A Simulation Approach to Account for the Information Effect

Chad Neufeld, Oy Leuangthong and Clayton V. Deutsch

Centre for Computational Geostatistics
Department of Civil & Environmental Engineering
University of Alberta

Ore and waste are always classified with incomplete information. The lack of complete information results in blocks of ore being mined as waste and vice-versa; called the information effect. We present an approach that is in use today, and a new simulation based approach to account for the information effect. Both methods can be used at the early stages of a project for estimating recoverable reserves that take into account the information effect.

Introduction

Ore and waste material are classified with incomplete and imperfect information. The blasthole or grade control drilling is spaced too far apart for error free estimates of grade. This leads to some ore being classified as waste and some waste being classified as ore. This incomplete knowledge, and the resulting misclassification, is called the information effect [2].

The information effect influences the recoverable reserves at the time of mining. It is important to account for the information effect when estimating recoverable reserves. A typical way of doing this is to assign a fixed dilution factor that attempts to account for the information effect and the impact of mining equipment. Dilution is correctly accounted for in this way, but the information effect is not.

The information effect results from estimating the block grades and mining the blocks based on estimated grades. The blocks are mined based on their estimated values, not their true value. As the error in the block estimates increases, the information effect becomes more pronounced. The quality of the block estimates is primarily a function of the blast hole spacing. Additional factors, such as sampling error, can contribute to the information effect as well.

This paper presents a methodology for calculating the information effect and the impact that it has on the estimated reserves. The results from the proposed methodology are compared to a theoretical result. This involves generating a reference model, outlining the methodology, performing the calculations and comparing the results.

Methodology

There are two methods that can be used for calculating the information effect: (1) using an assumption about the information effect and incorporating it into a change of support model, or (2) simulating the expected grade control sampling and calculating the effect on the reserves directly. The first method accounts for the information effect by smoothing the block scale distribution. The variance of the block distribution is reduced to account for the information effect. For a low cutoff, the number of tonnes recovered increases at a diluted ore grade. At a high cutoff, the number of tonnes will decrease with a lower ore grade. The second method uses a reference model and simulates sampling classification and the affect on reserves.

The theoretical approach requires an assumption for the impact that the information effect has on the recovered ore. The larger the impact, the smoother the block scale distribution becomes. For example: say the variance of blocks v is estimated to be 20.0 using a gammabar value. Reserves could be calculated using the calculated block variance, but that assumes that the selection of the blocks v is perfect, which is never the case. To account for the misclassified blocks, the variance can be reduced and the reserves calculated with the reduced variance [1]. The reduced variance is usually determined by using experience at similar deposits. The simulation approach can be used to calculate the variance reduction that should be used for a specific sampling regime.

The simulation approach aims at quantifying the information effect by simulating the grade control drilling and material classification. There are four steps in simulating the grade control and mining: (1) simulate the grade control drilling by extracting samples from the reference model, (2) use the extracted samples to estimate the gold grade for the mining blocks, (3) classify the grade control model using the kriged estimates, and (4) calculated the profit for the area using the reference model and classification model. No explicit assumptions are made for dilution. We assume that each block can be selected freely from the blocks around it.

A mining block size of 5m was used for this example. The reference model will be upscaled to provide an ideal profit that is only attainable with perfect information and selection. The results of the distribution upscaling and information effect will be compared to the ideal profit.

Profit will be used to compare the results. Grade, tonnage, or quantity of metal could have been used, but profit summarizes all of these variables with a single number. The profit calculation is straightforward: the profit for each block is calculated using the reference model for the block grades and the classification model to decide if it is ore or waste. The profit for each block is calculated as:

$$profit(\mathbf{u}) = \begin{cases} z_v(\mathbf{u}) \cdot p \cdot rec - c_o - c_t, & if \ z_v^*(\mathbf{u}) \geq z_c \\ c_w, & otherwise \end{cases}$$

where $z^*_v(\mathbf{u})$ is the estimated grade at location $\mathbf{u}$, $z_v(\mathbf{u})$ is the actual grade from the upscaled reference model, z_c is the cutoff grade, p is the gold price, rec is the processing recovery, c_o is the cost of mining ore, c_t is the cost of processing ore, and c_w is the cost of mining waste. The total profit is the sum of the profit for each block in the model. The following parameters were used for the profit calculation:

$$\begin{aligned} c_t &= 12 \ \$/t \\ c_o &= 2 \ \$/t \\ c_w &= 1 \ \$/t \\ p &= 18 \ \$/g \\ rec &= 80\% \end{aligned}$$

The cutoff grade is a function of the above economic parameters. The cutoff grade was calculated using the following formula:

$$\begin{aligned} z_c &= \frac{c_t + (c_o - c_w)}{p \cdot rec} \\ &= 0.90 \ g/t \end{aligned}$$

The calculated cutoff grade is within an acceptable range for open pit gold mines.

Reference Distribution and Model

A reference gold grade model was constructed using unconditional simulation and a reference gold distribution. The reference model is shown in Figure 1. The following variogram was used to construct an unconditional model using simulation:

$$\gamma(\mathbf{h}) = 0.1 + 0.9 \cdot Sph_{\substack{ahmax=40 \\ ahmin=40 \\ avert=10}}(\mathbf{h})$$

Back transforming the unconditional simulation provided the 2-D reference gold model; see Figure 2. The reference model is 200 blocks x 200 blocks and each block is 1m x 1m x 5m. The reference model will be used for simulating grade control sampling, classification and calculating the actual recovered ore.

The ideal profit was calculated by upscaling the reference model to the 5m x 5m mining block. The ideal profit will never be attained during mining. It was only used as a reference for comparing results. The maximum profit attainable is 16 million dollars.

Theoretical Results

The profit for SMU blocks of different sizes was calculated using the economic parameters and the up-scaled block distribution from the discrete Gaussian model. To upscale the reference distribution to larger blocks, the block scale variance is needed. The block variance is calculated using gammabar values for the different block sizes. Recall the dispersion variance equation:

$$\begin{aligned} D^2(v,A) &= D^2(\bullet,A) - D^2(\bullet,v) \\ &= \sigma^2 - \bar{\gamma}(v,v) \end{aligned}$$

Figure 3 shows the block variance for the different SMU sized blocks. The variance of the blocks decreases as the block size increases; this was expected. The reference distribution was upscaled to the larger block supports using the DGM.

As the variance of the SMU decreases the distribution becomes smoother. This is analogous to introducing dilution to the recovered ore. Dilution decreases the recovered grade and will often reduce the profit seen from the model area. The profit for the different SMUs is shown in Figure 4. As expected, the profit decreases as the SMU size increases.

For a 5x5m SMU, the profit from the discrete Gaussian model matches the ideal profit exactly. It is unrealistic to expect that the ideal profit is achievable. The imperfect information used to classify material at the time of mining will result in a lower profit. A larger effective SMU size is needed for estimating the recoverable reserves with the DGM. The simulation study presented next can be used to choose the larger effective SMU for reserve estimation.

Simulation Results

The ore waste classification improves as the amount of grade control sampling increases. Sparse grade control drilling results in more misclassified material. Simulated samples were taken at a drillhole spacing starting at 1m x 1m and increasing up to 35m x 35m. Kriging was done for each case to get a classification map and then a profit was calculated for each sample spacing case.

Consider the case where the grade control samples are 12m apart. The simulated samples are shown in Figure 5. The samples were extracted on a regular grid from the reference model and then used to estimate the grade of the SMU blocks. An ore/waste indicator was calculated from the kriged grade control model. Where the estimate was above the cutoff of 0.9, the material was considered ore, and where the grade was less than the cutoff the material was considered waste. The ore/waste map is shown in Figure 6. The profit was calculated using the ore/waste classification and the reference model. With a sample spacing of 12m, the profit was 15.6 million dollars. This is 97.5% of the ideal profit. These steps were repeated for the different sample spacing scenario's considered. Part of that 2.5% would be required for mineability.

Figure 7 shows the profit versus sample spacing. When the sample spacing is 1m x 1m, the classification model from kriging matches the ideal classification model exactly because every value is sampled. As the sample spacing increases the profit realized decreases. If the proposed grade control sampling is known, the percent decrease from the ideal profit is known. The percentage reduction can be used to determine the effective SMU size that can be used for reserve estimation.

Comparison of the Results

Both the DGM and simulation based approaches for quantifying the information effect produced the predicted results. For the theoretical case, as the block variance decreases, the block scale distribution becomes smoother, or less selective, and the profit realized decreases. And for the simulation case, as the sample spacing increases the quality of the classification decreases and the resulting profit decreases as well.

The simulated sampling, grade control, and mining results can be combined with the theoretical change of support results to choose an SMU size that can be used for reserve estimation. Choosing the reserve SMU size in this manner allows for the information effect to be incorporated into reserves calculated from a change of support model or from a simulated model.

Recall the profit versus sample spacing plot in Figure 7 and the profit versus SMU size in Figure 4. Say that the mine is planning to drill grade control samples on a 15x15m spacing and the mining equipment is capable of mining 5x5m blocks. According to the results of the study, the profit using a 15x15m grade control sampling program will be just under 97% of the total attainable profit. To accurately estimate the mineable reserves, while accounting for the information effect, an SMU size that will estimate the same profit as the grade control study should be used. The SMU size gives the same estimated profit is 21m. Figure 8 shows how the SMU size was chosen for this example. Reserves estimated with an SMU size of 21m will account for the information effect.

Conclusions

The classification of ore and waste for mining will always be done with limited information. The information effect has a similar effect on the reserves as dilution; ore lost as waste and waste included as ore. The spacing of the grade control or blasthole samples relates to the information effect. Dense drilling provides more information about the deposit and improved selection, while widely spaced sampling leads to a large information effect, that is, worse selection. The information effect can be included in a reserve estimate by increasing the size of the SMU. As the SMU size increases, it implies an increasing information effect, or that an increasing number of blocks are being misclassified.

References

[1] J. P. Chilès and P. Delfiner. *Geostatistics: Modeling Spatial Uncertainty*. Wiley-Interscience, New York, 1999.

[2] C. Roth and J. Deraisme. The information effect and estimating recoverable reserves. In *Geostats 2000, Geostatistics Congress*, Cape Town, South Africa, April 2000.

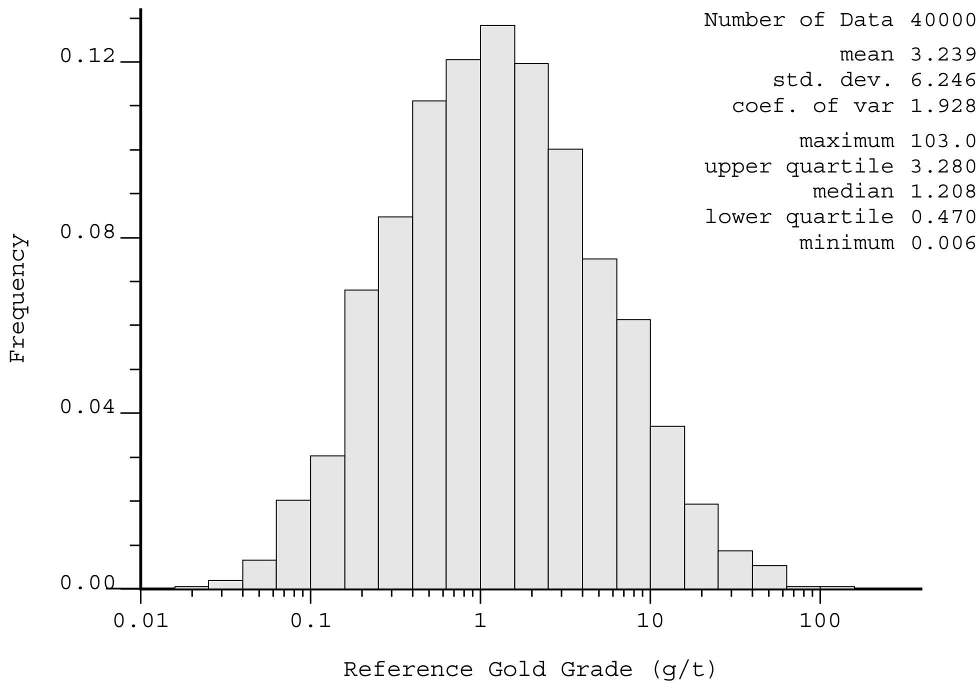

Figure 1: Reference gold distribution.

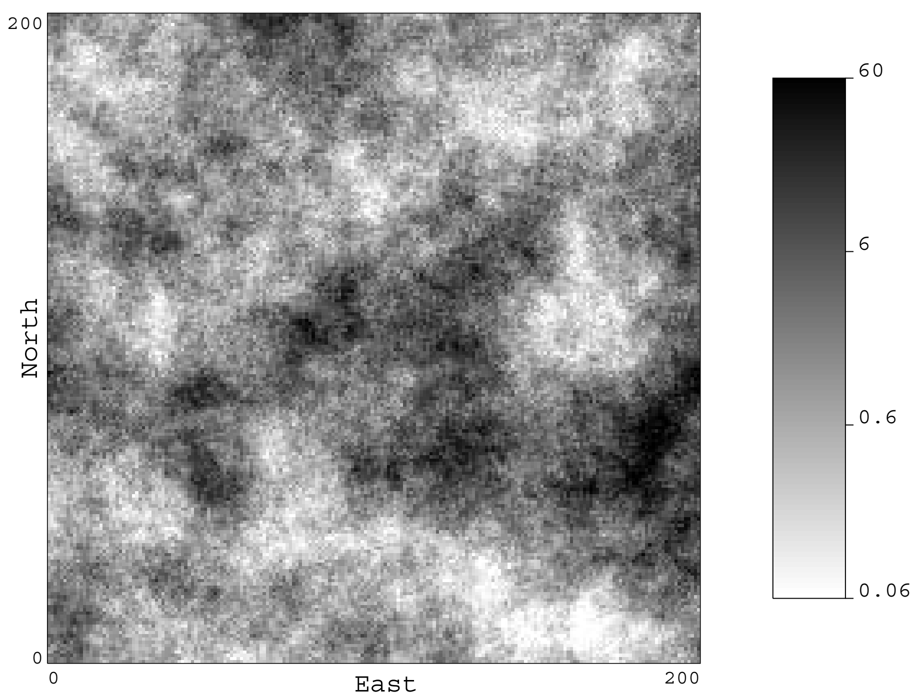

Figure 2: Reference 2-D gold model.

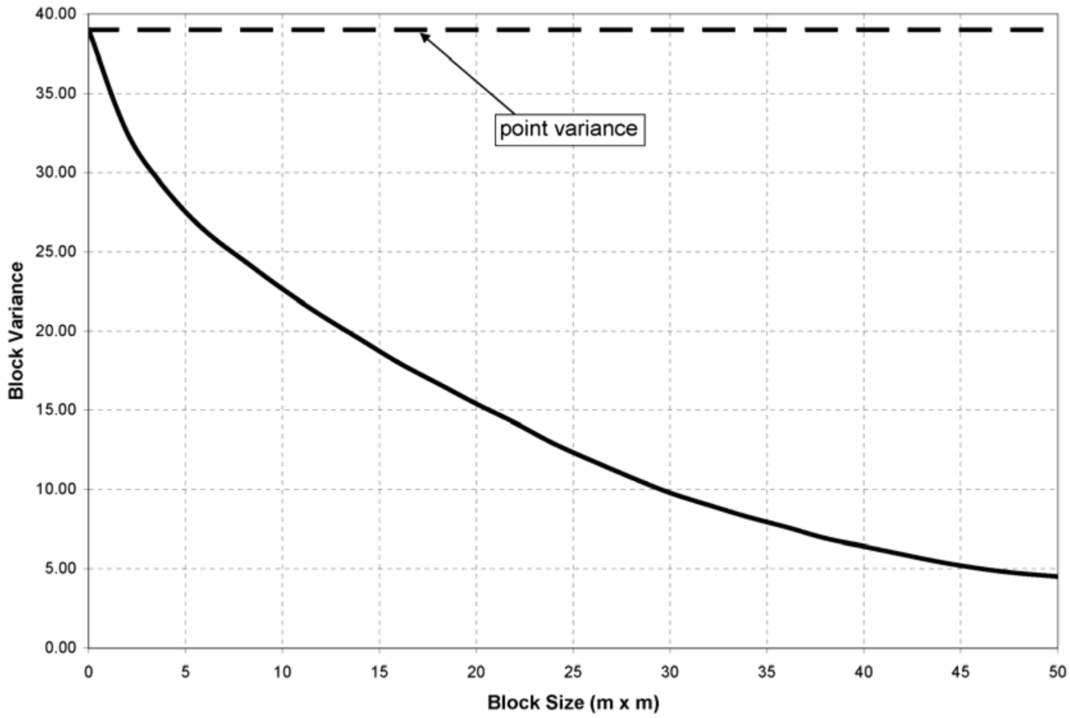

Figure 3: SMU Variance versus SMU size.

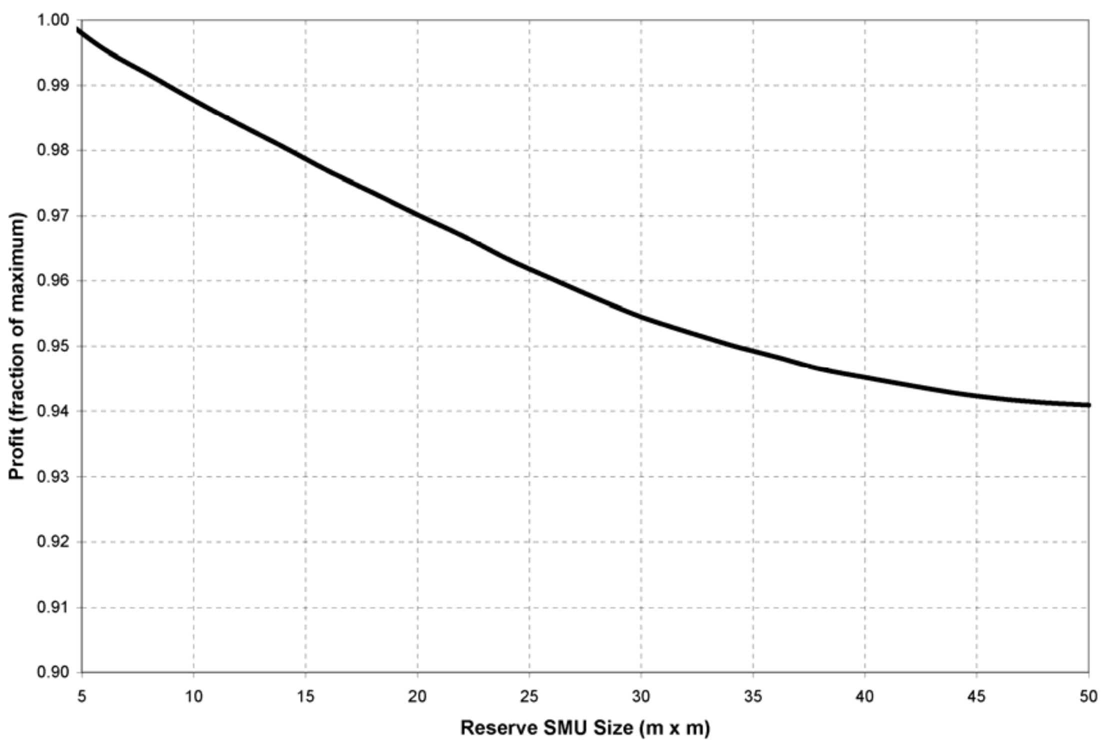

Figure 4: Profit from the Discrete Gaussian model versus SMU size.

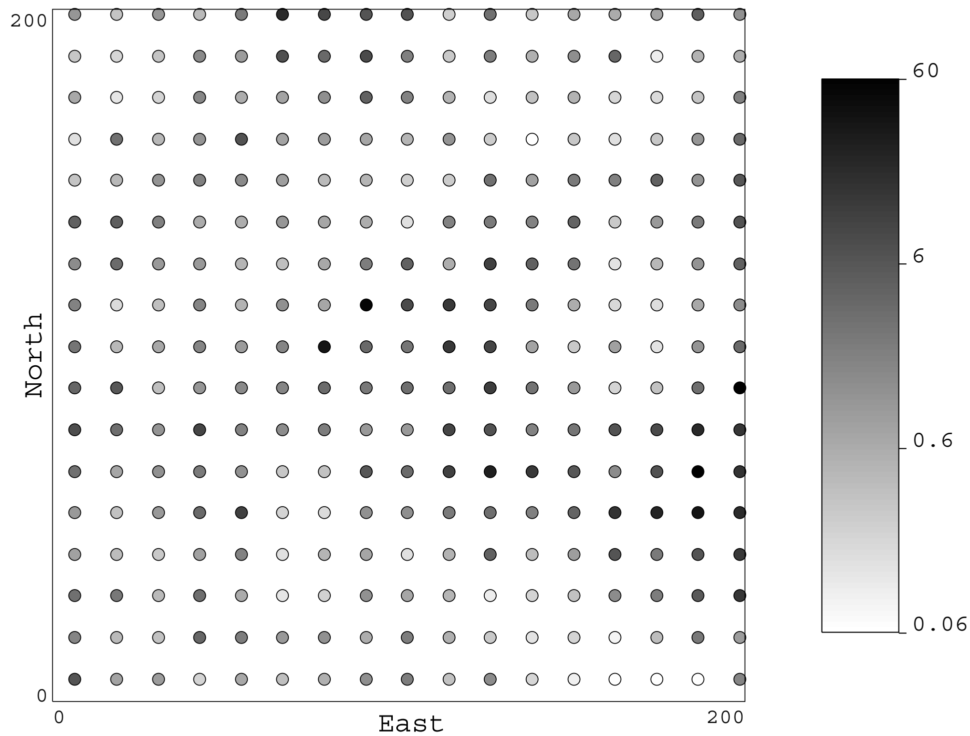

Figure 5: Simulated grade control samples.

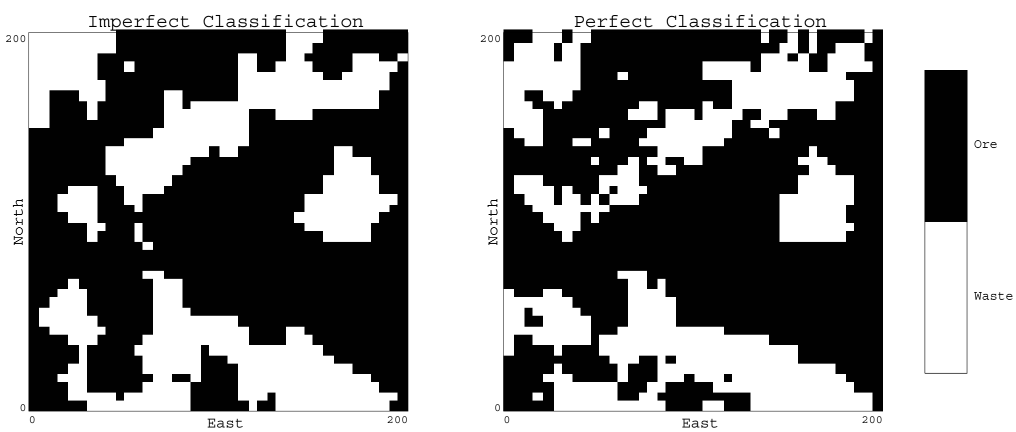

Figure 6: Comparison of imperfect and perfect ore/waste classification. The imperfect classification is on the left and the perfect classification is on the right.

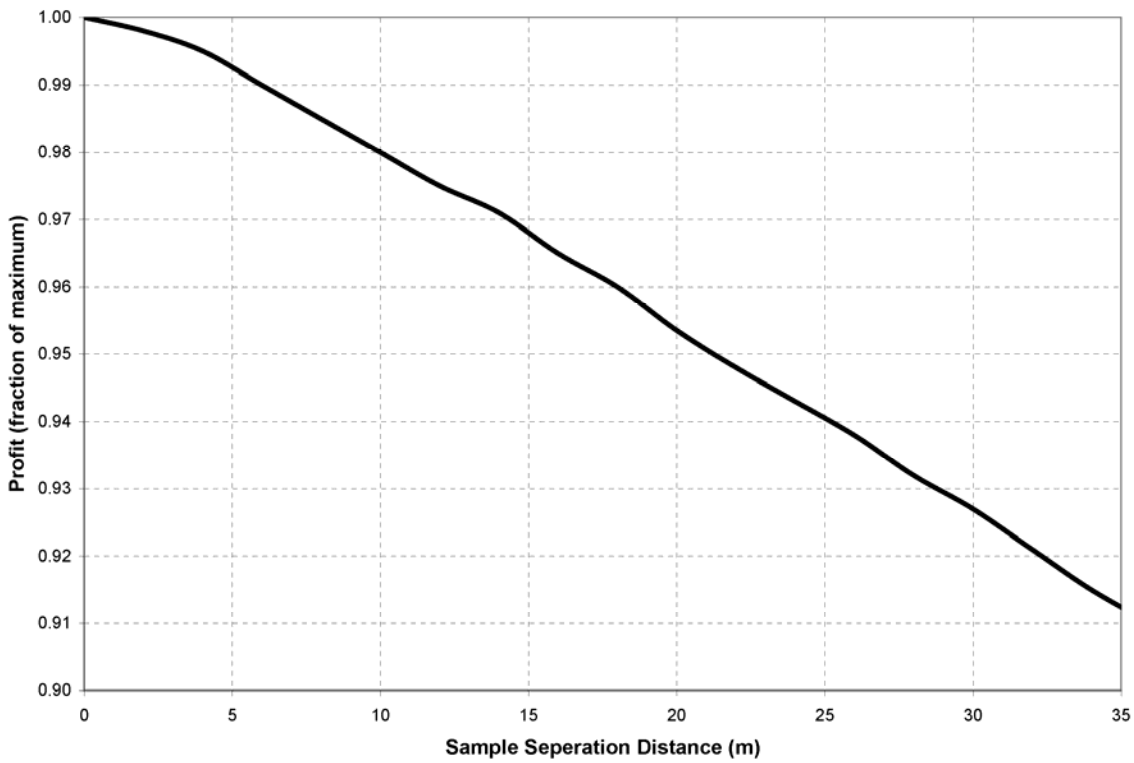

Figure 7: Profit from the simulation approach versus sample spacing.

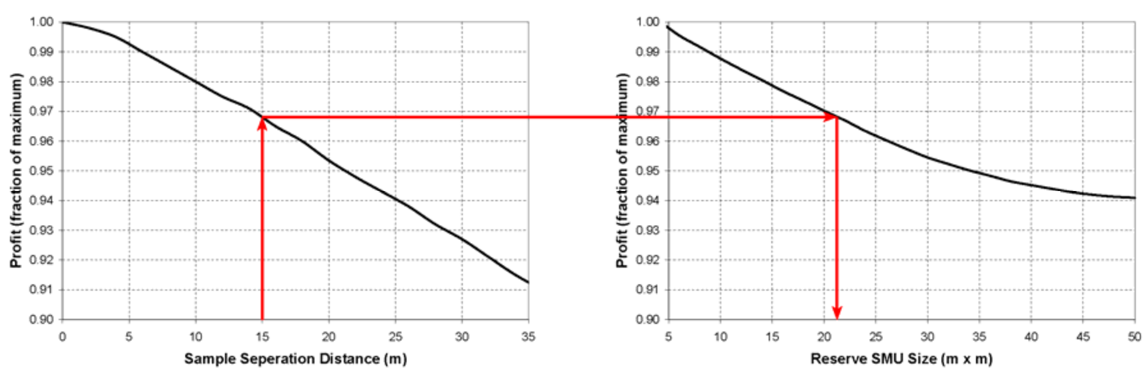

Figure 8: Choosing an SMU size.