Iron Ore Mine Reconciliation—A Case Study From Sishen Iron Ore Mine, South Africa

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ABSTRACT

Reconciliation at large iron ore operations is a complex and time-consuming process. Often the volume of data and the large range of different stakeholders makes the process almost impossible. Up until recently geologists and engineers at these operations would spend hours cutting and pasting data in and out of monster spreadsheets, diligently comparing how resource/reserve models, grade control and survey pick-ups compare to what was actually produced. In 2003 the Sishen Iron Ore Mine in South Africa broke this cycle by implementing Snowden's Reconcilor software.

The implementation of a dedicated reconciliation system required a number of existing practices to be changed, with the involvement of stakeholders right across the mine. Data sources had to be clarified and validated, terminology had to be standardised, processes needed to be documented and some methodologies needed to be updated. This was a task that required significant effort by Kumba personnel so that the system could be successfully implemented.

This paper provides a case study of the reconciliation system implementation at Sishen. It is a story of an operation that evolved from using a number of fragmented reconciliation processes to using a unified automated system. This paper outlines the key estimates and measurements that are used for reconciliation, details the characteristics of an automated web-based information management system to facilitate the process and provides some insights about the benefits that have been gained though the use of a rigorous reconciliation process.

FIG 1 - The location of the Sishen Iron Ore Mine and a view of the central area of the pit.

INTRODUCTION

Reconciliation is a bit like sex. Everyone thinks about it, many talk about it, most people do it, but only a select few ever arrive at the point where the results are remarkable. However, this does not need to be the case. Significant results can be achieved at most operations within one year of putting a system in place (Pitard, 2001).

In this paper the authors examine how Sishen Iron Ore Mine in South Africa implemented a reconciliation software system designed by Snowden and known as 'Reconcilor'. Sishen is one of the world's largest single open pit iron ore operations, moving approximately 110 Mtpa and producing around 27.5 Mtpa of iron ore from operations near Kathu at the base of the Kalahari Desert (see Figure 1). The mine is currently undergoing an expansion that will see production increase to 32 Mtpa by 2009 (Von Wielligh, 2005). The authors hope that by relating the experience at Sishen, and with reconciliation systems in general, others may identify similarities in their own operations and so will be able to adopt some of the learnings and practices detailed below to produce remarkable results of their own.

WHAT IS RECONCILIATION?

In a mining industry context reconciliation equates to the comparison of an *estimate* (a mineral resource model, a mineral or ore reserve model, or grade control information) with a *measurement* (survey information or the official production, usually from the processing or treatment plant) (Morley, 2003; Schofield, 2001). The basic aims of reconciliation are to (after Glacken and Morley, 2003):

- measure performance of the operation against targets;
- confirm grade and tonnage estimation efficiency;
- ensure valuation of mineral assets is accurate; and
- provide key performance indicators – in particular for grade control predictions.

BACKGROUND

Over the last five years Sishen personnel have been putting considerable effort into reviewing mining processes and implementing improvements. One of the major obstacles identified by site personnel was the lack of a centralised set of data that could be analysed and used to formulate strategies for improvement initiatives. Site personal were making a considerable effort to collect and analyse data and had been developing systems to address their individual needs. However, despite having honourable intentions, this resulted in fragmentation of the data, duplication of effort, and a lack of knowledge between disciplines (geology, planning, mining engineering, grade control, survey and production) of what information was actually available. Time was being wasted on discussing who had what data and which version was correct – and this meant there was less time available for analysing the data and making mining process improvements.

From Sishen's perspective the primary objectives of implementing a software system for reconciliation were:

- to put into operation a single, valid and universally used database for all production information;
- to automate the capture and validation of data from various sources around the mine;

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- to facilitate reconciliation between estimates (geology, grade control, mine planning) and measurements (dispatch, survey and the plant); and
- to routinely generate accurate and quality reports.

BREAKING OUT OF ESTABLISHED PRACTICES

Like any large organisation, Sishen's personnel work in discipline related groups that focus on doing the best in each of their respective fields. These 'silos' include the traditional mining departments of resource estimation, mine planning and design, grade control, survey, production and the plant. As different departments at any large and long life operation evolve, inconsistencies occur in the ways things are done and the terminologies that are used. The result is inaccurate information due to the differing assumptions and a tendency for data that could be used for process improvement not being widely communicated. At Sishen these issues had been identified and were being systematically addressed through a process of continuous improvement initiatives. The implementation of a reconciliation system that spanned all site departments was identified as an opportunity to not only solve reconciliation issues but also as a chance to examine work practices and to derive optimised processes.

Snowden worked with personnel from each of the relevant departments to understand their methodologies and to develop a process and data flow diagram (see Figure 2). This assisted with understanding what each group was doing while at the same time revealing opportunities to standardise some processes and reduce duplication of effort. Data sources had to be clarified and validated, some terminologies (such as stockpile naming conventions) had to be standardised across the site and some methodologies needed updating. Descriptions of many of these changes are documented below under the heading of 'Learnings'. The process of making these changes required significant effort by Sishen personnel to ensure that the full benefits could be obtained by the final reconciliation system solution.

LEARNINGS

Throughout the implementation at Sishen there was the opportunity to learn from the experience that both Kumba and Snowden personnel brought to the project. The authors have taken this experience, which includes some from other mining operations, and have summarised below some of our learnings. The objective of highlighting some of these issues is to provide a list that any site should consider when implementing or maintaining a successful reconciliation system.

It is important to note that these observations are based on a range of experiences at different mining operations. The list is not complete, but still may appear 'overwhelming' when considered in total. It is not the intention to 'boil the ocean'. Every company and mine site has different reconciliation processes and requirements. It is the author's experience that effective reconciliation results and benefits can be produced at most mine sites and the systematic resolution of issues such as those listed below will simply improve the quality of the results and increase the benefits. This is the ongoing experience at Sishen, which has been able to achieve a number of significant benefits from their reconciliation system (some of which have been documented in the section titled 'Benefits' below).

To make the observations easier to follow they have been grouped under the following headings:

- resource/reserve estimation and mine planning, which includes:
  - resource and reserve estimation;
  - long-term planning (life of mine);
  - medium-term planning (five year); and
  - short-term planning (forecasting) and annual reporting (budgeting);
- mining, which includes:
  - resource/reserve block depletion (despatch and survey data);

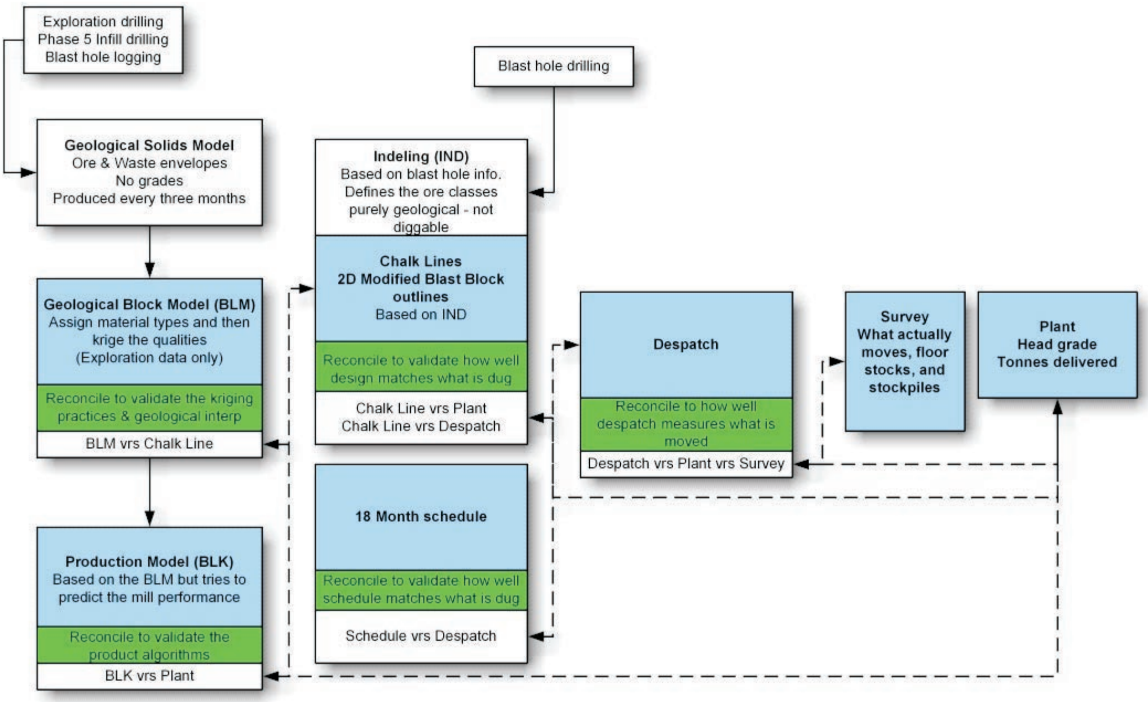

FIG 2 - Process and data flow diagram at the time of the reconciliation system implementation.

- stockpiling (ramp, run of mine, breaker and crushed stocks);
- plant processing, which includes:
  - feed, and
  - product;
- general observations and best practice.

Resource/reserve estimation and mine planning

- It is important that loss, dilution, quantity and quality assumptions are transparent throughout the resource, reserve, planning and scheduling process.
- Quality information and the way that it is smoothed for use at a planning level should be assessed so that confidence in the estimates can be quantified.
- The mine planning process should use internal standards for all parameters such as block sizes, orientation and naming conventions to allow meaningful reconciliation from long-term models through to budgets and schedules. This includes ensuring adequate block resolution is available in schedules, forecasts and budgets to allow reconciliation.
- Any modifying factors that are applied during the planning process should be examined to ensure they are valid and consistently applied between long-term, medium-term and short-term planning.
- Mine planning models should be centralised, limited in number, have some form of version control and be used by all different groups as the basis for scheduling and planning.
- Short-term planning models/forecasts/schedules should make use of any data that is more current/detailed than that used in the long-term planning process (such as grade control data, additional drilling or geological interpretations).
- Short-term planning processes should be examined and optimised to ensure there is no duplication of effort.
- The practice of applying ‘factors’ to resource or reserve model should be avoided. Reconciliation results should be used to calibrate the estimation techniques to ensure more accurately predicted plant performance and product results.

Mining

- Use of grade control and a grade control model should be considered as a standard practice.
- If in place, the Despatch system should carry block names and quality information provided by mine planning.
- Compositing of quality information within Despatch systems should be analysed and validated – but in general this should not be necessary and should be avoided.
- Material movement on and off stockpiles should be modelled on an appropriate basis. As a minimum arithmetic average, last on, first off, and first on, first off models should be used. For stockpiles that are critical to blending, layered or spatial models should be considered.
- Good stockpiling practice is to maintain small stockpiles that are frequently turned over (ie emptied and zeroed regularly).
- Large stockpiles should be surveyed and their volumes /inventories adjusted on an appropriate basis (relating to volume of material moving on and off the stockpile).
- A depletion process should be carried out on a regular basis and should use actual survey measurement data rather than human estimates.
- It is critical to reconcile ore blocks on the basis of how they are actually mined rather than as they are designed.
- If GPS equipment is being used then high precision GPS (<1 m resolution) should be considered to assist in defining mined floor positions and to aid in provision of loss and dilution data.
- Where possible, truck tonnage factors should be dynamic, not fixed and should be based on source (block or stockpile) and weather conditions.
- Where available, load weight information provided by VIMS should be captured and used to validate truck tonnage factors. Regular calibration of truck weightometers should occur as part of truck maintenance.

Plant

- Weightometer locations in the plant should be reviewed to ensure they provide a complete picture of feed, product and reject (both course and fine).
- Plant feed sampling should be examined to ensure composite feed samples are not being reported.
- Calibration of weightometers should occur on a routine basis.
- Sampling error (precision) should be calculated for all plant sampling stations to define level of confidence.
- It is necessary to collect quality information on reject material for plant balance and reconciliation.

General

- Any centralised database (ie a corporate database that receives data from line of business applications), which is proposed as a source of reconciliation data will need to be examined to ensure:
  - all relevant data is available; and
  - the data is at an appropriate resolution (ie not summarised to a level greater than a single shift).
- Databases/data sources should be examined to ensure that data is not being overwritten or deleted and that an audit trail exists to show why any adjustments are made.
- Manually entered data has the risk of transcription errors and time delays. If available electronically this data should be captured that way.
- The use of MS Excel and MS Access for core business functions in the resource estimation – mine planning – mine production – plant process should be examined and commercial grade systems/applications used where possible.
- Industry best practice is to have any corrections required to data made using the application that is generating that data and by personnel that use that application routinely.
- Having a ‘visible’ project sponsor supporting from a management level and assisting with obtaining buy-in at a site and head office management level greatly enhances any change management process.
- Key to the success of any project is having a project champion. On reconciliation projects this has typically been a senior mine geologist, or quality engineer. In Snowden’s experience the best project champion is someone who:
  - takes ownership over the system;
  - uses the system as part of their day to day routine;
  - has the support of management (politically and budgetary);
  - has the respect of peers; and
  - understands the reconciliation process.

- Software performance is often affected by the hardware that hosts it. A reconciliation system links many site processes and requires significant work to fine tune and optimise. Snowden recommend that the reconciliation system sit on a dedicated server.

Key estimates and measurements

Critical to the success of any reconciliation system is the capture of key metrics. Where possible this should be achieved by creating electronic links with source line of business applications and databases. Automated links drastically cut down the need for human processing of data and removes the risk of transcription errors. Typically data can be sourced from (Morley, 2003):

- resource and reserve models;
- mine plans;
- grade control designs;
- survey pickups of the actual mining activities;
- despatch systems or records;
- plant feed sources such as weightometers;
- plant performance indicators such as crusher power consumption, cyclone throughput, etc;
- plant calculations such as head grade; and
- plant actuals such as metal produced and tailings assays.

At Sishen automated data capture was established for:

- short-term mine plan,
- chalk line 2D modified blast blocks (grade control),
- drill and blast schedule data,
- despatch,
- survey (depleted tonnages and floor stock),
- some contractor data, and
- weightometers.

Import facilities were established to allow a number of geological block models and mine planning schedules (such as forecasts, budgets and production schedules) to be uploaded into the database. Table 1 summarises some of the data collected from these sources.

Sishen is currently in the process of commissioning a new sampling tower that will provide head grade information to the plant. Once this project is completed it is expected that feed quality data will be routinely captured by the reconciliation system, completing the process and allowing comparison of mine estimates to plant head grade.

With any measurement or estimate it is important to recognise and acknowledge the sources of error in the calculation. Where possible these should be minimised or eliminated as much as is practically possible. Such sources of error include (Glacken and Morley, 2003):

- sampling precision or accuracy issues as detailed above;
- survey errors, particularly with respect to stockpiles;
- stockpile grade modelling;
- ore held up in draw points and internal orepasses;
- any estimate of stocks associated with sublevel or block caving;
- volume calculation errors within overhanging or partially-blocked stopes; and
- estimating in-pit ore stocks.

These errors should not be confused with poor mining practice, such as dilution or ore loss. Reconciliation highlights the efficiency (or otherwise) of the mining process, and so it is important to separate the 'signal' (the true reconciliation result) from the 'noise' generated by the sources of measurement error (Glacken and Morley, 2003).

TABLE 1

Summary of some of the data captures used in the reconciliation system.

Source	Type	Parameters
Geological block model	Resource estimates	Tonnes, location, quality (Fe, SiO_2, Al_2O_3, K_2O, P and S), density and yield
Mine planning schedules	Budget, forecast, mine plans	Tonnes, location, quality (Fe, SiO_2, Al_2O_3, K_2O, P and S), density and yield
Production geology	Grade control dig blocks	Tonnes, material type, digblock ID, location, mining start and finish dates, quality (Fe, SiO_2, Al_2O_3, K_2O, P and S), density and yield
Despatch and survey	Mining and stockpiles	Tonnes, source, destination, double handling, volumes
Plant	Weightometer	Tonnes per shift, location

IMPLEMENTATION OF THE NEW SYSTEM

Implementation of the reconciliation system involved the participation from a wide range of personnel – each bringing experience and knowledge critical to the project's success. The team included geologists, mining engineers, surveyors, production personnel, IT specialists, software developers and database administrators. In summary the process involved:

1. process mapping of the data flows and reconciliation process;
2. commissioning of a dedicated database server;
3. implementation of commercial grade database software (Microsoft SQL Server 2000);
4. customisation and implementation of commercial reconciliation software (Snowden's Reconcilor);
5. establishment of links to other systems to automate data capture; and
6. design and implementation of reports.

Once the system has been fully implemented results from comparisons between geology, grade control, mine planning, dispatch, survey, plant weightometer and plant head grade can be analysed on a day to day basis. This enables Sishen personnel to identify a range of areas where process improvement processes can be applied. Some examples of these improvements to date are listed under the 'Benefits' section below.

Characteristics of the new system

Sishen's reconciliation system is a commercial solution provided by Snowden. The architecture is shown schematically in Figure 3 and consists of a centralised database into which all relevant data is captured and over, which sits a web browser based interface that provides reporting and analysis tools. The system runs off a single server that is located on site with the interface delivered to any user via a link on Sishen's intranet. For a reconciliation system it is critical that anyone on site can be provided with the relevant security level and then gain access to the system from wherever they are. By administering the system centrally from a single server, all information is instantly available to all users as soon as it enters the system. There is no software to install on

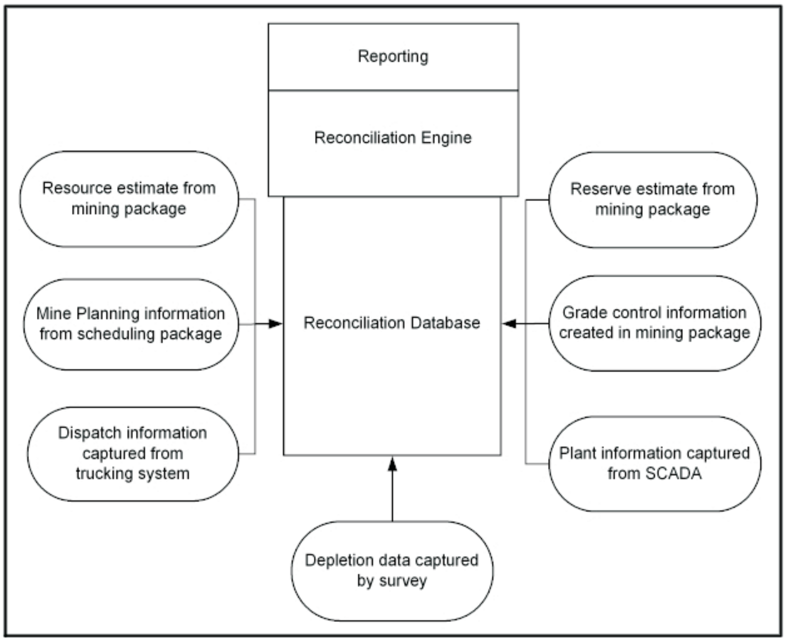

FIG 3 - Schematic illustration of a reconciliation system (Morley, 2003).

any of the users' PCs, so updating new features and reports is simple – as soon as they are uploaded to the server, they are available to everyone.

The front screen of Sishen's reconciliation system (see Figure 4) presents a process flow style overview of the entire operation from pit to plant. This screen includes both actual and forecast data so that daily and monthly performance is obvious at a glance.

Reporting is a critical part of the solution and is provided in the system via on-screen charts and tables (see Figure 5) as well as a reporting facility that provides users with the option to create standardised reports and view them on-screen, print them or export the data. Examples of some of Sishen's reports are shown in Figure 6.

BENEFITS

Often it is difficult to show how tangible benefits are being derived from the reconciliation process. Many sites are happy to report good reconciliation results (ie small variances) with a 'we told you so' type of attitude and then gloss over the results at a later date when they are poor. However, at Sishen the reconciliation system provides access to a wide range of data and this has allowed the operation to do more than just make monthly comparisons and derive 'mining factors'. Sishen has been able to produce remarkable results of which some examples are listed below. The authors hope other mines might be able to use these examples as indication of what can be achieved and therefore as justification for reconciliation solutions.

Ore gain/ore loss

At Sishen the difference between the budget value for a block and what is actually mined from that block results in an 'ore loss' or 'ore gain'. As the budget information is derived from the geological block model reconciliation between budget and actual results provides some indication of the accuracy of the block model.

Previously at Sishen final production results were compared with budget identifying ore losses and gains on a broad scale. With the implementation of a total reconciliation system the capacity has been obtained to compare data on a block-by-block scale – and with this detailed information improvement can be focused on areas where the variances are the greatest.

Underloading of trucks

Sishen was under the impression that they were, on average, just overloading their trucks. With a better understanding of the measurement process and improved access to the despatch data via the reconciliation system it was found that on average trucks were being underloaded. By increasing the average load on the trucks Sishen managed to increase production using the same fleet. Having the capability to analyse the despatch data and calibrate it with other production, survey and weightometer information has therefore assisted in better planning of Sishen's expansion of their truck fleet.

Double handling

Sishen has proactively implemented processes to constrain inefficient double handling of material in order to improve their production execution. As is practice in many operations Sishen maintains 'buffer stockpiles' that act as ore sources when periods of high rainfall affects production from within the mining operations. However, these stockpiles can often result in complex ore movements and the opportunity for inefficient double handling of material to occur – such as when material is moved from one stockpile to another. Routinely identifying where, when and why double handling of material has occurred has helped Sishen control the process and identify inefficient material movement. This has resulted in improved material movement efficiency and therefore lower costs.

Survey versus dispatch versus plant

Block naming convention differences was identified as one issue that has historically made it difficult to reconcile between survey, despatch and plant data. As a result of standardising conventions and automating the collection and reconciliation of the data, significant improvements have been made in the ore tonnes correlation between despatch, survey and plant data. In ore differences of less than two per cent between survey, despatch and plant data are now routinely achieved. Several initiatives are currently underway to improve the correlation between waste tonnes results from despatch and survey.

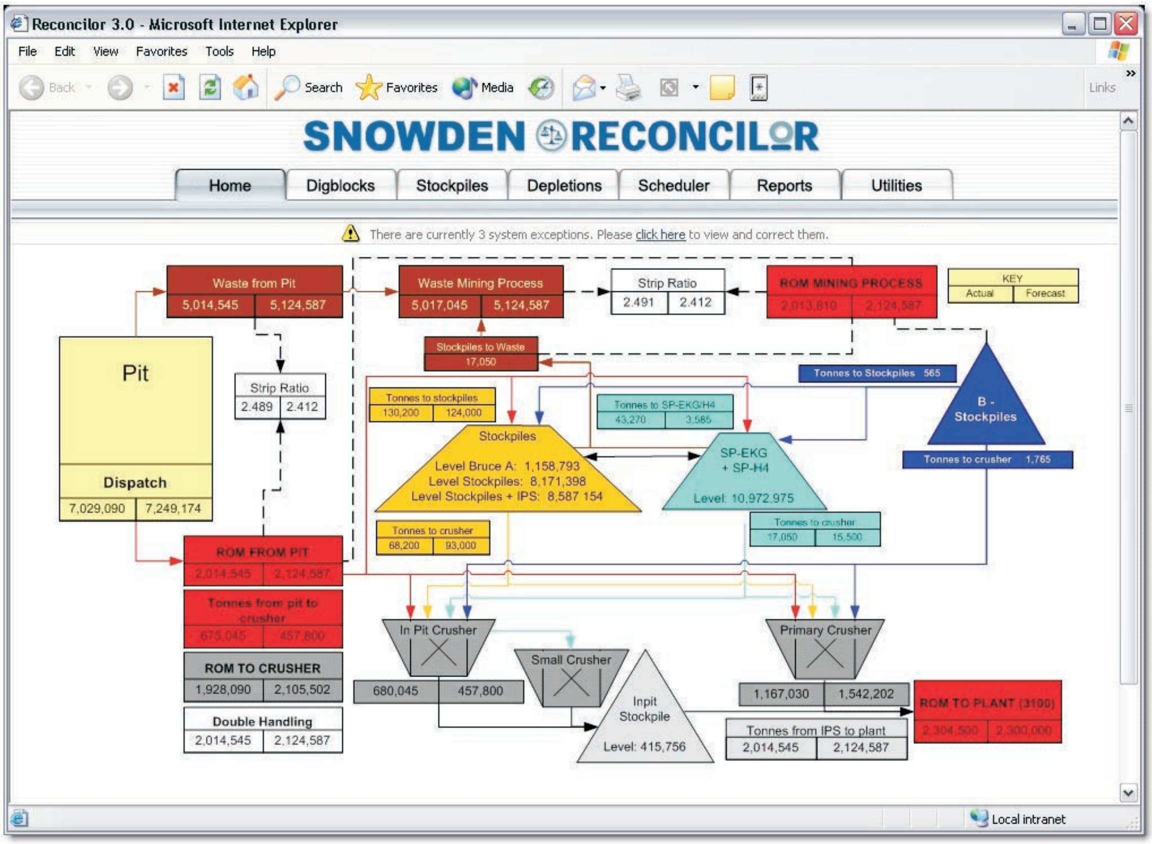

FIG 4 - The front screen of Sishen's reconciliation system.

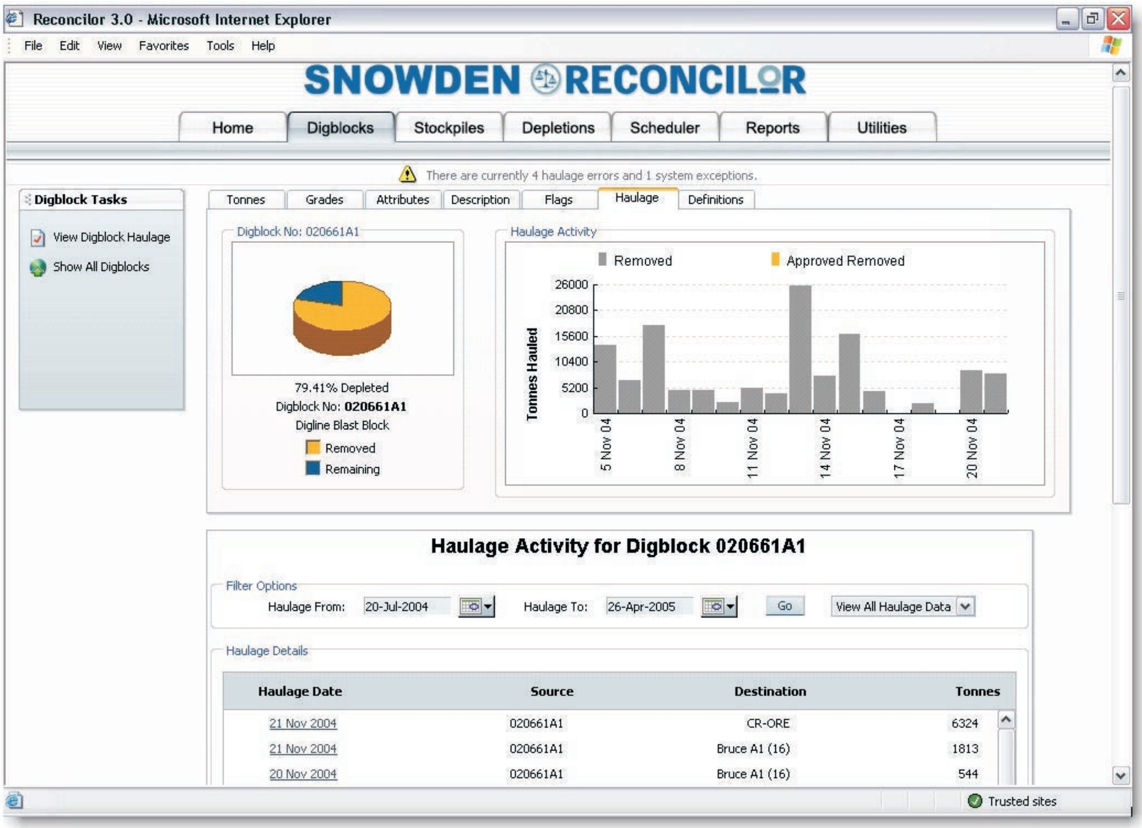

FIG 5 - An example of on screen reporting from Sishen's reconciliation system.

KUMBA RESOURCES

SISHEN IRON ORE RECONCILED MINING MONTHLY REPORT

SISHEN IRON ORE

Month: March 2005

Description	This Month					Annual Cumulative		
	Budget	Forecast	Reconciled	% Diff Budget	% Diff Forecast	Forecast	Actual	% Diff
Mining Operation								
ROM to Crushers	895 365	760 738	449 944	5.38%	1.26%	155 798	826 055	2.73%
ROM Mining Process	529 144	839 169	520 472	0.34%	1.23%	429 179	383 150	1.98%
Waste Mining Process	644 437	668 919	361 865	5.46%	4.84%	617 742	783 689	6.98%
Total tonnage mining process	173 581	508 088	882 336	9.88%	4.98%	46 921	166 839	8.90%
Stripping Ratio - Mining Process	1.836	1.644	2.127	5.84%	-29.36%	1.597	1.688	5.68%
ROM Mining Process	529 144	839 169	520 472	0.34%	1.23%	429 179	383 150	1.98%
Plus								
Ore Stockpiles to Waste			2 080				13 582	
Less								
Waste Stockpiles to Ore	0	0	3 219			0	47 019	
EX Pit Ore	529 144	839 169	519 332	0.39%	1.27%	869 179	349 712	0.13%
Waste From Pit	644 437	668 919	359 785	5.40%	4.80%	40 617 742	37 770 107	7.01%
Total ROM From Pit	173 581	508 088	879 117	9.84%	-4.94%	65 486 921	60 119 819	8.20%
Stripping Ratio - From Pit	1.836	1.644	2.127	5.85%	-29.37%	1.633	1.690	-3.47%
Less								
Contractor Waste Handled	545 706	545 706	407 080	8.97%	8.97%	920 774	783 156	6.54%
Total Tonnage By Sishen	627 875	962 382	472 037	5.00%	8.55%	566 147	336 664	6.14%
Stripping Ratio - By Sishen	1.225	1.100	1.569	28.06%	2.63%	1.114	1.207	8.42%
Plus								
Double Handling	377 878	148 280	89 873	28.16%	3.80%	474 087	210 382	2.07%
Total Handled By Sishen	005 753	110 662	461 910	6.51%	4.94%	040 234	547 046	7.13%
Survey (Digline) Tonnes Mined								
Survey (Digline) Ore			776 041				237 337	
Survey (Digline) Waste			194 061				200 309	
Survey (Digline) Total			970 102				437 646	
Stripping Ratio - By Survey			1.871				1.601	
Mining Process Ore Loss(-)/Gain(+)			55 569				54 187	
% Mining Process Ore Loss(-)/Gain(+)			9.206				3.676	
Mining Ore Loss(-)/Gain(+)(From Pit)			56 709				87 625	
% Mining Ore Loss(-)/Gain(+)(From Pit)			9.247				3.820	

FIG 6 - An example of a paper based style report from Sishen's reconciliation system (data is randomised numbers only and not actual results).

Mine planning process streamlining

Implementing a total reconciliation system gave Sishen the ability to define metrics, which helped personnel to better understand, quantify and improve the mine planning process. Metrics are usually defined as the gap between actual and planned results rather than quantifying the capability of the processes used to produce accurate results (Schneiderman, 1996). A thorough understanding of the mine planning process capability has given the confidence that if the mine plan is executed, the desired results will be achieved These improvements have not just improved Sishen's mine planning, but also energised personnel as they were able to quantify that the work they were doing was adding value.

Centralised data source

The implementation of a reconciliation system has meant the centralisation of a wide range of data that was previously stored in line of business applications or user built spreadsheets and databases. In some instances this distributed information was used for accounting purposes but was not conducive for use as a management tool. In the other instances invalid information resulted in Sishen personnel focusing on the wrong issues, causing inefficient use of resources and leading to attempts to solve symptoms and not the real causes.

Establishing a central source for all production related data has enabled Sishen personnel to focus on the actual problem areas, making it easier to identify the root cause of problems. With the ability to automatically get data from a wide area of stakeholders, it has made it possible to decrease long delays between the occurrence of a condition and the corrective actions that can be taken.

A central source of data has also helped improve communication. With the wide range of specialist fields in the mining process, change management can be a nightmare. Defining and reconciling the processes has helped to maintain change control, creating awareness between stakeholders on how they influence each other and encouraging all parties to keep communication open. Sishen's expansion project will see development work in new areas, so maintaining an integrated approach between processes and standardising notations and definitions will be very important. The reconciliation system will greatly assist in setting the benchmarks and maintain these processes.

CONCLUSION

The implementation of a reconciliation system at Sishen has resulted in a range of benefits such as lowering costs, improving efficiency, enhancing the accuracy of estimates and saving capital. Ongoing use of the system is expected to continue to provide similar benefits to the operation as the mine goes through an expansion phase between 2005 and 2009. In the authors experience application of the methodologies outlined above could be expected to deliver similar benefits at any iron ore operation where a rigorous reconciliation system has not been implemented.

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