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Predicting variability in coal quality parameters

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Abstract

Providing a run-of-mine product of consistent quality depends on:

(a) prediction of the quality of the coal mined on a day-to-day or week-to-week basis;
(b) effective blending of coal from various sources of production.

Both of these factors depend on the accurate valuation of coal qualities in situ and on the translation of these predictions into "mineable" production figures.

This paper shows how fast and reliable predictions may be made using proven geostatistical methods. We also discuss the evaluation of confidence in the predictions and how this can be used to aid in the assessment of risks of major deviation from production targets. A case study will be used to illustrate the points for discussion.

Geostatistical valuation methods

Geostatistical estimation and mapping techniques – such as kriging – are, basically, distance weighting interpolators. Kriging differs from more traditional distance weighting methods in two ways:

1. the distance function which applies to a particular valuation problem is derived from the available sample data, rather than being selected arbitrarily from a list of default functions;
2. kriging allows for clustering and irregular sampling patterns, using the complete sampling layout to determine optimal weighting factors for each sample;
3. a quantitative measure of reliability of the final prediction can be assessed using the "kriging variance" produced automatically during the estimation process.

Given a reasonably regular sampling pattern kriging estimates will not differ significantly from inverse distance estimators — provided the appropriate distance function has been used. However, traditional interpolators, including inverse distance and triangulation methods, do not produce measures of confidence in the final predicted values. Neither do they produce any measure of the likely variability in coal quality which could result in short term planning figures. In this brief paper, we will indicate where such measures could be of practical use in the production of coal of consistent quality over a specified time period — and the risks which are taken when this variability is ignored.

A geostatistical valuation is carried out in two stages:

1. For each variable — calorific value, thickness of seam, ash percentage – the appropriate distance function is derived from the sample data available. This "distance function" takes the form of a graph of *'distance between sample locations'* versus *'difference*

between sample values'. For various mathematical reasons, the quantity plotted on the vertical axis is actually the square of the difference in value between samples. For simplicity, sample 'pairs' are grouped into distance intervals — rather like intervals in a data histogram. Unlike a histogram, the "squared differences in value" are averaged in each interval. The graph is plotted and an appropriate distance function or "model" is fitted through the points. This function, known as a "semi-variogram model" is then used as the appropriate distance function in the later interpolations. These functions can be different in different directions, if the deposition has a preferential direction associated with it.

2. Inverse distance interpolation weights the samples used by the distance between each sample and the *unsampled point* at which a prediction is to be made. The actual weight selected is determined by the appropriate function of distance selected. In kriging, a set of equations is set up which incorporates these function values. That is, the semi-variogram model is used to determine the relationship between each sample and the *unsampled point*. In addition to these terms, the equations also include relationships *amongst* the samples themselves. This allows the kriging system to determine the optimal weightings allowing for the total sampling layout – including such features as irregularities in sampling and so on. The resulting estimated value is as close to the true value as can be achieved with the available sampling data.

As a by-product of optimising the estimation, a measure of that optimisation is obtained. This is usually termed the "kriging variance". According to geostatistical theory, the square root of this variance should give us a reliable measure of the likely magnitude of the error incurred in the estimation process. In an ideal situation, the error – that is, the difference between the true coal quality value and our estimate of it – should have a Normal (Gaussian) distribution around zero with a standard deviation equal to this quantity. This can be tested by a process known as "*cross validation*". If this ideal behaviour can be verified in reality, we can use the kriging standard deviation to obtain confidence levels on predictions of coal quality parameters. This method can be applied to "point" estimation – mapping – and to the estimation of the average value over a planned mining panel.

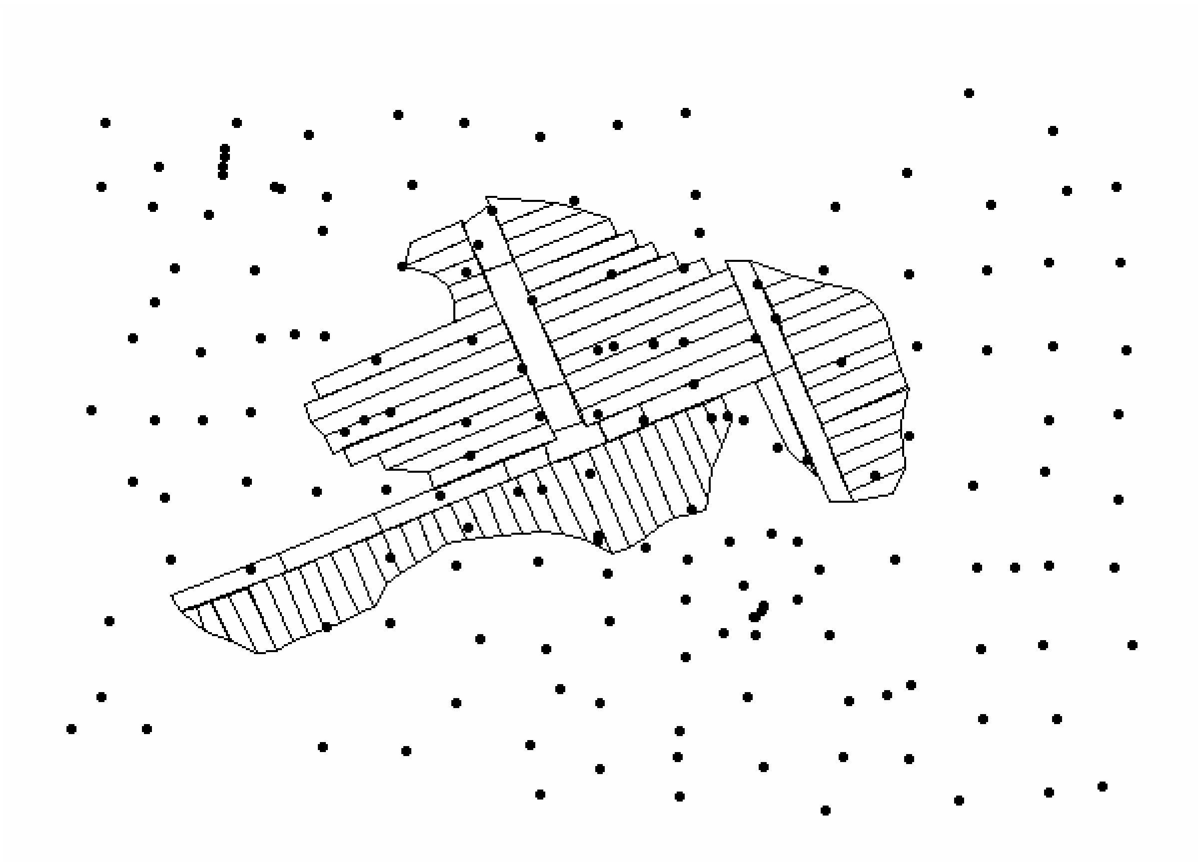
Short term variability

In production planning, a predicted value is generally assigned to each mining unit (panel) in the mine plan. This value is then used in projections of run-of-mine coal quality. Using the average value for the panel assumes that all of the coal within the panel is of the same quality – that there will be no significant variation from this average on a day-to-day or week-to-week basis. If the coal from the panel can be stockpiled until the whole panel is mined and then blended, this may be a realistic assumption. It is more likely that coal will be processed on a shorter term basis than the mining of a complete panel. In this case, we must be able to assess how far a "planning unit" will differ from the overall average of the panel.

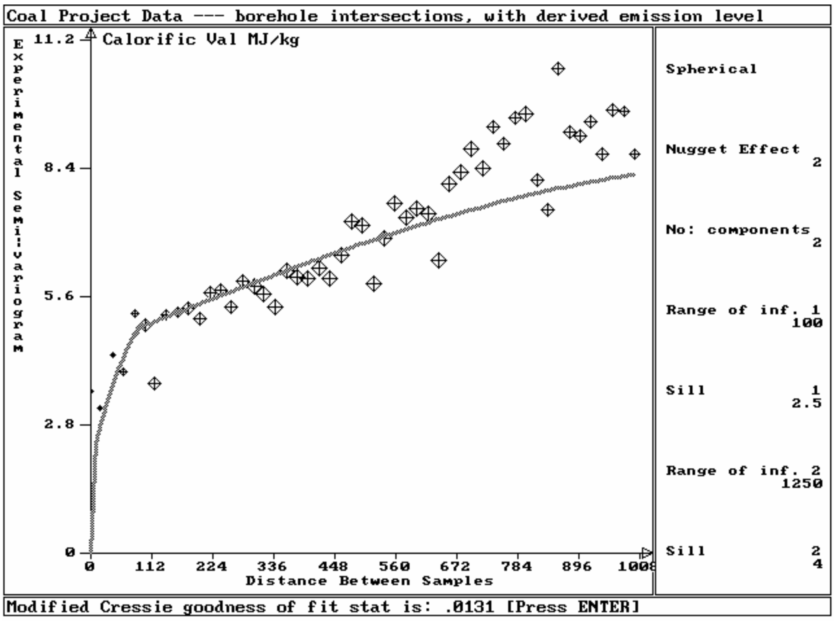
Unlike most traditional methods of estimation, geostatistical analysis offers the possibility to assess the likely variability of coal quality parameters for any specified size of planning unit. Using mathematical theory and/or simulation, variability can be predicted. One particular use for this kind of analysis is to determine whether any of the planning units fall below some threshold criterion for acceptability – an economic cutoff or a penalty level, for example. In this way, the risk of penalties or the need for blending product can be assessed well ahead of the date of implementation.

Case study

For this illustration, we take a typical single seam situation. We have illustrated this paper with calorific values but the principles hold equally well for seam thickness, ash content, sulphur levels and so on. We show an area 1 by 1.5 kilometres in size, with a subset of the planned mining panels for clarity. In this area, we have 170 boreholes and 85 mining panels of various sizes. A standard geostatistical analysis shows that the "semi-variogram model" for the calorific values is of the Spherical type with a maximum *range of influence* of 1250 metres.

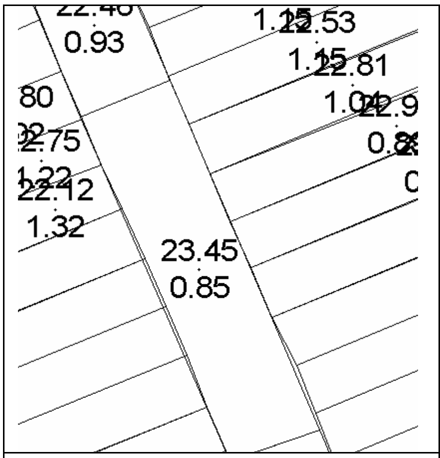


borehole data and mining panels

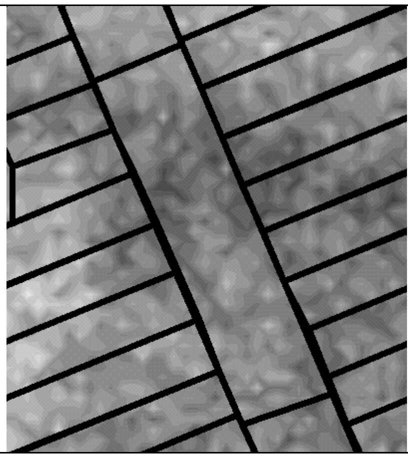


semi-variogram: calculated and model

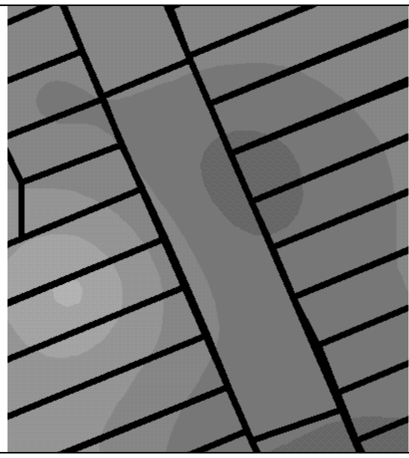
We have selected a single panel to study in depth:



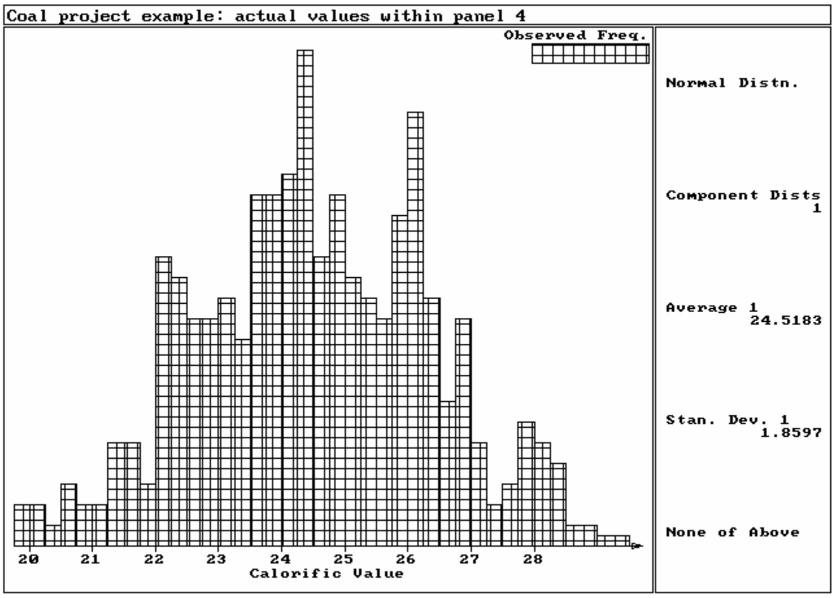
estimated CV and standard deviation



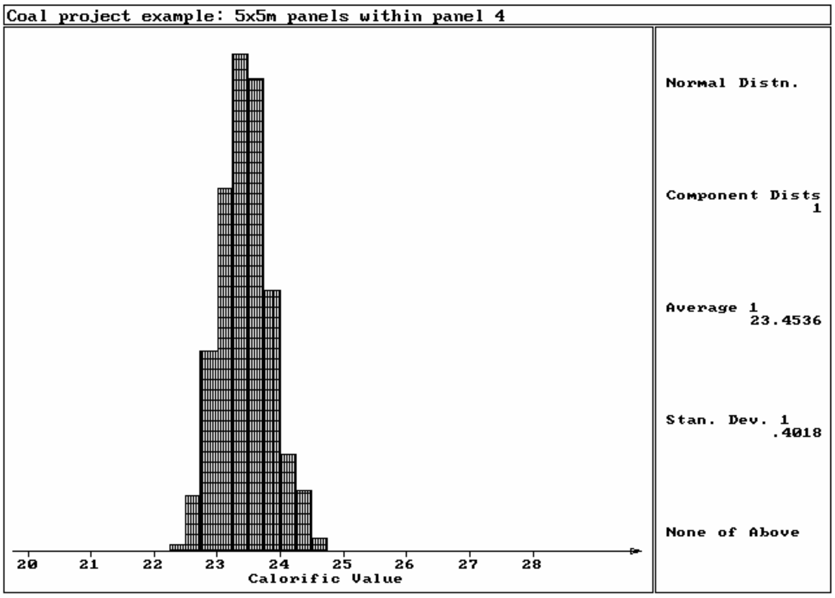
actual calorific values



kriged calorific values



actual calorific values within panel



kriged calorific values within panel