KBPL

Estimation of Open Cut Mining Recovery and Mining Dilution

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Summary

Loss and dilution of Mineral Resource grade occurs during mining activities. Mining Recovery and Mining Dilution estimates are a required consideration in the reporting of Ore Reserves for mineral projects. Good estimation of Mining Recovery and Mining Dilution improve mineral project economics and Mineral Resource utilisation. Mining loss and grade dilution can be reduced by adopting selective mining techniques, increasing the cost of mining, however improving the overall project economics. The estimation of Mining Recovery and Mining Dilution requires an understanding of resource estimation, mine geology, blasting, mining equipment, mine planning, mine surveying, mineral processing and information technology. While advances in computing and mining software have increased the accuracy of calculations the multidiscipline variables remain difficult to quantify and are frequently not understood. Typically many assumptions are poorly documented. This paper presents observations of past and present estimation practices, advances in computing techniques, and presents a methodology for better estimates.

Introduction

Mining Recovery is usually a percentage estimate of insitu ore recovered after mining has taken place. It is frequently described as mining loss which is economic mineralisation that has been lost during the mining activity. Mining Dilution is the percentage of material added to the insitu ore during mining. The mineral content of the diluent material is used to recalculate the grade of ore post mining resulting in a diluted grade estimate.

AusIMM JORC Code - 2012 Edition.

The AusIMM, JORC code, 2012 edition, requires that for a Reserve Estimate at least a Prefeasibility level study is required where Mining Recovery and Mining Dilution modifying factors are supported by reasonable assumptions. For a Feasibility Study appropriately detailed assessments of Modifying Factors are required and need to be documented. As a guide the Mining Factors are listed in JORC Table 1. Section 4. Considerations material to the Mining Recovery and Mining Dilution Modifying Factor estimates are;

- mining method,
- mine design,
- mine schedule,
- over burden,
- geotechnical pit slopes,
- preproduction drilling,
- grade control,
- optimisation assumptions and
- minimum mining widths.

As projects move through Scoping, Prefeasibility, and Feasibility studies into production the estimates progress from assumptions to quantified factors based on measurement and reconciliation. Thus Reserve estimates for operating projects have higher confidence levels. Mining Dilution can occur both before and after losses occur so care must be taken in the sequence of factor application. Generally mining loss is applied post mining dilution calculations.

Estimation Techniques

Historically several approaches have been used.
For feasibility studies;

- percentage estimates,
- surface areas (skins)
- regularisation of cellular models in optimisation programs and
- estimation of Selective Mining Unit (SMU).

For operating mines the

- resource models,
- grade control models,
- metallurgical models, and
- mining models;

can be reconciled to treatment plant feed tonnes, grade and actual mineral product produced.

Sample Collection and Compositing

The selection of drilling sample intervals and compositing strategies are typically planned very early in the exploration phase of projects. All too frequently this decision is made without due consideration of the impact on the analysis of selective mining opportunities. Too large a composite interval can mask internal waste zones and may preclude proper analysis of highly selective mining such as continuous surface mining.
Mine planning engineers need to be involved in these important early decisions.

Surface Area (Skins)

This technique requires the creation of a “skin” around the periphery of the deposit. It can be applied to polygonal estimates or block models by generating a new larger wireframe encapsulation of the deposit boundary. The thickness of the skin is an estimate of the dilution that might occur. The thickness of the “skin” is usually an assumption based on a judgement about the mining technique and equipment. The advantage of this approach is it enables the grade of the mineralisation just outside the deposit to be included in the diluted grade estimate. For example adding diluent that has near economic mineral content has less detrimental effect than adding waste with zero mineral content. Skins can be quickly calculated for tabular deposits with simple geometry, however for complex shapes with internal waste zones it can take time to create the wire frames. The disadvantages include;

- no Mining Recovery estimate is calculated and
- early assumptions about the mining method and scale of the mining equipment are made.

Resource Modelling Techniques

Resource model cell sizes can be a constraint on the estimates of Mining Recovery and Mining Dilution. There are many parameters that are considered by geologists in the selection of the cell size for resource block models, unfortunately the requirement to estimate Mining Recovery and Mining Dilution are frequently overlooked. The spacing of the exploration drill holes, the sample intervals and the inherent variability of the deposit are the main considerations influencing the selection of cell size. The modelling variables that impact on the ability to estimate Mining Recovery and Mining Dilution are;

- parent cell size in relation to the proposed mining method and production rate.
- cell orientation in relation to the direction of excavation,
- sub cell size and complexity of wire frames,
- unfolded models, while aligning cell orientation to variable strike and dip directions of ore boundaries for improved boundary definition is of little use to mining engineers utilising regularisation for Mining Loss and Dilution estimates,
- rectangular block model cells that are oriented to reflect predominant ore deposit strike directions can also be adversely oriented where deposit strike or orientations are variable,
- percentage ore models where the cell contains a percentage or ore and waste based in intersection of wireframe surface and
- probabilistic estimation of attributes assigned to cells.

Mining planning engineers need to be involved in the selection of resource modelling techniques to ensure resource models are suitable for Mining Recovery and Mining Dilution estimates.

Mine to Mill

Mine to mill is a process for optimisation of mining and processing recovery and costs. The choice of either selective mining or bulk mining techniques is a major consideration, however evaluations rarely undertake careful consideration of Mining Recovery and Mining Dilution in the context of mine to mill optimisation. The most complex deposits can be mined with highly selective mining techniques reducing mining loss and dilution improving project economics. The balance between incremental additional mining costs and improved treatment plant performance and reduced costs are frequently not well studied. Beneficiation of ore prior to high cost treatment processes can mitigate the impact of gangue minerals introduced in mining dilution and can significantly improve project economics. All too frequently, Mine to Mill optimisations are reduced to a cost benefit analysis which is used to determine the most cost effective balance between blasting and commination costs and selective mining cost benefit not completed.

Geo-metallurgical Models

The inclusion of metallurgical parameters in cellular block models allows for the observed variability in mineral deposits to be scheduled into mine production periods. Historically metallurgical parameters have not been well understood early in a project during the resource definition phase. Typically understanding grows as budgets allow test work to be undertaken enabling metallurgical recovery algorithms to be included in optimisation regularised block models. Geo-metallurgy models typically include parameters that impact processing capacity, mineral recovery and processing costs such has ore hardness.

For consistency the Mining Dilution estimate and the resultant grade dilution should be adjusted by metallurgical algorithms. For example where magnetic separation is used the silica in the contaminant material will be eliminated by magnetic separation, therefore contamination of the product by silica would only occur in a small percentage of unliberated silica in the dilution material composite particles that report to the magnetic concentrate. The estimation of silica in dilution material can be problematic if the metallurgical test work supporting the recovery algorithm has not included very low grade material found in dilution materials adjacent to deposit boundaries. This deficient analysis can result in poor estimates of contamination grades. It is therefore important that metallurgical sampling, test work and analysis are applied to both ore and waste adjacent to deposit boundaries.

Mining Recovery estimates also estimate the amount of ore lost to waste. Contamination of waste stockpiles with sulphidic ores can increase the potential for Acid Rock Drainage.

Optimisation Regularisation

Early optimisation programs required cell size regularisation to facilitate the optimisation process and the approximation of open cut wall slope angles. The regularisation process introduced dilution and loss at the deposit boundaries.

The location of the cell is determined by the centroid of the cell, so if the cell centroid is within the deposit boundary a cell is formed, thus cells can exceed or fall short of deposit limits introducing dilution and losses to the estimate. The orientation of the cell to the deposit dip or strike will influence the amount of dilution introduced into the estimate, for example; a tabular deposit with near horizontal of vertical orientation, would add zero or significant loss and dilution by just changing the origin of the cell centroids.

For a deposit dipping at 45 degrees the cells will “sawtooth” the edge of the deposit resulting in different proportions of loss and dilution depending on the location of cell centroids and the size of the cells. Regularised models can also include algorithms to estimate ore within and outside of intersected wire frame boundaries. This technique is used to limit the estimation error caused by the saw tooth effect.

Block model estimates of volumes within wire frames tend to be globally accurate, however do not provide good local estimates of ore volumes, due to edge effects caused by the random location of block centroids relative to the wireframe boundary.

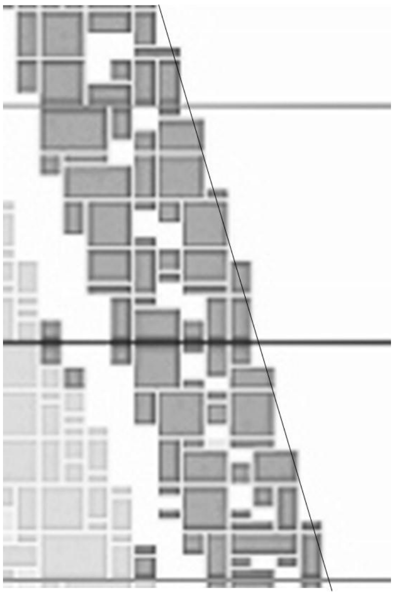

Figure 1 Resource model showing parent and sub cells near wireframe boundary

SMU Block Models

In recent years the use of Selective Mining Units (SMU) have become widely utilised to assist with the estimation of mining dilution. This technique involves the creation of a mining block model, with specific regularised cell size. The idea is to select the smallest regular cell size that can be practically mined by appropriately sized mining equipment. The size of equipment is selected to match the scale of the operation. This approach is based on the premise that large equipment cannot mine small SMU sizes. This is not always the case and is discussed later. Also there is an assumption that the mining fleet numbers should be minimised, by selection of the largest possible equipment, again this may not always be the case.
Typically consideration for SMU selection includes;

- resource model parent block size,
- the average width or depth of the deposit
- production bench height, or flitch height,
- final batter height,
- the effect on project economics of dilution and contaminants, and
- production capacity and thus a preconceived notion of excavation and haulage equipment size.

Once the cell size is selected the grades and other attributes are applied to the SMU cells.
To understand the inherent Mining Recovery and Mining Dilution of a Regularised SMU model grade and tonnes are compared to the resource estimate grade and tonnes. Some studies have used SMU size selection to facilitate the decision on bulk mining by calculating the dilution caused by the regularised cells "saw toothing" of the deposit boundaries. These Mining Recovery and Mining Dilution estimates will only be valid if the deposit is excavated by mining SMU blocks and not deposit boundaries as defined by grade control and survey. Some studies have determined that certain Mining Recovery and Mining Dilution estimates are appropriate or economically acceptable and have therefore selected a SMU that produces the desired estimates. The equipment selection is then made on notions of equipment ability to excavate the selected SMU size. Again this approach is based on the premise that SMU will be excavated not deposit boundaries as defined by grade control and survey.

Strengths of the SMU approach

The strengths of utilising SMU calculations include;

- relatively fast calculation times, enabling a variety of SMU sizes to be tested,
- can be used in combination with other mining recovery and dilution allowances,
- the inclusion of diluent mineralisation grades from boundary cells. This is particularly important with deposits with gradation grade boundaries,
- the loss of ore at deposit boundaries, and
- enabling the economic evaluation of diluted cell grades through optimisation software. This is an important consideration for marginal grade ore blocks at depth.

Limitations of SMU approach

The SMU approach has the following limitations;

- mining equipment can mine shapes other than rectangular cuboids,
- mining dilution and recovery estimates are based on accurately mining the SMU cuboid not the interpreted deposit geometry,
- deposits with strong physical and visual geological boundaries are not recognised in the dilution estimate,
- proposed grade control systems, such as further drilling, mapping and ore spotting are not allowed for,
- geological model and survey mark-up accuracies are not considered,
- displacement of ore resulting from blasting heave and throw are not considered,
- Ore loss due to edge effects in blasted ore are not considered (unexcavated toe of ore block adjacent to waste blocks),
- Ore dilution due to edge effects in blasted ore (crest of waste block falls into ore block during excavation),
- Ore dispatch misdirection is not included,
- SMU orientation to the deposit boundaries and cell centroids have a significant influence on mining recovery and dilution,
- SMU cell orientation changes are time consuming and generally not undertaken.

By comparing resource model tonnes and grade to the results of an SMU regularised mining model a comparison in terms of increased tonnes and diluted grade can be made. The difference in tonnes and grade is not a quantified estimate on Mining Recovery and Mining Dilution unless there is a direct calculation of the SMU based on the mining equipment performance and the planned grade control procedures.

Frequently there is no justification for the SMU cell size. There seems to be leap of faith here that somehow by mining a deposit, irrespective of the grade control procedures that the resulting recovery and dilution will be similar to that indicated by the sawtooth effect of a right rectangular cuboid of unspecified centroid relative to the boundary of a deposit. In fact, if the deposit was actually a right rectangular cuboid it would not be possible to mine it without allowing for Recovery and Dilution by another method.

Recovery and Dilution Parameters

The following parameters should be considered when determining Mining Recovery and Mining Dilution;

- Deposit geometry

The dip, strike, width and length of the ore zones within the deposit are the most significant consideration for Mining Recovery and Mining Dilution.
In addition to the absolute values, the variability in geometry will have a significant influence on the efficiency of the ore mining. The survey of resource exploration and definition drill holes is important to locate the deposit with sufficient accuracy to maximise Mining Recovery and minimise Mining Dilution.

- Physical and chemical characteristics

Deposits can have what are termed hard or soft ore boundaries. "Hard" boundaries have a clear boundary between ore and waste while gradational boundaries where grades slowly reduce in values are termed "Soft" boundaries. Some deposits may have a physical boundary between ore and waste such as a foliation plan, a shear or a contact discontinuity that may enable the ore to be cleanly separated from the waste. It could also be a colour change or and hardness change. The physical differences may enable what is termed "visual control" of ore and waste excavation.
Nugget effects refer to how the grades are distributed in the deposit. If the mineralisation is very spotty in the deposit it is inherently difficult to estimate Mining Recovery and Mining Dilution from adjacent material, which may or may not be "nuggetty" in mineral content.

- Resource sampling estimation techniques

The planning of drilling and sampling programs and the associated confidence that can be applied to the resource estimate will ultimately determine the accuracy of the Mining Recovery and Mining Dilution estimates. The interval over which samples are collected or composited will limit the selective mining opportunities for the project. The assay techniques should be directly translatable to process facility performance. Assay confidence should be well demonstrated in terms of laboratory performances QA/QC of results. Modelling techniques should take into account the continuity and inherent variability of the deposit.

- Grade control procedures

Additional sampling post resource estimation is typically undertaken to increase the accuracy of mining activities to increase Mining Recovery and reduce Mining Dilution. The additional data improves the understanding of the location and grade of the deposit. The techniques adopted for data and sample collection are typically designed with the deposit characteristics and proposed mining method in mind.

As mining progresses, data from geological mapping and production records becomes available. Visual control procedures can be developed to facilitate ore spotting by operators and pit technicians.
Because each deposit and mining method is unique the procedures and systems tend to be developed specifically for each project. The grade control data is typically used to develop a Grade Control Model to facilitate estimates and reconciliation against actual production.

- Mining methodology

The selected mining method has a significant impact on the Mining Recovery and Mining Dilution. The selection is sometimes purely based on estimates of losses and dilution associated with the methodology. As advances in mining equipment and technology occur, then methodology selection and associated loss and dilution estimates must change.
Recent advances in blasting systems, GPS, and equipment automation offer step changes in mining methods.
Because the various blasting, excavation, haulage, or continuous mining, conveying or dredging pumping methods have complex interdependencies with deposit characteristics, product quality, capital expenditure, and operation costs, the mining method selection can be a difficult task. The selection process is best undertaken through the phased approach to feasibility studies. This means that Mining Recovery and Mining Dilution estimates should also be incorporated into the studies and advanced with the accuracy of the studies. This is particularly important where new technology is proposed.
The scale of mining equipment and associated mining intensity can influence the projects Mining Recovery and Mining Dilution. Mining Intensity relates to the amount of activity in any part of the open cut. It can also be expressed in terms of vertical rates of advance and the amount of mining equipment per unit of area in the open cut. Grade control systems occupy both area and time; thus if production targets are too high then congested work areas will reduce Mining Recovery and or increase Mining Dilution.
Some ore treatment facilities require consistent mineralisation grade, physical properties and/or mineralogy to operate efficiently. Where local ore variability exceeds the treatment plant design parameters, blending of ore from various parts of the deposit will be required. To facilitate blending, mining operations are brought forward in time to expose multiple ore sources. The advancement of mining to enable in pit blending from blasted stocks or ROM blended stockpiles brings forward mining costs and reduces the project NPV. In these circumstances mining recovery and dilution estimates are an important consideration in estimating the blended ore grades.

- Equipment Selection

Some of the important considerations for hard rock open cut operations include the relationship between ore deposit geometry, bench height, blasting characteristics and mining intensity. Ore and waste blasting characteristics will influence the decision to bulk blast ore and waste together or selectively.
The selected loading equipment capabilities must match the blasted rock pile profile and dig-ability. The equipment bucket size, and direction of mining relative to deposit geometry and blast displacement will influence the Mining Recovery and Dilution.

For deposits where ore hardness and geometry are suitable continuous mining may offer precision in excavation not achievable by blasting and excavation. If ore variability is low then conveying of materials can be considered, if variability is high truck haulage may offer less grade dilution between ore types. Where ore loss and dilution are of little consequence to the treatment costs then bulk handling systems such as dredging or bulldozers pushing to feeder breakers and conveying systems can be considered.

- Mining systems

Mining systems are required to manage the large amounts of data that is generated during the mining activities. Modern online analysers and computing systems now facilitate the measurement and processing of real time information. This will fundamentally change the grade control systems from a retrospective this is what we have achieved concept to this is what is currently happening. For operations that can afford the real time management systems Mining Recoveries and Mining Dilutions will be better managed such that immediate corrections can be made to ore blocks and truck dispatch.

Alternative approach to estimation of Mining Recovery and Dilution

Mining Recovery and Dilution estimates are improved with a staged study approach similarly to many other estimations for mineral projects. Because Mining Recovery and Dilution estimates are dependent on many factors the estimates will evolve and become more accurate as projects progress through Scoping, Prefeasibility and Feasibility Studies.
The determination of the mineral project capacity is a fundamental step in determining the project feasibility. Open cut optimisations are usually undertaken at the beginning of each new study phases. The optimisations determine the open cut size and mining sequence to maximise the project discounted cash flow. Mining recovery and dilution estimates are therefore important as they impact revenue, costs, Reserves, and the project NPV.
Discipline is required to keep track of the Recovery and Dilution assumptions and estimates as projects evolve to ensure the documentation supporting the estimates is well maintained.
SMU and regularisation techniques are likely to be poor Mining Recovery and Dilution estimation techniques as they do not take into account the planned grade control systems and procedures.

KBPL has developed an approach that utilises a spreadsheet model to calculate and document assumptions supporting mining dilution estimates.
The model also provides a checklist and has weighting guidelines with PERT estimates of mean values for the many interrelated variables.
These values can then be applied to the raw mineral resource estimates.

The model facilitates:

- rapid assessment of estimates during the study phases facilitating cost benefit analysis;
- can be used to justify expenditure to gather data to support proposed mining methods,
- can identify opportunities for improvement for existing operations,
- provides documentation for Ore Reserve estimates, and
- enables compound learning to improve estimates.
- Documentation of negatives and positive factors in the estimate.
- Provides both a qualitative and quantitative approach.

Example of Estimate

New Project	Date	Rev 1
Mineralisation	**Loss**	**Dilution**
Soft ore zone boundaries will result in contamination with highly mineralised material close to cut off grade. Visual control is considered possible and may be developed during operations.	1.75%	1.75%
Deposit Geometry Ore Zone width is suitable for medium excavators due to moderate boundary effects. Ore dip is moderate enabling blast hole boundary definition. Ore strike continuity is continuous enough for medium size equipment. Sample composite intervals are well suited for the selected mining boundary definitions.	1.50%	1.50%
Resource Estimate Sample composite intervals are well suited for the selected mining boundary definitions. Resource model parent cell size is suitable for Loss and Dilution estimates of medium size excavators. Orientation of cell axis to dip is semi aligned with the ore boundary resulting in minor loss and dilution. Orientation of cell axis to strike is closely aligned to the ore boundary resulting in minimal loss and dilution. Resource model sub cell size is fine along strike adding minimal loss and dilution at ore waste boundaries. Resource model sub cell size is moderate down dip adding minor loss and dilution at the boundary. Measured Resource Classification make up most of the resource estimate the spacial location is well defined.	2.44%	2.44%
Optimisation Regularisation Cell Size is moderate suitable for monthly plans and medium scale equipment.	0.50%	0.50%
Mining Direction The mining direction relative to dip and strike will be variable sometimes constrained by the size of the open cut and the bench development sequence.	0.50%	0.50%
Grade Control Ore blending at ROM stockpile may introduce minor contamination and losses. Grade control drilling and mapping will reduce requirement to mine to SMU and associated boundary effects.	-1.44%	-1.44%
Geomet Model Confidence in geomet data will depend on the representativeness of sampling ore and potential diluents, No additional dilution has been allowed for .	0.00%	0.00%
Mine To Mill Optimisation Mine to mill optimisation studies have not be undertaken, opportunities for improved project economics are not understood	0.00%	0.00%
Hydrology High ground water in wall rocks will increase the risk of dilution of broken ore stocks through waste rock contamination from slopes, no dilution allowed for.	0.33%	0.33%
Geotechnical Waste rocks are generally stable and will not increase the risk of dilution of broken ore stocks through waste rock contamination from slopes, no dilution has been allowed for.	0.00%	0.33%
Blasting The selected bench height is suitable for small excavators with control of rilling of material between blocks during excavation. Blasting displacement is likely to be minimal due to the oxidized ore and proposed paddock blasting practice. Blasting back break will not contribute to dilution due to favourable blast geometry.	4.33%	4.33%
Equipment The selected excavator bucket width is slightly smaller than the proposed grade control blocks. The truck size has been selected to match production rates allowing some selectivity. Mining equipment operation will be by experienced staff.	0.33%	0.33%
Systems Mining technology will be utilised that is suitable for a project of this scale. Mining software wire framing and DTM estimates typically have an error of 0.5 precent. Truck dispatch systems are required due to fleet numbers and scale of the operation, reducing ore loss through miss direction. Survey inaccuracies occur during mark-up of ore boundaries. Grade control systems will be developed reflection the scale and complexity of the operation.	1.08%	1.08%
Total Mining Loss and Dilution Estimate	**11.33%**	**11.67%**
Diluted Grade Mineralisation grade adjacent ore zones is approximately 25% of ore body average grade.		**2.92%**
Total Mining Recovery and Mining Dilution Estimate	**88.667%**	**11.67%**