Quantifying dilution caused by execution efficiency

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Abstract

In open pit mining, dilution is not always a factor systematically analyzed and calculated. Often it is only an adjusted number, for example, calculated or even empirically determined for a certain operational condition perpetuating along time in the form of a constant applied to calculating reserves or mine planning in attendance of audit requirements. Dilution and loss are factors that should be always considered for tonnage and grade estimates. These factors are always associated and can be determined considering several particularities of the deposit and the operation itself. In this study, a methodology was determined to identify blocks adjacent to the blocks previously planned to be mined. Thus, it is possible to estimate the dilution caused by poor operating efficiency, taking into account the inability of the equipment to perfectly remove each block, respecting its limits. Mining dilution is defined as the incorporation of waste material to ore due to the operational incapacity to efficiently separate the materials during the mining process, considering the physical processes, and the operating and geometric configurations of the mining with the equipment available.

Keywords: dilution, mine planning, efficiency.

1. Introduction

All mining operations experience dilution at some time and in most cases, the elimination of the waste within the ore blocks is impossible. However, experience has shown that dilution can be controlled to acceptable levels by the implementation of correct mining engineering principles (Butcher, 2000). According to Pakalnis *et al.* (1996), ore losses and dilution are present at all stages of mining and while several models can investigate the influence of dilution, it is its quantification that represents the most serious challenge. Furthermore it is now recognized that what is considered acceptable dilution is a function of ore grade, percentage of dilution, production costs and ultimately of ore selling prices. Consequently the degree of acceptable dilution differs from site to site.

A definition for dilution is a portion of waste material incorporated into the ore during its extraction and transport to the processing plant, thus reducing the grades of ore previously estimated. And the loss, according to Villaescusa (1998), is defined as the economical material that is not mined due to geological aspects and operating conditions.

Dilution can be subdivided into two categories: internal and external to the ore. According to Sinclair and Blackwell (2004), both categories of dilution can be further subdivided on the basis of geometric considerations about the deposit itself or of the diluting material. External dilution can be related to minimum mining width, contact dilution and overbreak of wallrock relative to planned mining margins. Internal dilution can be considered from the perspective of volumes of barren rock within an ore zone or the inherent diluting effect resulting from either increasing the size of SMUs or the effect of blocks misclassification resulting from sampling and analytical errors occurring in grade control.

External dilution is a result of the mining method chosen, as well as the complexity of the contact between ore and waste, while the degree of influence will be dependent on how abrupt is the change in grades in this contact. External dilution can also be a result of the size and position of the block to be mined. In a block model representation, each one of the six blocks contiguous to the considered one have influence on a type of dilution, that can be horizontal or vertical (Figure 1). If the block to be mined is in contact with blocks that are not mineralized (or if they are of low grade ore), the dilution will occur in this contact when imperfect separation methods are used or to maintain the geotechnical slope angle of the wall face.

Rarely can the block be removed without incorporating any part of the lateral blocks. Also, considered must be the fact that the operator should have full control of positioning, and that the equipment selected for the block extraction should be properly sized, thus minimizing the dilution.

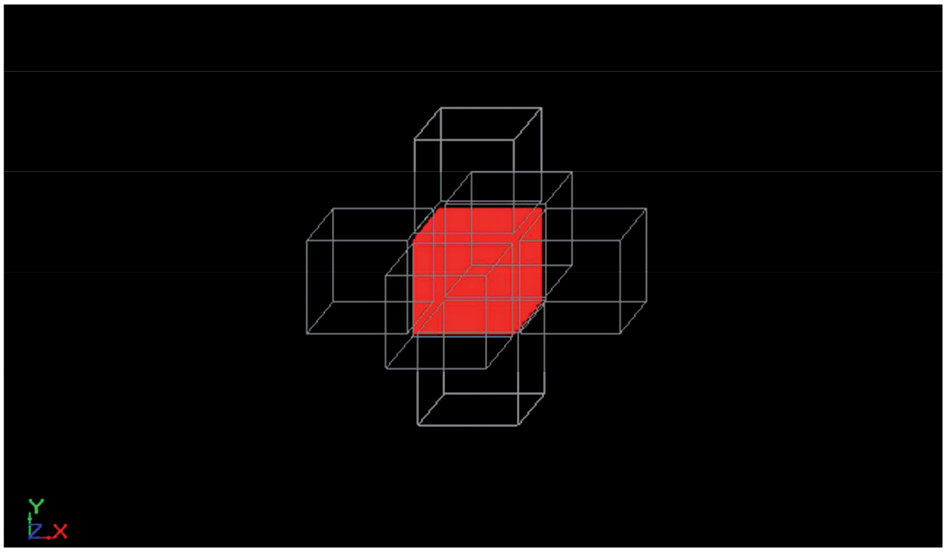

Figure 1
Block to be mined and the six blocks contiguous to the considered one.

2. Material and methods

In short term planning, polygons are usually defined to delineate the locations where mining should be made based on the processing plant requirements or product specification, such as average head grade, contaminants, rock hardness and total milling capacity (Câmara, 2013). The delimitation of these areas in the field can be made through the use of flags or any other physical marking on site.

In some companies that use more technology in their operations, many mining machines have Global Positioning Systems (GPS) installed. However, even with the use of technological resources, often due to operating problems (such as equipment's selectivity or, operator's skills) these polygons are not strictly followed, causing differences in relation to planning. This aspect can certainly be cited as one of the factors that cause differences during the reconciliation process. The dilution that occurs due to these problems in the execution can be calculated using the methodology shown in this study and this dilution can be associated as short term mine planning dilution.

Methodology

To apply the methodology, the first step is to select the blocks falling within the polygons of the monthly plan. Thus, the type of rock that is present in each polygon planned to be mined can be determined. These polygons are contained in a given reference level, normally associated with the base of the blocks. After, the polygons are projected to a distance equivalent to the block's height or to the bench height, depending on the operation approach. The union of the base and top polygons now sets a solid that represents the volume to be removed from the block (or portion) and weighted average considering the masses, allowing one to calculate the value of the variables of interest that are expected to be accomplished according to targets defined by the mine planning. Figure 2 shows a plan view of the deposit, where it can be observed that the model is represented in the colored blocks in the background representing different rock types that occur in the ore deposit, according to the legend provided. In pink, are representations of what would be the mining areas planned for a given period (monthly plans, for example).

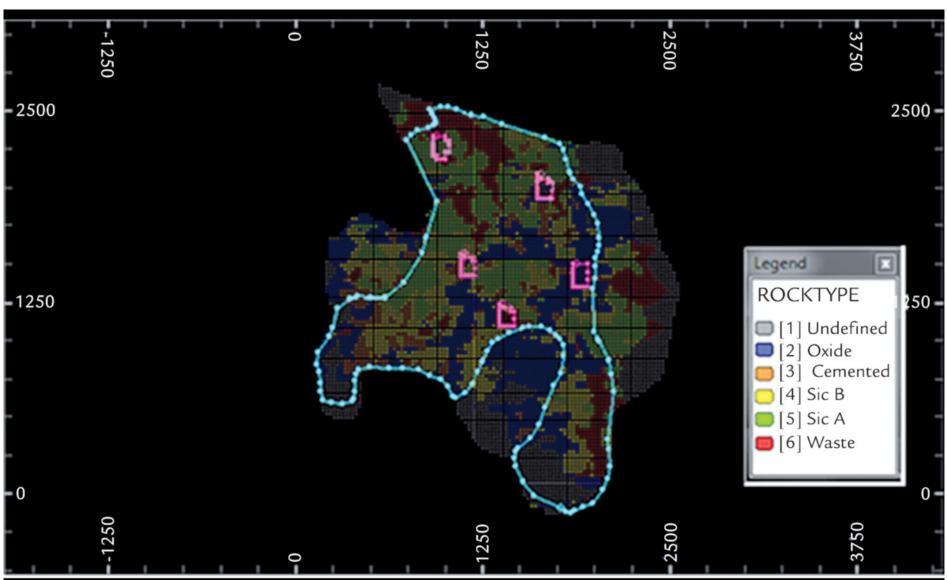

Figure 2
Planning polygons superposed to the block model.

After creating the solids from planning polygons, it is possible to identify the blocks that are inserted within these solids and the blocks that are in contact with the boundary blocks. Considering that the process of mining is imperfect, contact blocks will be diluted because the equipment is not able to select the block exactly where it ends or at the dig line previously determined, if this line does not coincide exactly with the boundary of the blocks. For the definition of the dilution, it was considered that the mining equipment includes 1 meter of each block that is in the contact area. For a block with dimensions of X, Y and Z corresponding to 25m, 25m and 10m, respectively, this addition of 1 meter represents 4% of the total mass to be mined. In this example it was considered that the equipment removes more material to calculate dilution, but the equipment could also remove less material, thus causing losses. Therefore, this methodology allows defining both dilution and losses in a block inside a planned area. To identify which blocks are on the external limit of the polygon, i.e., the blocks that will cause dilution if they are in contact with the planned blocks, considering they are low-grade ore or waste, the polygon was expanded horizontally taking into account the block dimensions in X and Y directions and transformed into a solid using the same process described above to select the planned blocks. After performing the step of selecting the blocks planned, the process is repeated for the expanded polygon, so that the contact blocks and their grades can be identified (Figure 3).

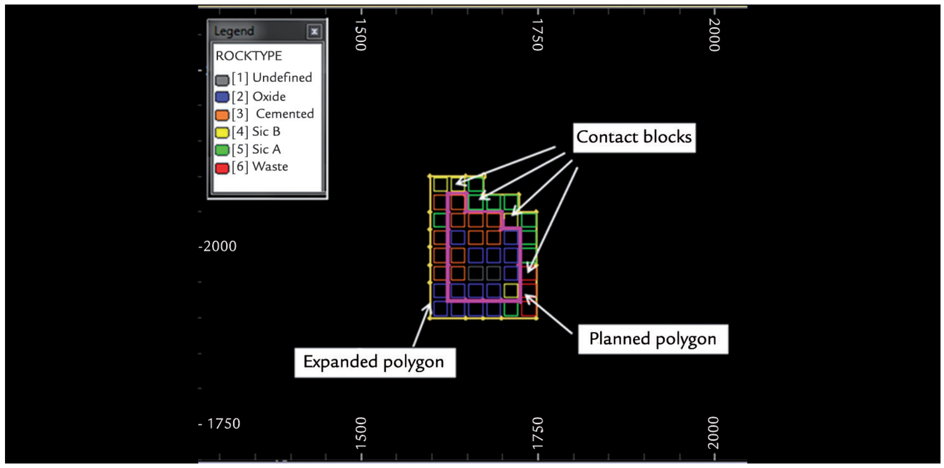

Figure 3
Blocks located in the dig line contact limit.

The selections of blocks are exported to an Excel spreadsheet. The first step is to analyze in the worksheet of the expanded model, which blocks are of the contact and which are not. Then, for the contact blocks, identify which blocks are the adjacent ones, and if they are blocks of ore or waste. To those blocks that are in contact with blocks of waste or low-grade ore, dilution is calculated and a new grade is now applied to that diluted block.

3. Results and discussions

Considering that the dimensions in the X and Y directions are of 25 m and that XC and YC represent the coordinates of the centroid of each block, the neighboring blocks can be identified using the calculation shown in Table 1.

Table 1
Identification of adjacent blocks.

	NORTH (N)	SOUTH (S)	EAST (E)	WEST (W)
XC	XC block	XC block	XC block + 25	XC block - 25
YC	YC block + 25	YC block - 25	YC block	YC block

After identifying the block, it is possible to query other important fields related to these blocks, such as ROCK TYPE and P_2O_5AP grade (apatite phosphate grade). By knowing the contacts and the corresponding grades, dilution can be calculated for each block analyzed. This analysis process evaluates each block individually, but the results can be computed together for the whole dig line. Table 2 shows an example of analysis for a specific block. As shown, the block located to the North of the original block is identified as low-grade ore, and it will cause dilution in the grade of the original block. This analysis is repeated for all the blocks that are in the contact region.

Table 2
Identification of location, P_2O_5AP grades and rock type of adjacent blocks.

	XC (m)	YC (m)	ZC (m)	P_2O_5AP (%)	ROCK TYPE
Analyzed block	1687.5	2037.5	1015	18.49	3
North	1687.5	2062.5	1015	9.03	5
South	1687.5	2012.5	1015	17.37	3
East	1712.5	2037.5	1015	9.03	4
West	1662.5	2037.5	1015	20.10	3

First of all, the location of the block is evaluated along upon direction this block has contact with unplanned blocks. Secondly, the rock type and P_2O_5AP grade of the contact is analyzed and if the rock type of the contact block is different from the rock type of the analyzed block, then dilution is calculated. As stated earlier, it is considered that the mining equipment incorporates 1 meter of the adjacent block in the mined block, a value that is also incorporated into the calculation of the total mass mined. This 1 meter was defined according to the mining equipment selectivity for this specific operation; however, it can vary according to the characteristics of each operation.

With the grades diluted according to the type of contact, the total dilution of the planned polygon can be calculated. In the example tested in this case, the plan was to mine the total mass with an average grade of 10.82%. After calculating the dilution, the new average grade was of 10.48%. The difference in grades is 0.34%, a value that corresponds to a dilution of P_2O_5AP grades of about 3.12%.

The dilution results show considerable values, which demonstrate that even where the reconciliation adherence is quite satisfactory, dilution may occur. In this example it occurs due to the lack of the selectivity capacity of the equipment and/or operator skills and mining delimitation practices. This demonstrates the importance of reconciliation between planning and execution in mining to control dilution, and if there are problems in reconciling these, the dilution will be much higher.

4. Conclusions

Controlling dilution in a systematic way allows for a better understanding of problems during mass and grade reconciliation processes and where they occur. According to Câmara *et al*. (2013), ore losses and dilution are problems that are often difficult to locate and quantify, but with a good method of control, it is possible to minimize them. The calculation proposed within this methodology is a way to systematically approach this subject that is commonly neglected or masked during mining. It was attempted to make a simple and direct approach to a parameter that is notoriously complex and difficult to control. It is known that most mining companies either simply disregard this effect or use a factor without considering the particularities of the deposit, just applying a fixed number for the entire deposit along the mine life without considering that the origin and consequences of this choice can lead to differences in reconciliation and generalizing to deposits that have different contexts. The analysis of the dilution caused by the execution efficiency proved to be quite satisfactory and with this methodology, it is possible to identify the contacts of the planned blocks and after determining their grades, calculate the dilution.

5. Acknowledgements

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