A Short Note Comparing Feasibility Grade Control with Dig Limit Grade Control

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Predicting recoverable reserves before mining commences is an important problem in ore reserve estimation. Automatic 'dig limits' are reasonable; however, they require significant professional time. A new method called Feasibility Grade Control (FGC) has been proposed that is more automatic and applies at the time of feasibility studies. It eliminates the time consuming practice of creating an initial dig limit and is able to establish dilution and lost ore. It is shown that the results of each method are nearly identical, with the results of FGC being more realistic.

Introduction

Accurate grade control is an important part of any mining feasibility study. The goal of the study is to determine the quantity and quality of the ore in place. Simulating many realizations of the variables of interest is the best way of determining this. Creating an expected profit model from the realizations will give an idea of the project economics. It also enables the classification of material as ore or waste through various methods. The most common method of classification has been through manually creating dig limits. This process is tedious and time consuming. Researchers at CCG developed a method which automatically determines the optimal dig limits. The limitation with this method is the need for the user to specify an initial dig limit for every bench in every realization. This can be quite expensive in terms of professional time. An additional disadvantage to the dig limit method is the equipment dependence inherent in the digability penalty function.

The goal has been to develop a grade control methodology which is completely automatic; there is no need for any time-consuming input by the user. This goal has been achieved through the development of Feasibility Grade Control (FGC). This method has been explained in depth in an earlier paper by the authors. (see Wilde & Deutsch, 2007) A comparison of these two methods is undertaken herein, with brief description of the methodology of each, along with examples of the results generated by each.

Methodologies

Common as input to each method is a model of the expected profits if ore. The details for creating this model will not be dealt with here, but the user is referred to the *Guide to Geostatistical Grade Control and Dig Limit Determination* published by the Centre for Computational Geostatistics (CCG). (see Neufeld, Norrena, and Deutsch, 2005) This guidebook also explores the dig limit methodology in depth. The expected profit model can be created by any method and using any software as is applicable to the mine of interest.

Dig Limits

As mentioned, the dig limit method requires an initial digging limit to be input by the user. It is this limit that is perturbed numerous times in order to find the optimal limit. A dig limit is found to be optimal if it maximizes the profit within the limit. The profit is found by taking the sum of the profits for each block within the limit, accounting for those blocks only partially within the limit by multiplying their profit by the fraction of the area within the limit.

The possibility exists for the dig limits to be unrealistic when the abilities of the mining equipment are considered. For example, a very small angle between adjacent vertices would not be realistic for large mining equipment whose selectivity is limited. As such, a penalty function termed digability is used to adjust the profit appropriately. Digability is equipment dependent with small selective equipment able to achieve a low digability and large unselective equipment restricted to a high digability. The user specifies an equipment factor from 0 – 1 with 0 being for very small, extremely selective equipment and 1 being for large indiscriminate equipment. A dig limit is termed to have low digability when the angles between adjacent vertices are small and high digability when angles between adjacent vertices are large.

The optimization of the dig limit proceeds as follows:

- Choose random vertex
- Move the vertex to a new random location
- Calculate the profit and digability
- If profit increases, accept the change
- If profit decreases, either accept or reject the change

This process is repeated over and over until an optimum profit is achieved. Classification is then performed by labeling the blocks according to whether they fall within or without the dig limit.

The dig limits methodology has not proven itself to be a worth while grade control technique at the feasibility stage. This is due to one main factor and that is the large amount of time required to input the initial dig limits. This step must be performed manually and can take a good deal of time. Multiply the time required by the number of benches and realizations and we can quickly see how unsuitable this method is at the feasibility stage. This factor can also influence the results. Often there are numerous small or minor pods of ore or waste which do not warrant the time necessary to create and optimize their initial limit. If these pods are isolated enough, there is no chance for the dig limits algorithm to account for them. This leaves a number of profitable blocks classified as waste and unprofitable blocks classified as ore, in other words, we have dilution and lost ore.

The advantage of the dig limits method is that it is better able to account for equipment selection abilities. This makes it better able to correctly classify blocks by accounting for the equipment's ability to reach them.

FGC

Feasibility Grade Control has some important differences from dig limit grade control. FGC utilizes mining units composed of 2, 3, or 4 blocks and aims to optimize the way in which the blocks are accumulated to mining units such that the unit is either all ore or all waste.

The first step in the process is to assign every block to a mining unit. The mining units are composed of blocks which are adjacent and are as compact as possible. The initial shapes of the units for 2-, 3-, and 4-block units are shown in Figure 1. Initially, these units can be composed of ore, waste, or a combination of the two. The units are accumulated purely by shape, with no consideration of the block values.

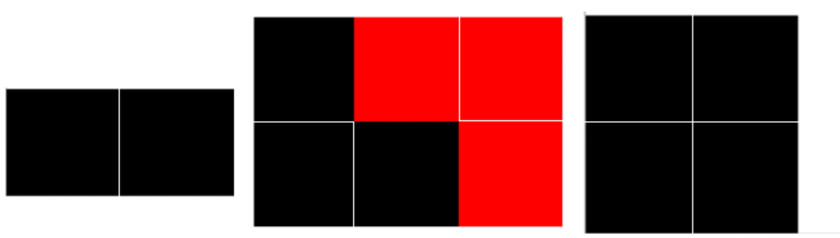

Figure 1: Initial accumulation of blocks into mining units for 2, 3 and 4-block units, respectively.

The profit for each mining unit is calculated by taking the sum of the profit values of the blocks within the unit. Each block's profit is the expected profit if that block were treated as ore. This means that for very low-grade blocks, the profit will be equivalent to the sum of the ore mining and milling costs. Mining units with a profit value of less than zero are called waste and mining units with a profit value greater than zero are called ore. The objective function aims to maximize the profit from ore blocks and to minimize the profit from waste blocks. The objective function is defined as the sum of the ore units minus the sum of the waste units:

$$P_T = \sum_{i=1}^{N_o} P_O - \sum_{j=1}^{N_w} P_W$$

where P_T is the total profit, P_O is the profit of the 'ore' mining units, N_o is the number of ore mining units, P_W is the profit of the 'waste' mining units, and N_w is the number of waste mining units.

The optimization procedure aims to maximize the profit by re-arranging the way the blocks are accumulated into units. Every block is visited randomly throughout the model. At each block, a random neighbor is chosen, the unit numbers of the two blocks are switched, and the profit is re-calculated based on the new configuration. If the profit has increased the switch is kept. If the profit has decreased or is equal to the previous profit, the switch is reversed. A new block is visited and the process repeated.

Left to itself, this process will create mining units that may have any shape and the blocks in the unit could be spread a great distance. This cannot happen because for this method to be meaningful, the mining units must be in a configuration amenable to mining. The best way to understand this is to think of each unit as a truck load and each block in the unit as a scoop by the loading equipment. Each scoop in a load is located close to the others in the load in an easily extractable shape. Therefore, the mining units must adhere to some special constraints. To accomplish this, an index of acceptable unit shapes has been generated for each of the 2, 3, and 4-block mining units as shown in Figure 2.

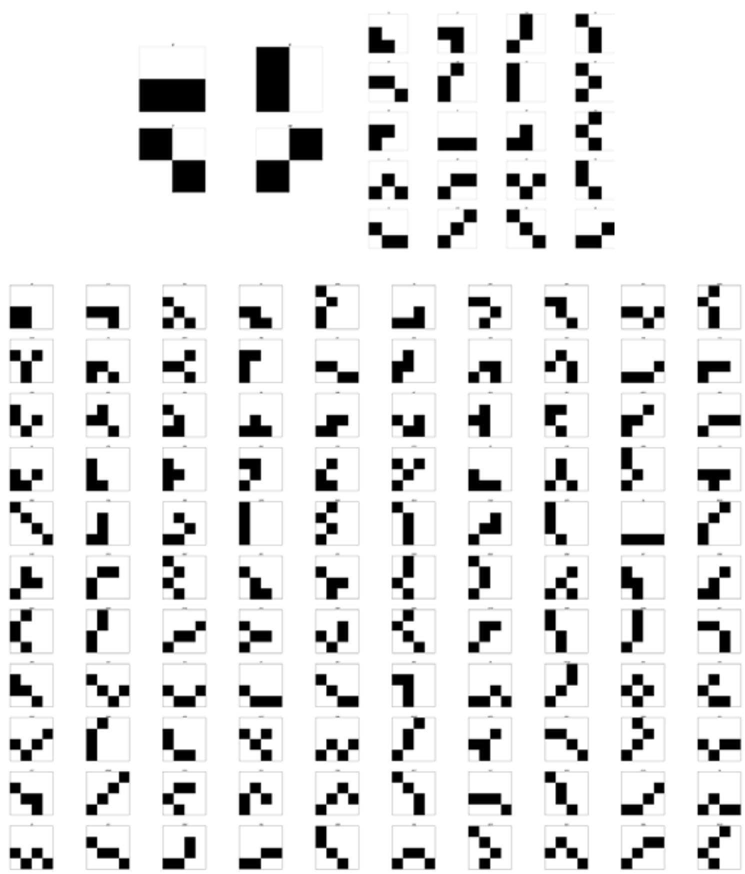

Figure 2: Acceptable unit shape configurations for 2-, 3-, and 4-block units.

Associated with each index is a penalty. The penalty is based on the unit shape. Mining units which have an undesirable shape receive a larger penalty than those with a desirable shape. The penalty is the percent decrease in profit the unit will receive due to its shape. As the optimization process proceeds, these penalties are assigned to the corresponding units and are included in the profit calculation. The optimization process will proceed until each block in the model has been visited 5-8 times, as specified by the user. No significant improvements in profit are realized by visiting the blocks additional times.

Once the optimization process is complete, the opportunity exists to classify blocks as dilution and lost ore in addition to ore and waste. A block is classified as dilution if it has a negative profit value, but belongs to a unit with positive profit. Conversely, a block is classified as lost ore if it has a positive profit value, but belongs to a unit with negative profit.

Comparison Examples

The goal of this note is to compare the results of these two grade control methods. It will be shown that the two methods create remarkably similar outputs with very different inputs. The first comparison example is performed using data from a copper porphyry bench. This data is shown in Figure 3. Variograms were calculated and 50 simulated realizations were created. From these realizations, a model of the expected profit was created. The copper e-type and expected profit models are shown in Figure 4. This profit model will be used to test each grade control method.

Dig limit grade control will be examined first. An initial polygon is required as the first step. This is shown in Figure 5. The polygon is created by roughly encircling the area where ore (positive profit) exists. The polygon and profit model are then input into the `diglim` program which optimizes the dig limit using the method described previously. An equipment factor of 0.3 and 50,000 perturbations was used to generate the final dig limit, also shown in Figure 5. The profit in the dig limit increased from $92,366.81 to $121,894.02. The optimized polygon is used to classify blocks as either ore or waste. The dig limit classification is shown in Figure 6.

FGC requires only the profit model and a penalty file as input. For this example, two-block units were used. The program visited every block 5 times and created the final classification also shown in Figure 6. The only differences between the results are found where there are small pods of either ore or waste where the dig limits method was not able to account for them. FGC performed better because it was able to more correctly account for these small pods. The more pod-like the deposit, the more applicable FGC becomes. More detailed results of these methods for this example are given in Table 1.

A profit model along with initial dig limits for a second example is shown in Figure 7. This example will better illustrate the weakness of the dig limits method. This profit model contains a number of different 'pods' of ore. The weakness of the dig limits method is that each individual pod must have an initial dig limit drawn around it. When considering multiple realizations of multiple benches, this can require a great deal of professional time. Also adding to professional time is the time necessary to optimize each dig limit as each must be done separately. These two processes are the major downfall of the dig limits method at the feasibility stage.

Each of the six dig limits were optimized with the same parameters as the first example; an equipment factor of 0.3 and 50,000 perturbations. The optimized dig limits are shown in Figure 8. From these dig limits a category model is created where those blocks within the limits are classified as ore and those without are classified as waste. This category model is shown in Figure 9.

For this example, FGC was performed using four-block units. Every block was visited five times during the optimization process whereby the final classifications were created as shown in Figure 10. We can compare this model with the one produced by the dig limits method (see Figure 9). Again, they are quite similar. FGC was able to account for the minor pods of ore where dig limits did not. But overall, the classifications produced by each method are quite similar.

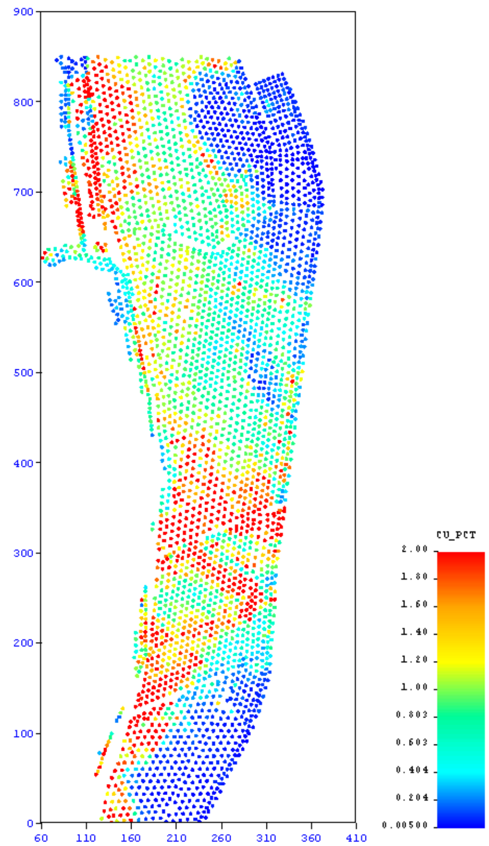

Figure 3: Blasthole locations on copper porphyry bench.

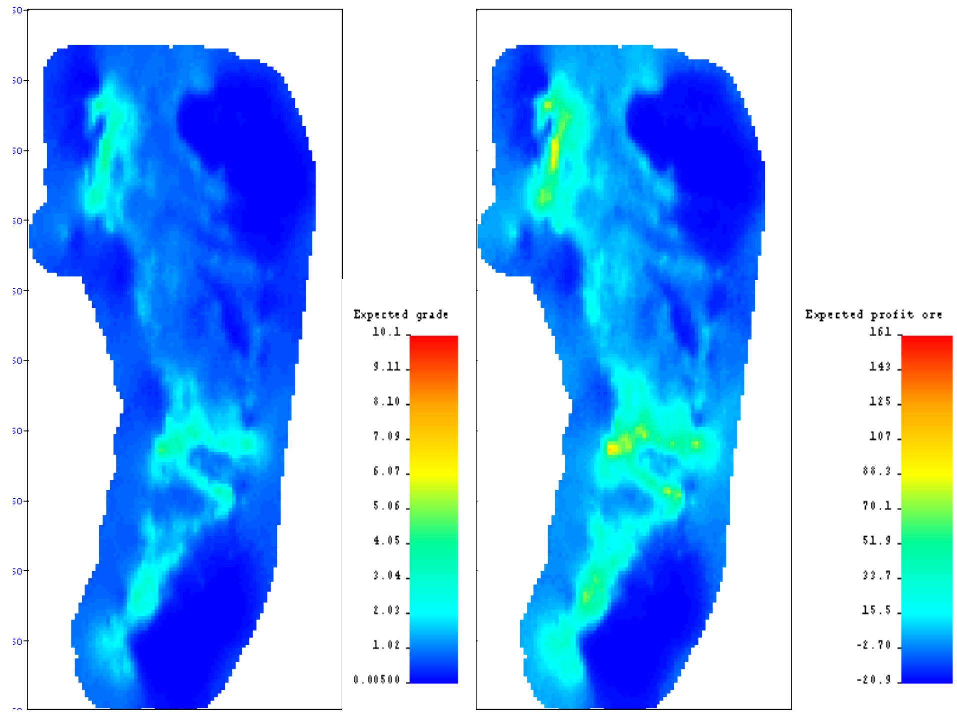

Figure 4: E-type copper model and model of expected profit.

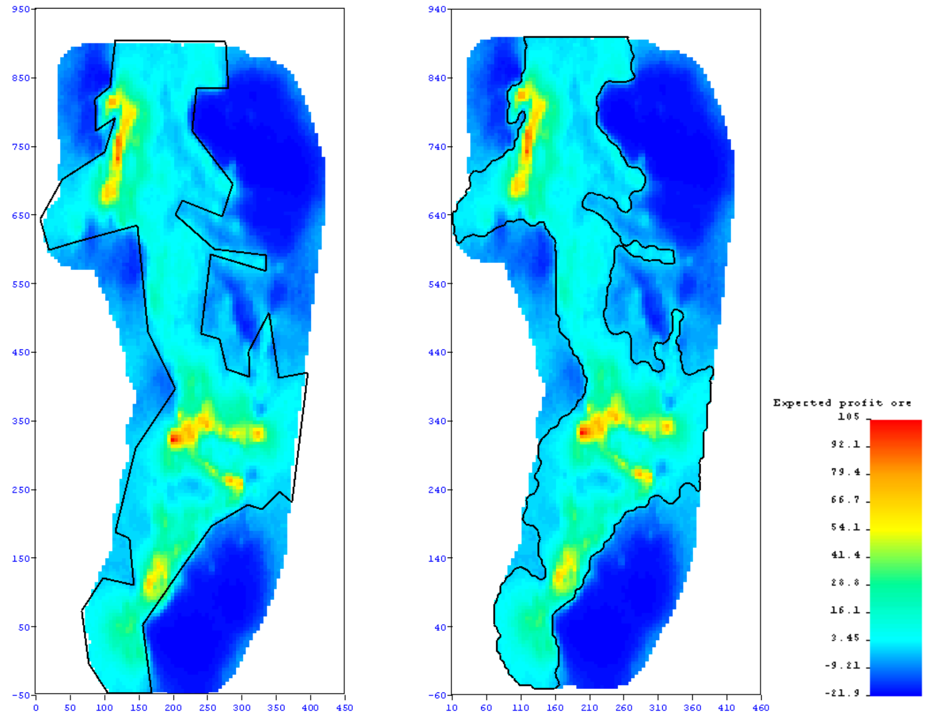

Figure 5: Expected profit model with initial and final dig limits.

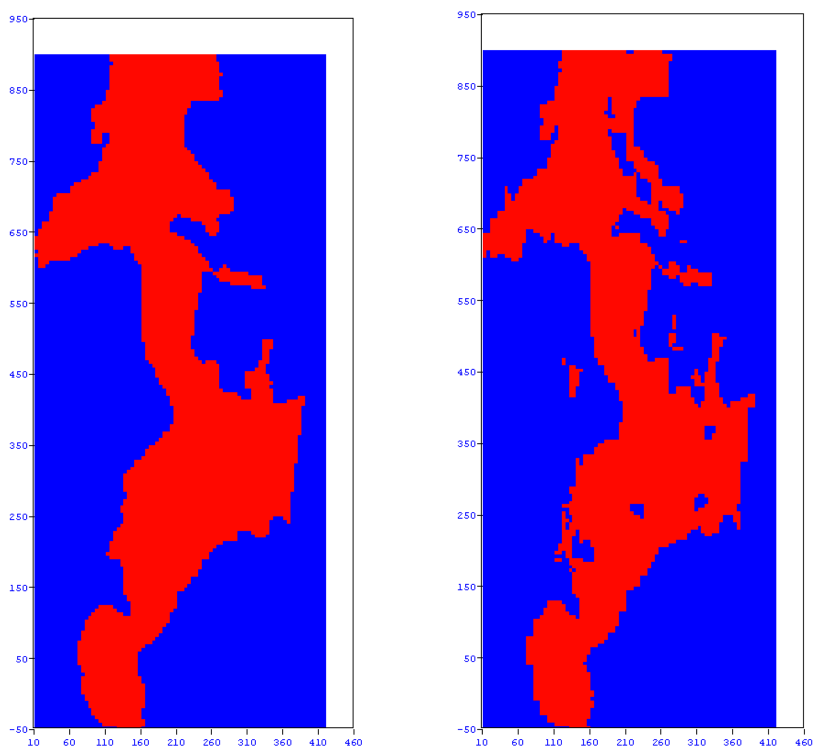

Figure 6: The results of dig limit and feasibility grade control compared. It is easily seen that they are very similar.

Table 1: Comparison of Grade Control Methods for Example 1.

Method	Tonnes – Ore	Tonnes - Waste
Truth	5252	5926
Dig Limits	5430	5748
FGC	5212	5966

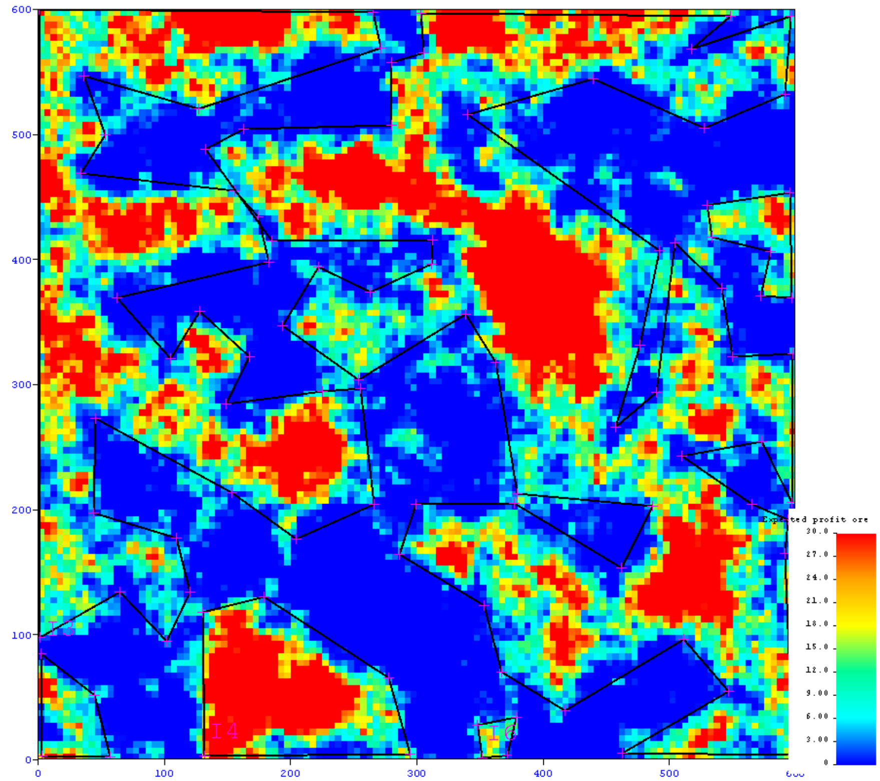

Figure 7: Expected profit model with initial dig limits for a second example.

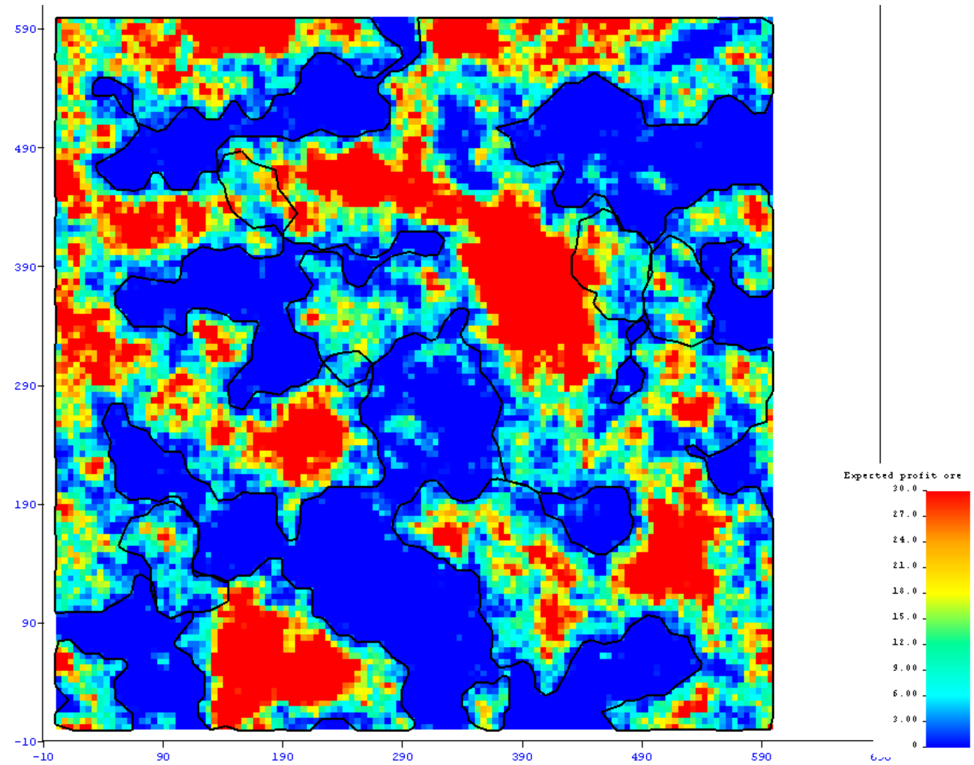

Figure 8: Profit model with optimized dig limits.

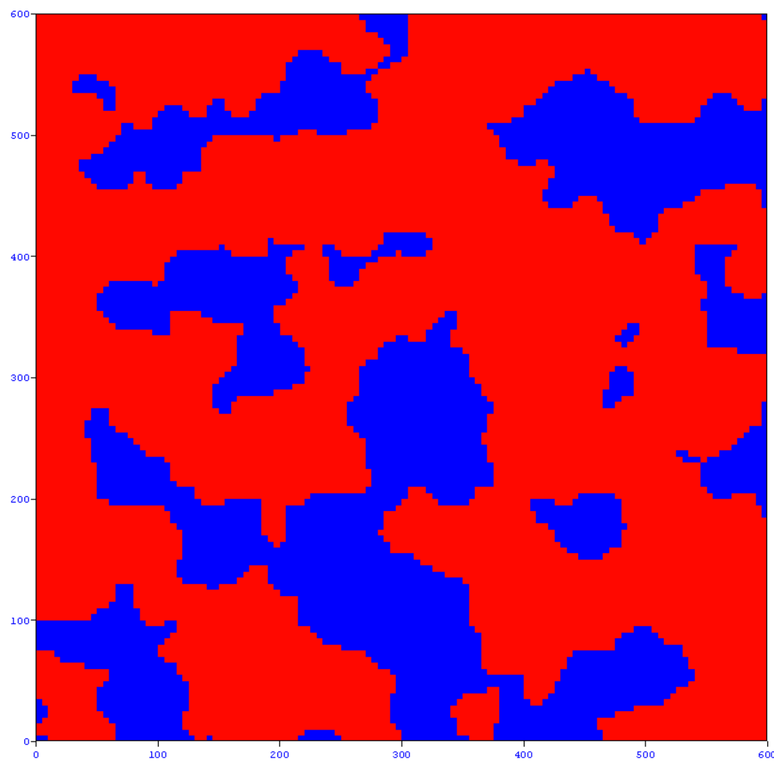

Figure 9: Category model created from dig limits.

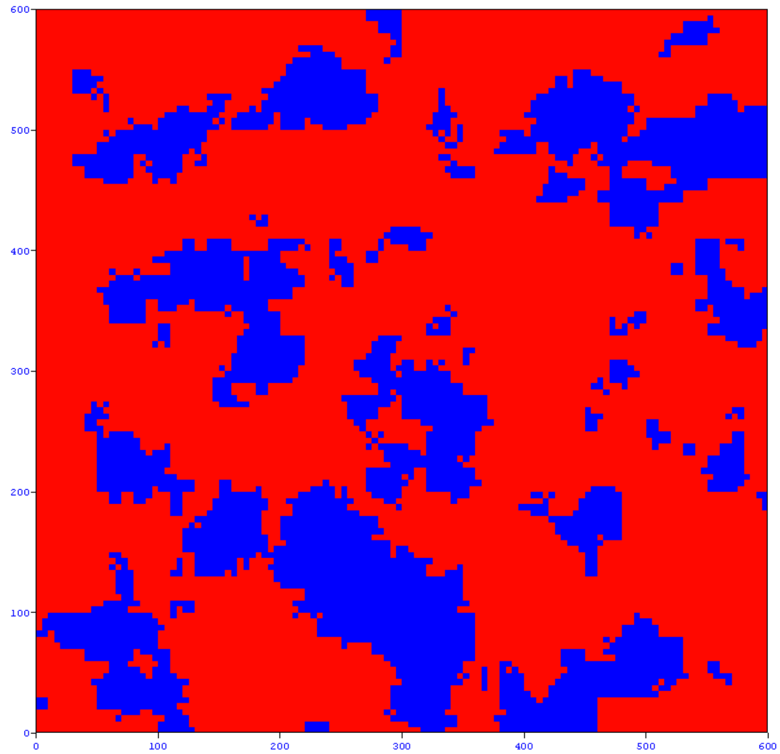

Figure 10: Category model produced by FGC.

Table 2: Comparison of Grade Control Methods for Example 2 along with the results of simply up-scaling the truth profit model.

Method	Option	Tonnes-Ore	Tonnes-Waste	Grade of Ore	Quantity of Metal	Profit
Truth	Point Scale	9963	4437	3.7	36905	208152
Diglim	0.1 digability	9927	4473	3.68	36568	205515
	0.5 digability	9942	4458	3.68	36564	205317
	0.9 digability	9966	4434	3.66	36519	204644
FGC	2 units	10014	4386	3.69	36934	207858
	3 units	10126	4274	3.66	37031	207499
	4 units	10168	4232	3.65	37081	207480
SMU	10x10	10228	4172	3.63	37092	206926
	15x15	10494	3906	3.55	37270	205598
	20x20	10704	3696	3.50	37460	204997
	25x25	10875	3525	3.45	37560	204016

Conclusions

Dig limit grade control and feasibility grade control provide good optimized classifications. Dig limit grade control is a good method because it accounts for equipment abilities and therefore does not classify material as ore which cannot reasonably be extracted. Its main disadvantage is the need for the user to specify initial dig limits and the time it takes to do this as well as optimize the limits. Feasibility grade control's advantages include the ability to report dilution/lost ore and the absence of time consuming user input. The limitation of FGC is the sometimes erratic classification boundaries, though as a method for use at the feasibility stage, this limitation is of little consequence. When clearly defined classification boundaries are needed, which is typically during short-range planning, the professional time for using dig limits is available. As a method for performing grade control at the feasibility stage on many benches and for many realizations, Feasibility Grade Control is the method of choice.

References

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