underground workings.

This paper has shown that Indicator Kriging (IK) has application in the estimation of underground reserves. It is a useful tool that directly yields values for the estimation variance associated with the probability estimates. The results obtained thus far show promise that the IK approach can be used as a practical tool for estimation of underground workings when either one only has a sample of the area or one needs a quick way to get around the size of the legal plans kept at the Department of Minerals and Energy.

It must be accepted that this is work in progress and that the refining of the technique is still being conducted. The future objective of furthering this technique will be to determine the optimal balance between defining the cycles (which will then give the size of the voids and unmined ground) and refining the full model especially as regards the nugget effect and short range component.

References

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