Simulating Grade Control on Feasibility Models on a Truck-by-Truck Basis

Brandon Wilde and Clayton V. Deutsch

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

An important problem in Mining Geostatistics is the calculation of recoverable reserves from widely spaced exploration data. There are many techniques that address this problem including SMU-based classification and dig limits. This paper proposes a methodology to simulate grade control on a truck by truck basis while accounting for an expected profit model that considers the uncertainty in grades, the size of the truck and its anticipated load, the number of passes required to load the truck, and the practical geometric configurations given this number of passes and the mining direction.

Introduction

Mining is the process of removing useful and valuable minerals and commodities from the earth. There are countless mines around the world extracting numerous materials. Before any mine is constructed, there must be adequate reason to justify building a mine there. This is determined by conducting a thorough study of the area, including drilling holes to get an idea of what is underground. With this information, a model of the underground formations can be constructed. This model can be used to then calculate how much profitable ore there is. Calculating the amount of ore is called grade control. There are various ways of performing grade control. This note outlines a new method called truck-based grade control.

Geostatistics is the basis of many variations of grade control. Geostatistical methods are used to characterize the resource using exploration data. The total resource is delineated by characterizing many small blocks within the volume of interest. Each block's profitability is calculated based on the amount of valuable of mineral it contains and its location within the mine. A block is considered profitable if the revenue from processing it as ore exceeds the cost of mining it as waste. The various geostatistical methods used for grade control include kriging-based grade control, profit-based grade control, and dig limit-based grade control. Kriging-based grade control estimates the ore grade for every block. A cutoff grade is established based on milling cost, ore mining cost, waste mining cost, recovery, and the metal price. A grade above the cutoff grade is considered profitable, below cutoff grade is not. Profit-based grade control uses multiple simulated realizations of the ore grade. These realizations are passed through a transfer function based on the same factors used to calculate a cutoff grade. The transfer function produces a model of the expected profit for each block. Profits above zero are profitable to mine; profits below zero are costly to mine. This expected profit model can be further used for dig limit-based grade control. By looking at the expected profit model, the user can specify dig limits. These dig limits are then perturbed to maximize the profit by taking as many profitable blocks as possible while leaving the unprofitable blocks.

Geostatistics is also used as the basis for truck based grade control. As with dig limit-based grade control, an expected profit model is required as input. Each block of the model is considered a pass by the loading device and will be part of a certain truck load. The size of the equipment will determine the number of blocks, or passes, which will be assigned to each load. Typically 2-4 passes by a loading device (shovel, front-end loader, etc) are needed to load a truck, thus 2-4 blocks will constitute a load. The goal of truck-based grade control is to arrange the loads such that every load is composed of either all ore or all waste. A small example is shown here.

This example is very simple. It is composed of an aerial grid with 100 blocks (10 x 10). For simplicity, we will first assume that each truck can carry four passes, or blocks. The majority of the blocks are ore, but there is a strip of waste running diagonally across the area of interest as shown here:

The blocks are assigned to loads with each load containing four blocks. We start with each load being a square, again, for simplicity's sake. Mining progresses from the lower left to the upper right. The truck loads are numbered from 1 to 25 in the order that they are removed.

Load 2 is a load of ore with one block of waste, load 6 is a load of waste with one block of ore. We can see that there is dilution of the ore with the waste. This lowers profit. We will assume that each ore blocks profitability is +$10/t and each waste block's profitability is -$2/t. The total profit of mining the area is calculated as follows:

$$\text{Profit} = \sum_{\substack{\text{ore}\\\text{loads}\\(l)}} \sum_{\text{blocks}} P_{l,k} \bullet tpb \quad + \quad \sum_{\substack{\text{waste}\\\text{loads}}} n_p \bullet P_{wm} \bullet tpb$$

Where $P_{l,k}$ is the profit of each block, tpb is the tons per block, n_p is the number of passes, and P_{wm} is the cost of mining waste and is a constant. For this example, the total profit with this configuration of loads is $51,150 if we assume that the tons per block is 75. It is apparent that this situation is not optimal as there are many loads that contain both ore and waste. The best results would come from having loads of all waste and all ore. This can be done as shown in this configuration. Using the same assumptions, we now have a profit of $53,400, a 4.4% increase.

This is a very simplified scenario. In reality, the profit model is much more discontinuous (that is, not all ore/waste blocks are adjacent) and dilution can never be completely removed. But the principle remains the same. We want to maximize profit by maximizing the value of each load of ore and by maximizing the amount of waste hauled in a waste load.

The assumption that trucks will be loaded with uniformly shaped blocks is also less than ideal. The selection abilities of the loading device (usually shovel or front end loader) would have to be much better than they are now. The loading device would also have to be extremely mobile which is not the case with todays machinery. A typical loading scenario is likely to follow one of the following configurations.

Methodology

As mentioned previously, truck-based grade control requires a 2-D profit model to be generated previously. The Center for Computational Geostatistics (CCG) has created a guidebook titled 'Guide to Geostatistical Grade Control and Dig Limit Determination.' It includes detailed instructions for creating the profit model. Refer to if for instructions for creating the profit model.

Ideally, the block size of the profit model will be the same as the SMU size for the given mine. Each block is assigned to a specific load, as shown previously in Figure 2. This is done differently depending on the number of passes the loading device must make to fill the truck. The beginning initial configurations are shown for two and three pass loading in

Figure 6 and

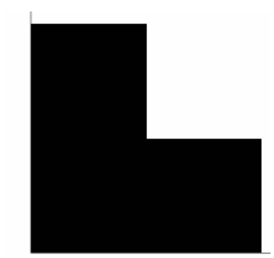
Figure 7, respectively. Four pass loading is initialized as squares as shown in Figure 2.

We can now begin the process of trying to find a more profitable configuration, as was done in Figure 3. To create this more profitable configuration there is a process we repeat over and over. The steps in this process are:

- Go to a random block in the model
- Choose a random neighbor from the eight surrounding blocks
- Switch the load numbers for those blocks
- Recalculate the total profit based on the new load configuration
- Compare this total profit value:
    - If it is higher, keep the switch and try again
    - If it makes no improvement, switch back the load numbers and try again

This process is repeated over and over until there are many consecutive attempts that yield no improvement.

Within the process there are some constraints that must be adhered to. The load geometry is the most important constraint. The following example will illustrate. It is done using three pass loading. Assume load 1 has the following aerial shape and that mining is progressing from the lower left:



Also assume that the bottom left-hand block is randomly chosen and its upper right hand neighbor is randomly selected to switch with. The switch is made and load 1 now looks like this:

Two problems are created by performing this switch. First, we have separated the white block from its load, that is, this block is no longer adjacent to the other blocks assigned to the same load. Secondly, we have put a block assigned to a higher load number in front of blocks which are supposed to be mined first. It is apparent that there are only a few allowable geometric configurations, some being better than others. Each geometric possibility was found for two, three, and four pass loading and they are shown here. Each has its own particular index number which is also shown:

After each switch, the new load configuration is compared to this library of possible configurations. If the new layout is found to be allowable, the new total profit is calculated and, if higher than before, the new layout is kept.

Not every configuration is possible and out of those that are, some are more desirable than others. For example, the configuration shown in Figure 11 is not desirable for mining that is progressing from the lower left.

As such, each configuration is assigned a penalty. The undesirable configurations have a very high penalty; the desirable configurations have a very low or no penalty. When a load number switch is made, the two new load configurations are checked for viability. If the configurations are allowable, the loads are assigned the corresponding penalties and the profit is recalculated, subtracting the total penalty. If the profit is higher, the switch is kept and the process begins again. The formula for calculating the profit and accounting for the penalty is:

$$\text{Profit} = \sum_{\substack{\text{ore}\\\text{loads}\\(l)}} \sum_{\text{blocks}} P_{l,k} \bullet tpb + \sum_{\substack{\text{waste}\\\text{loads}}} n_p \bullet P_{wm} \bullet tpb - \sum_{\substack{\text{all}\\\text{loads}\\(i)}} lcp_i \bullet np \bullet tpb$$

where lcp represents the load complexity penalty. It is in the units of dollars per ton ($/t).

Another important consideration is the direction of mining. This program works under the assumption that mining progresses from the lower left hand corner of the area and progresses to the upper right hand area as shown here:

If a different mining direction is desired, the user must specify it as an input parameter. There are 8 direction options. They are shown in Figure 13. As shown in Figure 13, there are two options for every corner. When mining of a bench begins, it usually starts at a corner, but only one side of the corner is typically accessible. These eight options account for this and allow for any mining direction to be allowed.

The process of choosing a random location, switching load numbers with a random neighbor, and recalculating the profit based on the change will lead to increased delineation of the recoverable reserves. The degree of improvement depends on how many random switches are made and tested. The number of switches that are made can be specified by the user. It depends on the number of blocks in the profit model. For our previous example with 100 blocks, we used 1000, or 10 times the number of blocks, random switches to optimize the profit. This is recommended as a minimum. Due to the random nature of the switching and the possibility of blocks already selected to be selected again, it is suggested that the process be iterated at least 10 times more than the total number of blocks. This will give optimal results.

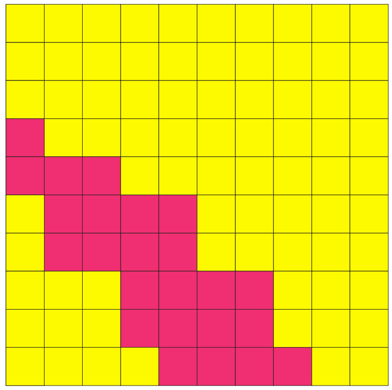


Figure 1: Layout of small example.

Figure 2: Initial load numbering sequence following mine progression**,** from bottom left to top right.

15	15	16	16	22	22	23	23	25	25
15	15	16	16	22	22	23	23	25	25
8	8	9	9	17	17	21	21	24	24
7	8	8	9	17	17	21	21	24	24
7	7	6	9	14	14	18	18	20	20
2	7	6	10	10	14	18	18	20	20
2	6	6	10	10	14	12	12	19	19
2	2	3	5	5	11	11	12	19	19
1	1	3	5	5	11	11	12	13	13
1	1	3	3	4	4	4	4	13	13

Figure 3: Modified load sequence. Each load carries only ore or waste.

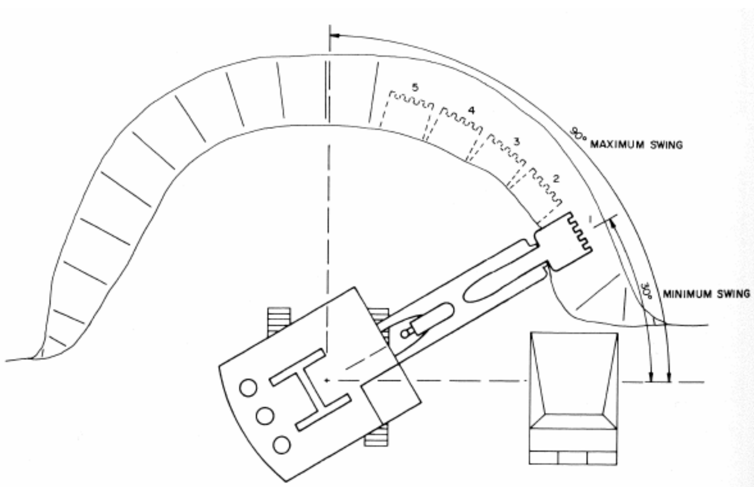


Figure 4: Pass configuration for double-backup operation. This is from The Bucyrus Erie Supervisory Training Manual.

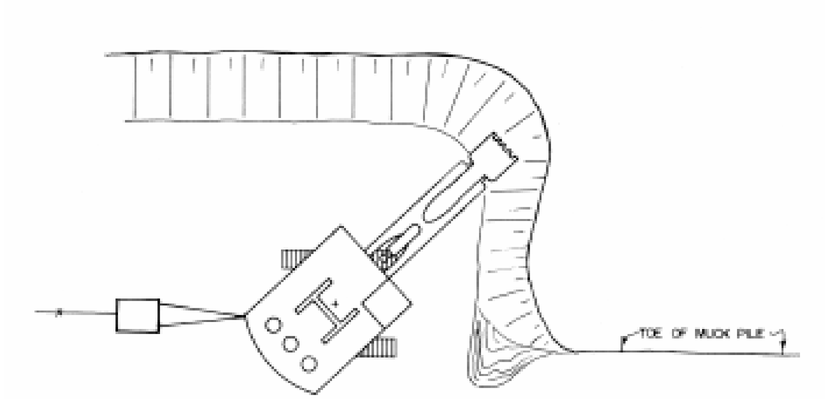


Figure 5: Pass configuration for drive-by operation. This is from The Bucyrus Erie Supervisory Training Manual.

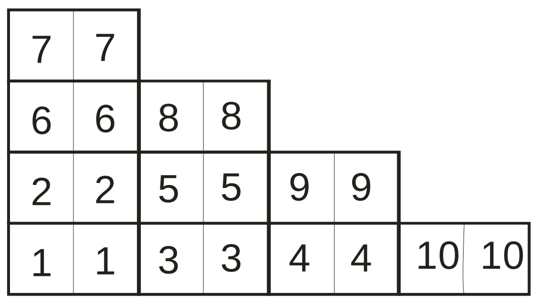


Figure 6: Initial load sequence for 2 pass loading.

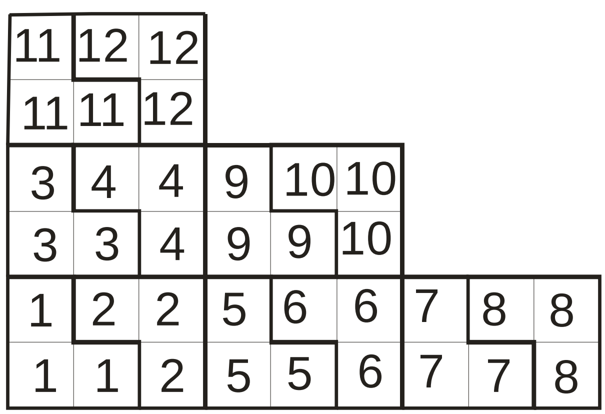


Figure 7: Initial load sequence for 3 pass loading.

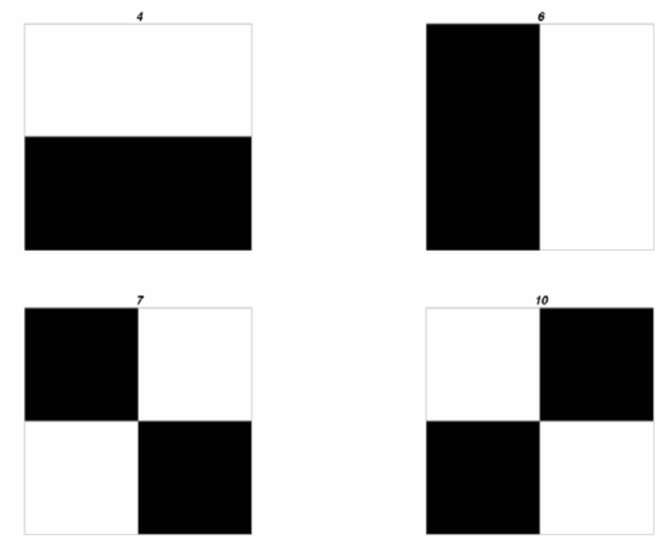


Figure 8: Geometric configurations for two-pass loading.

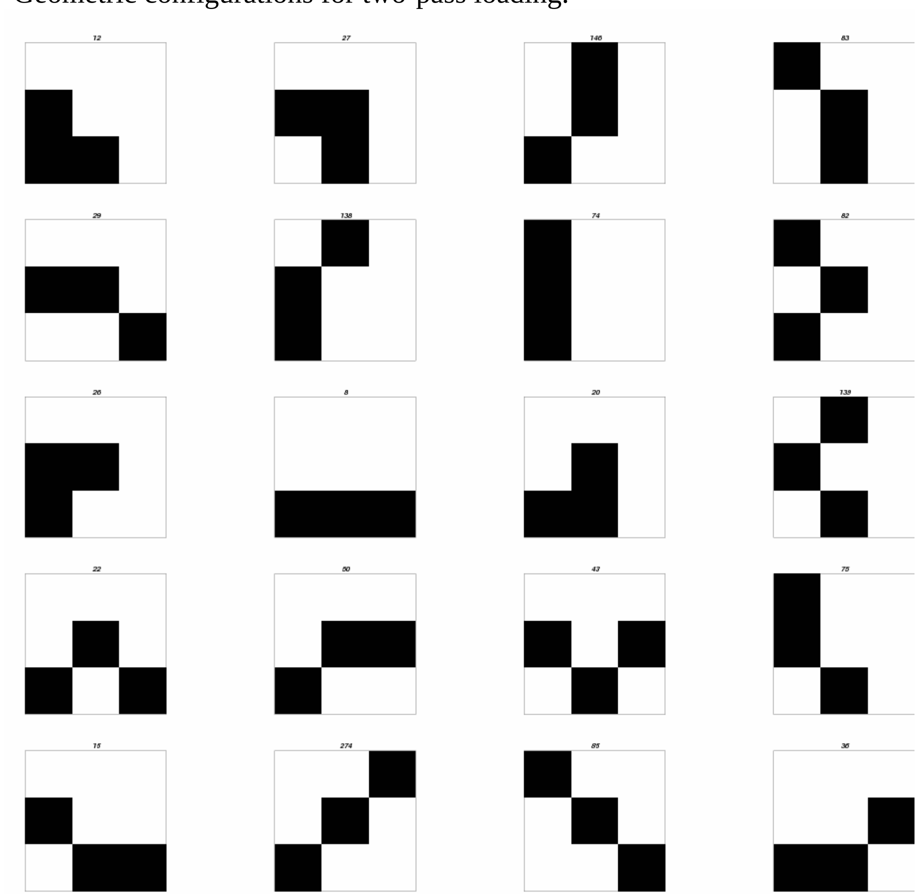


Figure 9: Geometric congifurations for three-pass loading.

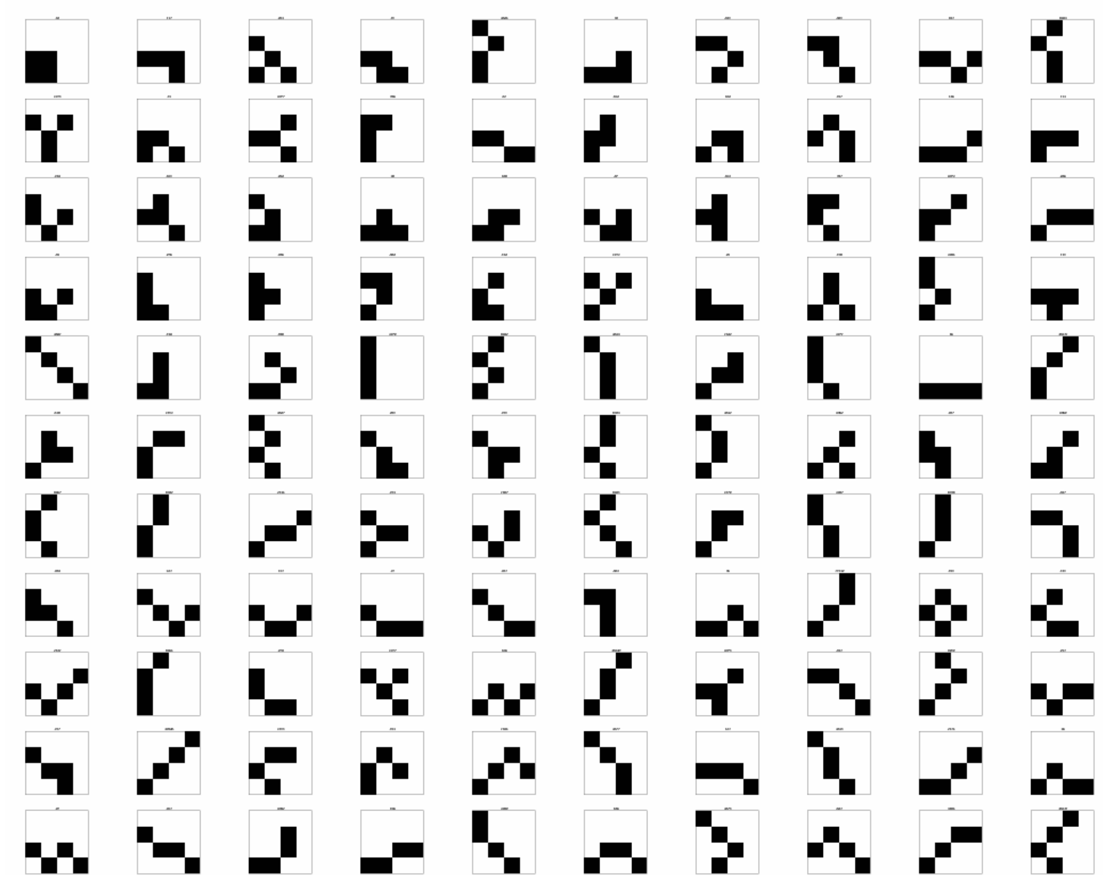


Figure 10: Geometric configurations for four-pass loading.

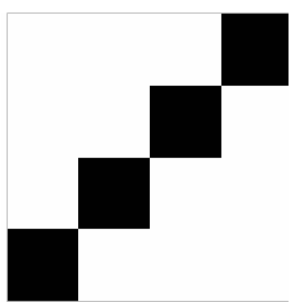


Figure 11: Undesirable configuration.

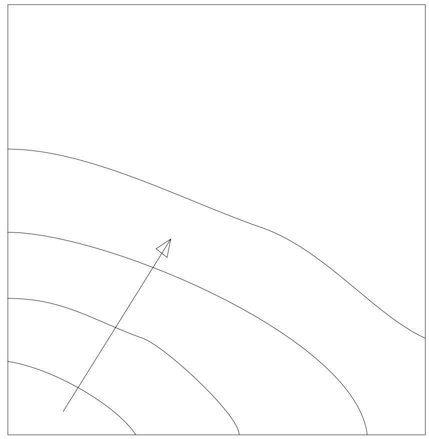


Figure 12: Assumed mining progression.

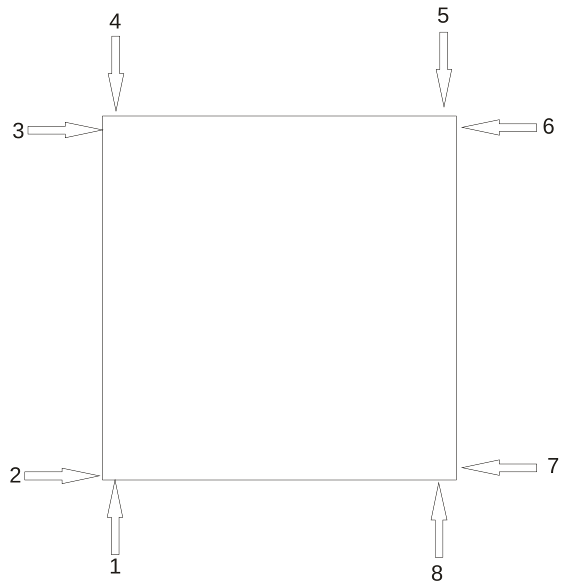


Figure 13: Options for beginning mining.