DILUTION CAUSED BY MINE EXECUTION INEFFICIENCY IN OPEN PIT MINING

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ABSTRACT

Developing a good mine plan is not an easy work; to do it correctly, all particularities, deposit characteristics and operational conditions must be considered. Among these characteristics, dilution and loss can be cited as factors that sometimes are neglected in mining operations or it is simply assumed a correction factor due to the difficulty to be implemented. Geological intricacies, geometrical aspects and operational characteristics, like experience of the operator and use of technologies will directly influence the occurrence of dilution. Dilution and loss are factors that should be seriously considered for tonnage and grade estimates during the reserves assessment procedures. In this study it was determined a methodology to quantify dilution during short term planning in open pit mining. The proposed technique consists in identifying the blocks belonging to periodical plans and its neighborhood considering the nature of the contacts and the differences in grades between adjacent blocks. With this method, it is possible to estimate the internal dilution block by block caused by operational inefficiency and also the dilution caused in the contact slopes at the end of the excavated dig line. The technique takes into account the equipment's inability to perfectly remove each block (respecting excavation limits), and the influence of bench slope angle when mining the boundary blocks. The obtained results demonstrate the need of systematically quantifying dilution, since the quantities of material incorporated or left behind might be significant and could have a great impact on tonnage and grades reconciliation between planning and production.

KEYWORDS

Mine planning, dilution, grade control.

INTRODUCTION

Dilution is defined as waste material that is taken during the ore extraction process, but there are multiple assumptions involved within this definition. It assumes that the operation knows with fair precision the location, shape and grade of a given ore block, and that the equipment operators are capable of mining at a similar resolution (Crawford, 2004). However, there are several sources of uncertainty about the accuracy of the information above such as: the geological model may contain misinterpretations; block grades are based on estimates of spatially scattered data, and the operator may not have the ability to visually select the materials in the field.

According to Sinclair and Blackwell (2002), dilution can be subdivided in two categories: internal and external to the ore. Internal dilution can be considered from the perspective of volumes of waste rock within an ore zone or the inherent diluting effect resulting from either increasing the size of SMUs or the effect of blocks misclassification from sampling and analytical errors during grade control. External dilution can be related to minimum mining width, contact dilution and over break of slopes relative to planned mining boundaries. In addition, Villaescusa (1998) defines loss as the economical material that is not mined due to geological aspects and operating conditions.

This work focuses in quantifying mining dilution in open pit mining. Usually, dilution is better controlled in underground operations than open pit mining due to the selectivity of the underground methods, where this parameter has a higher influence in the operation. Dilution is defined as the incorporation of waste material to ore due to operational inefficiency to separate materials during mining process, considering physical processes, operating and geometric configurations of the mining with the available equipment (Câmara, 2013).

Ore losses and dilution occur during all stages of mining and, while several models are capable to investigate the influence of dilution, its quantification is the greatest challenge (Pakalnis et al., 1995).

However, according to Butcher (2000), dilution can be controlled at acceptable levels, through the implementation of correct mining engineering principles.

METHODOLOGY

The main idea of this work is to characterize each block and its neighborhood contained in a certain set of polygons representing the mine plan (Figure 1). Figure 1 is a typical plan view of a deposit where it can be observed the model represented by the colored blocks in the background representing different cut off grades that occur in the ore deposit, according to the legend provided. In yellow, there are polygons representing the mining areas planned for the period and in green, the pit limit.

Through a routine implemented using JavaScript and an HTML interface running inside DATAMINE Studio 3, it is possible to estimate the grade dilution based on differences between planned blocks and their adjacencies and define the mined percentage of those contiguous blocks. The algorithm calculates the internal dilution of the planned blocks (only when there are waste blocks, or low grade ore, adjacent to an ore block) as well as the influence of slope angle in adjacent blocks to the mine plan in open pit mining. The excavation imperfection (in this case it is incorporated as dilution) can be chosen according to other factors already estimated, especially the selectivity provided by the mining equipment and operator's skill.

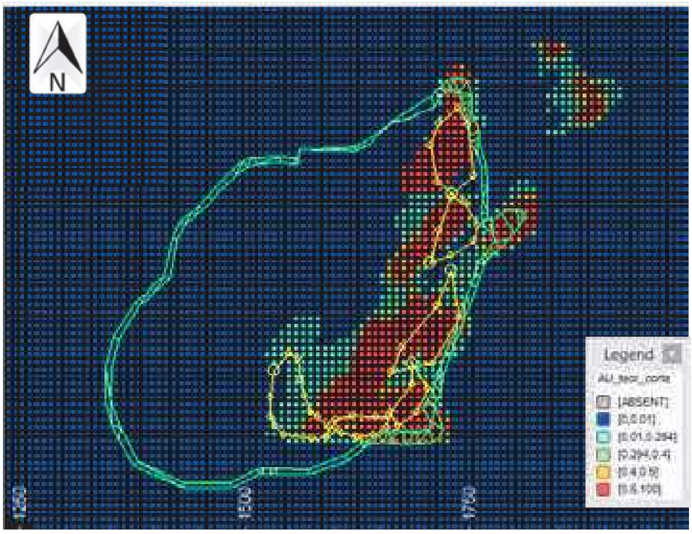

Figure 1- Planning polygons superposed to the block model

To apply the methodology, the first step is identifying the blocks located inside the planning polygons, with their respective grades. These polygons are located in a given reference level, normally associated with the base of the blocks (or bench floor). The polygons are then projected to a distance equivalent to the bench height, depending on the operation approach. Linking the bottom and top polygons now defines a solid representing the volume to be removed from the bench(or portion) and weight averaged considering its masses, allowing one to calculate the value of the interest variables that are expected to be accomplished according to the targets defined by the mine planning.

After creating the solids from the 2D planning polygons, it is possible to identify the blocks that are contained within these solids and the blocks that are in contact with the boundary blocks. All these steps are executed in the algorithm, summarized in the script interface shown in Figure 2.

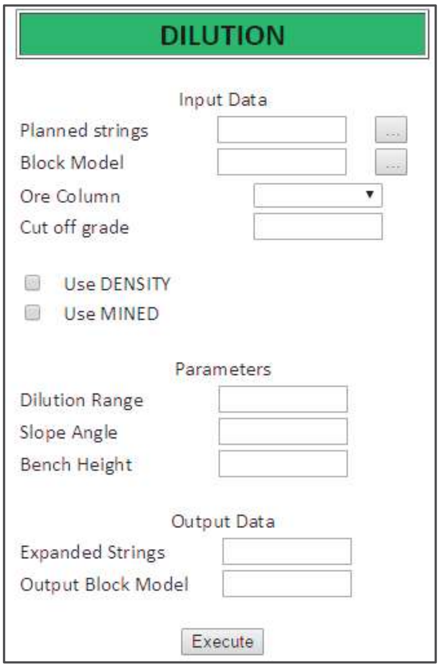

Figure 2- HTML interface of the dilution script

Through commands that transform the polygons in solids according to the bench height used in the operation, and after selecting the blocks contained within these polygons, it is possible to calculate the internal dilution as well the contact dilution and losses of blocks located in the boundaries exposed to the influence of the slope angle.

The major advantage of this script is the speed execution of the processes involved in the dilution calculation and its automaticity in use. The user needs to insert as input data the strings corresponding to planned polygons, the block model and set operating conditions: bench height, slope angle and dilution range (which is the imprecision, in meters, of the equipment when mining each block). With these data, the script identifies the blocks that lie within the planned polygons, the nature of the contact blocks and calculates the dilution for the period.

The script also calculates the percentage of the block within the planned polygon, in order to be more precise about the results of total tonnage found. Using this percentage is a user’s choice, checking the "Mined" checkbox. The "Density" is also a user´s choice, however it is recommended that whenever the block model has this column it should be used, thus it will be calculated the actual tonnage and not the volume.

Quantifying Dilution

Two types of dilution and loss are calculated and reported:

- Internal dilution, (planned ore block – planned non-ore block), which will take into account the dilution range chosen by user (Figure 3);
- External dilution, planned ore blocks that have waste external contact block in its neighborhood. From the slope angle and the block size chosen is calculated the contact block mass´ that are incorporated to the planned ore block (Figure 4).
- Loss, planned block portion that are not mined due to the influence of slope angle. It is always calculated together with the external dilution.

The dilution per block is calculated in two different ways:

1. For ore blocks that have internal contact with waste blocks (equation 1):

$$\text{Diluted Grade} = \frac{((M1 \text{ x Mined1 x } G1) + (M2 \text{ x Mined2 x } G2))}{((M1 \text{ x Mined1}) + (M2 \text{ x Mined2}))} \quad (1)$$

Where,

- M1 is the ore block mass, calculated by:
  Block mass = XINC x YINC x ZINC x Density

  Where,
- XINC, YINC and ZINC are the block dimensions in X, Y and Z directions respectively;
- Mined1 is the percentage of block within the polygon;
- G1 is the block grade;
- M2 is the mass of waste block adjacent to be added, calculated by:
  Adjacent block mass = Dilution range x YINC x ZINC x Adjacent Density
- Mined2 is the percentage of adjacent block within the polygon;
- G2 is the adjacent block grade (waste or low grade).

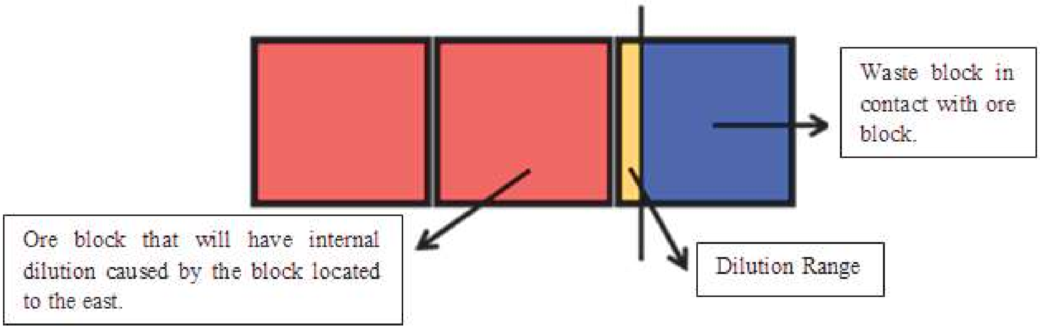

Figure 3 - Internal dilution

2. For ore blocks that have external contact with waste blocks (slope angle) (Equations 2 to 6):

$$\text{Mass of Loss} = \frac{(\text{Influence of slope angle x YINC x} \left(\frac{ZINC}{2}\right) \text{ x Density})}{2} \quad (2)$$

$$\text{Mass of Dilution} = \frac{\left(\text{Influence of slope angle x YINC x} \left(\frac{ZINC}{2}\right) \text{ x Adjacent Density}\right)}{2} \quad (3)$$

$$\text{Loss} = (\text{Mass of Loss x Grade}) \quad (4)$$

$$\text{Dilution} = (\text{Mass of Dilution x Adjacent Grade}) \quad (5)$$

$$\text{Diluted grade} = \frac{(\text{M1 x G1})+\text{Dilution-Loss}}{(\text{M1})+(\text{Mass of Dilution})-(\text{Mass of Loss})} \qquad (6)$$

Where,

- M1 is the ore block mass, calculated by:
  Block mass = XINC x YINC x ZINC x Density
- G1 is the block grade;
- Influence of slope angle is the triangular prism volume formed by the slope angle of the block that is mined.

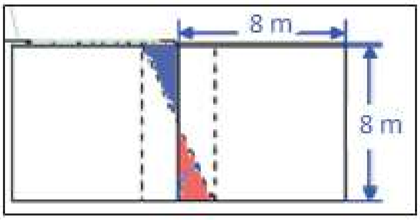

Figure 4 - External dilution, caused by slope angle influence

When a block model is estimated, usually the result is a set of prismatic blocks with X, Y and Z coordinates and orthogonal faces, without any kind of inclination. However, when the pit is designed with operational conditions and rock stability the slope angle should be considered.

If blocks contact is ore/waste, the dilution will correspond to the triangular prism volume formed by the slope angle configuration. In this study, it was considered a 60° slope angle and block dimensions of 8m in all directions. It is also considered that the bench face crosses the middle of the bench height. Using trigonometry (Equation 7) it is possible to calculate the amount of the block that is not mined (loss) and also the tonnage incorporated from the contiguous block (dilution). Both, loss and dilution affect the average grade of the block, which, at the end of the process, will affect the reconciliation in tonnage and grades.

$$\tan 60° = \frac{8}{x} \qquad x=\frac{8}{\tan 60°} \qquad x=4.61 \qquad \frac{x}{2}=\frac{4.61}{2} \qquad \frac{x}{2}=2.3 \qquad (7)$$

To illustrate how much 2.3 meters influence in mining, the volume of the triangular prism formed by the bench´s slope angle is calculated below (Equation 8):

$$\text{Influence of slope angle}=\left(\frac{\text{ZINC}}{2}\right)\times 2.3 \times \text{YINC} \times \text{Density}$$

$$\text{Influence of slope angle}=\left(\frac{8}{2}\right)\times 2.3 \times 8 \times 2.7$$

$$\text{Influence of slope angle} \approx 200 \text{ m}^3 \qquad (8)$$

This volume corresponds to 14% of the total mass of a block with dimensions of 8m, 8m by 8m in the x, y, and z, respectively, which represents a great influence. The product of the mass by the ore grade allows to quantify loss and multiplying by the waste grade (contact block) the dilution can be calculated.

To calculate the dilution of ore blocks that have external contact with waste blocks (slope), the block portion inside the planned polygon ("Mined") was not used, because, in this example, it is assumed that it is in full contact with the waste block.

The methodology proposes to calculate dilution for two types of contact: internal, when ore blocks have contact with non-ore blocks; and external, when blocks have external contact with non-ore blocks. In this study, the calculation of the diluted grade is given by the sum of the two types of dilution shown by the equation 9:

$$\text{Diluted grade} = \frac{\sum(\text{Masses x Grades})}{\sum(\text{Masses})} \tag{9}$$

RESULTS AND DISCUSSION

To validate the methodology, the script was tested using monthly dig lines related to planning polygons and calculate the dilution and losses considering the block model. The tested files are from an open pit gold deposit, and the planning polygons consist in dig lines design in the benches, containing ore and waste blocks. This dig lines represent the portion planned to be mined, according to mine plan. All scripts procedures were performed by an average of 1 to 2 minutes.

The output is a new model with all the original fields plus a new field containing the diluted grades after the calculations. The results shown in Figure 5 are a comparison between the planned average grades against diluted average grades in six months, considering external and internal dilution and loss for a typical set of polygons representing the short term mine planning.

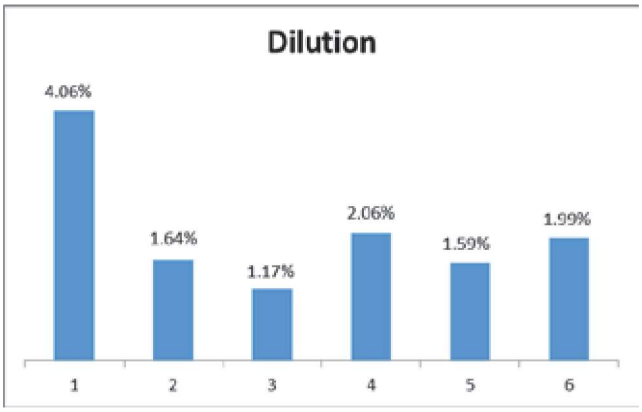

Figure 5 - Dilution per period

In order to estimate the dilution for the analyzed period it was calculated an average, weighted by the mass mined in each month. Thus, it is possible to obtain the average value of dilution of the period, which in this case was 2.1%. Assuming an average value for all months, could mask differences that happen in each month, like a difficulty to access determined area, or mining more waste to liberate the ore, etc. Using this methodology, the dilution is calculated, not a fixed value.

CONCLUSION

Crawford (2004) comment that contact dilution is determined by resolution; specifically, the ability to accurately define and then mine along the limits of an ore zone, such that the available mining equipment can successfully extract the material at those limits. This work allowed, in addition to calculate the contact dilution, (called here internal dilution), the calculation of external dilution and loss. These calculations aim to estimate an average dilution for the period.

The use of a dilution factor in the estimated block model, before mining, is a way to predict grades and masses closer to the mined. When a block model is estimated and the actual dilution is not considered, an arbitrary number is normally set to be the dilution used in the model. This arbitrary value often does not take into account all the factors that actually cause dilution.

The consideration about the deposit geometry, more specifically benches, slope angle and execution efficiency were the items that determine the calculation of dilution. It is known that each feature will contribute in the calculation, but it is the combination of those aspects that will determine the total dilution calculated.

This study demonstrates an attempt to make a simple and direct approach of a parameter that is known to be complex and difficult to control, and that the majority of companies in the mining sector or simply disregard this effect or when considered it was used inadvertently and obscurely by applying a fixed number or factor for the entire deposit without proper understanding the source of the problem and the consequences that this problem can have to when mining different deposits. In this case, the deposit tested is an open pit gold deposit, which is mined using mechanical extraction. The methodology could be adapted for different deposits and different operational characteristics, for example, to calculate dilution in a deposit mined using drill and blast, the dilution range would change to a percentage of the block that is diluted with his adjacent, instead of using the equipment imprecision (in meters) when mining the block.

The methodology has been tested in different types of deposits and the idea is to keep doing tests to check the impact of dilution considering the variability inherent to each deposit and operational conditions. Normally dilution is a number chosen by heart and not very well explained and calculated. This methodology details a way to incorporate dilution in the short term mine planning and to be systematically considered along the mine life.

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