Universal Reconciliation – A Multi-Disciplinary Approach Across The Entire Mining Value Chain To Identify Loss Of Value And Maximize The Operational Performance

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Universal Reconciliation – A Multidisciplinary Approach across the Entire Mining Value Chain to Identify Loss of Value and Maximise Operational Performance

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ABSTRACT

The authors often see problems on mine sites that are due to insufficient feedback between technical discipline silos as the realities on the ground fail to inform the models and plans used to drive resource exploitation. Resource modelling, reserve definition, life-of-mine planning, short-term mine planning and scheduling, mine operations and beneficiation operations are all processes that inform each other, but in many instances feedback between these processes occurs in an *ad hoc* way and only after problems have come to light.

Universal reconciliation uses a multidisciplinary approach across the entire mining value chain to identify both opportunity and loss of value and to maximise operational performance. This paper will look at the operational effectiveness of universal reconciliation and will outline the important elements that make it successful, including how to map out the detail underpinning modelling, planning and execution processes. We do this by documenting the physical processes, logical work practices, organisational roles and responsibilities, data origin and quality, working assumptions and information management practices at an operation. The results quickly show how misinformation and assumption causes suboptimal decisions to be taken, where inefficiencies exist and what the opportunity is to remedy these issues.

A universal reconciliation study opens up an opportunity for stakeholders to reassess how the operation should be run and how operational effectiveness should be measured. Clear envelopes for reconciliation become obvious and questions about the practicality and data quality can be addressed.

A reconciliation code of practice is a key element of a successful universal reconciliation project and the authors outline the important aspects that will provide an operating model, showing the effectiveness of the resource and reserve modelling, the practicality of the mine planning and scheduling practices, how well the mine operations team are executing these schedules and how effective the processing area is given what it is fed. Most importantly, a system that allows operations time to react before the losses become systemic and that is based on identifying early warnings from hard data when these processes start to wobble is outlined. Finally as a case study, the revenue and cost benefits resulting from universal reconciliation diagnostic projects for nine mine sites is documented.

INTRODUCTION

Companies get savaged in the market when production guidance is not met. These guidance numbers have been generated by diligent, intelligent and hard working professionals who have the best interests of their company and shareholders in mind. However the challenges of creating plans that can be mined and then mining to those plans spans a multidisciplinary team that must act effectively together if guidance numbers are to be achieved. Being clear, consistent and transparent about what is in the ground is a key pillar, but delivering on metal production promises is equally critical. Universal reconciliation uses a multidisciplinary approach across the entire mining value chain to strengthen the interplay between the technical disciplines and to identify opportunities and loss of value in order to maximise operational performance.

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The results of a universal reconciliation diagnostic quickly show how misinformation and assumption causes suboptimal decisions to be taken, where inefficiencies exist and what the opportunity is to remedy these issues. This can be realised by documenting the detail underpinning modelling, planning and execution processes by mapping the:

- physical processes
- logical work practices
- organisational roles and responsibilities
- data origin and quality, working assumptions
- information management practices.

UNIVERSAL RECONCILIATION

Resource modelling, reserve definition, life-of-mine planning, long-term mine planning, short-term mine planning and scheduling, mine operations and beneficiation operations are all processes that inform each other, but in many instances feedback to upstream processes occurs in an *ad hoc* way and only after problems have come to light.

Mining companies typically build management structures to reflect these functions in order to define an organisation with clear boundaries of accountability. This in itself is appropriate, however, what the authors often see are problems that originate through insufficient communication between these functions forming silos as the realities on the ground fail to inform the models and plans used to drive resource exploitation. As a definition of an approach to resolving these challenges fundamentally universal reconciliation focuses of four key principles:

1. use of a multidisciplinary team to facilitate communication and leverage experience
2. review of the processes and procedures being carried out to identify opportunity
3. documentation of a reconciliation code of practice that sets a benchmark and embeds knowledge and good practice
4. implementation of a system that monitors key points along the value chain.

Each of these aspects will be discussed in the following sections.

Use of a multidisciplinary team to facilitate communication and leverage experience

In the authors experience process mapping using a dedicated universal reconciliation team is beneficial. The team would typically include a resource geologist, mining engineer, and metallurgist plus a 'generalist' who has experience across the mining production life cycle. The primary objective of this team is to work closely with all professionals on the mine site to map out the detail underpinning the modelling, planning and execution processes. The initial exercise can typically takes about 4–5 days per site with a process (outlined below) that ensures all stake holders are consulted and the core project team reconnects each evening to merge the threads of each specialist discipline into the overall findings.

Using the methodologies described below the team maps out the mines material and information flow, physical processes, logical work practices, organisational roles and responsibilities, data origin and quality, working assumptions and information management practices. In the authors experience when all stakeholders see what they are doing and how they are doing it in the context of the wider picture, it quickly becomes apparent how misinformation and assumption causes suboptimal decisions to be taken, where inefficiencies exist and what the opportunity is to remedy these issues.

A critical aspect of the multidisciplinary team is for them to consciously communicate about all aspects of the site process and discuss what is occurring across the technical silos. In the authors experience significant improvements and opportunities arise when this type of collaboration occurs and each of the key members on the team understands what others are doing with the information and the decisions that are being made. The team can be compiled from site personnel, representatives from different departments, or an external consulting group.

Review the processes and procedure being carried out and identify opportunity

The process of following and mapping the ore and waste flow along the mining value chain and mapping the processes, activities, systems, inputs and outputs that occur during this journey provides significant insight into the complex array of models, designs, schedules and material movement activities that occur at a mine site. With this insight comes the chance to identify issues and opportunities that can result in significant value to the operation (Morley, 2014).

Process mapping is a specialised field in itself that has many techniques and formats. Some companies have adopted standard formats or defined their own methodologies and these can be readily utilised and applied to the task of mapping ore flow and material movement for reconciliation purposes (Morley, 2014). The authors have over a period of 15 years developed a hybrid and simple methodology that has been successfully applied as part of reconciliation studies to map many different mines globally across commodities including coal, gold, diamond, iron ore, base metals and mineral sands operations in both open pit and underground mining environments.

The mapping consists of two key elements:

1. a matrix that forms a framework in which the processes that occur can be drawn and recorded
2. a checklist which prompts the person carrying out the mapping to ask the right questions to ensure all information is captured on how processes are completed (Morley, 2014).

Each of these elements is explained in the following sections.

The matrix

It is common in process mapping to use 'swimming lanes' that are horizontal rows across a page and columns that divide the page vertically to create regions on the process map that document specific interactions (Figure 1). The methodology being outlined here assigns professional roles to the horizontal swimming lanes and activities or processes to the vertical columns. This effectively divides the process map into a matrix of who is doing things, in the swimming lanes and what are they doing, in the vertical columns (Morley, 2014).

Shown in Figure 2 are some examples of the swimming lanes which read (depending on the nomenclature of the technical functions at the mine) from the top left of the process map to the bottom. The vertical columns are shown in Figure 3 from left to right of the process map.

In this way the process map now provides a number of boxes in which detail can be recorded that clearly illustrates who is performing what processes and how. As not all technical silos perform all tasks the process map will tend to 'flow' from the top left hand corner of the map to the bottom right. Generally

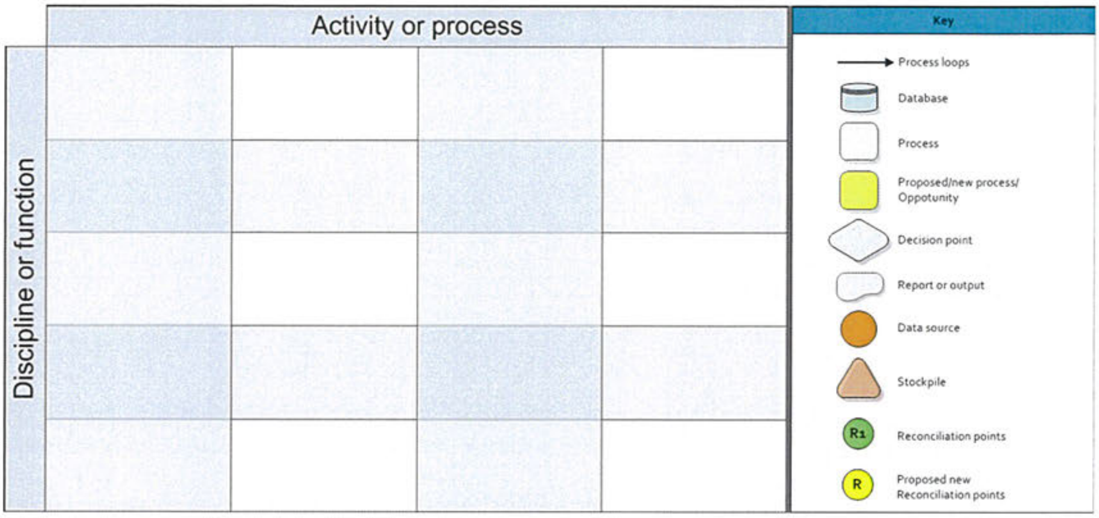

FIG 1 – The matrix showing horizontal and vertical swimming lanes.

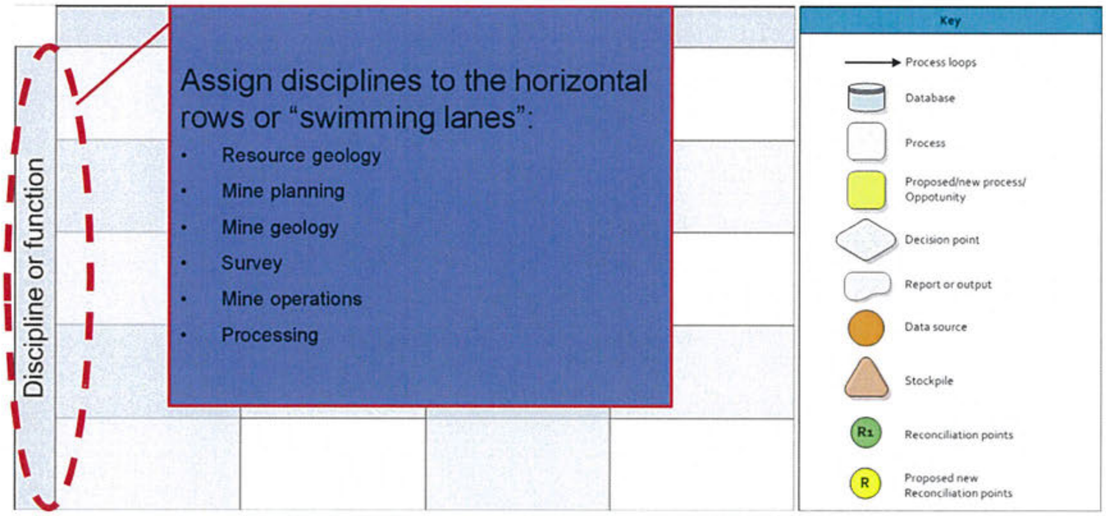

FIG 2 – The matrix showing horizontal swimming lanes (Hargreaves, 2014).

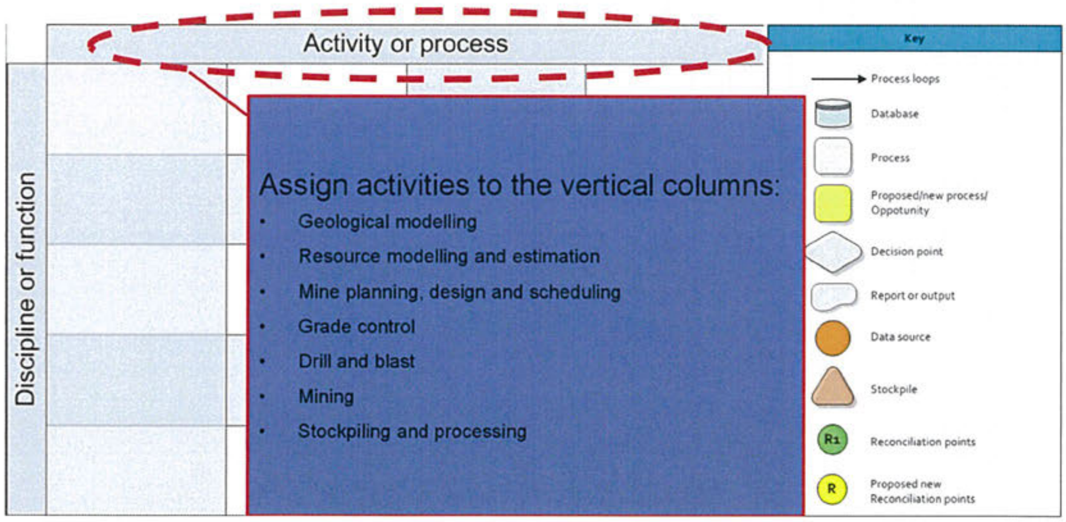

FIG 3 – The matrix showing vertical swimming lanes (Hargreaves, 2014).

the key aspect of universal reconciliation on most mines can be summarised onto a single A0 size sheet of paper using this methodology. It is not possible to provide an A0 diagram in this paper, however, Figure 4 gives the reader a 'helicopter' view of what a completed map will look like (Morley, 2014).

The checklist

In documenting how things are done on a site it helps to have a simple methodology that guides the process and ensures all elements of what is being done are captured. Process improvement schools of thought such as total quality management, six sigma and lean manufacturing have all drawn at different times from a simple 'supplier, input, process, output, customer' model known as 'SIPOC'. Below the authors present a modified explanation of the SIPOC model (Figure 5) that the reader can use as a prompt to ensure all relevant information is captured and used to draw the 'how' as described above (Morley, 2014).

For any operation to move beyond backward looking reconciliation to analysis and prediction, the authors recommend the SIPOC process (Hargreaves and Morley, 2014) and for this purpose the simple SIPOC checklist can be explained as:

- *Supplier* – where does the information required come from?
- *Input* – what are the inputs needed to complete the process?
- *Process* – detail what is actually done with the data/ information and how it is done. Are there decision points or quality control loops?
- *Output* – what are the results of the process? Is it more data, a model, a report?
- *Customer* – where does the output go? Who does this process become the supplier to?

By using this matrix of roles and activities and including details on suppliers, inputs, assumptions made, data collection points, outputs and customers it is possible to document the information and ore flow across a mine in such a way that anyone can easily visualise and understand the process (Figure 4).

Critical to the documentation of the process map is the process of meeting with those responsible for, and those that actually completing, the steps being documented. A significant amount of value is derived from the conversations that are held with all stakeholders in the processes being documented. This activity breaks down the technical silos and often clarifies things to site personnel who, due to the demands of production, workloads or knowledge, have not had time to ask these questions themselves. To paraphrase a proverb 'the benefit is in the journey of discovery' associated with drawing the process map rather than in the finished map itself (Morley, 2014).

The key outcome of this mapping exercise it to identify and record specific and actionable issues/opportunities.

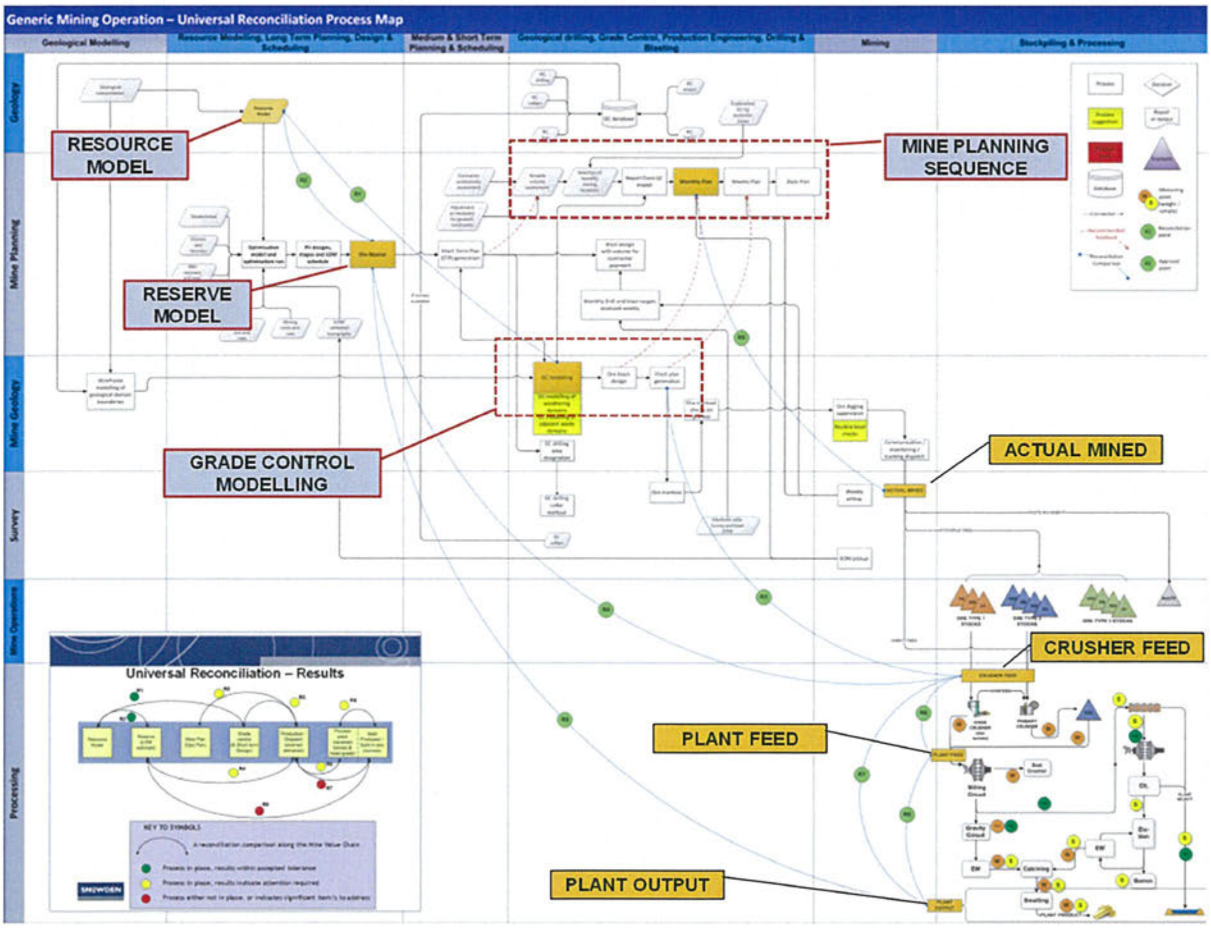

FIG 4 – A helicopter view of a typical mine site process flow.

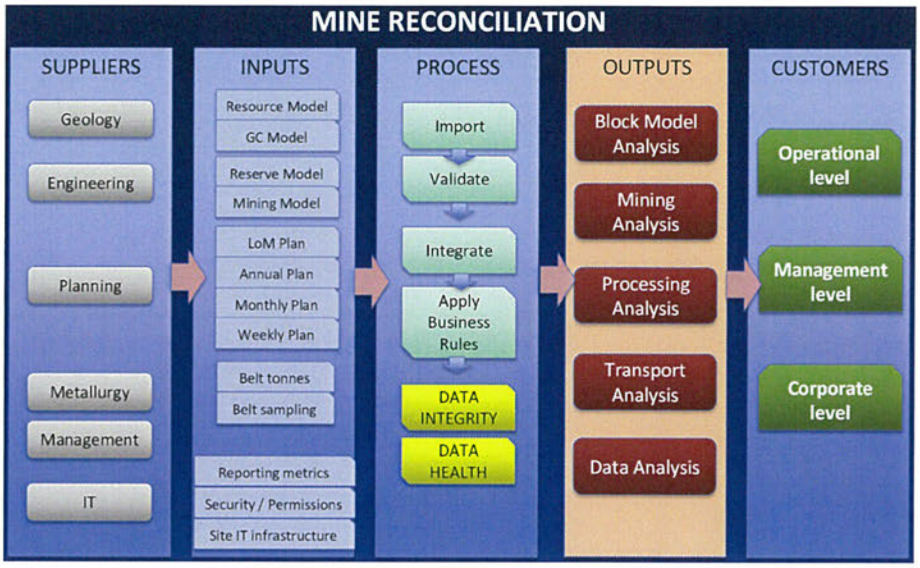

FIG 5 – Universal reconciliation works at an operational level using 'supplier, input, process, output, customer' (SIPOC) checklist (after Hargreaves, 2014).

Significant value can be identified by ensuring that a dollar or metal equivalent value is placed on the benefit associated with delivering each initiative. In the authors experience a universal reconciliation exercise can typically identify 60 to 100 of these opportunities per site.

Based on value and ease of execution, a heat map is a useful way to prioritise the opportunities. Inevitably a number of these initiatives are quick wins and many can even be executed and completed during the universal reconciliation mapping exercise.

Having created the ore flow and material movement process map will have resulted in the collection of information on a number of issues and opportunities that can be actioned as individual projects to improve the performance of the mining operation. A key objective of a universal reconciliation process is to achieve sustainable improvement. Once a range of projects are underway to address the opportunities identified during the mapping exercise it is also important to take another step to ensure that the learnings from the mapping are captured and that the mine site does not revert back to 'old habits'. The next step is the documentation of a reconciliation code of practice.

In the authors experience all the data required to document and define a mine site's reconciliation code of practice will also have been collected during the mapping exercise. The important aspects of what should be included in a code of practice will now be examined in more detail.

Document a reconciliation code of practice

Having gone to significant effort to establish a multidisciplinary team and then document the ore flow and material movement activities across the value chain and implement a range of improvements it is also important to put in place documentation based on these learnings to ensure that the changes can be made sustainable for the future. In this way the gains achieved through universal reconciliation can be made ubiquitous across a mine site or organisation.

> *A reconciliation code of practice is a high-level 'standard setting' document that sets out a series of principles that form part of a mine's or company's systems and procedures. In this case the objective is for the code to provide ideas or standards on how reconciliation issues may be approached and the code should also set the benchmark of what are acceptable practices and methodologies. Obviously these will vary in detail from company to company and in many cases will even change from mine site to mine site* (Morley, 2014).

However, the objective is to have an explanation of terminology, methodology and processes so that every individual and site is not constantly inventing their own.

Morley (2014) states that a reconciliation code should:

- identify key reconciliation relationships
- identify the data sources and record the activities involved in collecting, validating and storing the data
- clearly define any post processing that is carried out on the input data
- clearly define the calculations that are carried out using the data to derive reconciliation results
- document the standard reporting frequency, charting and end users of the reconciliation results.

To identify, define and document the key items above, it is necessary to have a comprehensive understanding and the ability to capture the entire mine value chain with all of its inputs, outputs and required reporting. Across the mining value chain, it is recognised that a range of activities are common to most deposits. There are definitive relationships along the mining value chain where comparisons can be routinely undertaken to measure and assess mine performance and highlight when issues may arise. Figure 6 shows a range of reconciliation relationships that the authors recommend should be considered across most mining operations.

In terms of nomenclature the reader will see in Figure 6 that each reconciliation relationship adopts a standard naming convention that is derived from the source of information along the mining value chain as follows (Morley, 2014): '… name of the earliest source of data' to 'name of the later source it is being compared to'.

Therefore, reconciliation of the resource model against grade control information is named 'resource model to grade control'. Table 1 provides a list of reconciliation relationships that in the authors experience the reader should consider including as part of any reconciliation code of practice.

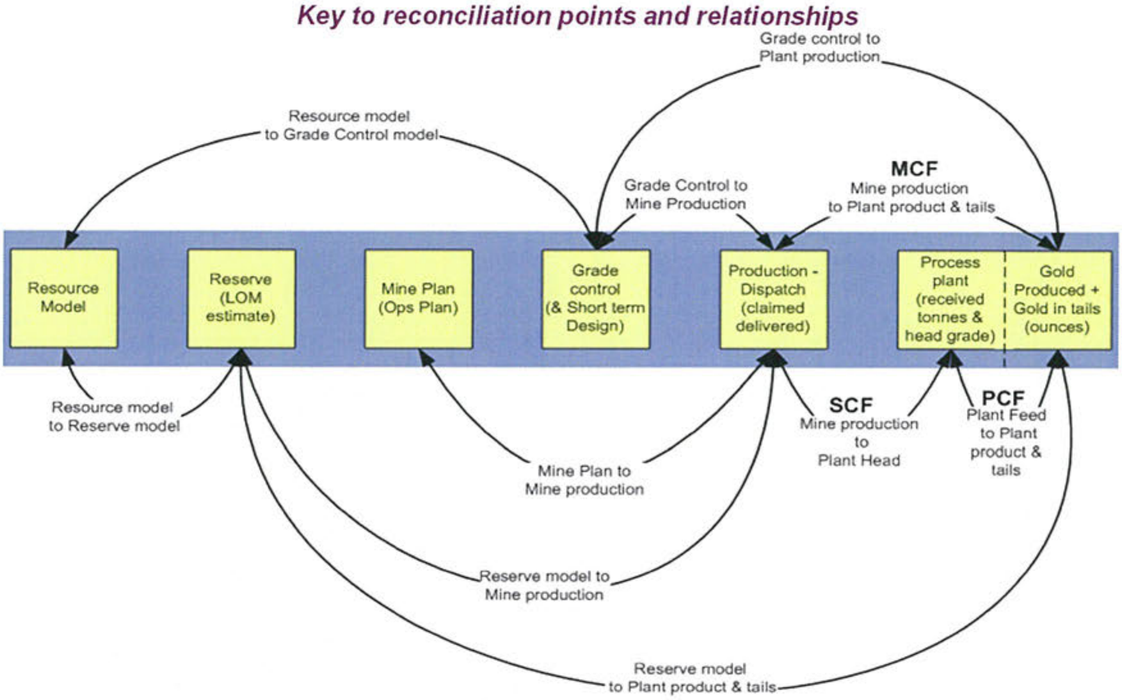

FIG 6 – Reconciliation relationships across the mining value chain (after Morley, 2003).

TABLE 1

Standardised reconciliation nomenclature (Morley, 2014).

Section within mining process	Standardised reconciliation relationship 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 verses actuals reconciliation	Resource model to mining production
	Resource model to plant feed
	Resource model to plant production
	Reserve (life-of-mine plan) to mining production
	Reserve (life-of-mine plan) to plant feed
	Reserve (life-of-mine plan) to plant production
	Reserve (life-of-mine plan) to shipping
Mining reconciliation	Grade control model to mining production
	Grade control model to plant feed
	Grade control model to plant production
	Mine plan to mine 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

Many mining businesses focus on mineral wealth management primarily at the execution end of the value chain (Figure 7). The reality is that significant value is lost across the entire spectrum (Figure 8).

Other key elements required for documenting a reconciliation code of practice include:

- data collection and validation processes
- data error ranges and tolerances
- methodologies and calculations
- reporting standards
- accountabilities.

An example of a standardised summary template is shown in Table 2. This template can be modified and used for all reconciliation relationships and will provide a basis for collating the information required for the reconciliation code of practice.

The details associated with completing a code of practice for reconciliation, including information on process mapping and templates to assist documentation are provided in Morley (2014) and so will not be repeated in this paper.

Implementing a system to make the changes sustainable and monitoring change

While a reconciliation code of practice sets the benchmark as a source of whom, how and what should be done, it is critical to also have a system that monitors performance on an ongoing basis and provides transparency and visibility of key reconciliation metrics along the mining value chain. Having gone to the effort of completing a diagnostic mapping exercise, implementing improvement projects, documenting a code of practice, training personnel and making changes within a mining operation or company it is critical to imbed a system that allows tracking of key metrics and can show early signs of potential issues arising. Such a system allows mining professionals on operations time to react before good practices are abandoned and losses become systemic.

All mines run a suite of line of business applications across the traditional technical silos in order to allow these mining professionals to complete their design, planning and production tasks. In the majority of cases a Microsoft Excel based system is also being maintained somewhere in this

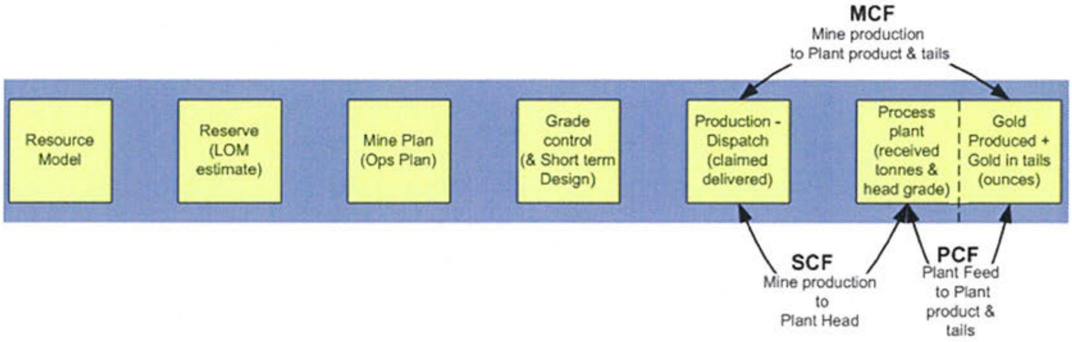

FIG 7 – Typical focus on mineral wealth management at the execution end of the value chain.

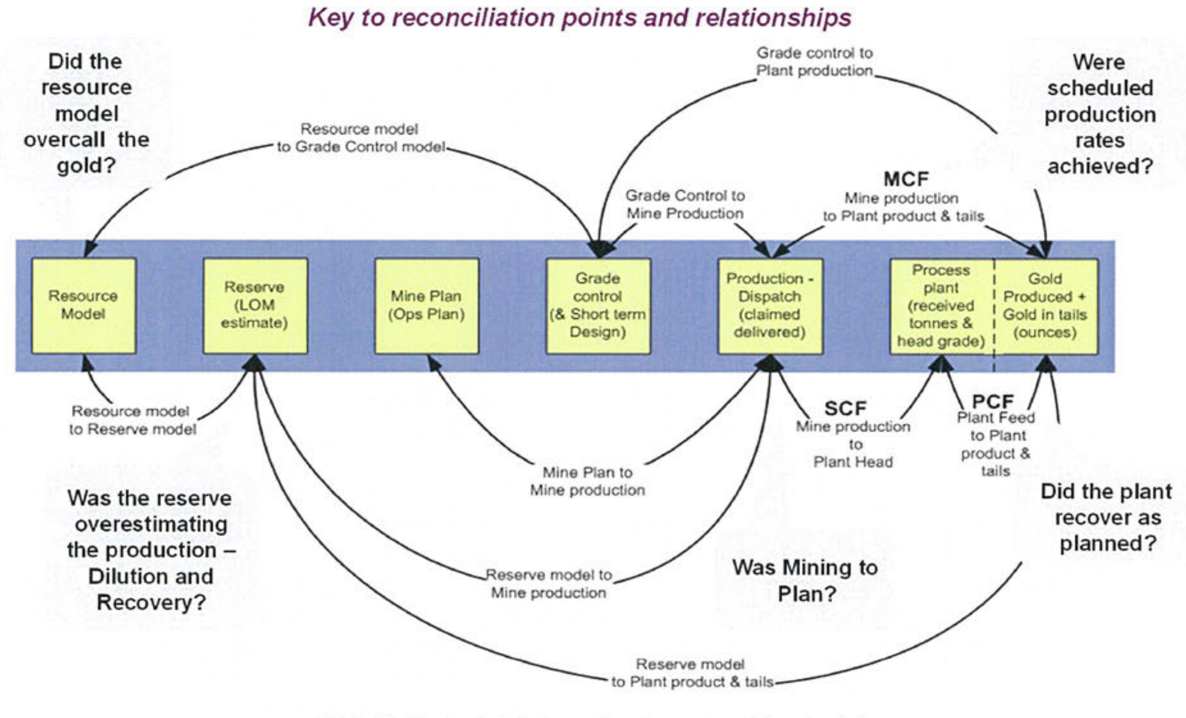

FIG 8 – Significant value is lost across the entire spectrum of the value chain.

process, in an attempt to tie all the information from along this chain together. However, in the author's experience such systems are complex, include significant errors, absorb huge quantities of personnel's time, lock up knowledge with specific individuals and are often duplicated by each professional silo resulting in most discussions focusing on who's data is right or wrong, rather than what the data is revealing.

A commercial system is a reliable solution that can produce accurate and validated results and in the authors experience will pay for the investment to implement it in less than six months. It will provide both technical professionals and managers with the analysis, reporting tools and dashboards they require to monitor the operation and continuously improve on the foundations that have been put in place. Figure 9 shows an example of such a system that, in the author's experience, has been effective over a wide range of companies, commodities and countries.

CASE STUDIES

The authors have been engaged by a number of companies to carry out universal reconciliation-site diagnostics, using the methodologies outlined above, to identify both issues and opportunities and then define actions to either mitigate or leverage these findings as the case warrants. Table 3 presents recent experience across nine mines located in five different countries where significant opportunities were identified along the mining value chain to increase the mines product output with subsequent benefits being expressed in US$.

These operations were viewed by their different owners as being at a wide range of efficiency and productivity. In the authors experience opportunities were identified and value could be added not only at operations that were labelled by their owners as having issues, but also at operations that the owners believed were world-class and that were free of issues.

The scope of work for the multidisciplinary universal reconciliation teams on these different projects included the following:

- documentation of a detailed process map to clearly indicate the existing processes
- provide experienced reconciliation knowledge across the mine value chain by having site personnel working

TABLE 2
Example of a template to document the methodology and calculations carried out for various reconciliation results of any given reconciliation relationship (Morley, 2014).

Name	Mining production to plant feed
Data required	• Mine production – dispatch data for material leaving the pit corrected using survey data. • Supervisory control and data acquisition (SCADA) systems for the plant production data and Laboratory information Management Software (LIMS) sampling results.
Frequency	• Monthly.
Accountability	• Owner – production manager. • Actioned by – short-term production engineer.
Calculation	• Tonnes = plant feed/mining production. • Grade = plant feed sampled grades/mining production grades (estimated or sampled).
Purpose	• Provides a measure of the effectiveness of estimates actual mining from direct feed ore sources (pit and/or underground) plus stockpiles, to material.
Comments	• Temporal reconciliation. • This factor will highlight issues with truck factors or weightometer calibrations. • 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 verses what the mill received.

with specialists in geology/resource estimation, mining/reserve estimation and metallurgy/mass balancing

- provide advice and guidance for critical data sources and make recommendations in relation to key reconciliation measuring points
- identify both best and substandard practice and make recommendations for standardisation
- produce a technical report evaluating current practices and provide each site with recommendations for developing effective and efficient systems for mine reconciliation.

Case study 1

In one specific example a diagnostic was commissioned because the owner was seeking answers to why the mine was struggling to meet its production guidance targets. A range of factors were involved including:

- ore grades achieved in fresh rock mining were not as reported in the resource model
- plant recoveries were not as predicted and included in the mine plan
- the operation was falling well below target production which was impacting the company's share price.

As a result of applying the methodologies outlined above during a one week diagnostic exercise on-site a number of recommendations were made including the following:

- improved material type definition and ore block designs
- focus on dilution and ore loss issues especially around blasting practices
- change the blending and ore feed strategy to optimise crusher feed
- improve coarse ore stockpile management and plant feed.

Of importance to note is that all of these recommendations required a change in practice rather than any capital expenditure or investment in new systems or technology. Under leadership by senior company executives the site executed the strategies defined during the diagnostic and subsequently moved the operation into a position where they started to meet the production objectives defined in their monthly mine plans and achieve the guidance results that they were reporting to the market. The benefit to the company in terms of increase product from the plant was estimated to be over US$94 M over a 12 month period.

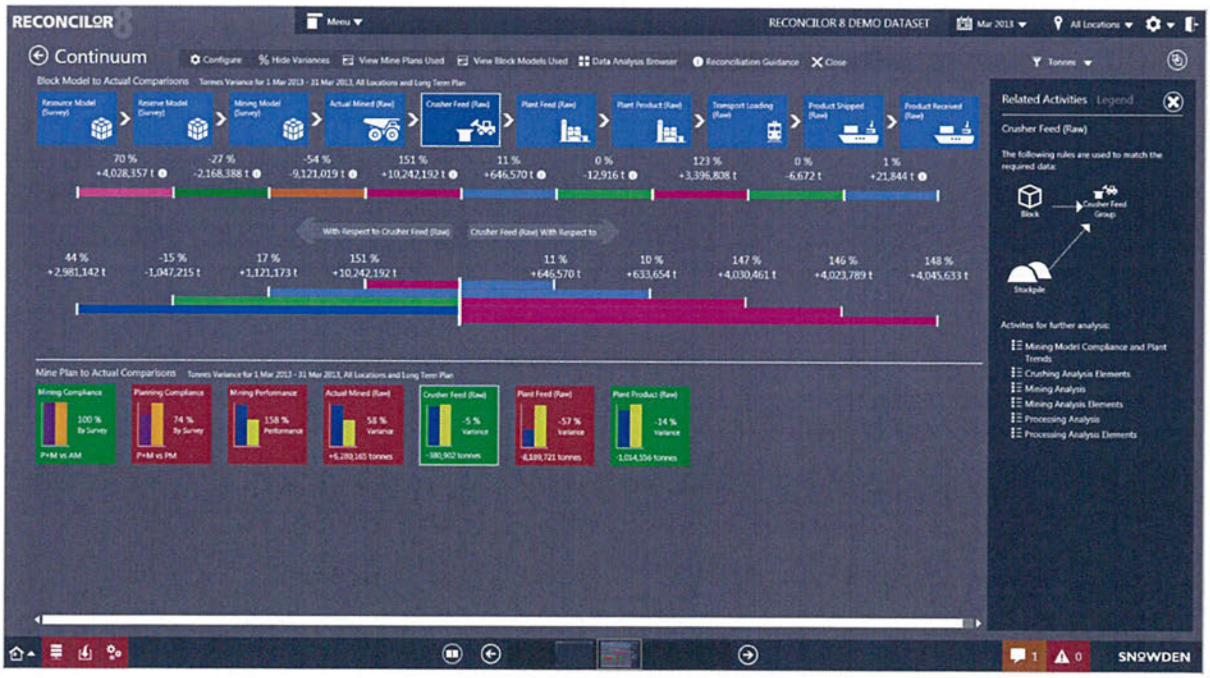

FIG 9 – A system that provides analysis and reporting tools and dashboards to monitor the operation and continuous improvement.

TABLE 3
Improvements to commodity produced shown as a percentage of total production.

	Geology and modelling (%)	Mine planning (%)	Grade control (%)	Mining and blasting (%)	Load and haul (%)	Plant (%)	Benefit in US$M
Site 1	2.0	2.0		0.5		0.6	12.9
Site 2					1.0		9.3
Site 3	0.5	0.5	1.0	1.5		0.5	19.9
Site 4		0.5		0.3			4.5
Site 5			9.0	2.0	3.0	24.0	94.0
Site 6			0.5	1.1	0.1	1.5	12.2
Site 7		1.0		1.1	0.5	0.3	40.8
Site 8		4.0	1.0	1.0		0.3	22.2
Site 9	0.5	2.5	2.0	2.0		0.3	17.7
Range	0.5–2.0	0.5–3	0.5–9.0	0.3–2.0	0.1–3.0	0.3–24.0	233.5

Case study 2

Converse to the experience described for case study 1 the authors experience at another site identified surprising results. The mine was continuously producing reconciliation results in line with those predicted by the mine plan and the owner believed the operation to be world-class with best practices being followed and little scope for improvement. The diagnostic mapping exercise resulted in some startling results.

While the mine was producing product at the targeted quantity and quality the authors discovered, while on-site, this was being achieved by use of a number of damaging activities that were high grading the mining operation. It was determined that resource modelling was significantly under estimating the quality of the ore grade material. This was resulting in the quality of the material being taken to the plant being higher than expected, but also that significant volumes of what was actually ore quality material was being sent to the waste dump. In addition, short-term mine planners and production personnel were targeting high-grade zones in order to exceed targets and attract bonuses. These two activities were being completely overlooked by off-site management who were only aware of results that reported the mine was producing product as planned and not that ore grade material was being put on waste stockpiles and mining practices were literally digging them into a hole that would sterilise ore reserves in the future.

Subsequent implementation of the findings exposed during the universal reconciliation exercise resulted in the reconciliation metrics reported by the mine taking a dip as they were aligned to accurately reflect what was actually happening on-site. However, over time as the issues were resolved the reconciliation metrics improved significantly and aligned with those predicted by the mine plan.

CONCLUSION

Universal reconciliation is a process designed to assess, define and prioritise actions required to improve the reconciliation systems and all mine value chain activities at a mining operation. Once the basis of the existing reconciliation practice is established and actions have been assigned to achieve the desired improvements, the application of a reconciliation code of practice ensures the process of reconciliation becomes sustainable and proactive leading to a situation of ongoing continuous improvement.

Fundamental to defining any reconciliation code of practice is defining the 'as-is' process. The foundations of a code of practice should include the agreed mine value chain for your operation, an agreed material movement flow and the reconciliation process map. The reconciliation code must identify the data sources, collection and validation activities. It should identify the key reconciliation relationships and define the calculations used for reporting reconciliation results along with reporting frequency, stakeholders and owners.

Finally in order to make the investment in universal reconciliation complete every mine should have a commercial grade reconciliation system that does not consist of Microsoft Excel spreadsheets. Such a system delivers a central repository of validated data, metrics, reports and dashboards that enable monitoring and subsequent early identification of potential issues and facilitates continuous improvement.

The results from the case studies presented show sites that have realised a benefit in the ranges of US$4.5 M to US$94 M per site over a 12 month period. This shows that by using a universal reconciliation approach and documenting a reconciliation code of practice, participants can realise tangible value in their mining operation.

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