Mine value chain reconciliation – demonstrating value through best practice

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Craig Morley
Anglo American

Mine value chain reconciliation – demonstrating value through best practice

C Morley[1] and H Arvidson[2]

ABSTRACT

Reconciliation has become very topical over the last ten years but how do we distinguish what is good practice, and even more importantly, show how it adds value? Reconciliation at Anglo American has received support from the very top of the company and this has enabled success in the design and implementation of a range of processes, reporting activities and actions. Focus has been on full Mine Value Chain Reconciliation (MVCR) from Resource to Product and on proactive cross-functional engagement. A standardised set of reconciliation definitions and relationships are used at all mines across the company to diagnose planning and performance issues. Results are formally presented in an efficient dashboard format, accompanied by a concise narrative to communicate what has been learned and what is being done to correct, improve or change practices. Importantly, effort has also been made to sustain MVCR by embedding good practice and quantifying the benefit of reconciliation explicitly via linking results to value.

This paper sets out the lessons learned from the past two-years' journey, highlighting areas where good practice has been defined and achieved. A ranking for quantifying reconciliation confidence over time is presented as a means of putting results into context and continuously improving the reconciliation process. Finally, a solution to define the value that can be derived from reconciliation is described, detailing how cross-functional personnel meet monthly to review results and implement actions that are tracked in terms of value creation.

INTRODUCTION

A mining company's proposition to investors is to create value by profitably mining, processing and ultimately selling mineral products to customers. To 'deliver what we say we will' there must be a process by which the performance of our estimates, plans and operations can be assessed, corrected and continuously improved. This process is called Mine Value Chain Reconciliation (MVCR) (Fouet *et al*, 2009; Macfarlane, 2013; Hargraves and Morley, 2014).

Mining is a business that requires the accurate prediction and measurement of quantities and qualities: in the ground, as mined, transported, processed and recovered for various time (temporal) intervals (Morley, 2003; Parker, 2011). At Anglo American a strategic shift has been made from measuring tonnes and product to measuring the planning and execution of tasks, the successful implementation of those tasks and reconciling estimates, plans and measurements against each other. This measurement is via MVCR, and is undertaken by:

- geographic area (spatial reconciliation by bench, stope or ore zone etc)
- time period (temporal reconciliation by shift, day, month, quarter, year)
- quantity and quality (physical characteristic reconciliation such as tonnes, grade, product and geometallurgical characteristics etc)
- process (short-term plan to long-term model, mill to ore control etc).

MVCR is a fundamentally scientific approach where the motivation is to continuously improve the quality of data and model-based predictions (Vann and Stewart, 2011) upon which our business planning is based. The MVCR process thereby aims to optimise extraction and processing of Mineral Resources and – importantly – demonstrate to shareholders that we reliably do what we say we will do.

MOTIVATION

The MVCR relationships which are defined as the minimum requirement across Anglo American have been selected to give a continuous view across the mine value chain and target relationships which are indicators of issues or good practice. The relationships selected do not represent all reconciliations that are possible. It is expected that based on commodity, mining style and specific mine requirements other reconciliation relationships will also be defined, measured and analysed by operations. The motivation for adopting a

1. FAusIMM, Head Mining Geoscience and Reconciliation, Anglo American, London SW1Y 5AN, United Kingdom. Email: craig.morley@angloamerican.com

2. MAusIMM, Lead Mining Geoscience and Reconciliation, Anglo American, Perth WA 6081. Email: heath.arvidson@angloamerican.com

consistent approach to a standard set of reconciliations is to enable:

- identification and correction of inefficiencies and errors in key areas of estimating, mining, processing and recovery of product (Schofield, 2001)
- increased confidence in key activities across the mine value chain thus increasing the confidence in the stated Mineral Resources and Ore Reserves, the associated mine plans, and the ability to achieve targets and objectives (Morley and Moller, 2005; Parker, 2011)
- better management decisions through the monitoring of key performance indicators, (measuring performance against targets) and taking corrective action
- improvement of delivery against plans and budgets, and thus confidence in meeting shareholder expectations
- improved Mineral Resource utilisation thereby making the most of the endowment
- more accurate and precise forecasting in the business, resulting in reduced risk and uncertainty (Morley 2003)
- ultimately reduced costs, enhanced revenue and associated improvement in shareholder value.

Personnel involved in MVCR must meet regularly to discuss reconciliation results and agree action plans to address any issues or opportunities identified. This requires a clear understanding of inherent and expected variation in processes and establishing appropriate criteria so that deviations exceeding tolerance limits are targeted and actions can be defined to identify:

- trends that may indicate a part of the process is at risk
- oscillations or periodic behaviour that may reflect the impact of a planned or unplanned change in process
- other 'irregular' behaviour that may indicate issues or opportunities.

Action plans are developed and implemented to reduce any differences to within acceptable levels, and then to pursue continuous improvement.

LESSONS LEARNED – EXAMPLES OF GOOD PRACTICE

Standardisation of terminology and calculations

Anglo American has adopted the terminology shown in Figure 1 below which illustrates both the mining value chain and some of the many reconciliations that can be measured. Anglo American have avoided F1, F2 type nomenclature (Parker, 2011; Johnston and Kelleher, 2003) to ensure that the MVCR relationships are descriptive. This aides both transparency and communication efficiency.

Reconciliation calculations are linked to each relationship and derived based on the order of the mining value chain (Morley, 2003, 2014a; Fouet *et al*, 2009; Hargraves and Morley, 2014). Each node represents a value adding activity and data collection point. When deriving the formula for calculation of variations between the node results (ie the reconciliation relationship) the following logic can be universally applied:

- the value chain is read from left to right and the variation is calculated as a percentage
- the earliest node is used to divide the later node (Parker, 2011) – ie the earlier node forms the denominator and the later node the numerator to derive the variation value (that is the earliest node is always on the bottom).

$$\frac{\mathit{Node\ 2} - \mathit{Node\ 1}}{\mathit{Node\ 1}}$$

Which mathematically simplifies to:

$$\left(\frac{\mathit{Node\ 2}}{\mathit{Node\ 1}}\right) - 1$$

To illustrate how this calculation works Table 1 provides fictitious data for comparison of Budget ore tonnes to Plant Received ore tonnes (highlighted in the black cells):

In this example the Budget ore tonnes are derived from the earliest node and therefore will form the denominator. The Budget ore tonnes are lower than the Plant Received tonnes indicating an increase in tonnes along the value chain and so

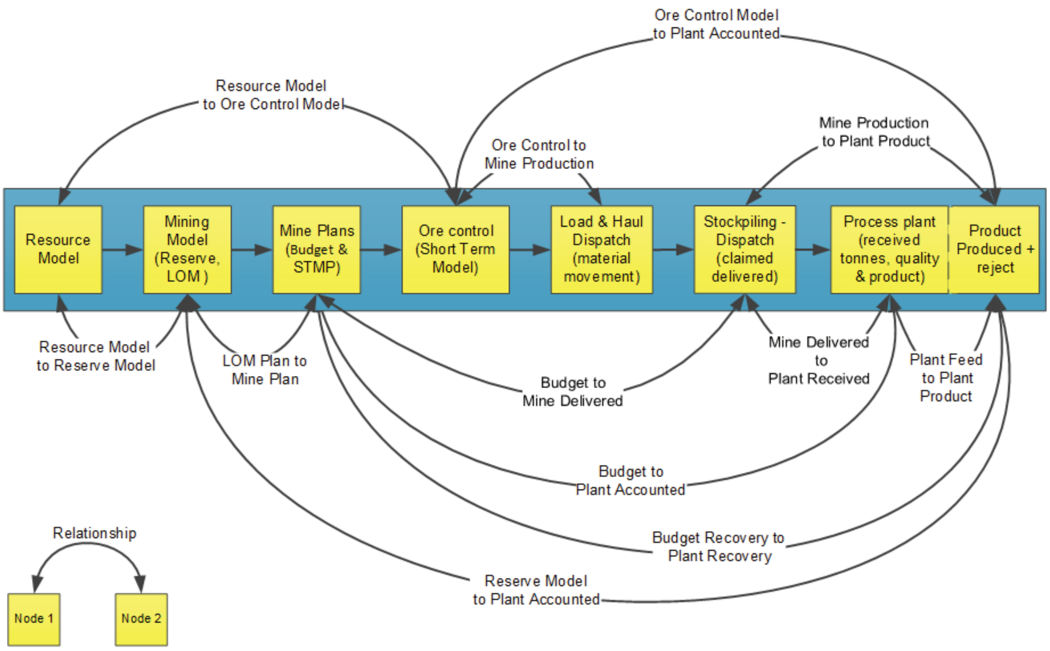

FIG 1 – The mine value chain – including reconcilation nodes and relationships (Morley, 2003; Hargraves and Morley, 2014).

TABLE 1

Example of budget to plant received reconciliation.

	Budget					Processing plant received			
	Tonnes (ore)	Tonnes (waste)	Quality (g/t)	Product (Oz troy)	Recovery (%)	Tonnes (ore)	Quality (g/t)	Product (Oz troy)	Recovery (%)
Month	4 974 000	9 840 000	3.45	551 716	87.8	5 172 960	3.64	605 385	89.2

the reconciliation relationship will report a 'plus' result. If there had been a decrease of tonnes along the value chain the reconciliation relationship would produce a 'minus' result.

A 'plus' result is not necessarily a desirable result. For example, a reconciliation relationship that consistently shows +25 per cent results over time means that the earlier node (usually the model or plan) is consistently under calling the later node (usually the measured outcome). This is not a good result and action should be taken to improve the quality of the model/plan or fix any issues with the measurement/sampling methods in order to lower the variation and improve the process.

In this example the calculation of the variation between Budget ore tonnes to Plant ore tonnes is as follows:

$$\frac{\textit{Plant ore tonnes} - \textit{Budget ore tonnes}}{\textit{Budget ore tonnes}}$$

Which mathematically simplifies to:

$$\left(\frac{\textit{Plant ore tonnes}}{\textit{Budget ore tonnes}}\right) - 1$$

Applying the example numbers shown in Table 1 to these formulae the results are:

$$\frac{5\ 172\ 960 - 4\ 974\ 000}{4\ 974\ 000} = 4\ \%$$

Which mathematically simplifies to:

$$\left(\frac{5\ 172\ 960}{4\ 974\ 000}\right) - 1 = 4\ \%$$

Therefore, the variation for the reconciliation relationship Budget to Plant received is 4 per cent and since this is a 'plus' number it is clear that from budget tonnes to plant received tonnes there was an increase in tonnes.

This approach can be universally applied to any reconciliation relationship as a standard methodology that ensures anyone reviewing the results will be able to interpret them.

Compliance to plan reconciliation

Comparison of tonnes, grade and product alone does not address the spatial and temporal aspects of mining to answer the question: did we mine *where* and *when* we planned to mine?

Spatial and temporal reconciliation is critical to answer this question. Across the industry, in our experience, this is routinely one of the worst performing metrics on any mine (and thus a significant value opportunity).

Which plan and what methodology?

It is critical to define exactly which plan or plans are to be used for reconciliation as there are a wide range of options including, for example: Life-of-mine (LOM) plan, medium term business or 5 year plans, budgets, forecasts, and short-term mine plans (STMP) (Morley, 2014b). Longer and shorter term plans are nested and provide increasing detail as they move towards execution. For example, a typical planning cycle may be development of the LOM plan which is used to generate a 5-year business plan from which Year 1 provides the Budget and a detailed STMP is then defined on a rolling 3 monthly basis which the mine executes on a shift by shift basis. It is important to reconcile to both the annual budget and the STMP for the following reasons:

- *Budget* – The annual budget, as announced to shareholders at the start of each year, is the company's commitment to the market. Budgets, and the forecasts released to the market, focus on cost, revenue and product targets. Investors and analysts use this information to assess the financial performance of a company. Senior management and investors focus on performance to this plan and the company's ability to deliver on their commitment.
- *STMP* – The STMP is the plan that the mine executes. All mines operate to a routine sequence of supporting activities and extraction that make spatial compliance and reconciliation a critical indication of performance. To answer the question 'did we mine *where* and *when* we planned to mine?' it is essential to reconcile actual mining activity to the STMP on both a spatial and temporal basis.

Calculating compliance

Clearly if mining occurs outside of the area/location planned for a given month and/or material planned for another month was mined, then production is not complying with the plan. Compliance to Plan should therefore be determined using spatial comparison of volumes (spatial) measured monthly (temporal) against the STMP to give a view of compliance.

Table 2 shows the recommended categories for tracking compliance to plan.

To obtain the spatial element of compliance to plan the volumes must be compared in 3D space. Figure 2 illustrates the relationship between these categories in a 2D cross-section

TABLE 2

Categories to explain compliance to plan.

Categories	Description
Mined in plan	Mined from the area planned and in the month planned (in Figure 2 area with no squares)
Mined not planned	Mined, but not in an area planned for the month (in Figure 2 area with small squares)
Planned not mined	Planned, but not mined in the month planned (in Figure 2 area with large squares)

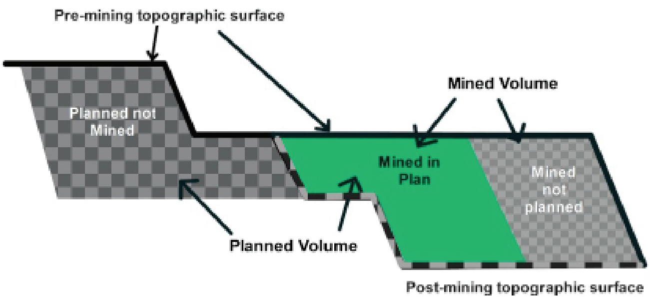

FIG 2 – Illustration (in cross-section) of surfaces and categories used in compliance to plan calculations.

view through volumes defined by an existing topographic surface, a planned surface and an as mined surface.

Compliance to plan can be calculated as follows using numbers representing volume (m^3):

$$\text{Compliance to plan} = \frac{\text{Mined in Plan}}{\text{Mined in Plan} + \text{Planned not Mined} + \text{Mined not Planned}}$$

Because this metric has a temporal element, it is calculated regularly, eg monthly, in which case it would be reported both in a monthly format and on a cumulative monthly basis, typically over a year or the budget period. This will show compliance to the STMP plan and, if the STMP is aligned to the annual budget, then the cumulative results will show overall compliance to the annual plans/budgets.

Table 3 presents two examples of calculations of the compliance to plan metric.

Why managing stockpiles is important to MVCR

Stockpiling is an integral part of most mining operations. Well-managed stockpiling can add significant value and so is part of the mining value chain as shown in Figure 1. For example, a low-grade stockpile takes material that is only marginally unprofitable for mill feed and stores it separately so that at some point in the future, when technology or market prices change, it can be easily accessed and treated. This effectively takes material that at the time of mining is waste and preserves it so it can generate revenue (add value) in the future. Other key value-adding opportunities are blending and providing buffers to the system. A strategic and well managed approach to stockpiles will assist the usefulness of MVCR.

Defining a stockpiling strategy

Creating a stockpile strategy clarifies both stockpiling activities and how to reconcile material movement through stockpiles (Morley, 2014b). Good practice is to do this at a site level encompassing all stockpiles and their interrelationships – but the principles can be applied to a single stockpile as well. A stockpiling strategy should at least cover these points:

- primary purpose (type of stockpile)
- efficiency and design
- implementation/execution.

TABLE 3

Examples of two monthly compliance calculations.

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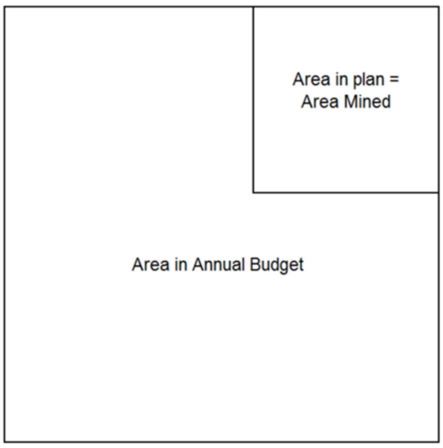
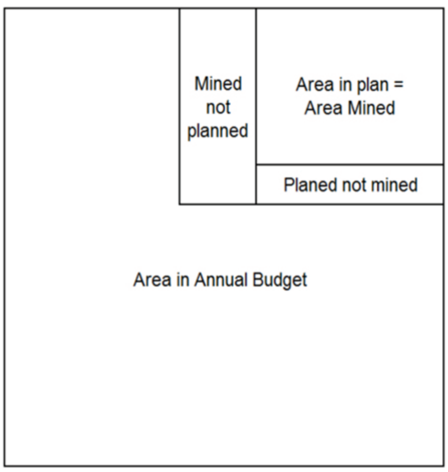
<tr><td>
</td><td>$\text{Mined in Plan} = 1600m^3$
$\text{Planned not Mined} = 0m^3$
$\text{Mined not Planned} = 0m^3$
$= \frac{\text{Mined in Plan}}{\text{Mined in Plan} + \text{Planned not Mined} + \text{Mined not Planned}}$
$= \frac{1600}{1600 + 0 + 0}$
$= 100\%$</td></tr>
<tr><td>
</td><td>$\text{Mined in Plan} = 1400m^3$
$\text{Planned not Mined} = 200m^3$
$\text{Mined not Planned} = 700m^3$
$= \frac{\text{Mined in Plan}}{\text{Mined in Plan} + \text{Planned not Mined} + \text{Mined not Planned}}$
$= \frac{1400}{1400 + 200 + 700}$
$= 61\%$</td></tr>
</table>

Primary purpose (type of stockpile)

What is to be achieved with the stockpile strategy? For example, at an individual stockpile level, such as a ROM pad stockpile, the objective could be to ensure optimised quality of the feed to the plant. Thinking about what you need to achieve with stockpiling and defining it as part of the strategy clarifies what is to be achieved and how success will be quantified.

Four main purposes (types) of ore stockpiling are described in Table 4.

Of course, it is possible to combine more than one approach into a single stockpile. Figure 3 shows crushed ore characteristic separation stockpiles that also provide buffer stocks.

Efficiency and design

When building a stockpile with the objectives outlined in Table 4 there are several elements to consider to enhance efficiency and design. Table 5 summarises the main considerations.

Implementation/execution

The final stage is to address the implementation of the stockpiles and their ongoing use. Key points to consider are:

- maintain focus on the primary purpose of the stockpiles
- keep stockpiles small and turn them over frequently (except for low-grade/long-term stockpiles)
- know and record what goes on and where. Build a 3D model for longer term stockpiles which will become the 'stockpile ore control model' when it is reclaimed
- use an arithmetic reclaim model for short-term stockpiles (eg Last in is first off (LIFO), or, first in is first off (FIFO)
- accurate despatch data is critical information to ensure the right material goes to the right destination and to allow modelling of reclaim (either by arithmetic or 3D models)

FIG 3 – Post crusher coarse ore characteristic separation stockpiles that are used for both blending and buffering (Riske *et al*, 2007).

TABLE 4
Ore stockpiling approaches (Jupp, Howard and Everett, 2013).

Purpose	Description and Example
Storing	Stockpiling ore material that doesn't meet current blend characteristics, where mining rate is higher than plant capacity, for emergency stocks, and stockpiling waste that is anticipated to become economic in the future (ie low-grade stockpiles).
Buffering	Creating stockpiles as a short-term solution to fluctuations in production or plant process for example loss of capacity in the pit during excavator maintenance or in the plant during crusher shutdowns. These are generally to buffer against planned events or events that happen regularly but exact timing is not known, and so can be continuously built and reclaimed on a scheduled basis.
Blending for characteristic separation	Stockpiling to provide choices of specific blends from the stockpiles into the crusher depending on requirements. For example, separating deleterious material to blend in to the plant in smaller quantities or stockpiling material with lower hardness characteristics to blend with direct tip feed from areas which have higher hardness in order to maximise throughput. In most mines blending typically happens into or after the crusher (see Figure 3).
Blending for homogenisation	Creation of a blended and/or homogenised stockpile and related reclaim processes for the reduction of variation in grade and other ore characteristics in plant feed. Homogenisation can be achieved either pre- or post-crusher.

TABLE 5
Stockpile efficiency and design considerations (Jupp, Howard and Everett, 2013).

Purpose	Efficiency and design considerations
Storing	Storage stockpiles often have a long-term life so it is important that their location will not hamper future mine expansion (always ensure the area is sterilised by drilling the location and consider final pit wall or future infrastructure locations). Create a 3D 'stockpile ore control model' as the stockpile is built since this will save future generations trying to guess the properties of reclaimed material or having to attempt difficult and costly stockpile drilling exercises.
Buffering	By nature, buffering stockpiles are short-term and can be built up specifically for a purpose (eg a scheduled crusher shutdown) or they may be built for use in a situation that cannot be forecast such as a weather event or breakdown in the plant. In either situation the stockpiles will usually be located close to the crusher or even maintained in a crushed ore state between the crusher and plant. Good practice is to turn these stockpiles over frequently.
Blending for characteristic separation	Ore characteristic separation stockpiles are typically located on the ROM pad close to the crusher to facilitate blending of the feed into the crusher. On some sites blending of crushed ore with different ore characteristics can be efficiently handled by the plant itself (as shown in Figure 3). Again, good practice is to turn these stockpiles over frequently.
Blending for homogenisation	Creation of a blended/homogenised stockpile and the related reclaim processes take considerable discipline from mine planning, ore control and production to ensure a good result. Smaller stockpiles which turn over rapidly are good practice and better than one large stockpile with unknown zones of material that will be difficult to manage. Ideally at any one time, while one stockpile is still being reclaimed, a second has been completed (providing a buffering stock) and another is being built (see Figure 4). Short-term mine planning is critical to ensure that appropriate feed is available to build these stockpiles. Modelling of the stockpiles as they are built is essential to ensure that the reclaim process will result in the desired feed characteristics.

FIG 4 – Example of a build and reclaim Stockpile layout designed to create homogenised/blended feed to a plant in Siberia (modified from Morley, Sulway and Muller, 2014).

- volume is important to define what stocks you have and data is generally collected monthly although increasingly it is normal to have weekly or even daily results available. Accurate surveys can be achieved via traditional theodolite survey, laser scanning or use of airborne scanning technology (drone scans/imaging)
- density is important to convert volumes to tonnes and is discussed further below.

Stockpile reconciliation

Tracking material across a mine for reconciliation cannot be done without considering the impact of stockpiles. As shown in Figure 5 the relationships between material movement can appear complicated but there are ways to unravel the challenges.

The role of despatch systems

Understanding the source, destination, tonnes and quality of material as it moves around the mine is critical to being able to reconcile stockpiles. Typically, this information is accessed from site truck despatch systems. Knowing what material has gone where and its relevant characteristics enables modelling and calculation of stockpile quality and geometallurgical characteristics, while tonnages can be derived either from despatch or via volume measurements.

The role of surveying

At many operations, the capture of volume information across a site, including stockpiles, is usually completed by surveyors as part of ongoing monthly reporting processes. Recently the use of automated capture technologies such as drones on the surface, or cavity monitoring system (CMS) scanning underground has provided the opportunity to achieve high quality results in a shorter time (or even on an as-required basis). A complication with volume measurement of stockpiles is converting the volume into a tonnage by use of an appropriate broken rock density factor (Makhuvha, Arellano and Harney, 2014). Measured volumes/tonnages can

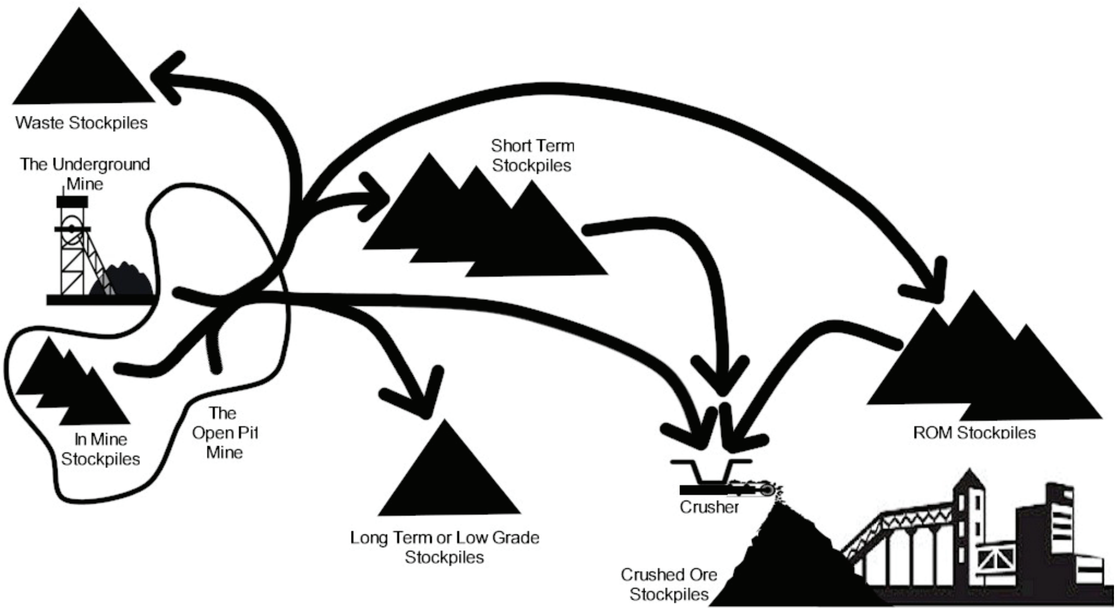


FIG 5 – Material movement and common stockpiles at a mine.

also be reconciled with despatch information for stockpiles to ensure accuracy of the inventory. However, because volume measurements cannot provide any estimation of grade or the geometallurgical information of the stockpile it is necessary to use a model to derive the information necessary for predicting ore feed from a stockpile and to carry out reconciliation.

Modelling stockpiles

A range of methodologies exist for modelling stockpiles. Some of the most useful are described below.

Arithmetic averaging models

This methodology assumes that the tonnes weighted average of the grade of all material put onto the stockpile provides an indication of the grade of every tonne removed from that stockpile. If there is significant variability in the grade range or geometallurgical characteristics of the material put onto the stockpile serious errors can occur by using this method because it assumes relatively homogenous distribution of values through the stockpile. The averaging model works best where the stockpile is built to a designed size and then fully reclaimed within the reconciled period, for example a homogenisation stockpile used to control the variability of feed to the processing plant.

Arithmetic sequential or genealogical models

This methodology applies logic in the calculation that recognises the sequence in which the stockpile, and hence the tonnes weighted grades within the stockpile, are built up. Two commonly used approaches are scenarios of FIFO and LIFO sequencing as shown in Figure 6.

Spatial models

Spatial stockpile models, constructed using ore control data as the stockpile is being built, can be described as an 'ore control model of a stockpile'. There are two principal types:

1. automated models built using simulation packages (Zhao *et al*, 2015)– typically used with bulk commodities and equipment such as stacker-reclaimers
2. manually constructed 3D models built using standard mining package tools – typically used for stockpiles on mine sites.

The advantage of these models is that they provide a tool for defining grade and geometallurgical information during reclaiming and therefore are a similar type of information to that provided by ore control during mining. Trying to construct a 3D model after a stockpile has been built using drilling or grab sampling can introduce significant bias and erroneous representation of the material being reclaimed.

Reconciliation calculations and stockpiles

Examples of the reconciliation relationships (see Figure 1) that can be impacted by stockpiles include:

- resource to plant received
- reserve to plant received
- ore control model to plant received
- budget to mine delivered (where stockpile movements are not budgeted)
- budget to plant accounted (where stockpile movements are not budgeted).

In each of these cases the sources (ie Resource, Reserve, Ore Control Model and Budget) must be adjusted and this can be achieved by using a simple calculation monthly such as:

$$\text{"source" (such as Budget, STMP, Mine or Ore Control Model) to plant received}$$
$$= \left(\frac{\text{Plant Received}}{\text{"source" - material delivered to stockpiles + material reclaimed from stockpiles}} \right) - 1$$

Grade or quality information can be derived with this calculation and would have to be tonnes weighted.

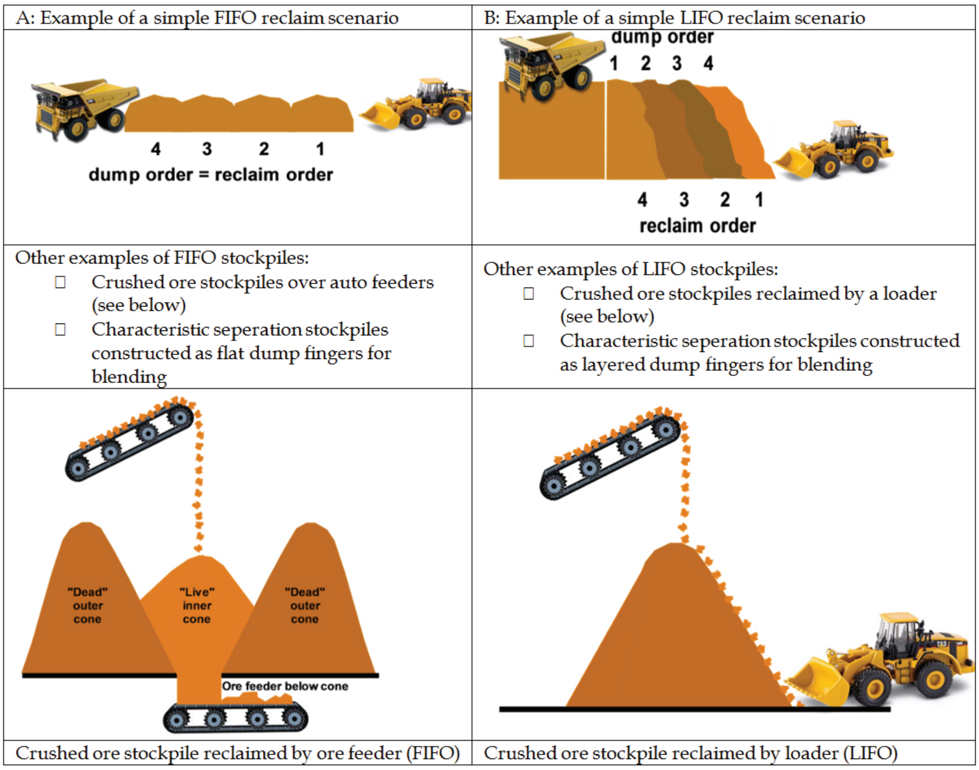


FIG 6 – Commonly used approaches of FIFO and LIFO sequencing.

Calculating the bulk density of stockpiles

Bulk density is one of the most critical and poorly defined variables use in mining calculations, reporting and reconciliation. All estimation of Mineral Resources and Ore Reserves require the estimation of grade or quality and tonnes. To estimate tonnes it is necessary to know volume and bulk density (Makhuvha, Arellano and Harney, 2014).

$$volume \times bulk\ density = tonnes$$

When it comes to stockpiles the calculation of tonnages is affected by the voids between the broken rock fragments that increase the volume. For example, if an *in situ* block of rock has a volume of 370.4 m^3, and a bulk density of 2.7 g/cm^3, its tonnage would be:

$$Tonnes = volume \times density$$

$$370.4m^3 \times 2.7g/cm^3 = 1000\ tonnes$$

When this material is blasted the tonnage remains the same however the volume changes. If for this example it is assumed that the volume increases by 35 per cent the new volume can be calculated as 1.35 × 370.4 m^3 = 500 m^3. Applying this new volume to our same 1000 t allows us to see the impact on the bulk density of the broken material.

$$bulk\ density = \frac{tonnes}{volume} \qquad \frac{1000t}{500m^3} = 2.0g/cm^3$$

The voids between the fragments lowers the bulk density, which is reflected in the results above. The bigger the fragments the larger the volume and the lower the bulk density as shown in Figure 7.

Two methods for calculating the bulk density of blasted material stockpiles are:

1. Good practice/best methodology – generates a broken stocks bulk density that can be used for planning, EOM calculations and reconciliation:
   - Use weighbridge to measure the tonnes of trucks as they build a new stockpile. Once completed have survey pick-up the stockpile and calculate the volume. Bulk density can then be calculated as tonnes/volume = bulk density (wet).
2. Alternative method where a weighbridge is not available:
   - Use truck scales tonnages, or truck counts multiplied by a truck factor, to measure the tonnes dumped onto a new stockpile. Once completed have survey pick-up the stockpile and calculate the volume. Bulk density can then be calculated as follows tonnes/volume = bulk density (wet).

Calculating the bulk density of crushed ore stockpiles

When a plant builds a new crushed ore cone it creates an opportunity to take a crushed ore bulk density measurement.

- Use post crusher weightometer data to calculate the tonnes of material that is added to the stockpile and the post crushed ore stockpile weightometer data to calculate the tonnes of material removed from the stockpile. Tonnes added less tonnes removed to the point in time of the survey pick-up gives the total tonnes on the stockpile.
- Survey pick-up gives the stockpile volume.
- Bulk density of the crushed ore stockpile can be calculated as tonnes/volume = crushed ore bulk density (wet).

With both methods, variation in moisture will affect bulk density – good practice is to use a dry basis and apply moisture factors for seasonal effects. The moisture basis of the bulk density results should always be indicated. Also the ratios of different material types will affect the bulk density of mixed material stockpiles. Crushed ore stockpiles can represent the consistent blended feed that is being delivered to the plant and so the bulk density should not vary if the material type blend ratios remain constant.

Using despatch data

Despatch is a critical function on any modern mining operation coordinating the efficient movement of ore and waste from their source to the right destinations. It is not only about ensuring loading equipment and trucks are used efficiently but also that ore doesn't end up on waste stockpiles and waste doesn't end up in the plant. The data that is generated by the combination of a despatch software system and high precision GPS on equipment gives excellent information on just how well mining operations are performing and is a critical input into production tracking and reconciliation analysis.

Ideally despatch will have its own error tracking processes, but on many mine sites it is still possible to look at the waste dumps and see the occasional load of ore grade material! Carrying out a health check on the quality of the despatch processes and data can often result in improvement of the data quality for use in reconciliation. The objective is to check the quality of despatch records to ensure that at an individual truckload level any errors are being identified and corrected. The accuracy of despatch information is important as this data is used daily to track production and blending into the plant. Not until a survey pickup occurs is there another estimate of the tonnes moved and location of that material.

Key focus areas are:

- material type versus destination type (check on material misclassifications showing the number of occurrences and the tonnes affected)
- accuracy of tonnage information (does the size of truck and/or the truck factor match the tonnes the system records as being moved?)
- every truckload has correct information (do all records contain source, destination, tonnes and quality information and are there any errors such as invalid source/destination locations, negative grades, missing material types etc).

Figure 8 shows an example of analysis of the minimum and maximum loads by truck for a fleet of identical trucks. Not only does it highlight large variations in the loads carried by the trucks (indicating loading issues), it also highlights that the despatch system is capping the weight of any load over 250 t, to equal 250 t. This will bias the despatch tonnages reported and mask any occurrence of trucks being overloaded. Combining the data from Figure 8 with loader/excavator operator data can highlight operators that consistently under load trucks who, with training, could contribute to increasing production and tonnes moved.

Regularly receiving a standard format dump of despatch data and performing a health check will build confidence in the data and allow work with despatchers to remove errors. Good practice is for the despatchers to run their own error reports at the end of every shift and correct errors immediately – ensuring high quality data is stored for future use.

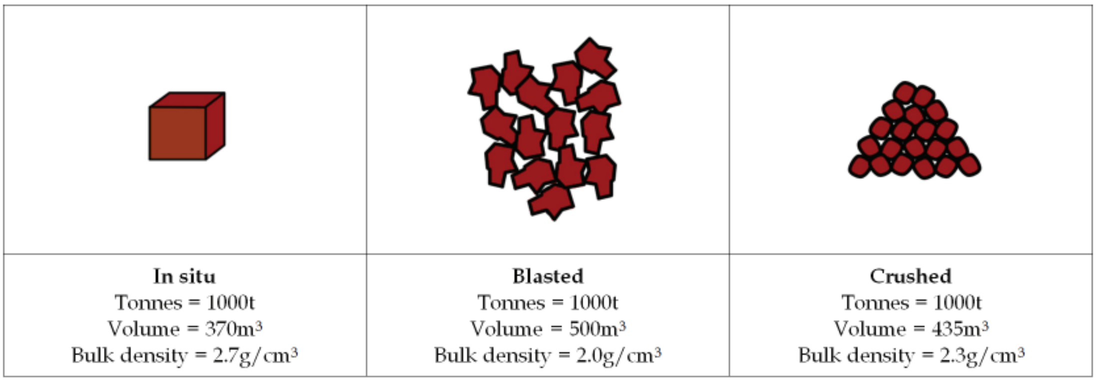


FIG 7 – Example of changes in bulk density and volume due to blasting and crushing.

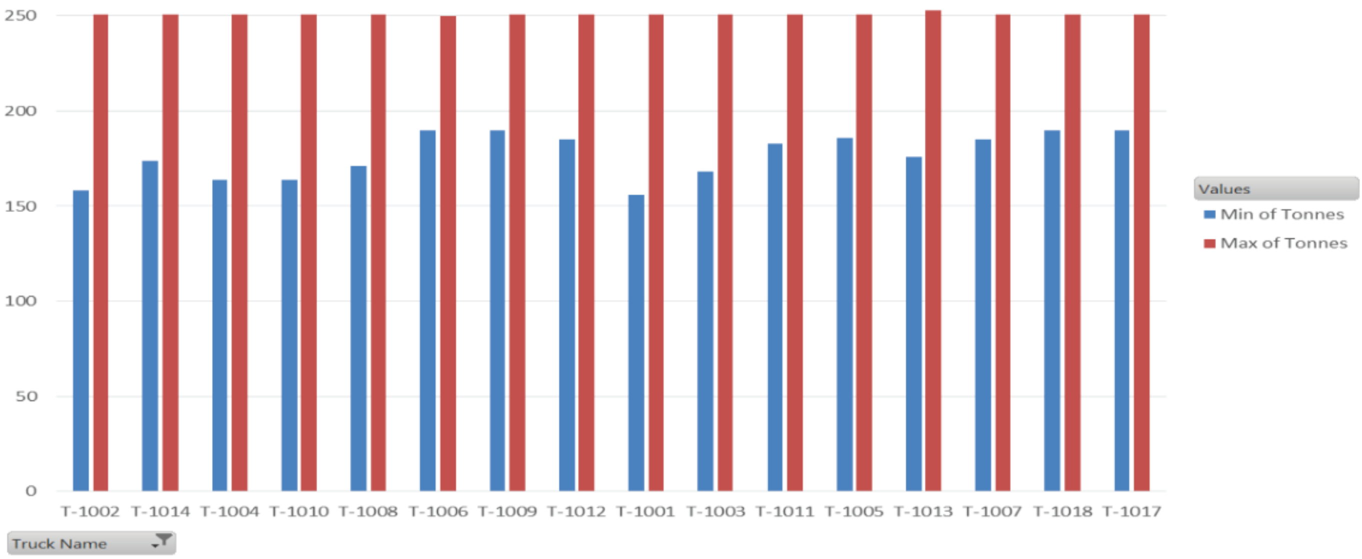


FIG 8 – Minimum and Maximum truck tonnages overall data by truck number

Truck factors

A truck factor is applied to haul trucks to convert the tray volume or number of loads to tonnes. Ideally all trucks would have fully maintained scales and a Vehicle Information Management System (VIMS) that captures a stable tonnes measurement. However, it is necessary to use a truck factor in situations such as:

- where trucks don't have scales
- the scales and/or VIMS on the truck breakdown and no tonnes data is available
- validating that the scales on trucks are being maintained and calibrated correctly.

Truck factor is affected by bulk density and fragmentation sizes both of which can vary by material type and blasting practices. The effect of bulk density and volume is shown in Figure 9a and 9b below.

Because trucks loaded using visual control (no VIMS) can have different load weights and trucks loaded by VIMS balances will have different volumes it is important to ensure appropriate truck factors are derived where bulk density varies significantly by material type. Truck factors may also vary on an individual load basis depending on how much an excavator/shovel operator puts in the truck.

It is still not uncommon in the industry for truck factors that have been derived from empirical work to be applied year after year with no validation. Good practice is to use truck scale data for all truck tonnage measurements *and* to continually reconcile this data against truck factor calculations.

There are a range of methods to calculate truck factors. The least accurate method is to use the manufacturer's specifications for tray volume multiplied by the bulk density of the material type to provide an approximate tonnage. This obviously does not consider loading practices or any measurement of weight – however if VIMS data or a weighbridge is not available this may be the only approach available. If VIMS data and/or a suitable weighbridge is available, then it is possible to measure accurate truck factors.

Calculating the truck factor using a weighbridge is as follows:

Trucks are weighed empty using the weighbridge and then weighed loaded. It is essential to collect data for all material types including waste to derive truck factors appropriate for all material types.

The calculation is as follows:

$$\textit{Weight of loaded truck} - \textit{weight of truck} = \textit{tonnes by material type}$$

$$\frac{\textit{Total tonnes of material by type}}{\textit{Total number of truck loads}} = \textit{Truck factor for that material type}$$

Calculating the truck factor using truck scales (VIMS) data:

By grouping despatch data to show number of loads by truck type and material type it is possible to calculate an average weight and thus the truck factor in tonnes. Good

A

B

FIG 9 – (A) Trucks with the same mass/weight but different bulk density and so different volumes. (B) Trucks with the same volume but different bulk density and therefore different tonnes.

practice is to use the Reconciliation system to collect and report this data on an ongoing basis. Trend lines plotted monthly over a twelve-month period will show if any of the truck factor values by truck type or material type are drifting over time. Drift could indicate issues with truck scales going out of calibration, changes in loading habits of operators or changes in density of material types as different volumes are mined.

With any truck factor application it is important to remember that variation in moisture will have an effect and in areas of high seasonal rainfall appropriate application of moisture factors will also be necessary.

Truck factors can be unique to individual trucks, for example a Cat 777 with a rubber tray will have a different truck factor to a Cat 777 with a metal tray because the tray volumes are different. Be aware of these variations in your truck fleet. An error due to application of the wrong truck factor, such as not applying different truck factors for different material types, can have a significant impact on tonnage calculations. A 4 per cent error in truck factor in a 100 Mt/a operation can result in an annualised error of 4 Mt.

Understanding reconciliation confidence

How reliable is the reconciliation process at any mine? In Anglo American a qualitative measure is used to provide an indication of how much confidence can be applied to reconciliation processes and results.

Routine reporting of a self-assessment ranking metric provides a standardised and transparent measure of performance and ensures that targeted actions are occurring to deliver value for the operation.

Table 6 presents an example of the qualitative measures applied across Anglo American operations and each criteria is described in more detail below.

Figure 10 provides an example of how reporting can be used to show current confidence level and the mines journey over 12 months from no reconciliation system to achieving a confidence level of 92 per cent.

Reconciliation champion

Every mine needs a single point of accountability to focus reconciliation activities (Blucher, 2002) and this is achieved via a reconciliation champion who is assigned to drive the reconciliation process and ensure that the best possible data collection, analysis, reporting and action planning is carried out. The champion must be able to influence senior management and to hold data area owners to account for the quality of their data and the timeliness of their actions.

The reconciliation champion coordinates and chairs monthly meetings where a cross-functional group discusses the reconciliation results and agrees on priority actions. The key objective that will boost Reconciliation confidence is that the Champion is actively managing the process.

Mapping nodes and relationships

All mining operations (strictly their on-site value chains, from *in situ* ore to plant product) are unique in configuration, and therefore the nodes and relationships that are measured will vary. The selection of nodes and relationships to be measured at each site will be driven by the technical team in order to control and improve the site planning, geology, mining and processing practices. Documentation of what is measured, and where it is measured, in the form of a process or value chain map, is important to ensure clarity of the process and knowledge longevity as people change roles.

Measurement of nodes

Reliable measurement and data transfer at every node relevant to MVCR is critical for both transparency and for having confidence in reconciliation results. Direct measurement is always preferable to inferred or back-calculated data.

Data quality assurance and quality control (QAQC)

In addition to having measured data at each node, the accuracy and precision of the data must be able to be demonstrated. This ensures that the limitations of the conclusions drawn from it are understood. The work done to understand the

TABLE 6
Reconciliation confidence rating (Arvidson, 2015).

Item	Criteria	Score (1 to 5)	Weighting %	Weighted Score
1	Champion assigned and actively managing the process	5	10%	0.5
2	Nodes and relationships mapped and agreed	5	10%	0.5
3	Measuring systems in place at all nodes	5	10%	0.5
4	Measurements QA/QC (data is shown to be acceptable quality)	5	20%	1
5	Data management and reporting in a commercial database system	4	20%	0.8
6	Cross-functional workshop held to discuss results and agree actions	4	10%	0.4
7	Actions on track	5	10%	0.5
8	Monthly report formally approved by senior management	4	10%	0.4
			Rating	**92%**

Score	Description
1	0% complete
2	25% complete
3	50% complete
4	75% complete
5	100% complete

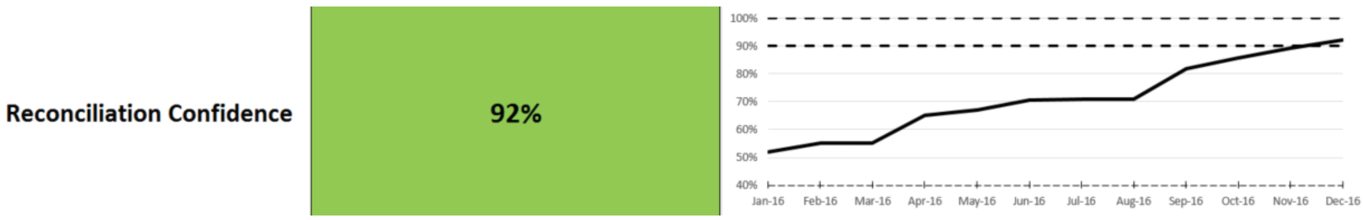


FIG 10 – Reconciliation confidence reporting from the reconciliation report template.

data quality should be documented to demonstrate the level of confidence in the data.

Table 7 shows some typical data types and QAQC protocols.

Data management

Microsoft Excel Spreadsheets and customised Microsoft Access Databases are common solutions; however, they do not provide secure, auditable and sustainable solutions (Panko, 2000; Morley 2003). An industrial grade centralised database (such as SQL Server or Oracle) has many benefits such as allowing all personnel to use the same data and providing controlled access that ensures integrity and security (Morley and Moller, 2005). Commercially available systems (Riske *et al* 2007; Helm, Hargreaves and Morley, 2013) provide automated data collection, QAQC and a wide range of functionality and analysis tools.

Having all disciplines contributing their own data, preferably electronically via an automated process that includes validation, and all users being able to access all the information, minimises disputes over whose data is right and wrong and maximises analysis and accurate decision-making (Best and Gallant, 2004). A single source of data empowers decisions to correct and improve planning, geology, mining and processing practices and is one of the most important corporate data stores at any mine.

Cross functional engagement

The reconciliation champion should bring together the key cross functional technical and management staff on a routine basis (for example each month) to discuss reconciliation results, agree on the analysis and conclusions drawn from the data, and prioritise the actions for improvement. This process ensures that valid technical root causes are identified, reconciliation results are analysed and actions are taken.

Actions are tracked and delivered

Good practice is to ensure all actions follow the SMART approach – Specific, Measurable, Achievable, Resourced and Time-bound. The reconciliation champion is responsible for tracking actions arising from the reconciliation process and ensuring they are delivered.

Reporting

Formal reporting of reconciliation results and actions ensures transparency and support across the mine. It is recommended that the report is presented monthly to the senior management team/Executive.

Reporting of MVCR

Figure 11 presents examples, using fictitious data, of the general format for reporting that Anglo American has adopted. These examples show a metal focused format, however reports to suit commodities such as coal and diamonds have also been constructed along with reconciliations that include geometallurgical characteristics. Of importance is the *chart structure,* which:

- clearly states the reconciliation relationship using full descriptions of the nodes for clarity
- uses a traffic light approach to highlight both quarterly and annualised results. In the colour version of

TABLE 7
Nodes, data types and typical QAQC protocols (Arvidson 2015).

Node	Data types	Typical QAQC protocol
Resource	Drill hole samples and assays	Field duplicate samples, repeat assays, independent lab check assays, certified reference material samples, comparison of different analytical techniques
	Geological logging	Comparison of geological logging to geochemistry and geophysical test results
	Geological mapping	Independent review of interpretations; volume checks
	Geological interpretation/model	Logical field values; volume comparison to wireframes.
	Geological block model	Analysis of kriging parameters; visual inspection of results.
	Grade estimation	Independent audits
	Resource estimation	Comparison to previous estimates and between resource and reserve
Reserve	Pit design	Comparison between pit design, drill holes and resource model
	Mine schedule	Mine schedules are peer reviewed for practicality and achievability
	Beneficiation	Validation of processing performance in bulk samples, pilot plant or full scale plant
	Modifying factors	Independent audits, including validation of licenses
	Ore reserve	Comparison to previous estimates and sign-off process for approval
	License to operate	Security of tenure and community engagement
Budget	Monthly physical movement targets	Version control on budget sheets
	Monthly ore and product grades	Centralised storage and access control to information
	Monthly product quantities	Alignment between mine plans and budget targets
Ore control	Drill hole sampling and assays. Geological mapping	QAQC protocols as per resource
	Geological logging	
	Geological mapping	
	Geological interpretation/model	
	Geological block model	
	Grade estimation	
	Ore polygon designs	Ore polygon designs are peer reviewed and signed off prior to digging
	Material type classification	Decision tree documented for material type classification
	Blast movement monitoring	Post-blast adjustment of ore polygons to allow for blast movement
Mining	Loading	All required information is available prior to digging and visual inspection during mining
	Hauling	Sources match material type classification
	Despatch source, destination, tonnes and grades information	Destinations exist and match material type classification; truck tonnes match truck capacity; tonnes calculated from truck scales or validated truck factors and grades come from ore control
	Survey volumes	Surveys are double checked and reconciled monthly
	Stockpile management	Stockpile tonnes are based on tests of loose bulk density
		Stockpile grades are tracked and controlled by disciplined build and reclaim strategies
Processing	Tonnes and grades of ore fed to the plant. Tonnes/volume and grade of any plant reject (tailings, oversize)	Tonnes are measured using weightometers, which are regularly calibrated and certified
	Quantity and grade of products leaving the plant	Samples of ore, reject and product are subject to appropriate QAQC protocols
		Mass balance process is transparent, documented, reported routinely and signed off by a senior metallurgist every month

Figure 11, green (in monochrome, medium grey) indicates a process in control, orange (in Figure 11 light grey) means something may be trending out of control and needs monitoring and red (in monochrome, dark grey) means a relationship has moved out of control and action is needed

- shows data trends by month over a rolling 12-month period.

In addition to these charts, all reconciliation reports include conclusions, recommendations and actions for any red coloured result as well as list of action items or tasks associated with initiatives that are planned or underway.

Demonstrating value

It is generally understood that significant benefits and results can be achieved by carrying out reconciliation at a mine (Pitard, 2001; Arnesen and van der Westhuizen, 2002; Shaw *et al*, 2002; Best and Gallant, 2004; Johnston and Kelleher, 2005; Parker, 2011; Morley, 2014a) however directly attributing value to reconciliation can be complex. One method is to ensure that links are made between the

Division Name - Mine Name	Q4 2016 Tonnes Ore	Q4 2016 Quality	Q4 2016 Product	2016 Tonnes Ore	2016 Quality	2016 Product	Monthly charts (last 12 months raw data)
Resource Model to Grade Control Model	1%	4%	5%	-1%	-7%	-8%	
Mine Delivered to Plant Received	-4%	10%	8%	2%	10%	13%	
Resource Model to Plant Received	-2%	1%	3%	7%	-2%	2%	
Grade Control Model to Plant Received	-1%	8%	9%	9%	6%	11%	

Division Name - Mine Name	Q4 2016 Tonnes Ore	Q4 2016 Tonnes Waste	Q4 2016 Quality	Q4 2016 Product	2016 Tonnes Ore	2016 Tonnes Waste	2016 Quality	2016 Product	Monthly charts (last 12 months raw data)
Budget to Plant Received	4%	na	5%	9%	3%	na	2%	5%	
Budget to Mine Delivered	0%	22%	4%	6%	1%	0%	4%	6%	
	Q4 2016				2016				
Budget to Plant achieved recovery	1%				2%				
Spatial compliance to plan	85%				88%				
Reconciliation Confidence	93%								

FIG 11 – Examples of reporting formats. Key to table colours: Green = Maintain. Orange = Monitor. Red = Action. Key to charts: Red = Tonnes (ore). Brown = Tonnes (waste). Blue = Product. Green = Quality.

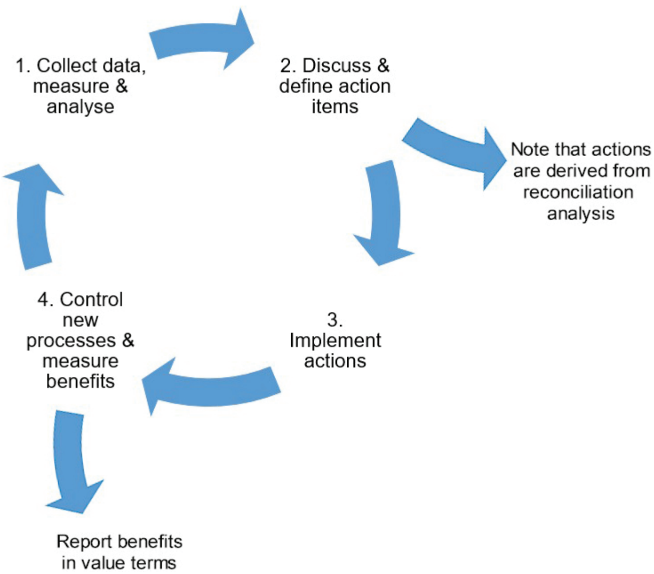


FIG 12 – Capturing reconciliation actions and measuring the benefits.

process of collecting the data, discussing the reconciliation results, defining actions and implementing the actions. This continuous process is shown in Figure 12 below along with two key additional activities:

1. noting actions that are derived from the reconciliation analysis
2. reporting the benefits, in value terms, post implementation.

By noting that the action items were derived from reconciliation analysis, diagnosis and discussions before implementation the source of the initiative can be directly traced back to reconciliation. While it is the work associated with the action item that delivers the value it is important to highlight the value being derived originates from reconciliation activities, and this will lead to benefits in terms of cost savings, additional revenue or mitigating value destructive processes.

Some examples of initiatives that have been derived from reconciliation analysis at Anglo American include:

- improvement in definition of ore during ore control processes resulting in increased volumes of ore delivered to the processing plant
- identification of compliance to plan issues resulting in changes to production activities to enable the operation to return to the plan
- identification of incongruent bulk density values being utilised resulting in misreporting of tonnages
- removal of errors in model wireframes that were resulting in misclassification of material types.

CONCLUSIONS

Anglo American is benefiting significantly from the development of MVCR that includes a standardised approach to terminology and calculations and a simple and easy to understand dashboard for diagnosis and communication. The key driver of success is, we believe, a mandate and support from the highest executive levels in the company. Quality data, a mapped value chain, cross-functional teamwork and a value based focus on continuous improvement are also essential drivers of success.

For any mining operation to achieve ongoing improvement, that optimises activities along the mine value chain, reconciliation is an essential foundation that will ensure both success and value add.

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