Why Choosing One Realization for Mine Planning is a Bad Idea

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Simulation is a powerful tool for assessing uncertainty; however, it is difficult to perform mine planning with multiple realizations of the grades. It is also not advisable to choose one realization for mine planning. When it is intractable to consider simultaneous planning with multiple realizations, we propose a partial block approach for mine planning. Partial block models can be constructed from simulated realizations or from a probabilistic estimation method. The justification and rationale is explained.

Introduction

Mining companies are becoming more interested in quantifying uncertainty. They realize that with limited information, there will always be uncertainty in predictions away from the drill holes. Conditional simulation is increasingly being used for quantifying geological uncertainty. This geological uncertainty is easily transferred to uncertainty in resources or reserves at a mine. However, transferring this uncertainty to mine planning/scheduling is not a trivial matter and is usually not done. Mine planning tools have not kept pace with the use of simulation and how to account for multiple realizations. Practitioners do not have the time to generate 100 different mine plans. This raises the question of "Which model or realization do we use for mine planning?"

Geologically modelling must be approached pragmatically. Not only are there a variety of methods for constructing these model, different people need different types of models at different, times in the production process. For example, during initial phases of mine feasibility, it is crucial that the recoverable reserves in the model be correct. At later planning stages, not only are the reserves important, but ensuring that the local estimates are accurate is just as important for mine planning and pit optimization. Add in geological uncertainty and the problem continues to grow.

This short note discusses some aspects that will influence building a single model for mine planning. Methods for building models and for transferring geological uncertainty through to economic evaluation will be presented.

Geological Uncertainty

There will always be uncertainty in a geological model. It is simply not economic to collect enough data to know everything that is going on in the deposit. The drill hole density used is a compromise between cost, variability, and risk that the mining company is willing to take. The spacing usually changes during the life of the mine as the deposit is better understood.

Geological uncertainty can be differentiated at three separate scales: (1) local uncertainty, (2) joint uncertainty and (3) global uncertainty. Local uncertainty is the uncertainty in some small volume that is usually estimated as a block or panel. Joint uncertainty refers to the uncertainty in a collection of blocks or panels, but not the entire deposit. Global uncertainty is the uncertainty for the entire deposit.

Local uncertainty is the easiest to calculate. It can be calculated with almost any estimation or simulation method. However, local uncertainty is only relevant at that specific small scale. It cannot be upscaled to a larger block size or production volume.

Global uncertainty is the uncertainty for the deposit. Global uncertainty should include uncertainty that is a function of the modelling approach and parameter uncertainty. Parameter uncertainty is the inherent uncertainty present due to limited sampling. For example, uncertainty in the histogram or variogram. Parameter uncertainty can be very important at the global scale.

Joint uncertainty is the hardest uncertainty to calculate. Joint uncertainty represents the uncertainty at a scale larger than a block, but smaller than the deposit. It could be a pit or a pushback within a pit or a production time period. The volume does not even have to be contiguous. Simulation is the only way that joint uncertainty can be calculated.

Conditional simulation is one of the most powerful model building tools available. It is the only method that can be used to calculate local, joint, and global uncertainty. The multiple realizations can be post-processed to calculate uncertainty in the geology or the mining process. However, it is not ideal. One of the most common questions about simulation is "Which realization do I choose for mine planning?" Unfortunately, there is no single realization that should be used for mine planning.

Why Choosing one Realization is a Bad Idea

Conditional simulation provides multiple realizations that are all equally probable and honour the input data. There can be significant differences in a particular area from realization to realization. Figure 1 shows four realizations all generated with the same input data.

One approach is to rank the realizations and extract one realization that is near the median. The ranking involves calculating some summary statistics from each realization, recoverable reserves, and then ranking the realizations based on the summary statistic. Although global rankings are useful, the global ranking does not equal local ranking. In any one realization there will be areas that are high and areas that are low. Even in realizations that are close to the P50, see Figure 1. Figure 1 shows four realizations that all ranked near the median case. Note the large differences between realizations, even thought they are all close to the median globally.

The results from mine planning depend on the input model. Each realization shown in Figure 1 will produce a different optimal mine plane. It is not desirable to have the optimal mine plan depend on the choice of a realization. An approach is needed that will produce an optimal pit that accounts for all of the realizations.

One Model for Mine Planning

We propose a partial block approach for producing one model for mine planning. A partial block model is defined by 3 numbers for each grade variable instead of a single number. The three numbers in a partial block model are: (1) fraction of ore, P_o, for the block above a cutoff Z_c, (2) grade of ore, Z_o, greater than the cutoff and (3) grade of waste, Z_w, less than the cutoff. The fraction of waste is calculated from the fraction of ore.

Partial block models allow the uncertainty in a block to be used for mine planning. The fraction of ore can also be thought of as a probability of ore for a given block. The higher the fraction of ore, the higher the chance that the entire block is ore and vice versa.

Another advantage of partial block models is that almost any method can be used to generate the probabilities and grades of ore. For example, a partial block model calculated from simulated realizations will be very similar to a partial block model calculated from multi-Gaussian kriging, uniform conditioning or indicator kriging. In fact, any method that estimates the uncertainty in a block can be used for generating a partial block model.

There are several different methods that can be used for building partial block models. Estimation methods include: restrictive kriging, uniform conditioning (UC) and local uniform conditioning. Simulation, or probabilistic, methods include: indicator kriging (IK), multi-Gaussian (MG) kriging, block LU simulation, and indicator or Gaussian simulation.

Transferring Geological Uncertainty

Even though a single model is built and used for mine planning, geological uncertainty can be carried forward past resource and reserve calculations. Recall the different scales of uncertainty discussed earlier. We are interested in the joint uncertainty from our model using the results of the mine planning. We can calculate the uncertainty in our mine plan for given time periods, monthly or annually, or within certain production volumes, pits or pushbacks. There are a few requirements for carrying the uncertainty forward: (1) a production schedule or pit outline with pushbacks and (2) a simulated model of grades and rocktypes if necessary. Joint uncertainty can only be calculated from a simulated model. Estimation based models, kriging or uniform conditioning, cannot be used.

The joint uncertainty is a summary statistic calculated from the simulated model within an indicator defining a specific zone. The zone could be a time period or pit as outlined earlier. An example of the uncertainty for different time periods is shown in Figure 2. Five of the realizations that were used for the summary plot in Figure 2 are shown in Figure 3. These are very informative plots to make. They show the uncertainty within stages of the model and the variability that can be present in just one realization. Consider Figure 2 for a moment. It shows the grade and uncertainty in the grade over the different years of the mine life. The grade during the first few years is quite high, and then the grade decreases in the later years of the mine life. We can also show the uncertainty in the estimated grades over the life of the mine. It may be beneficial to reduce the uncertainty in the model for the first few years of mining. This would help ensure the return on investment for the mine.

Another way of carrying the uncertainty beyond reserves is to use it for economic evaluation. The uncertainty in the tonnes and grade of ore for each year can be used to estimate the economic uncertainty for each year. Depending on the range of uncertainty, target drilling can be done to reduce the overall uncertainty without spending a significant amount of money on delineation drilling before the mine starts production.

Conclusions

Simulation is a powerful tool for modelling geological uncertainty. The best approach is to perform planning with multiple realizations simultaneously. In many cases, however, practitioners are reluctant to embark on this tedious and demanding task. This raises the question of "Which realization do we use for mine planning?" A simple answer is to use a partial block model. Partial block models are advantageous since many methods can be used to generate them and the results between methods will be similar.

By using simulation and partial block models, uncertainty can be transferred beyond a simple global estimate of uncertainty. Joint uncertainty for a specific time period or pit pushback can easily be calculated from the simulation output and used for economic evaluation.

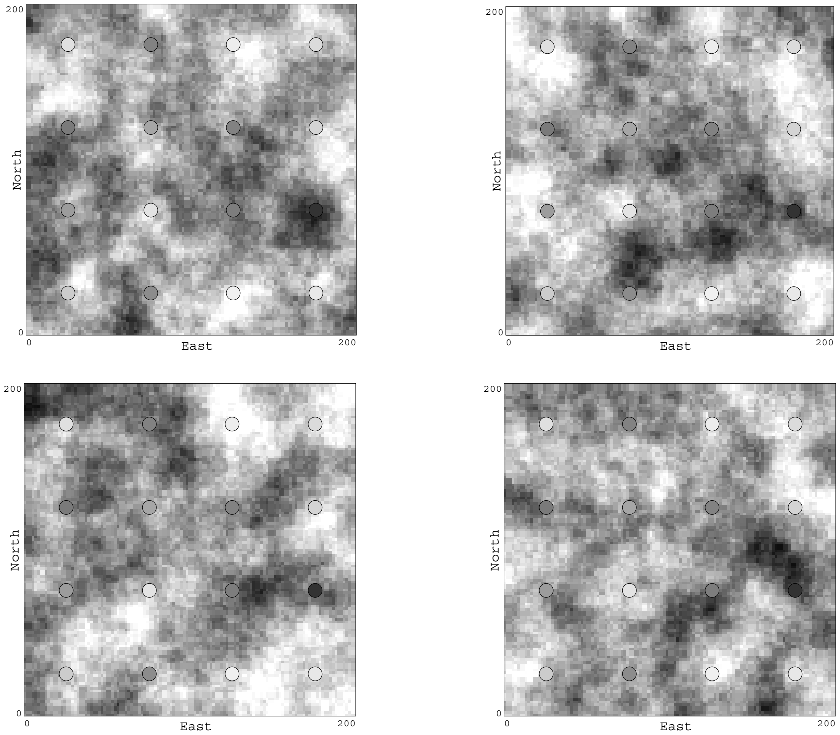

Figure 1: Multiple realizations that ranked near the p50 case (P48, P49, P50, P51, P52)

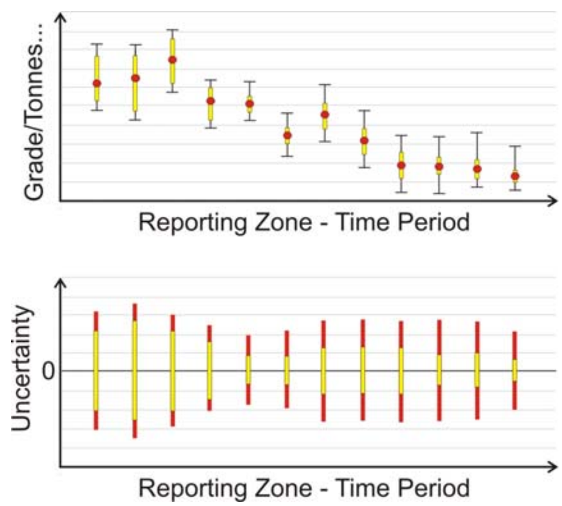

Figure 2: Uncertainty at different times during mine life **Error! Reference source not found.**.

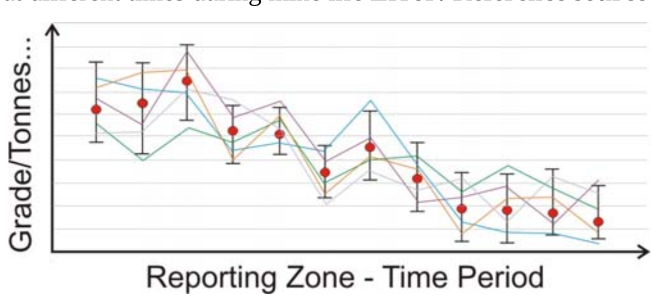

Figure 3: Joint uncertainty versus reporting zone (time period) represented by five realizations (the different color lines) **Error! Reference source not found.**.