# Standardising the Reconciliation Factors Required in Governance Reporting

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# Standardising the Reconciliation Factors Required in Governance Reporting

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## ABSTRACT

Why is it so difficult? Why are there differences throughout the resources industry in how reconciliation factors are reported and calculated? Why is there no standard formula to use? These are common questions asked when mining companies try to compare reconciliation results across operations or attempt to undertake internal or corporate governance reporting processes.

For many mining companies the calculation of reconciliation factors is often a very time and resource intensive part of mandatory reconciliation reporting. Some major mining companies, that move millions of tonnes of material per annum, dedicate full time resources to the calculation of reconciliation factors. The willingness of these companies to set aside resources demonstrates the value that operations place on good reconciliation reporting.

Reconciliation is about measuring the variance between two like measures at different points along the mining sequence. It can be undertaken between predictive models, forecast plans and actual measured performance. Calculations are used to derive a variance between two sections within the mining sequence, with the result being commonly known in the resources industry as a ‘factor’. Mining companies use the calculation of reconciliation factors as key performance indices (KPIs) to provide a ‘health check’ of their operation, with variances often pointing to issues either with the accuracy of the original estimate or the quality of the measurement being used in the comparison.

There are many reconciliation factors that can be calculated and reported. This paper will set out, clarify and provide a recommended standard means of calculating each specific factor that, where adopted by a company, will ensure compliance with the international reporting codes, such as JORC. Using case studies from Rio Tinto Group (Rio Tinto) and BHP Billiton Mitsubishi Alliance (‘BMA’), and the authors experience across a wide range of mine sites, the outline of a generic solution for tracking a parcel of material from the pit through to the port along with appropriate reconciliation factors is provided.

The intention of proposing standardised reconciliation factor terminology and methodology is to provide the foundations of a system to enable communication and comparison across different commodities, companies and mines sites.

## INTRODUCTION

In a mining industry context, reconciliation equates to the comparison of an estimate with a measurement and this comparison can result in the calculation of a variance, which is often called a ‘factor’. For example the ‘mine call factor’ is commonly defined as the variance between the estimation of what grade control predicted would be sent to the mill against what the mill measures as being received. Issues are highlighted where large variances occur, or where variance changes over time, depth or geology, whether it is related to the accuracy of the original estimate or the quality of the measurement being used in the comparison.

Reconciliation is important because mines are designed and planned based on estimated values. If predictions are difficult, then typically, reconciliation will be difficult. Mining and processing activities react daily to the results reported by various measuring apparatus such as plant auto samplers, weightometers and truck despatch systems. Clearly if any of these sources of data are inaccurate there will be significant consequences to optimal performance of the operation. Reconciliation of any data is a pointless activity unless best practice is used across the entire value chain including drilling, sampling, resource model and reserve model estimation through to final product sampling. Operators should know their deposit and ensure realistic expectations are set based on the deposit geology and processing modes.

To enable mining companies such as Rio Tinto and BMA to obtain the most value from their reconciliation reporting, both companies have found that each of their mine sites must use common factor nomenclature and calculations. Reconciliation factors could only be compared across their mine sites if they are comparing and reporting like measures. In this paper, the authors present case studies from both Rio Tinto and BMA’s experience in the standardisation of factors. Based on these case studies, and experiences conducting reconciliation studies at a wide range of mines, the authors propose a standard set of terminology that readers may find useful when dealing with reconciliation at their own mine sites or across their companies.

The standardised reconciliation factor proposed here can be used across companies and different commodities with the only requirement being for readers to determine which of the factors are relevant to their specific operations. It is intended that this paper may be used as a guideline to the definition and calculation of standard reconciliation factors within the resources industry worldwide.

## DEFINING RECONCILIATION

Mine reconciliation is the comparison of an estimate (a mineral resource model, a mineral or ore reserve model, grade control information, or a mine production plan or schedule) with a measurement (survey information, material movement records or the official production, usually from the processing or treatment plant) (after Morley and Moller, 2005; Schofield, 2001).

The basic aims of reconciliation are to (after Morley, 2003):

- measure performance of the operation against targets,
- confirm grade and tonnage estimation accuracy,
- ensure evaluation of mineral assets is accurate, and
- provide key performance indicators.

There are three main types of reconciliation; spatial, temporal and physical. Spatial reconciliation is the three dimensional or ‘X, Y and Z’ form of reconciliation and can be derived from comparison of successive predictive models or actual measurements based on a geographic location. An important aspect of

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any reconciliation process is to ensure that 'apples are compared with apples' – that is when comparing an estimate against a measurement it must be ensured that the material for which the estimate has been made, is the same as the material being measured. Mining activities have significant impact on reconciliation results if spatial considerations are not taken into account (ie over digging ore blocks, survey of the actual mining areas after mining). Spatial reconciliation measures the absolute performance between predictive models and the actual results discovered through mapping and survey measurement. It is important in situations such as 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 back to original geological interpretations and models.

Temporal (or 'time based') reconciliation is the most common form of reconciliation. Temporal reconciliation compares performance across the mining sequence on time based ranges (such as shifts, days, weeks, months, years, etc). It does not necessarily compare information from a spatial perspective, which may vary over the short-term, but relies on the fact that these geographical discrepancies 'smooth out' over longer periods of time (normally months or years – known as volume variance). Temporal reconciliation allows tracking of trends, typically useful on a monthly basis over an annual basis. Temporal reconciliation can also be applied on a spatial basis, for example such as measuring the performance of an individual underground stope, or open pit bench over time.

Physical reconciliation is focused on attributes such as contained metal, various quality parameters and volumes. Typically physical reconciliation is combined with temporal data and is generally reported over long time periods, again such as monthly results reported on an annual basis. However, it is also often useful to compare physical characteristics of a model such as total metal, designed dilution, and quality results between different versions of resource and reserve models.

Most reconciliation reports concentrate over long time periods (monthly, quarterly or annually) due to the difficulty in handling residence times of material in stockpiles and processing plants and the time-consuming nature of gathering the necessary data to analyse for reporting. Data that is generated regularly over long periods of time will naturally result in larger data sets that smooth out any short-term anomalies and so more accurately reflect trends (after Riske *et al*, 2007).

Of course there are many reconciliation relationships that can be used to calculate factors and reported key performance indicators ('KPIs'). This paper clarifies and provides a basic means of calculating a number of the specific reconciliation factors that the authors have found to be useful across most commodities and mining methodologies.

## Case study 1 – reconciliation factor standardisation at BMA

In 2004 BMA mine sites combined to produce a systematic methodology to track and reconcile coal recovery. The outcome of this review was the *'BTRAK Guide: The BMA way for tracking and reconciling coal recovery'* (BHP Billiton Mitsubishi Alliance, 2004). This document defined the reconciliation factors required by BMA to measure the effectiveness of the planning and accuracy of mining across all of their operations in Queensland, Australia.

Two groups of reconciliations were defined:

1. F factors – required for governance reporting purposes, and
2. R factors – involved block and strip reconciliation and used to guide future resource and reserve estimations and enable operational business improvement.

### *BMA F factors*

The F1 reconciliation factor is used by BMA to provide a comparison of coal reserves to the grade control (mining) model and was designed to assess the efficiency of the reserve estimation practices.

The BMA F2 factor provides a comparison between the grade control (mining) model and plant feed. This factor enables BMA to determine the suitability of assumptions and adjustment factors used to generate the grade control (mining) model.

Comparison of coal sales to marketable coal reserves is defined by BMA as the F3 factor. This factor enables the suitability of the assumptions used during modelling to estimate the marketable reserves.

### *BMA R factors*

There are four R factors which BMA uses for process improvement reconciliation:

1. R1 factor used to measure the efficiency of the mining process using a comparison between the grade control (mining) model and run-of-mine (ROM) production,
2. R2 factor used to determine the amount of material rejected at the breaker by comparing the tonnes and quality of the plant feed to ROM coal,
3. R3 factor provides a measure of efficiency of the coal washing process in terms of yield by comparing plant feed to plant product, and
4. R4 factor which provides a measure of the efficiency of the distribution system and the extent of any transport and/or stockpiling losses.

By standardising this terminology and the calculations and measuring points across all BMA operations it was possible to compare results between sites and leverage of best practices at one mine across other operations.

## Case study 2 – reconciliation factor standardisation at Rio Tinto

In 2006 (Cook, 2008) Rio Tinto began using a series of reconciliation factors (names 'F' factors), that enabled their mines to report like for like calculations for reconciliation and to comply with Rio Tinto's resources and reserves standards as well as JORC, see Figure 1.

During this same year, Rio Tinto Coal Australia ('RTCA') dedicated a team to review coal reconciliation and the currently used F factors. RTCA adopted those factors which fitted their model, adjusting those factors that did not fit, and creating a range of coal specific factors. The detailed technical manual produced following that review, provided the Rio Tinto group with a range of new factors and nomenclature which included factors in three main groups: geological (G), mining (M) and plant (P) factors.

Many Rio Tinto business units loosely adopted the Rio Tinto F factors, and similar to RTCA, fashioned them to fit their individual site and commodity needs. Whilst there was common intent, the variations between sites created issues for reporting and potentially masked compliance issues with the Rio Tinto reconciliation standards.

By 2008, business units throughout the Rio Tinto group were beginning to recognise the value delivered by the use of the factors and the common nomenclature. However, some of that value was being lost as small local variations resulted in the mines not being able to compare like measures. For example, 'F1' was not calculated or measured in the same way across each of the Rio Tinto sites. This created confusion and resulted in incorrect conclusions being drawn from reports that compared results across the different sites.

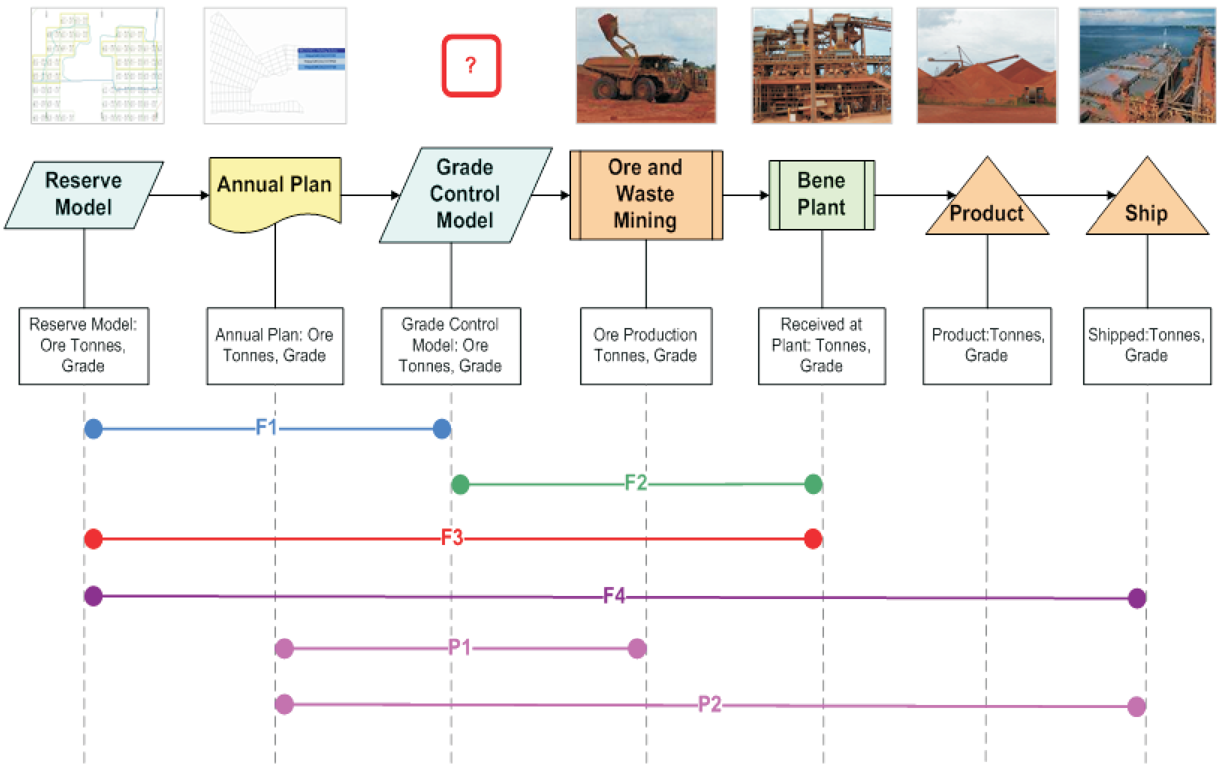


FIG 1 - F Factors used by Rio Tinto in 2006 (Cook, 2008).

This resulted in the need to review the reconciliation factors, and involved a range of stake holders including RTCA and Rio Tinto Iron Ore (RTIO) and Rio Tinto's Technologies and Innovation group ('T&I'). With a global reconciliation brief the T&I group had an interest in ensuring the factors were valid, could be utilised by mines exploiting different commodities and could achieve the aim of being able to deliver consistent reporting across all Rio Tinto business units.

A new series of reconciliation factors were thus created for uses across Rio Tinto. These factors, shown in Figure 2, have since been validated across a number of Rio Tinto business units and commodities and are now accepted as the basis for Rio Tinto governance reporting worldwide.

The factors effectively report a normalised variance between two steps in the mining sequence. Factors can be calculated in tonnes, volume, grade/quality and physical properties such as specific gravity ('SG') with comparisons made between models, plans and actual measurements including the movement of material between areas such as pit to plant to stockpiles to rail. Waste volume comparisons can also be calculated as a ratio between models predictions, plans and actual movement extending reconciliation into this important aspect of mining.

### *Rio Tinto 'R' factors (spatial reconciliation)*

Similar to the original Rio Tinto 'F1' factor of 2006, the 'R' factors describe the relationship between the resource model and/or the reserve model and or the grade control (mining) model.

### *Rio Tinto 'G' factors (temporal reconciliation) (spatial if ore is single sourced)*

The introduction of G1, G2 and G3 enabled Rio Tinto to reconcile from the resource model to in-pit and ROM stockpiles, feed to the plant and final product. Rio Tinto only reports these factors if a reserve model has not been produced and planning on an unmodified resource model has been undertaken.

G4, G5 and G6 are equivalent to G1, G2 and G3 but are for reconciling where a reserve model has been developed. Rio Tinto business units with both resource and reserve models (RTIO) are able to report all six G factors.

In the case of business units which do not use grade control models the G4, G5 and G6 factors are also equivalent to the following M1, M3 (HP F3) and M4 factors.

### *Rio Tinto 'M' factors (temporal reconciliation)*

The 'M' factors are focused on the relationships between the grade control model, mining and what is delivered to the processing plant. M1 and M2 track the material flow and allow traceability of mining and potential issues with digging accuracy. These factors combine to provide M3 which is designed to describe the relationship between the grade control (mining) model and what is delivered to the plant.

The introduction of M4 created a factor that measures all losses between the mining model and final product. Whilst this measure does not determine exactly where losses occur as they are additive across a number of mining stream processes it is a very useful factor to be utilised in planning.

Business units that do not have grade control models cannot report M1, M3 and M4. G4, G5 and G6 factors mentioned above are the equivalent ratios used in that case.

### *Rio Tinto 'P' factors (temporal reconciliation)*

The P1 factor was created to give a measurement of losses through a plant. Rio Tinto only created one processing plant focused reconciliation factor as every plant was different and site by site detailed calculations carried out as part of metallurgical balancing often already cover this area.

### *Rio Tinto 'T' factors (temporal reconciliation)*

The T factor is representative of the transport factors. Rio Tinto's T&I created the T factor to give a measurement of losses through transport from site to port.

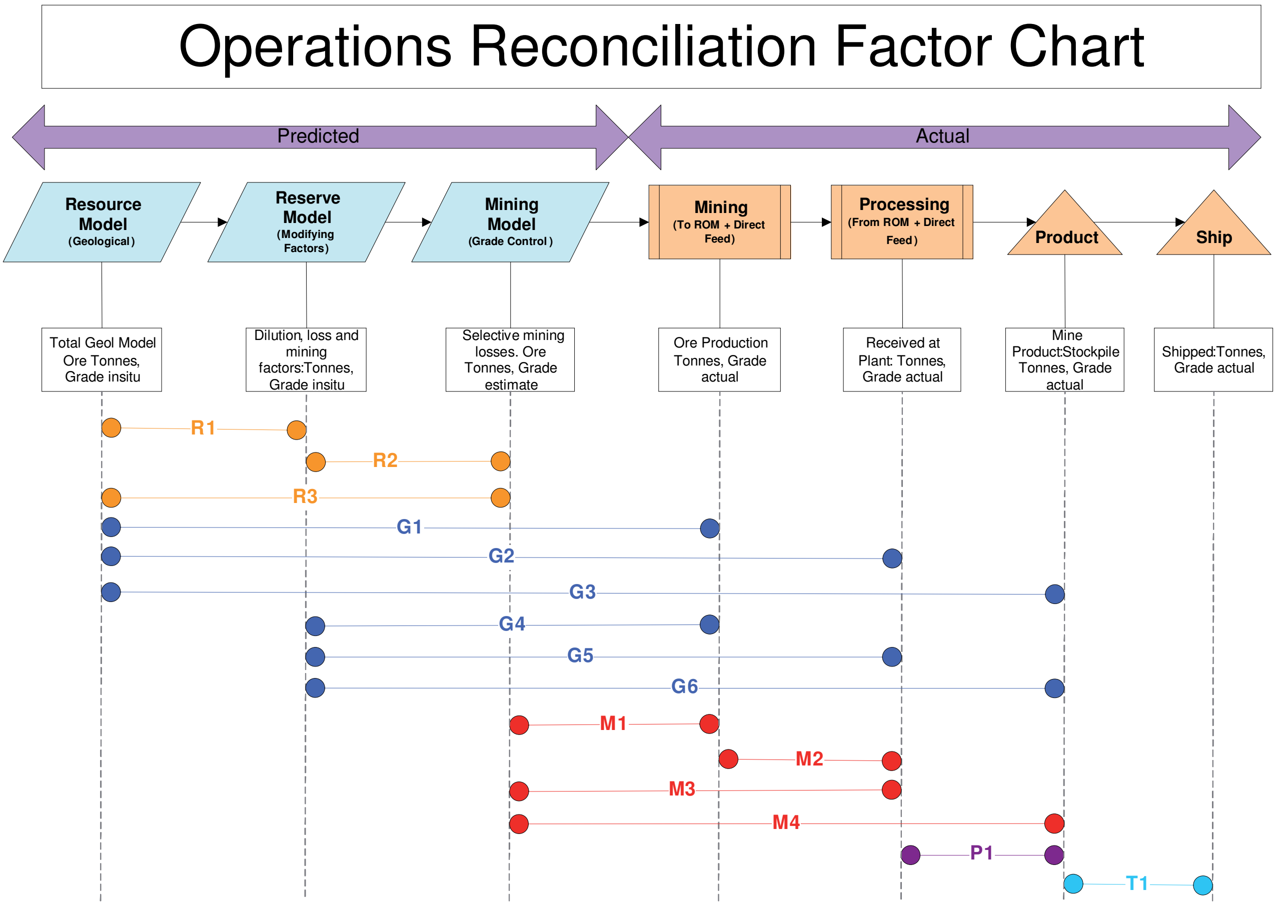


FIG 2 - Rio Tinto reconciliation factors 2009 (Cook, 2008).

### *Other reconciliation reporting best practices*

Within the mining industry there are two common schools of thought around the concept of volume/tonnes and quality/product reconciliation. Briefly these are that:

- All material moving through mining operations should be accounted for in such a manner that inputs and outputs balance. Therefore, where variances occur they must be adjusted or factored so that the inputs and outputs results match (mass balance).
- Inherent estimation error on the many different data types make it impossible for all inputs and outputs to balance. Therefore, a variance range is used to define acceptable results, and where variances fall outside of that range the cause is analysed with the objective of lowering the variance (Morley, 2008).

The second scenario outlined above is considered by the authors as industry best practice and is the process followed at both BMA and Rio Tinto. The iterative cycle of reporting variances, identifying where variances fall outside acceptable limits and taking corrective action associated with that estimation or measurement, results in a cycle of continuous improvement that greatly enhances the quality of the outcomes of any mining operation. The act of applying a factor, or back-calculating a measurement, provides a perfect result that hides any real issue the mine may be experiencing and so this practice should be discouraged. It is understood however, that many mines have accounting processes that require a metal balance for accounting or finance reporting on a monthly basis along the lines of the first scenario outlined above (Morley, 2008). This paper focuses on reconciliation and the standardisation of the nomenclature and calculation required under scenario two described above.

## STANDARDISATION OF RECONCILIATION NOMENCLATURE

The work completed by BMA and Rio Tinto, and experiences with numerous other mining companies has led the authors to the conclusion that the mining industry will benefit from the proposal of a standardised system for the naming and calculation of reconciliation factors across the industry. Such a system will provide a foundation for communication, comparison/ benchmarking and where adopted by a company will assist in complying with the international reporting codes, including JORC.

### Reconciliation factor nomenclature

As illustrated in the case studies above the trend in reconciliation factor nomenclature to date has been for alpha numeric codes that differ across the industry (see Table 1). Although factor names such as ‘R1’ are perfectly acceptable if everyone knows what ‘R1’ means, there is little consistency between mine sites and companies nomenclature. An ‘F2’ at BMA for example, makes the comparison between coal reserves and the grade control model. However, at Rio Tinto the comparison between coal reserves and the grade control model is called an ‘R2’. Outside of BMA and Rio Tinto there are a wide range of terms and alpha numeric codes that also mean the comparison between reserves and the grade control model.

The standardised reconciliation factor nomenclature presented in Table 2 provides an easily understood naming convention for reconciliation governance reporting. It is based on using nomenclature composed of descriptive words rather than codes or acronyms with the objective of enabling mining personnel to work out exactly what is being described. The naming convention

**TABLE 1**

*Example of current reconciliation factor nomenclature.*

| BMA reported comparison | BMA factor name† | Rio Tinto reported comparisons | Rio Tinto factor name‡ |
|---|---|---|---|
| | | Reserve model/resource model | R1 |
| | | Mining model (grade control)/resource model | R3 |
| | | Ore production/resource model | G1 |
| | | Plant feed/resource model | G2 |
| | | Plant product/resource model | G3 |
| Grade control model to coal reserves | F1 | Mining model (grade control)/reserve model | R2 |
| | | Ore production/reserve model | G4 |
| | | Plant feed/reserve model | G5 |
| | | Plant product/reserve model | G6 |
| Sales to marketable reserves | F3 | | |
| ROM Production to grade control model | R1 | Ore production/mining model (grade control) | M1 |
| Grade control model to plant feed | F2 | Plant feed/mining model (grade control) | M3 |
| | | Plant product/mining model (grade control) | M4 |
| Plant feed to ROM production | R2 | Plant feed/ore production | M2 |
| Plant product to plant feed | R3 | Plant product/plant feed | P1 |
| Coal sales to product coal | R4 | Shipping/plant product | T1 |

† BHP Billiton Mitsubishi Alliance, 2004.

‡ Cook, 2008.

**TABLE 2**

*Standardised reconciliation factor nomenclature.*

| Section within mining process | Standardised reconciliation factor name |
|---|---|
| Geological model reconciliation | Resource model to reserve model |
| | Resource model to grade control (mining) model |
| | Reserve model to grade control (mining) model |
| Geological model versus actuals reconciliation | Resource model to mining production |
| | Resource model to plant feed |
| | Resource model to plant production |
| | Reserve model to mining production |
| | Reserve model to plant feed |
| | Reserve model to plant production |
| | Reserve model to shipping |
| Mining reconciliation | Grade control (mining) model to mining production |
| | Grade control (mining) model to plant feed |
| | Grade control (mining) model to plant production |
| | Mining production to plant feed |
| | Mining production to shipping |
| Plant reconciliation | Plant feed to plant production |
| Rail and shipping reconciliation | Plant production to shipping |

proposed simply adopts the names of the primary data sources for the calculation as the factor name. Mining companies with existing acronyms or codes can easily continue their use internally and simply map their codes (ie the Rs, Fs etc) to this standardised nomenclature for external reporting, thereby eliminating confusion about what is actually being compared and reported.

Table 2 contains a range of reconciliation factors that the authors believe to have a wide relevance across the industry, however specific mining operations will only need to adopt factors for which they have the capability to record and measure the inputs. For example, coal mines that do not use a grade control (mining) model will not be able to report factors in which this model is required for the calculation.

Mining reconciliation encompasses a multi-disciplinary approach across geology, mining engineering, operations, and metallurgy to deliver benefits throughout the mining value chain. Figure 3 shows the range of reconciliation relationships that the authors recommend should be considered across most mining operation.

## Geological model reconciliation

### *Definition of the resource model*

The characteristics of a resource model are defined in sections 19 to 27 of the JORC Code and covers 'reporting of mineral resources'. The following quotes are specifically from Section 19 of the JORC Code (2004).

> *The location, quantity, grade, geological characteristics and continuity of a mineral resource are known, estimated or interpreted from specific geological evidence and knowledge.*
>
> *Any adjustment made to the data for the purpose of making the mineral resource estimate, for example by cutting or factoring grades, should be clearly stated and described.'*

A resource model can be created using geological interpretation, assay results and a valid grade cut to enable definition of minable mineralised continuity with reasonable chances of economic extraction (Cook, 2008).

### *Definition of the reserve model*

The characteristics of a reserve model are defined in sections 28 to 35 of the JORC Code and covers 'reporting of ore reserves'. The following quotes are specifically from Section 28 of the JORC Code (2004).

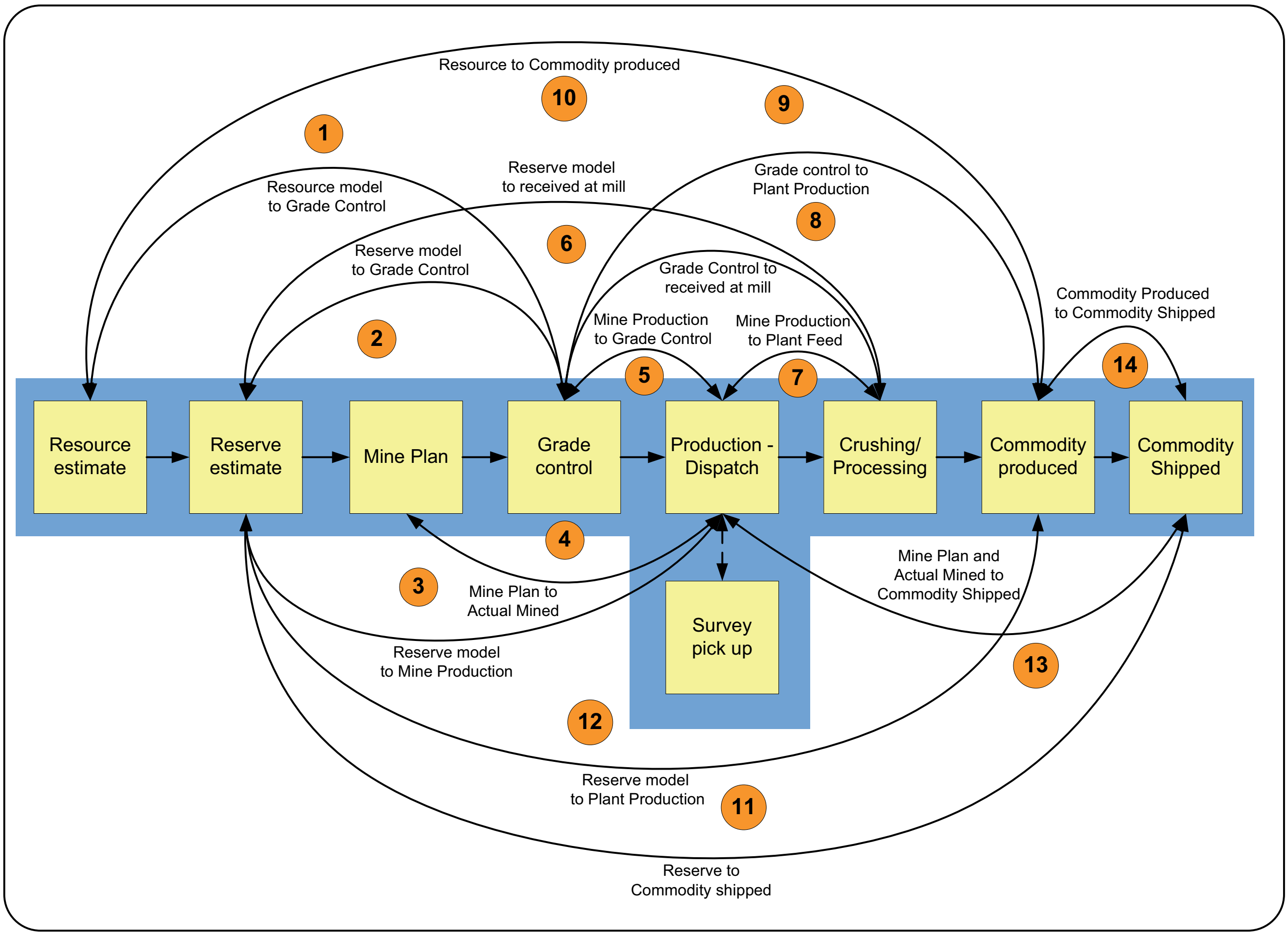


FIG 3 - Reconciliation across the mining value chain (Morley, 2008).

> *An 'ore reserve' ... includes diluting materials and allowances for losses, which may occur when the material is mined.*
>
> *Ore reserves are those portions of mineral resources which, after the application of all mining factors, result in an estimated tonnage and grade which, in the opinion of the competent person making the estimates, can be the basis of a viable project, after taking account of all the modifying factors.*

A reserve model is a resource model with a number of modifying factors applied to it which will deplete the resource and provide a more likely mineral recoverable estimate.

### *Definition of a grade control (mining) model*

Grade control models, also known as mining models, can be generally described as resource models where additional definition steps have been applied to locally define geology, tonnage and grade/quality of mineralisation for mining purposes. These models are often derived by the updating the geological interpretation through detailed mapping or surveying and also often updating quality information using additional closely spaced drill holes (blast hole samples, trenching or dedicated reverse circulation (RC) drilling in open pit operations or diamond drill hole, sludge hole or ring drill hole sampling in underground operations) logged and analysed prior to mining.

Typically, continuous flat lying or strata bound mineralisation (ie bauxite or coal) with low horizontal variability may not require additional definition beyond the reserve model. As such many operations mining these styles of deposits do not create additional models utilised for mining, and therefore use their reserve model as a mining model.

## Geological model reconciliation factors

Tables 3, 4 and 5 outline the calculation and data required to produce the geological model reconciliation factors.

## Geological model versus 'actuals' reconciliation factors

The resource factors primary role is to test for issues in underlying ore body knowledge in the resource model and/or issues in the conversion factors used to create the reserve or grade control models. Rio Tinto uses this test point to determine whether the planning process has a solid base.

These reconciliation factors also enable reconciliation from the resource model to in-pit and ROM stockpiles, feed to the plant and final product ('actuals'). The measurements assist with planning and scheduling by allowing for measured historical performance of an ore body to give some indication of whether the ore is likely to be in the ground or if you can expect variability when mining.

The resource versus 'actual' factors should only be reported if the operation does not produce a reserve model and undertakes planning on an unmodified resource model. They can, however, deliver value to resource geologists in understanding their interpretations and estimations into the resource model.

**TABLE 3**

*Resource model to reserve model.*

| Name | Resource model to reserve model |
|---|---|
| Calculation | • Tonnes = reserve model depletions/resource model depletions.<br>• Grade = reserve model depleted mass averaged grade/resource model depleted mass averaged grade. |
| Data required | • Resource model depletions.<br>• Reserve model depletions. |
| Comment | • Spatial and temporal reconciliation.<br>• Can be generated using survey depletion polygons inside the modelling package.<br>• Polygon to be provided through in pit surveys. The same polygon needs to be used to cut both models for the depletion period being reconciled.<br>• This measures the losses from the Resource model due to modifying conversion factors to the reserve model. |

**TABLE 4**

*Resource model to grade control (mining) model.*

| Name | Resource model to grade control (mining) model |
|---|---|
| Calculation | • Tonnes = grade control model depletions/resource model depletions.<br>• Grade = grade control model depleted mass averaged grade/resource model depleted mass averaged grade. |
| Data required | • Resource model depletions.<br>• Grade control model depletions. |
| Comment | • Spatial and temporal reconciliation.<br>• Can be generated using survey depletion polygons inside the modelling package.<br>• Polygon to be provided through in pit surveys. The same polygon needs to be used to cut both models for the depletion period being reconciled.<br>• If the grade control data is not available in the modelling package, it will be important to ensure the data used from both models represents the same depleted area.<br>• This will compare the grade control model tonnes and grade against the resource model tonnes and grade for a specified period and/or location. The factor will measure the effectiveness of the resource model estimate to the grade control (mining) model estimate. |

**TABLE 5**

*Reserve model to grade control (mining) model.*

| Name | Reserve model to grade control (mining) model |
|---|---|
| Calculation | • Tonnes = grade control model depletions/reserve model depletions.<br>• Grade = grade control model depleted mass averaged grade/reserve model depleted mass averaged grade. |
| Data required | • Reserve model depletions.<br>• Grade control model depletions. |
| Comment | • Spatial and temporal reconciliation.<br>• Can be generated using survey depletion polygons inside the modelling package.<br>• Polygon to be provided through in pit surveys. The same polygon needs to be used to cut both models for the depletion period being reconciled.<br>• If grade control data is not available in the modelling package, it will be important to ensure the data used from both models represents the same depleted area.<br>• This will compare the grade control model tonnes and grade against the reserve model tonnes and grade for a specified period and/or location. The factor will measure the effectiveness of the reserve model estimate to the grade control (mining) model estimate. |

Tables 6 to 12 outline the calculation and data required to produce the geological model versus the 'actual' factors; mining, plant feed, plant production and shipping.

Although similar to the resource model factors, these reserve model factors may assist in ascertaining the accuracy of mining assumptions used to create the reserve model.

**TABLE 6**

*Resource model to mining production.*

| Name | Resource model to mining production |
|---|---|
| Calculation | • Tonnes = mining production/resource model depletions.<br>• Grade = mining production grades (estimated or sampled/resource model depleted mass averaged grade. |
| Data required | • Mine production: dispatch data for material leaving the pit corrected using survey data.<br>• Resource model depletions. |
| Comment | • Temporal reconciliation.<br>• Resource can be generated using survey depletion polygons inside modeling package.<br>• Polygon to be provided through in pit surveys.<br>• This will measure the effectiveness of the resource model predicted to actual mined production.<br>• If grades have not been sampled, the estimated grades would come from the grade control model for the mined blocks. |

**TABLE 7**

*Resource model to plant feed.*

| Name | Resource model to plant feed |
|---|---|
| Calculation | • Tonnes = plant feed/resource model depletions.<br>• Grade = plant feed sampled grades/resource model depleted mass averaged grade. |
| Data required | • Supervisory Control and Data Acquisition (SCADA) systems for the plant feed data, and Laboratory Information Management System (LIMS) sampling results.<br>• Resource model depletions. |
| Comment | • Temporal reconciliation.<br>• Resource can be generated using survey depletion polygons inside modeling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the resource numbers to account for stockpile latency is recommended.<br>• This measures the precision and accuracy of the Resource model predicted to ore received at plant. |

**TABLE 8**

*Resource model to plant production.*

| Name | Resource model to plant production |
|---|---|
| Calculation | • Tonnes = plant production/resource model depletions.<br>• Grade = plant production sampled grades/resource model depleted mass averaged grade. |
| Data required | • SCADA systems for the plant production data and LIMS sampling results.<br>• Resource model depletions. |
| Comment | • Temporal reconciliation.<br>• Resource can be generated using survey depletion polygons inside modeling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the resource numbers to account for stockpile latency is recommended.<br>• Calibration of the resource numbers to represent expected recovery/yield is recommended.<br>• This will measure the effectiveness of the resource model predicted to the final mine product stockpile. |

**TABLE 9**

*Reserve model to mining production.*

| Name | Reserve model to mining production |
|---|---|
| Calculation | • Tonnes = mining production/reserve model depletions.<br>• Grade = mining production grades (estimated or sampled)/reserve model depleted mass averaged grade. |
| Data required | • Mine production: dispatch data for material leaving the pit corrected using survey data.<br>• Reserve model depletions. |
| Comment | • Temporal reconciliation.<br>• Reserve can be generated using survey depleted polygons inside modelling package.<br>• Polygon to be provided through in pit surveys. This will measure the effectiveness of the Reserve model predicted to actual mined production.<br>• If grades have not been sampled, the estimated grades would ocme from the grade control model for the mined blocks. |

**TABLE 10**

*Reserve model to plant feed.*

| Name | Reserve model to plant feed |
|---|---|
| Calculation | • Tonnes = plant feed/reserve model depletions.<br>• Grade = plant feed sampled grades/reserve model depleted mass averaged grade. |
| Data required | • SCADA systems for the plant feed data, and LIMS sampling results.<br>• Reserve model depletions. |
| Comment | • Temporal reconciliation.<br>• Reserve can be generated using survey depleted polygons inside modelling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the reserve numbers to account for stockpile latency is recommended.<br>• This measures the precision and accuracy of the reserve model predicted to ore received at plant. |

**TABLE 11**

*Reserve model to plant production.*

| Name | Reserve model to plant production |
|---|---|
| Calculation | • Tonnes = plant production/reserve model depletions.<br>• Grade = plant production sampled grades/reserve model depleted mass averaged grade. |
| Data required | • SCADA systems for the plant production data, and LIMS sampling results.<br>• Reserve model depletions. |
| Comment | • Temporal reconciliation.<br>• Reserve can be generated using survey depletion polygons inside modeling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the reserve numbers to account for stockpile latency is recommended.<br>• Calibration of the reserve numbers to represent expected recovery/yield is recommended.<br>• This will measure the effectiveness of the reserve model predicted to the final mine product stockpile. |

## Mining reconciliation

The important first step in reconciling mined material movements is to clearly define all the material flows throughout the mining operation. This will enable key data sources generated by those activities to be determined. It is recommended that as far as possible data is collected electronically on the basis of when it becomes available.

**TABLE 12**

*Reserve model to shipping.*

| Name | Reserve model to shipping |
|---|---|
| Calculation | • Tonnes = shipping/reserve model depletions.<br>• Grade = shipping sampled grades/reserve model depleted mass averaged grade. |
| Data required | • The validated tonnes reported as being loaded into ships.<br>• The grades as sampled for the material loaded onto the ships.<br>• Reserve model depletions. |
| Comment | • Temporal reconciliation.<br>• Reserve can be generated using survey depletion polygons inside modeling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the reserve numbers to account for stockpile latency is recommended.<br>• Calibration of the reserve numbers to represent expected recovery/yield is recommended.<br>• This factor provides a measure of the effectiveness of the reserve model predicted to the final sales at the port. |

Table 13 provides an example of data sources that are likely to be generated and used as the input into the mining reconciliation process.

Of course during the mining stage material movement data is one of the most significant sources of information feeding into any reconciliation system. If you don't know where it came from, how much was moved and where it went to any attempt at reconciliation is almost futile. Two important aspects that affect reconciliation results during this stage are the calculation of truck factors and stockpiling. Both of these subjects are dealt with in more detail below.

### *Truck factors*

The term 'truck factor' is commonly used to describe the ratio applied to a truck to convert one load (or one 'truck count') to tonnes.

While it is normal practice to have a different truck factor for different truck types in a fleet it is best practice to also have different truck factors for different material types where the specific gravity or moisture content of the material types varies significantly. This is defined in more detail below.

### *How and when to validate and update truck factors*

Industry standard practice is to maintain an annual record of truck factors updated on a monthly basis. This is normally achieved by the tabulation and plotting of truck count data against load cell, survey and weightometer results on a monthly basis. Variables that can affect truck factors are:

- operator loading habits,
- fragmentation size,
- specific gravity changes between material types, and
- seasons (wet/dry) in areas where precipitation (rain or snow) is significant can effect moisture content.

Changes in any of the above should result in a review of the truck factors being used. The objective is to look at longer term trends rather than month to month results. Truck factors can be used on a quarterly basis to provide an indication of loading efficiency of excavator operators, highlighting operators that consistently overload or under load their trucks. Wet and dry seasons should be considered if loading is resulting in significant volumes of water (or ice) being added to the trucks. On an annual basis truck factors are important as an input into the scheduling

**TABLE 13**

*Example of key data sources used in mining reconciliation process (Morley, 2008).*

| Data name | Source | Time frame | Key elements | Comment |
|---|---|---|---|---|
| Grade control | Grade control model | Daily or on an 'as designed' basis | Tonnes material type grades | Data is needed on an ore block by ore block basis |
| Short-term mine plan | Mine planning | Daily/weekly/monthly | Volume/tonnes material type | May also contain grade information |
| Budget/forecast | Mine planning | Monthly | Volume/tonnes material type grade | |
| Dispatch | Operations dispatch system | Shift summaries | Source destination material type truck counts tonnes | Tonnes are collected via truck load cells |
| Stockpile surveys | Survey | Weekly/monthly (EOM process) | Volume | Survey may calculate tonnes using volume × density<br>Surveys should include both ROM fingers and medium grade stockpiles<br>Survey could include waste stockpiles as well |
| ROM loader | Operations dispatch system | Shift summaries | Source tonnes bucket counts | |
| Crusher tonnes | Plant | Shift and monthly summaries | Tonnes | Weightometer measurement on crushed materia<br>Note: monthly metallurgical balance process may result in changes to previously reported results |
| Head grade | Mill | Shift and monthly summaries | Grades | Monthly metallurgical balance process may result in changes to previously reported results |

process for mine planning. As mining progresses into new and deeper areas it is not valid to assume that truck factors will remain consistent.

Industry best practice is to annually or bi-annually conduct a truck factor calibration exercise which consists of sending empty and loaded trucks across a weighbridge. Where a representative sample of data is obtained, this will quantify both the truck factor and the quality of the truck load cell calibration

## Stockpiling

Stockpiling activities introduce a delay in the timing of some material reaching the mill. Where the residence time of material on a stockpile is greater than one or two days this delay must be accounted for, to ensure accuracy of the reconciliation results.

In the past, when the industry standard practice was to reconcile using spreadsheets, a simple tonnes weighted arithmetic averaging technique was used. However, best practice is now provided by a number of software systems that can provide more sophisticated stockpile modelling results such as first-on-first-off, last-on-first-off and three dimensional modelling.

## Stockpile adjustments

Stockpile adjustments are required when stockpiles have long life spans. Inherent estimation errors and rounding during arithmetic averaging can result in stockpile balances getting out of synchronisation with reality. It is therefore considered ordinary practice to survey stockpiles on a monthly basis and to use these survey results to adjust, or calibrate, the stockpile tonnages.

Other events that would trigger a stockpile adjustment would include:

- calculations reports a 'negative' tonnage result;
- stockpile is visibly empty, but calculations still shows inventory;
- adhoc stockpile surveys; and
- stockpile sampling to delineate grade.

General practice is to adjust stockpile tonnages where necessary on a monthly basis based on survey measured volumes, but to accept the average stockpile grades. On long-term stockpiles this can result in compounding errors in the tonnes weighted average grade results. Where very large stockpiles are built and reclaimed simultaneously this can be a significant problem, as the calculations may report unrealistically increased average grades and thus an inventory of metal or product that do not exist. Best practice is to keep stockpiles small and turn them over regularly so as to avoid these cumulative error issues.

As discussed above, a common source of error in a data used in reconciliation is incorrect truck factors and handling of stockpiles. Other common sources of error in the data sources used for the reconciliation process are defined in Table 14.

Errors may also occur where mining differs from plan. It is therefore important that a mining engineer or geologist with knowledge of what is occurring in the pit (or underground) on a day to day basis review the monthly reconciliation and mass balance data to ensure the figures reflect what has occurred during mining.

For example, if the survey calculated tonnes for a ROM stockpile are greater than the sum of the ore block tonnes survey estimated were mined and sent to that stockpile, there can be a number of explanations for the error including:

- an error in survey calculations,
- material from other ore blocks has been mined and sent to the stockpile (such as digging into the floor or surrounding ore blocks), and
- waste material has been sent to the stockpile (dilution).

Based on the knowledge of what has occurred in the operation the engineer or geologist would choose one of the following solutions to correspond with each of the explanations above:

- contact survey to correct the calculation,
- assign the additional material a grade control grade based on the source of the material and make a note for future reconciliation that material from that source has already been mined, and
- assign the additional material an appropriate waste grade.

Actions such as those described above will assist in keeping the reconciliation and mass balance results aligned with reality and metal variances in the stockpile inventory low.

As described previously if the ROM stockpiles are regularly turned over, mined out and 'zeroed' this will greatly reduce the occurrence of rounding and cumulative errors that are inherent in the addition and subtraction of data with the error ranges shown in Table 14.

### *Mining reconciliation – predicted versus actual*

An important aspect of any reconciliation process is to ensure that 'apples are compared with apples', that is, when comparing an estimate against a measurement it must be ensured that the material for which the estimate has been made is the same as the material being measured. Activities such as visual grade control and stockpiling have significant impact on reconciliation results if they are not taken into consideration.

Specifically, it is important to reconcile ore blocks based on how they are actually mined, and not as they are planned or laid out, since these two situations may differ for many reasons (for instance if there is significant visual control on the mining activities, as shown Figure 4).

Based on the example shown in Figure 4, analysis of just the grade control estimate for tonnes and the dispatch measurements, without an understanding of what was actually mined could result in the conclusion that 1000 t of material type B was sent to the incorrect destination. However, with the knowledge of what actually occurred during mining it is clear that the material was in fact sent to the correct destination, however the original grade control estimate was incorrect. Thus, the variance should be fed back to the grade control modellers to ensure reassessment of their material type boundary assumptions.

## Mining reconciliation factors

Tables 15 to 19 outline the calculation and data required to produce the mining reconciliation factors.

In-pit or underground material movements commence with a grade control (mining) model definition of each source ore block.

**TABLE 14**

*Common sources of error (Morley, 2008).*

| Source of error | Normal range | Common range | Comments | Strategies to reduce errors |
|---|---|---|---|---|
| Grade control model estimation methodology accuracy | ±10% | ±-50%‡ | Can vary significantly depending on the understanding of geology and estimation methodology chosen | Ongoing reconciliation and review of estimation methodologies |
| Dispatch errors – incorrect source and destination | <5 incorrectly coded results per week‡ | One to ten errors per day‡ | Electronic despatch systems greatly enhance accuracy – but only with constant monitoring and reconciliation | Shift by shift review by operations and sign off<br>Errors corrected by dispatchers in the dispatch system |
| Truck factors | ±15%‡ | Between 15 and 30%‡ | Often empirical numbers that have not been validated for a long period of time | Monthly compilation of dispatch results against weightometer or survey results |
| Truck load cells | ±5%§ | ±20%§ | When truck load cells fail it is not uncommon for that truck to be kept in production – resulting in truck factors being used for tonnage estimates | Regular maintenance and calibration schedules |
| Specific gravity estimations (including *in situ* density estimates) | ±5% | ±10% | SG is often an empirical number used by mining, geology, survey and dispatch to convert volumes to tonnes | Routine charting of survey versus dispatch versus weightometer data<br>Annual SG laboratory testing |
| Swell factors (stockpiles) | ±5%† | ±10%‡ | Includes factors used to convert insitu density to a 'stockpiled' density. On large stockpiles this can also include some allowance for compaction of material within the stockpile | Use of stockpile density measurement devices for example as described by Treasure (2006) |
| Loader bucket factors | ±15%‡ | Between 15 and 30%‡ | Often empirical numbers that have not been validated for a long period of time | Monthly compilation of dispatch results against weightometer results |
| Weightometer measurements | < ±5% | ±20%§ | Incorrectly positioned, poorly maintained and infrequently calibrated weightometers will give spurious tonnage measurements | Regular maintenance and calibration schedules will result in weightometers delivering results within their design error tolerances |
| Head grade sampling errors | ±10%‡ | ±20% up to 200%‡ | Auto-samplers are notoriously difficult to design install and maintain. Plants with high volume of throughput make it almost impossible to maintain a sampling regime that is statistically appropriate | Appropriate installation and regular maintenance of an auto-sampler<br>Sampling protocols need to be adhered to<br>Reconciliation to metal produced rather than head grade |
| Survey volume errors | ±10%‡ | ±10%‡ | Recent trends to use GPS for survey pickup can result in lower precision of the surface volume calculation | Use of surface pickup by theotolite<br>Routine aerial flyovers to provide calibration for survey surface pick ups |

Note: 'Normal range' presents the range in which acceptable errors occur, ie the normal limit of accuracy expected for the estimate. 'Common range' presents error ranges that are commonly found with estimates of these type and so this column gives an indication of the scale of errors that may (and do) occur on mines sites.

† Treasure, 2006.

‡ Empirical industry experience.

§ Pan, 2003.

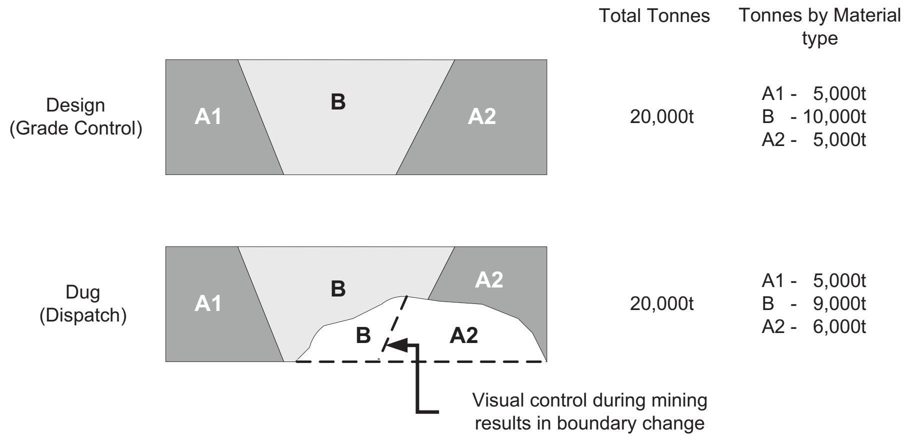


FIG 4 - Importance or capturing material type as it is actually mined (Morley, 2003).

**TABLE 15**

*Grade control (mining) model to mining production.*

| Name | Grade control (mining) model to mining production |
|---|---|
| Calculation | • Tonnes = mining production/grade control (mining) model depletions.<br>• Grade = mining production grades (estimated or sampled)/grade control (mining) model depleted mass averaged grade. |
| Data required | • Mine production: dispatch data for material leaving the pit corrected using survey data. Grade control (mining) model depletions. |
| Comment | • Temporal reconciliation.<br>• Grade control (mining) can be generated using survey depletion polygons inside modeling package.<br>• Polygon to be provided through in pit surveys.<br>• This reconciliation factor measures the effectiveness of the grade control model to actual mining to stockpiles plus direct feed to plant.<br>• If grades have not been sampled, the estimated grades would come from the grade control model for the mined blocks. |

**TABLE 16**

*Grade control (mining) model to plant feed.*

| Name | Grade control (mining) model to plant feed |
|---|---|
| Calculation | • Tonnes = plant feed/grade control (mining) model depletions.<br>• Grade = plant feed sampled grades/grade control (mining) model depleted mass averaged grade. |
| Data required | • SCADA systems for the plant feed data, and LIMS sampling results. Grade control (mining) model depletions. |
| Comment | • Temporal reconciliation.<br>• Grade control (mining) can be generated using survey depletion polygons inside modelling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the grade control (mining) numbers to account for stockpile latency is recommended.<br>• This factor provides a measure of the effectiveness of the grade control model to what is received at the plant. The issues and confusion that this factor has caused in the past, was due to the fact that a large proportion of mines run in-pit stockpiles and ROM stockpiles which often make this factor difficult to measure and calculate. By breaking this factor down to the grade control (mining) model to mining production and the mining production to plant feed reconciliation factors the process flow can be tracked and may be used to highlight such issues as digging inaccuracy. |

**TABLE 17**

*Grade control (mining) model to plant production.*

| Name | Grade control (mining) model to plant production |
|---|---|
| Calculation | • Tonnes = plant production/grade control (mining) model depletions.<br>• Grade = plant production sampled grades/grade control (mining) model depleted mass averaged grade. |
| Data required | • SCADA systems for the plant production data and LIMS sampling results.<br>• Grade control (mining) model depletions. |
| Comment | • Temporal reconciliation.<br>• Grade control (mining) can be generated using survey depleted polygons inside the modelling package.<br>• Polygon to be provided through in pit surveys.<br>• Some calibration of the grade control (mining) numbers to account for stockpile latency is recommended.<br>• Calibration of the grade control (mining) numbers to represent expected recovery/yield is recommended.<br>• This factor measures all losses between the grade control model to the final mine product stockpile. Although sometimes difficult to determine exactly where in the mining stream the losses have occurred, the factor can be useful for planning purposes.<br>• Mining operations that do not have a grade control (mining) model, the equivalent reserve model reconciliation factor can be used. |

**TABLE 18**

*Mining production to plant feed.*

| Name | Mining production to plant feed |
|---|---|
| Calculation | • Tonnes = plant feed/mining production.<br>• Grade = plant feed sampled grades/mining production grades (estimated or sampled). |
| Data required | • SCADA systems for the plant production data, and LIMS sampling results.<br>• Mine production: dispatch data for material leaving the pit corrected using survey data. |
| Comment | • Temporal reconciliation.<br>• This factor will highlight issues with truck factors or weightometer calibrations.<br>• This factor measures the effectiveness of actual mining from ROM stockpiles plus direct feed from pit, to material received at the plant.<br>• Stockpiling affects reconciliation due to the impact on the material that ultimately reaches the mill. Reclaimed material must be included with direct tip material when reconciling material delivered to the mill versus what the mill received. |

**TABLE 19**

*Mining production to shipping.*

| Name | Mining production to shipping |
|---|---|
| Calculation | • Tonnes = Shipping/mining production.<br>• Grade = Shipping sampled grades/mining production grades (estimated or sampled). |
| Data required | • The validated tonnes reported as being loaded into ships.<br>• The grades as sampled for the material loaded onto the ships.<br>• Mine production: dispatch data for material leaving the pit corrected using survey data. |
| Comment | • Temporal reconciliation.<br>• This factor measures the effectiveness of actual mining from ROM stockpiles plus direct feed from pit, to material received at train load out or onto the ship. |

The material type predicted by the grade control (mining) model, is generally indicative of the destination of the material once it is dug. It is therefore important to ensure that the material types predicted by the grade control (mining) model are reconciled against what is actually mined.

Once mining commences, dispatch information provides details on where the material goes to and the associated volume (truck counts) or tonnage (truck load cells). Regular maintenance of the truck load cells and an understanding of when the data is collected, for example on loading or when the truck changes to second gear, is essential to ensuring the quality of this data.

## Plant reconciliation factors

Mass balancing within the plant is the domain of metallurgists and beyond the scope of this paper. From a mine reconciliation perspective it is important that material sent to the plant balances with that produced by the plant. Obviously across different commodities and processing methodologies the details vary but Figure 5 provides a general schematic view that represents the important aspects of most plants when it comes to reconciliation.

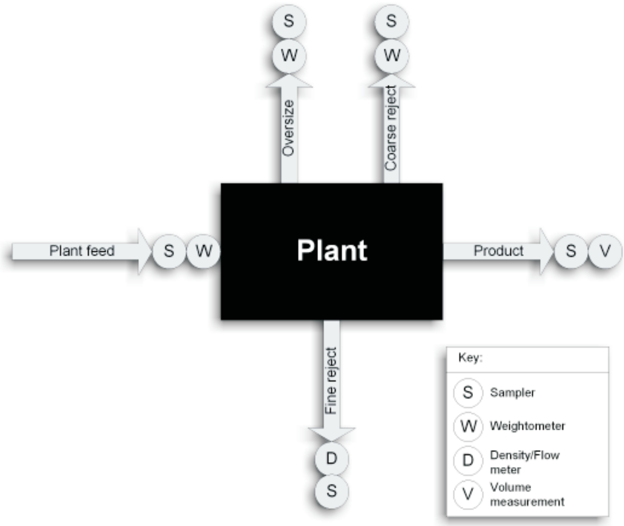


FIG 5 - Schematic view of a typical plant for reconciliation purposes.

From a reconciliation perspective it is important that the input (ie plant feed) equals the sum of the outputs (ie oversize, course and fine reject and product). Simplistically this is the mass balance around the plant. Unfortunately in the real word not every plant will have volume or mass measuring and sampling equipment on all the output streams – this obviously makes reconciliation difficult as one or more stream/s will typically be back-calculated. Table 20 outlines the calculations and data sources required to produce the plant reconciliation factors.

**TABLE 20**

*Plant feed to plant production.*

| Name | Plant feed to plant production |
|---|---|
| Calculation | • Tonnes = plant production/plant feed.<br>• Grade = plant production sampled grades/plant feed grades (estimated or sampled). |
| Data required | • SCADA systems for the plant feed and production data, and LIMS sampling results. |
| Comment | • Temporal reconciliation.<br>• This factor measures the losses through the plant such as plant reject.<br>• This factor will assist in investigating the yield performance of the plant. |

## Rail and ship reconciliation factors

An important area to consider is the effect that railing, stockpiling at port, and shipping has on the final product delivered to customers. Sites need to be aware if the rail and shipping process is changing the quantity and quality of the material they have produced. Variances between these numbers can be a result of an over-representation of product, losses incurred due to railing or port stockpiling process, or misallocation of material at the port. An understanding of these variances is important for determining the causes behind variances in other factors such as the reserve model to shipping reconciliation. Table 21 outlines the calculations and data required to produce the rail and ship reconciliation factors.

**TABLE 21**

*Plant production to shipping.*

| Name | Plant production to shipping |
|---|---|
| Calculation | • Tonnes = Shipping/plant production.<br>• Grade = Shipping sampled grades/sampled production grades. |
| Data required | • The validated tonnes reported as being loaded into ships. The grades as sampled for the material loaded onto the ships. SCADA systems for the plant feed and production data, and LIMS sampling results. |
| Comment | • Temporal reconciliation.<br>• This factor measures the losses through transport from site to port.<br>• Often a factor overlooked, this factor will help identify if there are losses experienced between the site and the customer. |

# WORKING WITH RECONCILIATION FACTORS

So now that the reconciliation process has been completed to best practice standards, and reported using the standard reconciliation factor nomenclature, the next common question asked is ‘When do you react to deviations away from one?’

Unfortunately this is something that cannot be generalised. For example, do you react when a factor deviates by ten per cent, two standard deviations, or another statistically valid amount? Equally valid would be to react when a trend of three or more similar deviations are recorded. Each mine will have its own noise levels to filter out, however patterns will appear over time and individual mine sites will need to work on the triggers for action depending on local variables.

It is important that when there is a deviation the cause behind it is understood. If the underlying cause is known and understood then decisions can be made as to what appropriate action may be taken. The factors merely point out a difference, they do not resolve the issues, and it takes human intervention to do this. If sites are unable to or unwilling to interrogate the variance reported by the factors they are wasting their time reporting them. This is not only about compliance to governance reporting, this is about utilising a tool to enable systems or process improvement which will improve efficiency at a site and turn invisible dollar losses into gains.

## FINAL THOUGHT

The author's intention with publishing this paper has been to provide the industry with a recommended set of terminology for the description of a wide range of mining reconciliation relationships. It is beyond the scope of this paper to define all relationships or to explain what variances in each of these 'factors' reflect - perhaps these topics can be addressed in future publications. With the definitions provided above it is both expected and hoped that there will be some discussion across the industry over the terminology suggested. Any discussion on reconciliation and an increase in its understanding can only help operations improve their performance through increased efficiency and optimisation of modelling, extraction and processing activities.

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