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Ore Grade Reconciliation Techniques – A Review

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Abstract The essence of ore grade reconciliation is to identify, analyse and manage variance between planned and actual results in a way that highlights opportunities. A consistent record of poor reconciliation is an indication that this variance has not been adequately managed. This would inevitably result in significant economic impact on mining companies. Unfortunately, the issue of poor reconciliation has been an age-old one most mining companies have been battling with and resulting in failure of several mining companies to estimate ore grade accurately, despite good grade control sampling and geological control. This paper reviews various practical and theoretical approaches to ore grade reconciliation, and further reveals inefficiencies in the mining value chain that contribute to poor reconciliation. Key recommendations, pertinent to observations and findings of the study, are thus made towards improving ore grade reconciliation.

Keywords: *ore grade reconciliation, grade control, exploration, mine call factors, ore loss, dilution, sampling*

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1. Introduction

Parhizkar et al. [6] define ore grade reconciliation as comparing the values of grade estimation in exploration stage with actual grade obtained from blasthole data. Riske et al. [8], in their definition, also refer to reconciliation as the process of identifying, analysing and managing variance between planned and actual results in such a way that highlights opportunities. The opportunities commonly include: methods to create better estimates, improved designs, tighter and more accurate plans and schedules, improved mining techniques to minimise ore loss and dilution, and identifying ways to increase metal recoveries during the extraction processes. The ability to measure and analyse data in this way enables an operator to design and implement process improvements across the entire mining value chain.

Therefore, reconciliation has, over the years, served as a tool that tests for internal consistency in the quality of data, and it is able to reveal discrepancies between predictions and actual outcomes, which go a long way to help improve future predictions. Reconciliation studies may provide early warnings or signs for problems that can occur either in the predictions or subsequent production steps.

Unfortunately, poor reconciliation has been an age-old one that most mining companies have been battling with. Ironically, these companies have not been able to harness reconciliation as a discrepancy-revealing tool that subsequently improves future predictions of grade and tonnage. For instance, the works of Clow [2], Knoll [5], Rossi and Parker [11] and Thomas and Snowden [12] have established that several mines fail to estimate ore grade accurately despite good sampling regime and geological control.

Though challenges with reconciliation cannot be completely eliminated, they can be adequately mitigated.

It is, thus, the objective of this paper to review the various techniques adopted in reconciliation studies, establish the challenges faced by mining companies in respect of reconciliation, and to recommend pragmatic means by which these challenges can be better addressed.

2. Reconciliation Techniques

Literature reveals various reconciliation techniques adopted by mining companies. These have been described as Depletion by Mining; Reconciliation of Resources with Grade Control; Reconciliations between Ore Reserves, Grade Control and Production; and the use of Reconciliation Factors (mine call factors).

A mine with a consistent record of poor reconciliation may be battling with one or more of the following issues: Perceived Complexity of the Reconciliation Process; Shifting of Blame/Responsibilities; Poor Material Tracking; and Superfluous Parameter Alterations to meet expectations [1].

3. Classifications of Reconciliation

Ore grade reconciliation can be put into three broad categories: temporal, spatial and physical [8]. In Fig. 1, the mining value chain pyramid has reconciliation as the reality check between the various layers. The figure shows how these classifications of reconciliation relate to the various activities of the entire mining value chain. The pyramid is inverted because the quantum of information available to mining personnel grows as one progresses up the pyramid.

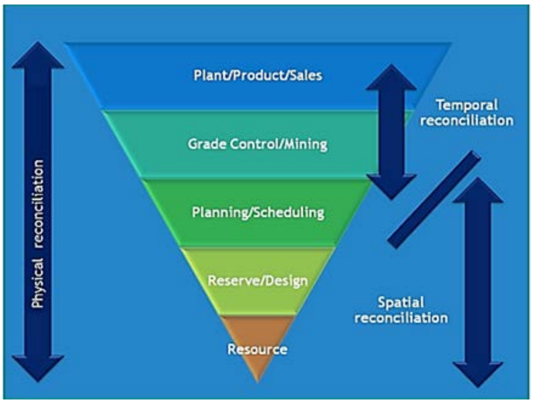

Figure 1. The Reconciliation Pyramid (After Riske et al. [8])

3.1. Temporal Reconciliation

Temporal reconciliation, the most common form of reconciliation, compares performance across the mining operation on time-based sequence. It covers periods such as shifts, days, weeks, months, years etc. Being time-based, it does not necessarily compare information from a spatial perspective, which may vary over short term, but relies on the fact that these geographical discrepancies smoothen out over longer periods of time, normally months or years [8]. Temporal reconciliation allows tracking of data over time, typically, monthly or yearly. It may also be applied on a spatial basis; for instance, from the perspective of measuring the performance of an individual underground stope or open pit bench over time.

3.2. Spatial Reconciliation

Riske et al. [8] define spatial reconciliation as a three dimensional form of reconciliation. This form of reconciliation measures the absolute performance between predictive models and the actual results determined by mapping and survey measurement. Mining activities could have significant impact on reconciliation results if spatial considerations are not taken into account. It is important in situations where material type boundaries are adjusted on the basis of visual ore control or where measurements such as hanging wall pickups are taken during mining. This spatially orientated information forms actual data that can be compared with original geological interpretations and models.

3.3. Physical Reconciliation

Physical reconciliation is concerned with attributes such as contained metal, various quality parameters and volumes. It is characteristic of mining companies to combine physical reconciliation with temporal data, the report of which is usually done over long time periods (quarterly or annually). However, it is also often useful to compare physical characteristics of a model such as total metal, planned dilution, and quality results between different versions of resource and reserve models [3].

4. Reconciliation as an Indicator of Discrepancies

Reconciliation studies have, over the years, been helpful in revealing discrepancies between ore resource and comparable grade control estimates and/or discrepancies between grade control estimates and mined production. Usually, these discrepancies may be the result of one or more underlying issues. Mining personnel across the entire value chain would then need to take pragmatic steps towards identifying the definite sources of such discrepancies. According to Gilfillan and Levy [4], such discrepancies could be early warnings of some or all of the following:

i. Inappropriate ore resource estimation methodology;
ii. Incorrect estimation of ore continuity causing inappropriate allowance for internal dilution, mining dilution and mining losses.
iii. Unrepresentative and/or biased exploration data;
iv. Ineffective grade control and mining practices that lose ore and/or increase dilution;
v. Inappropriate assumptions about the degree of selectivity during mining;
vi. Incorrect bulk densities applied to the mineralisation, the gangue material and/or the waste material that dilutes the ore;
vii. Mismatches existing between the techniques used for ore resource estimation, grade control and mining; and
viii. Inadequate documentation of stockpiles and other ore sources.

Outcomes from reconciliation studies may be put into two categories; misclassification of significant tonnages of ore grade material (common), and discovery of problems in post-mining processing and documentation (less common). A definite consequence of the former is the haulage of misclassified ore to waste dumps or waste to the mill.

5. Practical and Theoretical Approaches to Reconciliation

Years of practice have yielded various means of conducting ore grade reconciliation in a typical mine. The variety of techniques to reconciliation include [4,6,9,10]:

i. Depletion by mining;
ii. Reconciliation of resources with grade control;
iii. Reconciliations between ore reserves, grade control and production; and
iv. The use of reconciliation factors (mine call factors).

5.1. Depletion by Mining

The availability of grade control and production data from a definable part of the orebody makes it possible to extract the ore reserve estimated for that part of an orebody from the total mineral resource estimates. This subset from the total mineral resource estimates is termed Ore Reserve Depleted by Mining [4]. Having obtained this subset, the resource engineer is able to conduct direct comparison with grade control, mine output and processing results.

5.2. Reconciliation of Resources with Grade Control

This technique involves the use of grade control data in estimating the total in-situ mineralization above a particular cut-off grade. Comparison is thereafter made with prior estimated mineral resources from that same area. By so doing, the resource engineer is able to determine if the mineralisation is indeed present in the quantity and quality estimated at the mineral resource estimation stage.

According to Gilfillan and Levy [4], a significant advantage of reconciling grade control and mineral resource is the ability to produce a total mass balance comparison including ore, low-grade mineralisation and waste.

5.3. Reconciliations between Ore Reserves, Grade Control and Production

The adoption of this method requires that both grade control and ore reserves estimates be based on the same assumptions in respect of bulk densities of mineralisation, gangue and waste, mining block sizes, as well as appropriate assumptions about mining dilution and mining losses.

The technique aids in the identification of losses and discrepancies at each stage of the mining value chain; and the advantage this presents is that management is able to undertake optimized approach towards effective operations.

5.4. Calculation of Reconciliation Factors

5.4.1. Traditional Methods

The use of comparison factors, often called Mine Call Factors, for reconciliation is not new to the mining industry. These factors have been extensively applied in performing production reconciliations [9;10]. They are calculated with the aim of separately evaluating the model estimates to daily grade control estimates and to process head-grade estimates. The following information is required to successfully compute these factors [10]: tonnes, grades and metal content of the long-term (block) model, short-term model, grade control model, and also tonnes, grades and metal content as produced by the mine for the period.

The reconciliation technique may further consider stockpiles between the mine and the mill. Consideration may also be given to material found within the crushing and grinding streams prior to the head sampler.

The case for a monthly comparison period is presented by Rossi and Camacho [10]. They define the Mine Call Factors as follows:

i. F_1 factors - F_{1t}, F_{1l} and F_{1f}, defined for tonnes, grades and metal content respectively, are based on the corresponding tonnes, grades and metal of the long-term model versus the short-term model and are calculated generically as:

$$F_1 = \frac{\text{Short-term model}}{\text{Long-term model}} \tag{5.1}$$

ii. F_2 factors - F_{2t}, F_{2l}, and F_{2f}, defined for tonnes, grades and metal content respectively, are based on the corresponding tonnes, grades and metal content of the grade-control model versus the short-term model and are calculated generically as:

$$F_2 = \frac{\text{Grade-control model}}{\text{Short-term model}} \tag{5.2}$$

iii) F_3 factors - F_{3t}, F_{3l}, and F_{3f}, defined for tonnes, grades and metal content respectively, are based on the corresponding tonnes, grades and metal content of the monthly mine report versus the grade-control model. Sometimes, mine reports for tonnage and grades are simply taken from the grade control model and are considered as material sent to the mill. In other instances, they use the grade provided by the grade-control model while the reported tonnage is based on truck counts or volumetric measurements of the advances. If applicable, the F_3 factors are calculated generically as:

$$F_3 = \frac{\text{Mine reported}}{\text{Grade-control model}} \tag{5.3}$$

iv. F_4 factors - F_{4t}, F_{4l}, and F_{4f}, defined for tonnes, grades and metal content respectively, are based on the corresponding tonnes, grades and metal content of the received-at-mill material versus the mine reported. The F_4 factor provides a direct measure of ore loss and dilution in the haulage and stockpiling system. This factor may be calculated generically as:

$$F_4 = \frac{\text{Received at mill}}{\text{Mine reported}} \tag{5.4}$$

These four classes of factors serve as the basis for the direct determination of several performance measures. One of such measures quantifies the accuracy of the long-term model (LTM) in terms of tonnes and grades of ore delivered to the mill. That is, it measures how well the reserve block model predicts material delivered to the mill. This factor is calculated as:

$$F_{LTM} = F_1 * F_2 * F_3 * F_4 = \frac{\text{Received at mill}}{\text{Long-term model}} \tag{5.5}$$

In a similar fashion, another performance measurement, shown in eqn. 5.6, quantifies the benefits achieved by, for instance, in-fill drilling, with the assumption that this is the difference between a long-term model (LTM) and a short-term model (STM):

$$F_{STM} = F_2 * F_3 * F_4 = \frac{\text{Received at mill}}{\text{Short-term model}} \tag{5.6}$$

It is worth noting that appropriate time scales are considered when performing reconciliation via mine call factors. In this regard, resource engineers sometimes engage in an unacceptable practice by comparing the long-term model with material sent to the mill on a weekly or even monthly basis. The reason being that, the long-term model serves the purpose of supporting mine planning and scheduling for relatively longer time periods such as six months, one year or more. It therefore becomes inappropriate to conduct such a comparison at a smaller time unit. The long-term model is based on widely spaced data and hence not recommended for small-scale estimation.

On the other hand, the F_3 and F_4 factors, depending on whether stockpiles exists and how large they are, could be compared on a weekly or even daily basis since they measure the mine reported material versus the received at mill material.

5.4.2. Reconciliation Factors from Probabilistic Models

Reconciliation has, over the years, been extensively researched beyond the use of the traditional mine call factors. Researchers have sought to develop probabilistic models from which reconciliation factors may be computed for the reconciliation process.

One such model is the "Parhizkar Probabilistic Model" [6]. In their work, Parhizkar and other researchers investigated the factors related to estimated grade which affect the reconciliation process. These factors were identified to be the sources of uncertainty in the rest of mine life. In their research, the most important factors considered included: inherent variability, statistical uncertainty and systematic uncertainty. The inherent variability, represented by the nugget effect, is accounted for by the estimation method (e.g. kriging). The model, therefore, assigns a correction factor for each of the remaining uncertainties to the estimated grade in order to reconcile them with actual grade. This is expressed as:

$$G_a = C_r C_s G_e \tag{5.7}$$

where

Ga and Ge represent the actual and estimated grade respectively; and

Cr and Cs are the correction factors for the statistical (random) and systematic errors respectively.

Statistical (random uncertainty) results from limited number of samples while systematic uncertainty deals with the error resulting from differences between in-situ (real) and laboratory conditions due to scale effect and anisotropy [6].

After further modelling, eqn. 5.7 develops into eqn. 5.8, representing the overall uncertainty of actual grade in the reconciliation process. The researchers express this as:

$$CV_{G_a} \cong \sqrt{\frac{S_{G_e}^2}{\overline{G_e}^2} + \frac{CV_{G_e}^2}{n} + CV_{C_1}^2 + CV_{C_2}^2} \tag{5.8}$$

where

CV_{G_a} is the overall uncertainty of actual grade (Coefficient of variation of actual grade);

$\frac{S_{G_e}^2}{\overline{G_e}^2}$ represents the inherent variability with $S_{G_e}^2$ being the variance of estimated grade, and $\overline{G_e}$ being the mean estimated grade;

$\frac{CV_{G_e}^2}{n}$ represents the random or statistical uncertainty with CV_{G_e} being the coefficient of variation for estimated grade, and *n*, the sample size;

$CV_{C_1}^2$ and $CV_{C_2}^2$, together, represent the systematic uncertainty (with CV_{C_1} and CV_{C_2} referring to the coefficients of variation of the correction factors for scale effect and anisotropy respectively).

According to the researchers, the model suits all deposit types. Its validity was checked using real data from an iron open pit mine, and implementation was successful as it yielded improved reconciliation.

6. The Reconciliation Process – Pertinent Observations and Issues

The study identified a number of issues that depicted reality on the ground; they revealed practical challenges to good ore grade reconciliation in the mining industry. These are: perceived complexity, shifting of blame/shirking of responsibility, poor material tracking and superfluous parameter alterations.

6.1. Perceived Complexity

The reconciliation process is most often seen as a complex process [1,6]. Establishing correct values for each data item in the reconciliation process with outright certainty is of significant challenge to practitioners. Blucher [1] identifies some of the reasons for the perceived complexity of the reconciliation process:

i. The process requires too many variables to manage or characterise;
ii. Lack of on-site experience; and
iii. Lack of understanding of how a rigorous approach to reconciliation can benefit the whole operation.

6.2. Shifting of Blame/Shirking Responsibilities

Another observation has to do with the challenge of inflexible reconciliation systems and partisan/insular points of view, leading to shifting of blame or shirking of responsibilities. There are times the practitioners involved even fail to recognise and act on flaws in the overall system, owing to the aforementioned challenge. Usually, the mill is blamed for shortfalls instead of being recognised as the source of invaluable information needed for managing all aspects of the ore reserve, grade control and mining process. Unfortunately, practitioners usually fail to recognise the mill as the largest, continuous sampling system on the mine site capable of providing quality information for the reconciliation process.

6.3. Poor Material Tracking

The delivery of ore to the Run of Mine (ROM) from multiple sources and the feeding of material to a common ore pass from multiple stopes are issues of significant concern to the reconciliation process. These, inadvertently, could lead to difficulty in tracking material through the mining and milling processes. A consequence on the reconciliation process is the smoothening out of the differences that may exist between the various sources, and subsequently obscuring any issues that may exist.

6.4. Superfluous Parameter Alterations

Various mines consistently change bulk and loose densities as well as truck factors so as to balance their books. Thus, the underlying reasons for reconciliation inconsistencies are neglected.

7. The Way Forward

Issues with reconciliation cannot be completely eliminated. The fact that activities and processes across the entire value chain (for instance sampling and resource estimation) can never record accuracy of 100% attests to this [7]. This, notwithstanding, can be mitigated with pragmatic efforts. The way forward to ensuring effective and good reconciliation performance are presented in the following:

7.1. Identification of Causes in Discrepancies in Reconciliation Process

All four approaches to reconciliation, as outlined in Section 5, have been utilised over the years. However, extensive reconciliation studies have revealed that the use of mine call factors or correction factors could be deceptive [4,7]. The reason being that it could lead to the masking of the inefficiencies inherent in poor practices. Thus, it results in creating false sense of security to management. It does not encourage the identification and subsequent correction of the causes of reconciliation misbalances. A good reconciliation process is expected to identify discrepancies as they are, and proceed to identify and correct the underlying causes. It should be able to lead to the economic quantification of the significance of the identified misbalance/discrepancies.

7.2. Effective and Efficient Collaboration across the Entire Value Chain

Effective and efficient reconciliation requires the collaborative effort of both suppliers of input data and recipients of output product in recognising the entire process as a system that uses data collected from various sources over different time frames. The data, therefore, should be summarised into information that relates to the performance of the individual sources. With such collaboration, practitioners will be adequately informed of the inherent variation from each source, over time. This will further lead to the determination of the impact of these variations on performance, and subsequent decision making process balanced against fiscal, mining and milling requirements. This is essential in mitigating the perceived complexity associated with the reconciliation process. It will also help eliminate the unpleasant scenario where practitioners from the various departments of the mine tend to have insular points of view, leading to the shifting of blame/shirking of responsibilities. By this, practitioners become proactive instead of reactive.

7.3. Good Material Tracking

Good material tracking in a timely manner would help identify the extent of discrepancy or variation resulting from a given source. It is advised that mining companies, especially new and potential ones, should as much as practicable secure mill feed systems that incorporate stockpiling according to source. This, though may be a huge financial and economic burden on established mining companies, would readily ensure the timely management of issues as they arise.

7.4. Opting for an Integrated Approach to Sampling, Statistical Process Control, Resource Modeling, and Total Quality Management

It is very necessary that management adopts pragmatic efforts towards the in-depth understanding and implementation of Integrated Sampling, Statistical Process Control (SPC), Resource Modeling and Total Quality Management (TQM). The entire process should not be kept as separate programs handled by different departments who rarely communicate; they should rather be integrated into one common programme. The essence is to enable management come up with effective mine-specific strategy that is based on accurate sampling capable of providing reliable data, thorough statistical evaluations capable of identifying the causes of variability, and a Total Quality Management philosophy that provides a platform for proactive decision making [7].

This integrated programme would lead management to the realisation that the mining value chain, at any stage, is filled with variability. This then calls for commitment on the part of all stakeholders to strictly adhere to a plan to reduce the variability of any given process parameter by a constant improvement strategy, after appropriate variability analyses have been done. This can be achieved through the use of Geostatistics as a tool for analysing variability at the mine.

The adoption of such integrated programme would also lead to good sampling culture that provides reliable data for improved grade control and subsequent reconciliation. Sampling protocols ought to be optimised according to heterogeneity. There is also the need to quantify the accuracy and precision of sampling and subsampling protocols, and analytical measurements.

8. Conclusions

Ore grade reconciliation, when properly managed, would lead to significant process improvements across the entire mining value chain. It is not uncommon to find several mines struggle with the process of achieving good reconciliation results. Though challenges encountered cannot be completely eliminated, they can be adequately mitigated.

Key recommendations, pertinent to observations and findings of the study, are thus made towards improving ore grade reconciliation. These are: avoiding dependence on the use of reconciliation factors; ensuring effective and efficient collaboration across the entire value chain; ensuring good and timely material tracking; and opting for an integrated approach to sampling, statistical process control, resource modeling, and total quality management.

Statement of Competing Interest

The authors have no competing interest.

References

[1] Blucher, I. D. (2002). “Reconciliation – Towards an Ideal Process”, in Proceedings of *Value Tracking Symposium*, Brisbane, Queensland, Australia, pp. 187-189.

[2] Clow, G. (1991). "Why Gold Mines Fail", *Northern Miner Magazine*, Vol. 2, No. 4, pp. 31-34.

[3] Fouet, T., Riske, R., Morley, C., Cook, A., Centofanti, J. and Conti, D. (2009). "Standardising the Reconciliation Factors Required in Governance Reporting", Proceedings of *7th International Mining Geology Conference*, The Australasian Institute of Mining and Metallurgy, Melbourne, pp. 127-139.

[4] Gilfillan, J. and Levy, I. W. (2001). "Monitoring the Reserve", in *Mineral Resource and Ore Reserve Estimation – The AusIMM Guide to Good Practice*, Edwards, A. C. (ed.), The Australasian Institute of Mining and Metallurgy, Melbourne, pp. 537-544.

[5] Knoll, K. (1989). "And Now the Bad News", *Northern Miner Magazine*, Vol. 4, No. 6, pp. 48-52.

[6] Parhizkar A., Ataee, M., Moarefvand, P., Rasouli V. and Bangian, A.H. (2010). "A New Model to Improve Ore Grade Reconciliation between the Exploration Model and the Mine", Proceedings of *Mine Planning and Equipment Selection (MPES) Conference*, Fremantle, Western Australia, pp. 89-94.

[7] Pitard, F. F. (2001). "A Strategy to Minimise Ore Grade Reconciliation Problems between the Mine and the Mill", in *Mineral Resource and Ore Reserve Estimation – The AusIMM Guide to Good Practice*, Edwards, A. C. (ed.), The Australasian Institute of Mining and Metallurgy (The AusIMM), Melbourne, pp. 557-566.

[8] Riske, R., Mark, P.D. and Helm, S. (2010). *Mine Reconciliation – for better or worse!*, Snowden Mining, Canada, 8 pp.

[9] Rossi, M. E. (1999). "Improving the Estimates of the Recoverable Reserves", in *Mining Engineering*, Volume 51, Society for Mining, Metallurgy, and Exploration (SME), pp. 50-54.

[10] Rossi, M. E. and Camacho J. V. (2000). "Using Meaningful Reconciliation Information to Evaluate Predictive Models", *Society for Mining, Metallurgy, and Exploration (SME) Transactions*, Volume 308, pp. 78-82.

[11] Rossi, M.E. and Parker, H.M. (1993). "Estimating Recoverable Reserves, Is It Hopeless?" in *Geostatistics for the Next Century*, Dimitrakopoulos, R. (ed.), Kluwer Academic Publishers, Boston, MA, pp. 259-276.

[12] Thomas, M. and Snowden, V. (1990). "Improving Reconciliation and Grade Control by Statistical and Geostatistical Analysis: Strategies for Grade Control", *AIG Bulletin*, Volume 10, pp. 49-59.