Extreme Reconciliation—A Case Study from Diavik Diamond Mine, Canada

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Extreme Reconciliation — A Case Study from Diavik Diamond Mine, Canada

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ABSTRACT

The Diavik Diamond Mine is a world-class operation located in an extreme environment 220 km south of the Arctic Circle in Canada's Northwest Territories. The mine has a number of distinctive characteristics – such as limited winter access via an ice road, mine infrastructure being located on an island, with mining taking place behind dykes holding back a lake, temperatures at the mine that get down to -45°C in winter, and the presence of bears, wolves, foxes and wolverines! One thing that Diavik does have in common with other mines around the world is the need for reconciliation.

In late 2005 Diavik implemented Snowden's Reconcilor software system to facilitate the process of reconciling geological models, mine plans, production data and plant results. This paper provides a case study of the reconciliation system implementation. It outlines the migration of Diavik away from a comprehensive and effective spreadsheet-based reconciliation process to a commercial grade, automated and web-based information management system. This paper documents the reasons for moving away from the spreadsheet system, the key parameters used for reconciliation, and the benefits gained by closing the loop between reconciliation and ongoing process improvement.

INTRODUCTION

The Diavik Diamond Mine is a fascinating operation. Located 220 km south of the Artic Circle and 100 km north of the tree line (see Figure 1) the operation lies in the Canadian Arctic 'Barren Lands', the domain of bears, wolves, foxes and wolverines. For eight months of the year the tundra, with numerous lakes, bedrock outcrops and glacially deposited boulder fields and eskers, is frozen and covered by snow. Temperatures at the mine get down to minus 45°C with wind chill lowering the temperature even further. For most of the year the site is only accessible via air, but during winter an ice road provides access for thousands of tonnes of equipment and fuel.

The Diavik mining operations are currently centred on three kimberlite pipes that are all located beneath the waters of Lac de Gras. The lake is 60 km long and approximately 16 km wide with an average depth of 12 m. The mine infrastructure is located on an island only 20 km^2 in size, with mining taking place behind dykes that hold back the lake (see Figure 2). All construction in this area is further complicated by the existence of permafrost, which can occur within 1 m of the surface. Diavik's first dyke around the A154 pit was completed in July of 2002 and built from four million tonnes of crushed rock, flexible concrete and pressure-grouted bedrock. Thermosyphons were installed where the dyke crosses islands to maintain the permafrost. Construction is currently underway on the second dyke for the A418 pit.

The kimberlite pipes represent the roots of relatively young volcanoes (dated at 55 million years old) and are surrounded by Precambrian granites and metamorphosed sedimentary rocks that are approximately 2.7 billion years old (Diavik, 2005). The Diavik Diamond Mine pipes range in surface area from 0.9 to 1.6 ha, and extend below 400 m. An image of the pipes as currently modelled is shown in Figure 3. These pipes are the host rock for gem quality rough diamonds, which are split between the two joint venture partners Aber Diamond Corp and Diavik Diamond Mines Inc.

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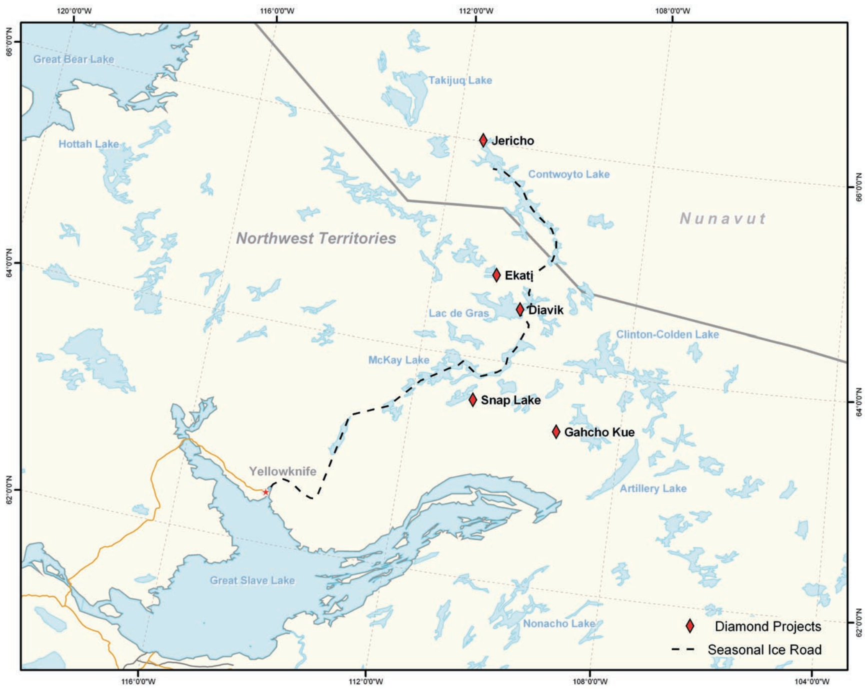

FIG 1 - The Northwest Territories of Canada showing the location of Diavik Diamond Mine.

FIG 2 - View of the Diavik mine from the air showing mining behind the dyke wall and infrastructure.

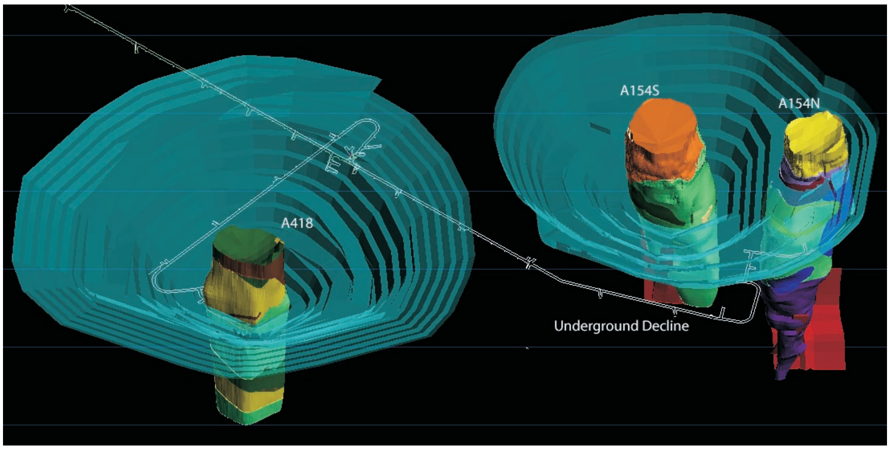

FIG 3 - Computer modelled image of the diamond pipes.

Diavik is a comparatively new operation with the discovery of the pipes occurring in 1994/95. In July 1996 a 5900 tonne bulk sample was taken from an underground exploration decline. Mine construction then began in January 2001 and mining followed 11 months later. Diamond production commenced in November 2002, with the operations producing one million carats by May 2003. Mining continues with ore processing at approximately two million tonnes annually.

Since mining commenced, reconciliation at Diavik has been completed using a comprehensive and effective spreadsheet-based system involving annual compilation and processing of all relevant data to produce a result. In mid-2005 Diavik began the implementation of Snowden's Reconcilor software system to facilitate the process of reconciling geological models, mine plans, production data and plant results. This paper provides a case study of the implementation of a commercial grade, automated and web-based reconciliation information management system.

MINING RECONCILIATION

Reconciliation is all about the comparison of an *estimate* (a Mineral Resource model, a Mineral or Ore Reserve model, Grade Control information, or a mine production plan or schedule) with a *measurement* (survey information, material movement records or the official production, usually from the processing or treatment plant) (after Morley and Moller, 2005; Schofield, 2001). The basic aims of reconciliation are to (after Glacken and Morley, 2003):

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

When monitored on a regular basis, the reconciliation process will uncover problems with grade and tonnage estimation, sampling, mining methods, processing problems and a host of other technical problems (after Crawford, 2003). These problems can then be analysed and improvements in the process can be implemented to resolve them. The anticipated result of this cycle will be continuous improvement resulting in improved carat forecasting, mine planning, process plant performance and overall optimisation of the Diavik resource.

Increasingly reconciliation is playing an important role in a statutory context as a result of industry codes such as the Australasian Code for Reporting of Mineral Resources and Ore Reserves (the JORC Code, 2004), the South African Code for

Reporting of Mineral Resources and Mineral Reserves (SAMREC, 2000), the Canadian National Instrument 43-101 (2001) and legislative requirements such as the Sarbanes-Oxley Act (SOX). The purpose statement of SOX summarises the intent of these codes and legislation as:

> *to protect investors by improving the accuracy and reliability of corporate disclosure made pursuant to securities laws and for other purposes* (Leech, 2003).

In a mining context these codes primarily deal with the issues surrounding the accuracy and public reporting of Resource/Reserve estimates and production statistics. As described in Biddle and Means (2002) more than ever before there is an emphasis on maintaining the audit trail of how these estimates are made and how they are validated. This is one of the roles reconciliation plays, where a company can demonstrate that not only has it created a Resource or Reserve estimate but that the company is also monitoring the mining of that material, diligently comparing actual performance with the original estimates and, where necessary, modifying and improving the estimation methodologies to ensure more accurate prediction. This reconciliation process is key to demonstrating that the company is ensuring that corporate disclosures on Resource, Reserve and mining performance are accurate and auditable.

KEY PARAMETERS USED FOR RECONCILIATION

Critical to the success of any reconciliation system is the capture of key data. Typically data can be sourced from (after Morley, 2003):

- Resource and Reserve models;
- survey pickups of the actual mining activities;
- mining personnel's observations of mining activities;
- plant feed sources, such as weightometers and auto samplers;
- plant performance indicators, such as crusher power consumption, cyclone throughput; etc
- plant balance calculations; and
- plant actuals, such as commodity produced, reject and tailings volumes and assays.

Where possible this information should be captured automatically; this removes the risk of transcription errors. 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 ore passes;
- 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).

As stated above, reconciliation is about the comparison of estimates with actuals and so it is important to recognise which parts of the process reconcile together. Figure 4 presents a schematic process flow summary of a generic mining operation from Resource estimation through to production of a commodity. On this diagram, eight key relationships have been highlighted using arrows and numbers. In the authors' opinion these are the key reconciliations that any mining operation should be monitoring on an ongoing basis. Table 1 provides an explanation of the data sources, time frame and purpose of each of these eight key relationships.

The authors also acknowledge that in some commodities it will also be important to reconcile between the plant and the point of delivery, such as a port or rail head, where further blending of material may occur. Reconciliation between plant and sales could also be important if further refining of the plant product takes place prior to sale to customers.

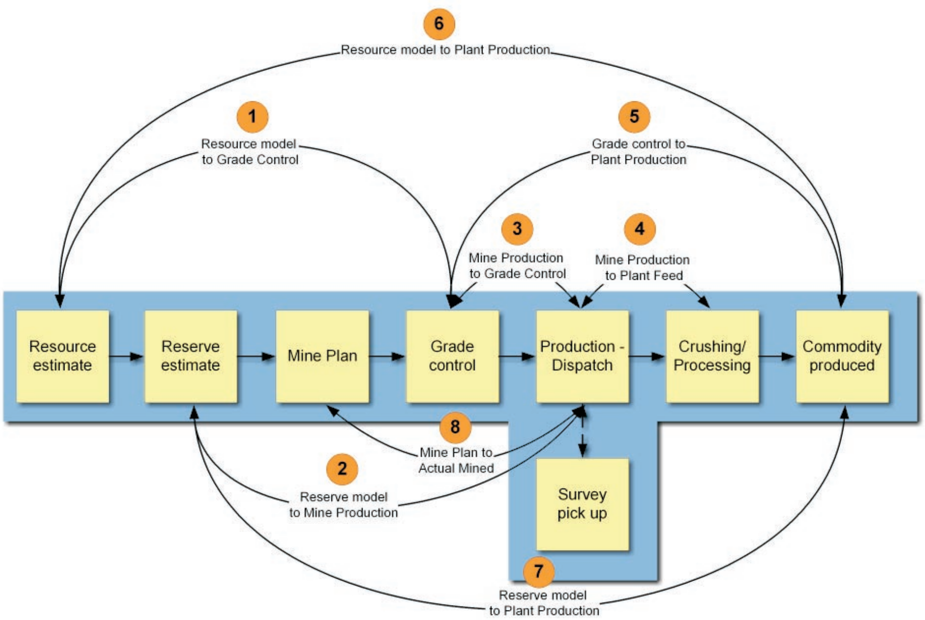

FIG 4 - Generalised mining process map showing eight common reconciliation points.

TABLE 1

Key reconciliation relationships on a mining operation.

	Reconciliation	Data sources	Time frame	Purpose
1.	Resource model to grade control	Resource model Grade control mining block designs	Monthly data showing annual trends	Used to validate resource model estimation and tonnage calculation assumptions. Long-term view with the objective of improving the quality of resource model estimates.
2.	Reserve model to mine production	Reserve model Survey pickups Plant feed tonnes and grade	Monthly data showing annual trends	Used to validate reserve and design assumptions against actual mining practices. Long-term view with the objective of improving the quality of mine design parameters.
3.	Mine production to grade control	Survey pickups Grade control model	Based on survey frequency, which should be at least monthly, but could be weekly or fortnightly	Used to compare what grade control designed to be mined and what was actually mined. Also allows tacking of truck factors. Short-term view to assist in improving grade control block design.
4.	Mine production to plant feed	Dispatch tonnes Grade Control Grades Plant feed tonnes Plant head grade samples	Daily data showing monthly trends and annual compilation	Used to validate grade control grade and tonnage predictions on a short-term basis. Assists in guiding daily mining activities.
5.	Grade control model to plant production	Grade control model Survey pickups Plant commodity produced	Based on survey frequency, which should be at least monthly, but could be weekly or fortnightly	Used to validate grade control total contained commodity predictions to plant actual commodity produced. Medium-term view with the objective of improving grade control estimation techniques.
6.	Resource model to plant production	Resource model Survey pickups Plant commodity produced	Normally monthly with annual trends	Used to validate Resource model total contained commodity predictions to plant actual commodity produced. Long-term view with the objective of improving resource model estimation.
7.	Reserve model to plant production	Reserve model Survey pickups Plant commodity produced	Normally monthly with annual trends	Used to validate Reserve model total contained commodity predictions to plant actual commodity produced. Long-term view with the objective of improving design and scheduling parameters and assumptions.
8.	Mine plan to actual mined	Budget/forecast/schedules Dispatch Grade control grades	Daily data showing monthly trends and annual compilation	Used to show variance to plan. This can be achieved in a number of different ways – but the authors recommend using Dispatch so that variances can be tracked on a daily basis. Short- to medium-term view with the objective of improving mine planning.

RECONCILIATION AT DIAVIK

Over the first few years of operations at Diavik reconciliation was carried out via the manual collection of data from sources such as:

- the Resource model,
- the Reserve statement,
- mine planning,
- truck counts,
- plant processing results, and
- production sorting facility results.

This information was compiled into a number of Excel spreadsheets and Access databases by a range of Diavik and Rio Tinto personnel and tonnage and grade reconciliation was carried out at irregular intervals in response to corporate requirements. The focus of the reconciliation was primarily on the quality of the resource estimates in terms of tonnes and grade. There was no waste rock reconciliation and the analysis of variation to mine plans and production schedules was completed as a separate exercise.

REASONS FOR CHANGE

In 2005 Rio Tinto personnel investigated alternative solutions to the current manual reconciliation process and commenced a project to trial a commercially available reconciliation system designed to automate the process and to provide daily information to the operation. The primary objectives in implementing the system were:

- to improve the transparency and recording of the data to satisfy statutory requirements,
- to automate the process in order to optimise personnel's time usage, and
- to provide ongoing quality reconciliation information to assist with fine tuning the operation.

THE SOLUTION IMPLEMENTATION PROCESS

The implementation of any new system requires defining the corporate requirements and site business activities in order to configure the final solution. In the authors' experience there is significant value in viewing these business activities as a series of linked processes instead of isolated tasks, activities and departments. The approach employed during the implementation of a reconciliation solution is therefore to use a multidisciplinary team consisting of both mining and IT consultants and site personnel to carry out process mapping to model the as-is process and to identify relevant data stores and flows.

An iterative interview and review methodology with key individuals is used to create a detailed flow diagram and system specification notes. Throughout the mapping exercise at Diavik, the team collected examples of data and reports and also drew on the experience of site personnel to provide suggestions. Consultants provided ideas on industry practice, alternatives and general advice and guidance. Figure 4 shows the breadth of the process mapping. Table 2 lists the range of technical staff that were consulted during the mapping exercise.

The production stream at Diavik consists of four key pieces, with the first being the geology and resource model for the kimberlite pipes. Prior to 2005, all resource work was done in MineSight using outside consultants to build the model. In 2005, with underground development on the horizon, the decision was made to change software packages and begin to build the resource model internally. A regular system of reporting grades,

TABLE 2

Roles of site personnel consulted during the process mapping.

Role	Description
Resource geologists	Geologist responsible for creating the resource models
Mining engineers	Mining engineers that do design and optimisation work to create the mine Reserves
Mine planners	Mining engineers that schedule mine production – long, medium and short term
Surveyors	Surveyors that measure mining progress
Dispatchers/ Production personnel	Personnel that track material movement in the mine and coordinate stockpiles
Plant personnel	Plant personnel that monitor plant performance and access data from equipment as samplers, belt weighers and plant production results
IT/Network administrators	Personnel responsible for the administration of the network and site databases
Management	Site management that have an requirement for production and reconciliation information

specific gravity and geology has been implemented on an ore cut level. This information is stored in a SQL-based acQuire database, which the reconciliation system can draw from.

The second piece is mine planning and pit operations. The mine plan is currently run using a customised reporting program called the Diavik Interactive Mine Planner (DIMP). This provides an Excel-based report that can then be loaded into the reconciliation system. The pit operations data is stored in an Oracle-based database using Ellipse. Mine clerks enter truck counts, source and destination data manually on a daily basis to track material movement.

The third piece is the process plant and recovery. The plant processes approximately two million tonnes of material annually and uses a non-chemical, largely gravity-based process to separate the diamonds from the waste rock. A data collection system, PI is used to monitor all the instruments in the plant; from the weightometer at the beginning of the process to flow meters at the end. It is important to understand that the PI system is designed to record inconsistencies in the flow of material so operators can identify any possible problems with instrumentation. Having a dataset with these inherent errors and unvalidated data, however, does not provide a proper dataset for reconciliation.

The final part of the stream is the product splitting facility (PSF) in Yellowknife. The final diamond sort is sent from recovery to the PSF for cleaning. Then the cleaned diamonds are split into two packages, 60 per cent for Diavik (Rio Tinto), and 40 per cent for Aber. The final numbers of carats produced after the cleaning process is the last piece of data needed for reconciliation. This number is stored in an SQL database known as the Diamond Tracking System.

FEATURES OF THE NEW SYSTEM

The general architecture of Diavik's reconciliation system is shown schematically in Figure 5 and consists of a centralised Microsoft SQL Server 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 Diavik's intranet. Anyone on site can be provided with a relevant role type in the system and security then dictates what they can see and do within the system. 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 any of the users

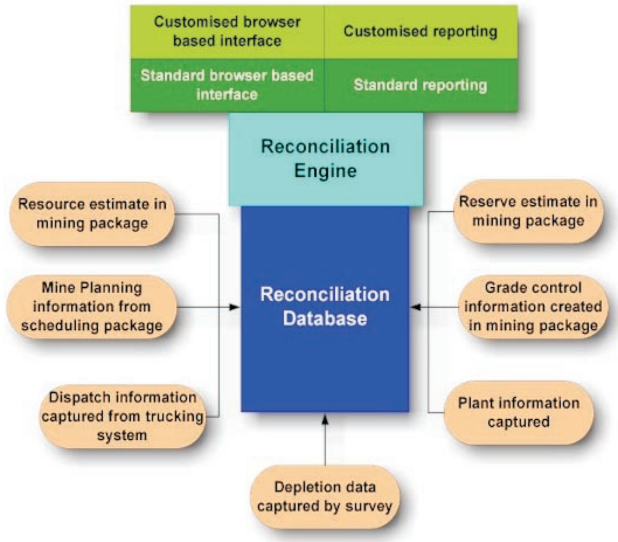

FIG 5 - Generalised architecture of the reconciliation system implemented at Diavik (Morley, 2003).

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 Diavik's reconciliation system (see Figure 6) is designed to provide site personnel with a snapshot overview of how the operation is performing. While this is not reconciliation information it is data sourced by the system automatically and the compilation provides a useful summary for the entire team. The screen presents a summary of production by shift, the last 24 hours and month to date. Forecast tonnages for the last 24 hours and month to date are also provided to allow personnel to see how the operation is progressing against plan. Ore inventories for ore exposed in each kimberlite pipe and for stockpiled ore are displayed.

Reporting is a critical part of the solution and is provided in the system via on-screen charts and tables (see example in Figures 7) 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 two of Diavik's reports are shown in Figures 8 and 9. A list of the types of reports being produced by Diavik from the system is presented in Table 3.

RECONCILIATION ISSUES

During the reconciliation system implementation project a number of issues were identified by Diavik personnel as having an impact on the process and thus the quality of any results. In the authors' experience these issues will have similarities to those found at other mining operations. A brief description is presented below in order to highlight them so that other mine sites may be able to identify and deal with them also.

Month end cut-off

In mid-2005 surveying of month end mining activity commenced at Diavik. Previously surveying had focused on the completion of the mining of a bench, rather than time-based pickups. This change in process caused some problems, as mining, the plant and the PSF then had to coordinate to achieve the same cut-off dates. At some mine sites dispatch information is used to cover the 'gap' between the time the pit faces are surveyed and the close of month for the other departments such as mining, plant and refinery. Diavik, however, managed to collaborate across the operation to ensure a consistent month end date, simplifying the process.

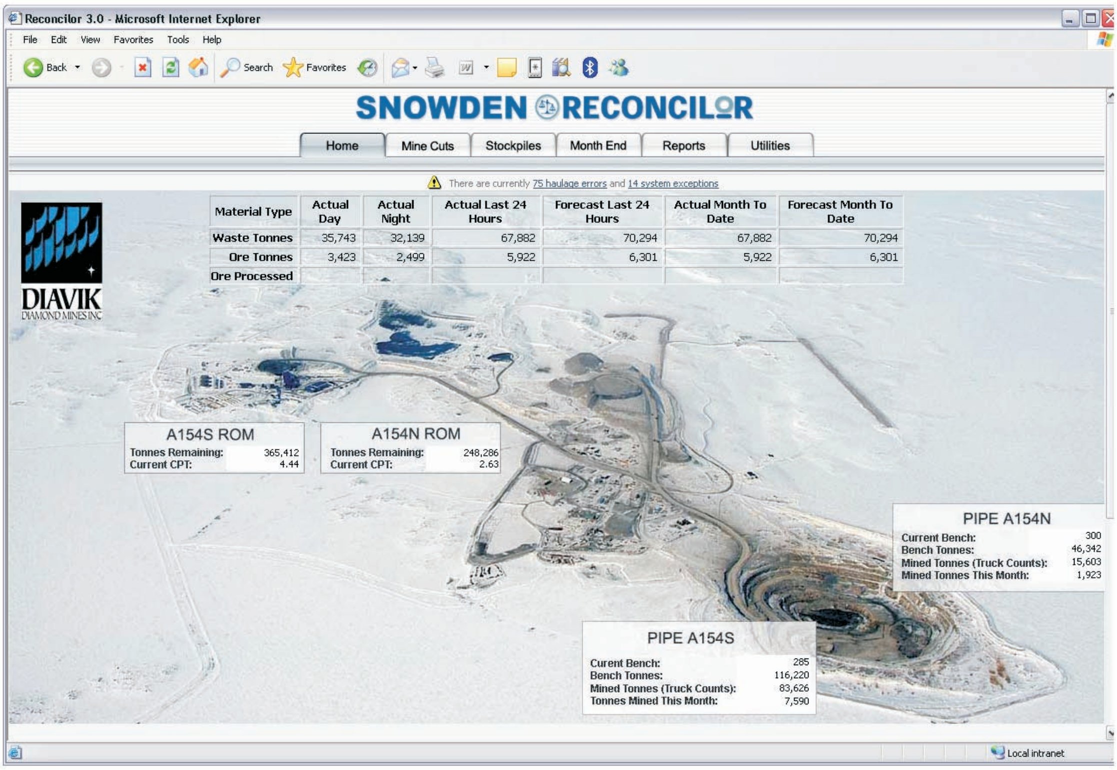

FIG 6 - Screen shot of Diavik's Reconciliation System's front screen showing general production data.

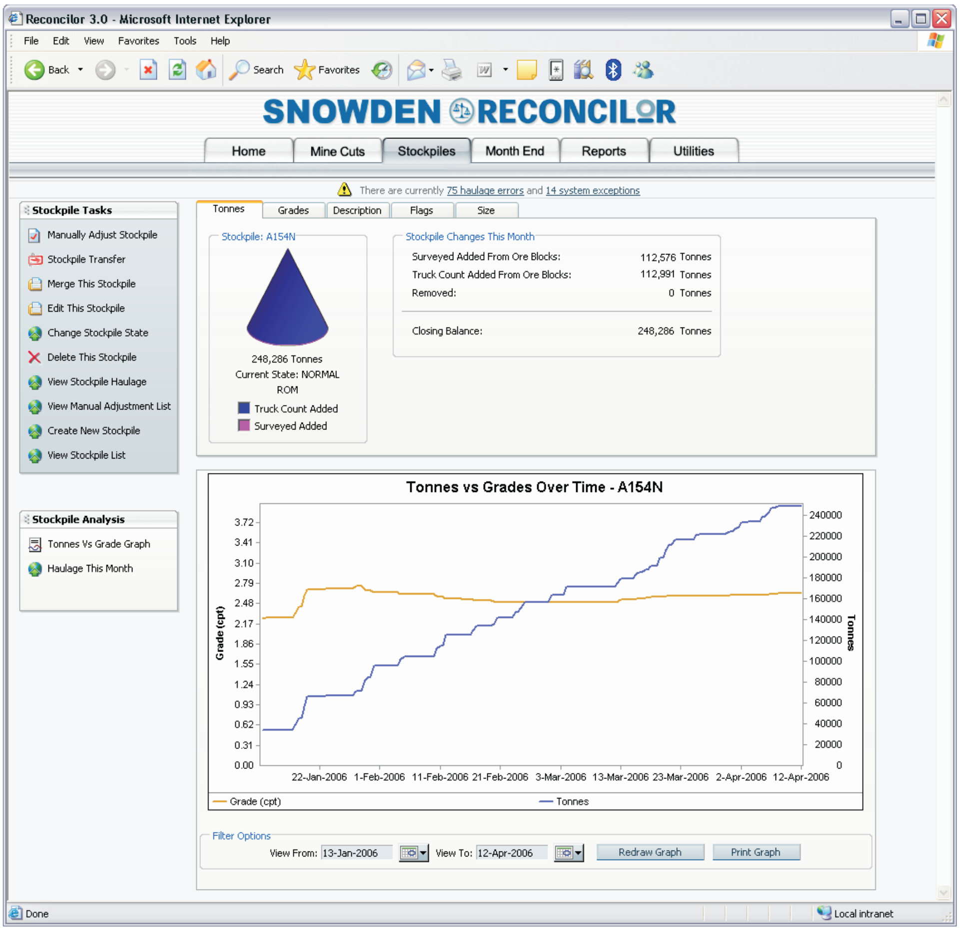

FIG 7 - An example of one of the screens presenting data and charts within the system.

TABLE 3

Types of reports being produced by the reconciliation system at Diavik.

Report group and name	Description
Reconciliation reports	
Reconciliation summary	Summary of Resource model versus survey and plant production
SG summary by bench	Summary of SG, moisture, BCM and tonnes by bench and geology
Daily dilution summary	Summary of plant tonnes and daily dilution by ore batch
Recovered grade	Chart showing recovered grade by bench against 2000 and 2003 model
Grade reconciliation	Chart showing model and plant grade reconciliation by ore haul
Grade reconciliation and DMS CT	Chart showing model and plant grade reconciliation with DMS coarse tails by ore haul
Grade reconciliation and DMS concentrate	Chart showing model and plant grade reconciliation with DMS concentrate by ore haul
Grade reconciliation and recrush	Chart showing model and plant grade reconciliation with per cent recrush by ore haul
Mine geology reports	
Recovered grade	Recovered grade by ore haul
Mine dry tonnes chart	Chart showing mined dry tonnes from survey and truck counts using mine density samples by month and cumulatively for the year
Mining summary	Summary of mining showing current bench, ore haul, volume, material movement and processing by kimberlite
Mine planning reports	
YTD mining chart	Chart showing cumulative YTD BCM mined by month
Volumes mined	Comparison between truck counts and survey BCMs

Plant residence time

In past reconciliations at Diavik the pit/plant numbers have been directly compared to the results produced by the PSF by date. However, due to a delay in diamond cleaning, which is typically two weeks, the diamonds produced do not actually relate directly to the material put through the plant during the same time period. This is a common issue on many mine sites with residence time on stockpiles or in the processing plant varying from hours to days in plants, to months or years in the case of stockpiles. Residence time often expresses itself in the form of a phase shift in reconciliation curves where it is reasonably consistent (such as in a plant). However, where residence time can vary, such as on stockpiles, it can cloud reconciliation results. Either way residence time should be taken into consideration when drawing conclusions from reconciliation data.

Plant batch blending

Prior to 2005 Diavik would batch all ore through the processing plant. However, in an effort to optimise the operation of the plant, blending was started in 2005. This successfully increased production but now makes it impossible to directly determine which diamonds come from which pipe. Blending to increase the efficiency of processing plants is common in the mining industry. Plants like consistent feed and often blending is the only way to ensure the optimum grade, hardness and level of contaminants is maintained. As Diavik has found, the only way to allocate the commodity quantity back to the source is via back calculation of weighted grades. This is a common practice and relies heavily on accurate values for mined volumes and careful tracking to provide the ratios to achieve this back calculation. Where possible, trial batches of material through the plant will greatly assist calibration of reconciliation results – however, the opportunity for conducting such trials are often rare due to the disruption of production.

Distributed data and expertise issues

At Diavik all mining, processing plant and geology data is located at the mine site. The PSF data is located in Yellowknife and the financial and production data is stored in an accounting system (Ellipse), 2000 km south of Yellowknife in Salt Lake

DIAVIK DIAMOND MINES INC.

Reconciliation Summary Report

Report Year: 2005

Pipe A154S

	Pipe Predicted			Actual Plant			Recovery
Ore Cut	Tonnes	Grade	Carats	Tonnes	Grade	Carats	(Predicted - Actual) / Predicted Carats
Bench 295							
A295-01S	64,331	4.32	277,844	57,898	4.49	260,062	93%
A295-02S	45,609	4.96	226,038	41,048	5.25	215,640	95%
A295-03S	59,885	4.73	283,437	53,897	4.92	265,297	93%
A295-04S	20,882	4.50	93,887	18,794	4.86	91,258	97%
A295-05S	36,489	4.76	173,869	32,840	4.96	162,741	93%
A295-06S	16,502	4.99	82,281	14,852	5.43	80,718	98%
Bench 300							
A300-01S	17,352	4.32	74,910	15,617	4.71	73,486	98%
A300-02S	64,261	4.49	288,402	57,835	4.62	267,349	92%
A300-03S	45,926	4.87	223,752	41,334	5.31	219,501	98%
A300-04S	36,852	5.10	187,834	33,167	5.45	180,884	96%
A300-05S	66,443	4.84	321,783	59,799	5.28	315,669	98%
A300-06S	64,558	4.72	304,390	58,102	4.81	279,430	91%

FIG 8 - An example of a tabular report from the system presenting reconciliation results.

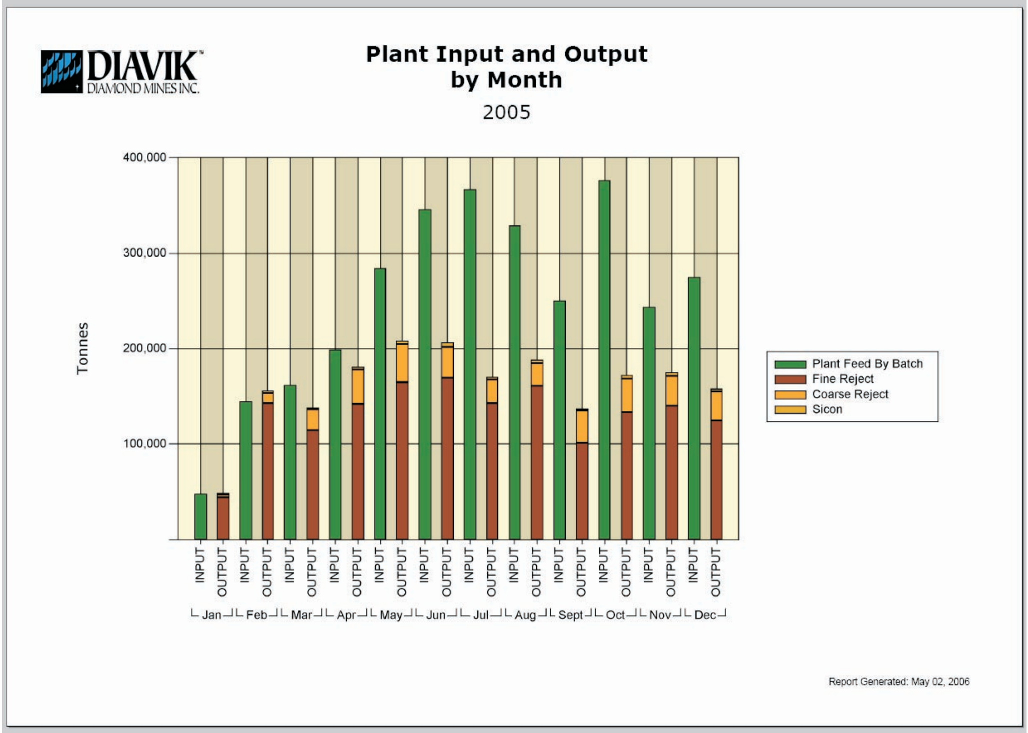

FIG 9 - An example of a chart produced from the system showing plant information.

City, Utah. In addition, all consulting expertise on the reconciliation project was sourced out of Australia (Perth). As a result it was a challenge to communicate, access data and meet deadlines throughout the project implementation.

Buy-in

Diavik was chosen by Rio Tinto Technical Services as a test project for the reconciliation system. It was therefore a challenge to prove to the plant/PSF/geology and management personnel that they would benefit from having another software system installed at site. As with any new system, the collaboration of a wide range of personnel across different disciplines such as geology, mining, survey, production and metallurgy in contributing to the project and understanding its objectives, is an essential part of the change management process. The speed of uptake will vary from mine to mine and person to person. At Diavik, this is an ongoing process with the new reconciliation system.

High staff turnover

A skill shortage within the mining industry and concurrent mining boom is expressing itself at many mines through a high turnover of staff. Since the first reconciliation project meeting at site Diavik now have completely new management in the plant and PSF and a new COO. Only the geology team has remained consistent and so it has been a challenge to build and rebuild relationships.

BENEFITS

While the process of implementing the reconciliation system is not complete it is apparent that some of the goals set out initially are achievable. Linking all of the necessary data within the system will provide an automated and reliable source of data for recording, reporting and reconciliation in the future. Some of the specific benefits achieved are described below.

In the initial stages of this project's development it became apparent that the communication among the key groups was not optimal. While creating the flow diagram and exploring the systems in place within geology, operations, processing and the PSF, relationships were strengthened and a greater understanding of the data collected at each step was achieved.

At the operations level the daily haulage data entry has been simplified. This allows the mine clerks to enter the data once, in a single location with validation built in, as well as automatic calculations and reporting of results. This is much more efficient than the previous method of data entry which was done directly into Ellipse, using a slow Citrix connection.

The system provides live daily production information on tonnage and grade for both the pit and ROM to everyone on site with intranet access. It also provides the plant with more detailed information on the material being delivered from the pit in terms of geological units, grade and rock hardness of the ore. This saves employees time and effort by providing a reliable centralised source for the information crucial in daily operations.

In mid-2005 it became apparent that monthly production reporting would become the standard. Currently three sets of data are reported separately to management in MS Word documents and tables: model carats and pit survey tonnes from geology and engineering, plant tonnes from the process plant and final carats from the PSF. The new system will be the repository for this month end data entry and reporting in the future. Again, this will provide a reliable and centralised source for current and historical monthly production numbers.

Looking forward it has been important to get the reconciliation system organised and bedded down at this stage of Diavik's development while the operation is still a single pit mining two kimberlite pipes. In the future the operation will be concurrently mining at least two open pits and operating underground mines in three kimberlite pipes. As the complexity of the mining increases there will be more need to ensure resource and grade estimates are accurate and that mine planning schedules are executed efficiently. By having a centralised and automated system in place Diavik is ideally placed to gain the maximum benefit from its reconciliation data.

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