Desmoothing Block Models for Underground Mine Design

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ABSTRACT

Block models generated with all linear interpolation algorithms contain inherent smoothing that typically results in an underestimation of grades and overestimation of tonnes in resource estimates. For mineral deposits that are anticipated to be exploited by underground mining methods excessive smoothing may result in materially misleading estimates of Mineral Reserves.

To account for smoothing in the open pit mining environment recoverable reserve techniques such as indicator kriging and uniform conditioning are employed to provide non-spatially located proportions of the large blocks above the cut-off grade. These models are not suitable for underground mine planning where the actual location of material above cut-off is required to design its extraction.

To correct for excessive smoothing it is proposed to modify the ordinary kriged block estimates *a posteriori* using an affine correction with a local variance adjustment factor. The proposed methodology is demonstrated for a base metal deposit during a feasibility study.

INTRODUCTION

For mineral deposits that are anticipated to be exploited by underground mining methods, drill hole data in the early phases of evaluation is normally widely spaced relative to the block size desirable (and necessary) for realistic mine design and financial evaluation. In such instances, block models generated with all linear interpolation algorithms contain inherent smoothing that typically results in an underestimation of grades and overestimation of tonnes in resource estimates. The degree of smoothing depends in part on the relationship between block size and drill hole spacing. Excessive smoothing may result in materially misleading estimates of mineral reserves.

For open pittable mineral deposits smoothing is typically overcome by 'recoverable reserve' approaches (eg indicator or disjunctive kriging, or uniform conditioning) to estimating the mineral resource. However, for these estimation methods, very large blocks may be required and the outcomes provide non-spatially located proportions of the large blocks above the cut-off grade. Such estimation approaches are appropriate for open pit mine planning methods where all of the large block will be extracted, with ore and waste discriminated at the time of extraction. However, they are not suitable for underground mine planning where the actual location of material above cut-off is required to design its extraction.

Few approaches to correct for excessive smoothing that may be appropriate for the underground environment have been suggested in the literature. Journel, Kyriadkidis and Mao (2000) proposed a theoretically complex spectral post-processor that reproduced the covariance model but with a considerable loss of local accuracy. Abzalov (2006) suggested a localised uniform condition (LUC) approach for direct modelling of small blocks. LUC involves decomposing large panel estimates into individual parcels grades of the SMUs. Assibey-Bonsu, Tolmay and Krige (2008) proposed a localised direct conditioning (LDC) method for this problem in underground gold mines on the Witwatersrand. LDC involves using the known SMU grade distribution from adjacent production data to assign non-smoothed individual grades to SMU-sized blocks in extension areas. Whilst all of these methods have some merit a simple approach to account for excessive smoothing may be more acceptable to the mining industry.

To correct for excessive smoothing it is proposed to modify the block estimates *a posteriori* using an affine correction with a local variance adjustment or *f* factor. The affine correction is a well-known variance adjustment process that can 'squeeze' or 'stretch' a distribution whilst maintaining a constant mean grade value. The local *f* factor is introduced to account for the fact that smoothing tends to be higher for blocks located distant to sampled locations. In other words, the global variance adjustment factor typically used in the affine correction is adjusted locally to account for the distance between the block under consideration and sampled data locations. The proposed methodology is demonstrated for a base metal deposit during a feasibility study.

DESMOOTHING BLOCK MODELS

The proposed correction for smoothing of ordinary kriging block estimates using an affine correction with local variance adjustment factor, calculated as:

$$z_K^{**}(x) = \sqrt{f(x)}\left[z_K^{*}(x) - E(Z(x))\right] + E(Z(x)) \quad (1)$$

where:

$z_K^{*}(x)$ is the kriged estimate for block x

$z_K^{**}(x)$ is the smoothing corrected kriged estimate for block x

$E(Z(x))$ is the expected Z value or block mean grade value

$f(x)$ is the local variance adjustment to correct the smoothing effect

In Equation 1, $f(x)$ represents the local variance adjustment factor that is a function of the global variance adjustment factor f_G and the relative local data configuration, as measured by the kriging variance, calculated as:

$$f(x) = 1 + (f_G - 1.0)\frac{\sigma^2_{OK}(x)}{\bar{\sigma}^2_{OK}} \quad (2)$$

where:

$\sigma^2_K(x)$ is the local kriging variance

$\bar{\sigma}^2_K(x)$ is the average kriging variance

In Equation 2, f_G represents the desired increase in the variance of the block estimates. For example, f_G could represent the ratio of the theoretical variance of block estimates σ^2_γ calculated from the variogram model and Krige's relationship to the actual variance of the ordinary kriging block estimates σ^2_{OK}, ie:

$$f_G = \sigma^2_\gamma / \sigma^2_{OK} \quad (3)$$

Thus, if smoothing is present, $f_G > 1$, and the corrected distribution of block estimates would have a larger spread. To

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account for the fact that smoothing tends to be higher for blocks located distant to sampled locations, the global variance adjustment factor f_G is adjusted locally to account for the distance between the block under consideration and sampled data locations using the local kriging variance. In Equation 2, the higher the kriging variance (essentially, the greater the distance between the block and sampled data), the greater the local correction $f(x)$. Note that, the average local correction factor $\bar{f}(x) = f_G$. However, unlike the traditional affine correction, there is no guarantee that the variance of the corrected block distribution will equal f_G.

Calibrating f_G by considering conditional simulations is an alternate approach. For non-stationary domains, it may necessary to calculate $E(Z(x))$ in Equation 1 locally, based on a moving window or user-specified template.

APPLICATION TO A LEAD-ZINC DEPOSIT

This section demonstrates the proposed concepts for a large lead-zinc deposit under feasibility study for underground extraction. Drill hole spacing at the scoping study stage was not sufficient to estimate accurately blocks of a dimension suitable for mine planning without introducing excessive smoothing. Smoothing tends to lead to estimates for blocks more distant to samples being closer to the mean, where the larger f values are applied in the proposed method. As a consequence, computation experiments showed that the average correction to block grades is less than required to achieve the desired global variance increase. An iterative procedure of increasing the input f_G until the desired result was achieved was used to overcome this issue.

Figure 1 shows the zinc grade-tonnage curves for both the smoothed and desmoothed block models. To validate the approach, the discrete Gaussian (DG) or Hermitian polynomial change-of-support method was used to generate a theoretical grade-tonnage curve, shown in Figure 1. The DG curve was calculated with an f factor from the modelled variogram and Krige's relationship. Note that, the desmoothed model data closely matches the DG grade-tonnage curves supporting the affine correction approach.

In other applications of the proposed method by the authors, conditional simulation has been used as a validation tool to support the modified global grade-tonnage curves. Figure 2 shows smoothed and desmoothed grade tonnage curves for a copper deposit as well as the curves for 25 conditional simulations. Note that, the smoothed grade-tonnage curve lies outside the cloud of conditional simulation curves except at low

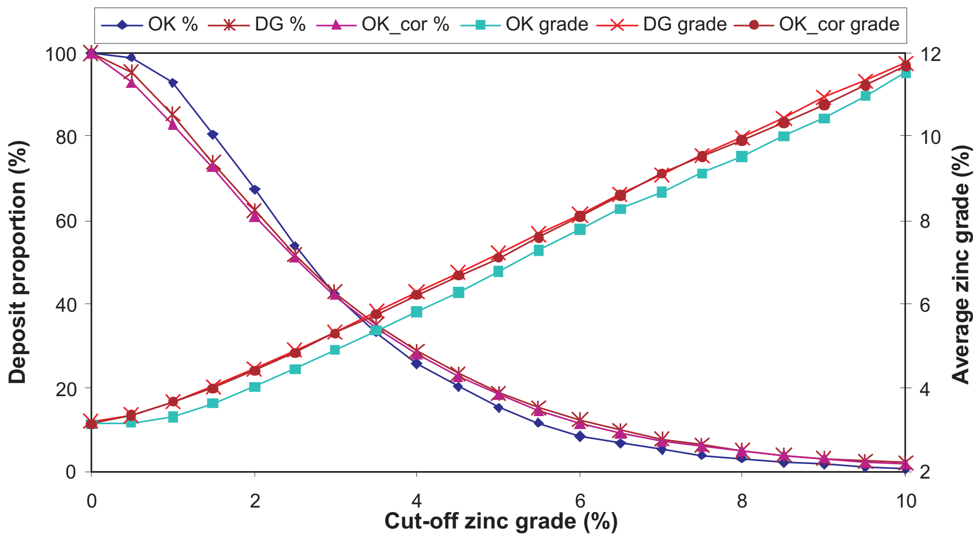

FIG 1 - Grade-tonnage example for lead-zinc deposit.

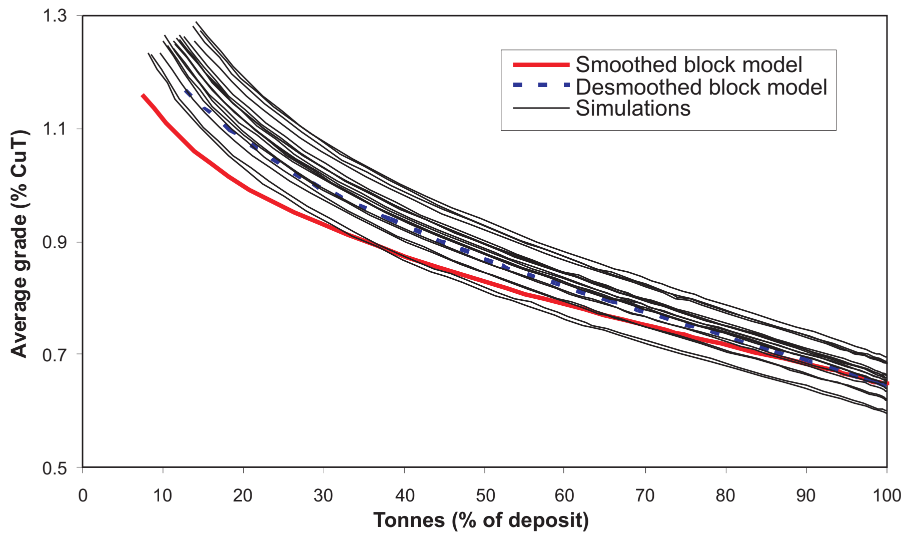

FIG 2 - Grade-tonnage example for copper deposit.

cut-off grades, whilst the desmoothed curve falls within the cloud of conditional simulation curves except for very high cut-off grades.

CONCLUSIONS

A novel method for desmoothing block models using the well-known affine correction was proposed. Essentially, the distribution of estimated block grade values was stretched until the desired variance was achieved. The approach used in this study employed a local variance reduction or *f* factor to ensure that blocks estimated in well sampled areas are little changed, and that those distant to samples potentially undergo the greatest adjustment.

The methodology was demonstrated for a lead-zinc deposit and a copper deposit. The former was validated by the theoretical DG change-of-support method. The latter was validated by a conditional simulation study to support the modified global grade-tonnage curves. Both examples showed that the proposed methodology produced grade-tonnage curves that indicated that the desmoothed block models would be suitable for mine planning purposes.

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