IMPLEMENTING BEST PRACTICES OF METAL ACCOUNTING AT THE STRATHCONA MILL

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ABSTRACT

The importance of coherent material balance results has long been recognized by mining and metallurgical companies. Although this is still true nowadays, various stakeholders are increasingly concerned about the origin and the accuracy of the reported numbers. The last decade has shown that most metallurgical accounting concerns can be addressed by making two important changes to plant performance monitoring practices. First, introducing data redundancy into the metal balance procedure allows the estimation of measurement errors. Second, the migration from spreadsheet-based to relational database based systems brings transparency, data integrity, traceability and auditability into metallurgical accounting. Relational databases also facilitate the production of reports that metallurgical accountants must issue routinely. Recognizing the caveats of the spreadsheet-based metal accounting method they had been applying for years, Strathcona decided to switch to a commercial relational database system in 2008. For the most part, the migration was seamless. Some challenges were raised but they could all be overcome and outweighed by benefits gained from day-to-day utilization of the system.

KEYWORDS

Metallurgical accounting, Flotation, Best practices, Technology migration project

INTRODUCTION

Metal accounting (Morrison, 2008) has always been essential to high-quality corporate governance of mining and metallurgical companies. Although the importance of coherent material balance results has long been recognized, various stakeholders are increasingly inquisitive about how the reported numbers were obtained and how much accuracy can be attributed to them. This accrued scrutiny is obviously no stranger to the corporate governance tightening that happened through the years in response to outrageous accounting scandals. It is also in continuity with securities laws (such as NI-43-101 in Canada) that were passed to protect the public from other market fraud.

Recognizing the importance of spotless metal accounting in their reports to the public, a group of global mining companies gave AMIRA International the mandate of developing a set of rigorous yet practical metal accounting guidelines for the mining and metallurgical industry. The AMIRA P754 project was launched in 2004 and the first version of the resulting Code of Practice was released the following year. Since then, the Code was reviewed twice and revised releases were issued (Anonymous, 2007). While some parts of these guidelines are in continuity with current commonplace practices, other parts recommend changes to inherited practices that may be significant. For example, they highlight the importance of data redundancy (Lachance & Flament, 2011) which in many operations is either already available but unexploited or achievable with reasonable efforts. These guidelines also stress the importance of state-of-the-art metal accounting systems, such as those based on relational databases, which are secure and entirely auditable by a Qualified Person. Because most spreadsheet software packages allow data and formulae to be modified at any time, without a trace and anonymously, they do not meet these requirements.

The main goal of this paper is to describe the implementation of new metallurgical accounting practices at the Strathcona mill and to compare them to the AMIRA P754 Code of Practice. Main issues encountered on the road to implementation are raised along with applied solutions and the benefits gained from day-to-day applications of the new practices. This case study will also be analyzed bearing in mind the results of a recent survey (Gaylard, Morrison, Randolph, Wortley, & Beck, 2009) of AMIRA P754 project sponsors about their current use of the guidelines.

The paper begins with a short description of the metallurgical accounting challenges that the Strathcona mill staff face on a daily basis. It is followed by a summary of the Code of Practice which is essentially the listing of the ten basic principles of metallurgical accounting put forward by AMIRA. The list is then used as a basis for analyzing and discussing the Strathcona mill case.

METALLURGICAL ACCOUNTING AT THE STRATHCONA MILL

The Strathcona flotation plant (see Figure 1) is part the Sudbury operations of Xstrata Nickel which also include the Nickel Rim South mine, the Fraser mine and the Sudbury nickel smelter. Strathcona is currently a custom milling operation and processes ores from Xstrata and non-Xstrata mining sites. Its two main products are a nickel-copper and a copper concentrates.

Given that the plant must report coherent metal production balances to different customers (including their own management) and that blending between feed sources may at times be required to maximize plant feed rate, metal accounting at Strathcona is somewhat more challenging than at a typical single-feed flotation plant.

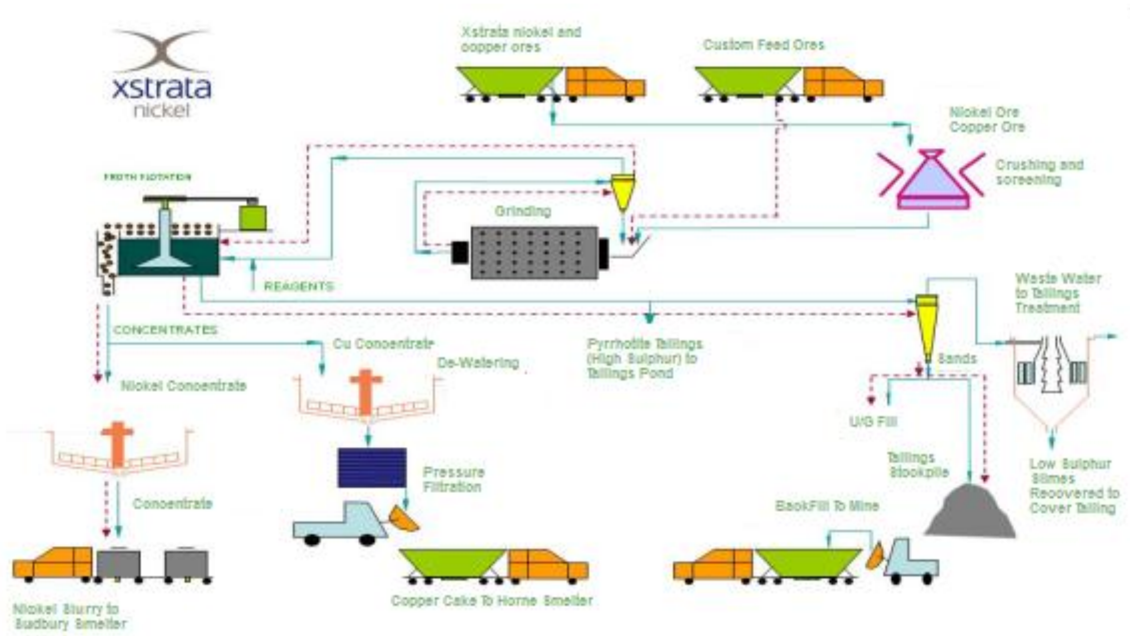

Figure 1 – Simplified flowsheet of the Strathcona flotation plant

THE TEN PRINCIPLES OF BEST METALLURGICAL ACCOUNTING PRACTICES (BMAP)

In order to qualify the metal accounting practices of the Strathcona mill, the ten principles of metal accounting put forward by AMIRA are used as a reference. These principles were defined by the P754 project team through the development of the Code of Practice for Metal Accounting (AMIRA 2007). In a nutshell, they represent the requirements for a metal accounting system to be accurate, credible, practical, reliable, transparent and auditable. The principles are meant to be applicable throughout the mining and metallurgical industry, from precious to base metals and from mine to product.

Table 1 is a slightly re-arranged list of metallurgical accounting principles that AMIRA had originally put together. Essentially, it highlights the criteria that each principle addresses specifically and it groups them into two categories. While five principles deal with data quality, five specifically describe the characteristics of a state-of-the-art metal accounting system.

Table 1 – Edited list of the ten AMIRA principles of BMAP

Category	Criteria	#	Details
Data	Measurement accuracy	10	The metal accounting system must ensure that every effort is made to identify any bias that may occur, as rapidly as possible and eliminate or reduce to an acceptable level the source of bias from all measurement, sampling and analytical procedures, when the source is identified.
	Targeted accuracy	8	Target accuracies for the mass measurements and the sampling and analyses must be identified for each input and output stream used for accounting purposes. The actual accuracies for metal recoveries, based on the actual measurement accuracies, as determined by statistical analysis of the raw data, achieved over a company’s reporting period must be stated in the report to the company’s audit committee. Should these show a bias that the company considers material to its results; the fact must be reported to shareholders.

	Data validation and redundancy	7	The system must generate sufficient data to allow for data verification, the handling of metal/commodity transfers, the reconciliation of metal/commodity balances, and the measurement of accuracies and error detection, which should not show any consistent bias. Measurement and computational procedures must be free of a defined critical level of bias.
	Provisional data	6	Where provisional data has to be used to meet reporting deadlines, such as at month ends when analytical turn-around times could prevent the prompt issuing of the monthly report, clear procedures and levels of authorisation for the subsequent replacement of the provisional data with actual data must be defined. Where rogue data is detected, such as incorrect data transfer or identified malfunction of equipment, the procedures to be followed together with the levels of authorisation must be in place.
	In-process inventory	9	In-process inventory figures must be verified by physical stock-takes at prescribed intervals, at least annually, and procedures and authority levels for stock adjustments and the treatment of unaccounted losses or gains must be clearly defined.
System	Completeness and integration	1	The metal accounting system must be based on accurate measurements of mass and metal content. It must be based on a full check in-check out system using the best practices as defined in this code, to produce an on-going metal/commodity balance for the operation. The system must be integrated with management information systems, providing a one-way transfer of information to these systems as required.
	Timeliness	5	Accounting results must be made available timeously, to meet operational reporting needs, including the provision of information for other management information systems, and to facilitate corrective action or investigation. A detailed report must be issued on each investigation, together with management's response to rectify the problem. When completed, the plan and resulting action must be signed-off by the Qualified Person.
	Transparency	2	The system must be consistent and transparent and the source of all input data to the system must be clear and understood by all users of the system. The design and specification of the system must incorporate the outcomes of a risk assessment of all aspects of the metal accounting process.
	Auditability	4	The system must be subject to regular internal and external audits and reviews as specified in the relevant sections of the code to ensure compliance with all aspects of the defined procedures. These reviews must include assessments of the associated risks and recommendations for their mitigation, when the agreed risk is exceeded.
	Documentation	3	The accounting procedures must be well documented and user friendly for easy application by plant personnel, to avoid the system becoming dependent on one person, and must incorporate clear controls and audit trails. Calculation procedures must be in line with the requirements set out in this code and consistent at all times with clear rules for handling the data.

Obviously, the Code is more than just these ten principles. It is a complete report where standards and best practices can be found for mass measurement, sampling, sample analysis, data reconciliation and data management that comply with the basic principles. The Code even deals the cases where it is not possible to comply with the prescribed standards by asking for an exception report to be thoroughly prepared, setting out the reasons for non compliance (cost, risk, etc.).

The path toward the fulfillment of all ten principles should not be understated. Unravelling a metallurgical accounting procedure often requires a multi-disciplinary approach (summarized in Table 2) involving senior management, operations management, process engineering, information technology, maintenance, internal and external laboratories, consultants, financial accounting, etc.

TYPICAL STRUCTURE OF METALLURGICAL ACCOUNTING SYSTEMS

As suggested by Gaylard et al. (2009), the metallurgical accounting system of Strathcona will be decomposed into its four main components (Figure 2) to be analyzed separately. This proposed structure is very intuitive as it follows the flow of information from the mass flow rate measurement up to the final production report. Mass flow rate measurement (Wortley, 2009) and stream sampling (Holmes, 2004) components always lie at the very foundation of metallurgical accounting systems. However, as it was the case with the Strathcona mill, the most important changes often occur around mass balancing, data handling and reporting methods.

Table 2 – Main components of metal accounting systems

Component	Stakeholders
Mass flow rate measurement	Process engineering, Maintenance, Consultants, Operations management
Sampling, sampling management and analysis	Process engineering, Maintenance, Consultants, Operations management, Laboratories
Mass balancing and reconciliation	Process engineering, Operations management, information technology
Data handling and reporting	Process engineering, Senior and Operations management, information technology, Financial accounting

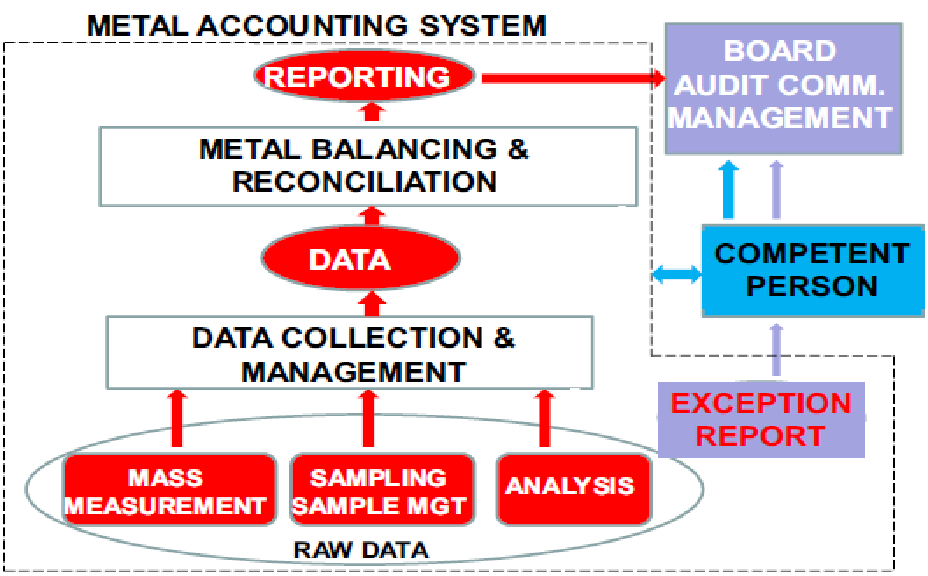

Figure 2 – Metal accounting system structure (Gaylard et al., 2009)

INITIAL METAL ACCOUNTING PRACTICES OF THE STRATHCONA MILL (BEFORE 2008)

The main components of the initial Strathcona metallurgical accounting system are summarized in Table 3. They are very typical of systems that plants were using before implementing BMAP.

Table 3 – Summary of the initial metallurgical accounting practices

Component	Description
Mass flow rate measurement	Plant feed only Humidity level was measured for this stream
Sampling, sampling management and analysis	Three assays (Ni, Cu, S) were used on a daily basis on each stream.
Mass balancing and reconciliation	The 4-product formula was applied PGM balances of Xstrata Nickel feeds were determined on a monthly basis PGM balances of non-Xstrata Nickel feeds were determined on a daily basis
Data handling and reporting	Daily and month-end reports were generated by copying-and-pasting data into different worksheets or were channelled through dynamic linking to other spreadsheet workbooks. Metallurgical accounting was not integrated with management information systems

Mass Flow Rate Measurement and Sampling

Only the plant feed mass flow rate was measured by combining the wet mass weighted on the feed belt conveyor with a measured value of the humidity level. The sampling scheme considered the mill as a single node, as shown in Figure 3, having one feed, two product streams and two tailings streams. Therefore, five composite samples were collected over a 24-hour period (or until the plant feed changes) before being assayed. This sampling strategy is referred to as primary accounting (Morrison, 2008) and is motivated by the fact that these streams are the most critical.

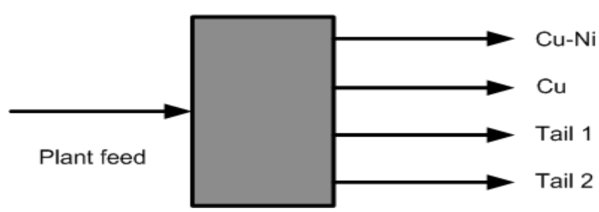

Figure 3 – Strathcona flotation plant primary metallurgical accounting diagram

Mass Balancing and Reconciliation

The four unmeasured mass flow rates of product and tailings streams were computed using the 4-product formula (Hodouin, Lachance, & Poulin, 2011). The daily metal balance needed three assays (Ni, Cu and S) on each stream as those were sufficient to uniquely determine each unmeasured mass flow rate of product and tailings stream. However, due to the measurement random errors that are inherent to process data, this balancing method reported values that were carrying a degree of inaccuracy that was not quantified. According to BMAP Principle #8, the level of accuracy should be assessed and indicated in metal accounting reports.

Although the 4-product formula does not make use of data redundancy, this method was considered good enough at that time. It is now known (Hodouin et al., 2011), however, that it is particularly sensitive to sampling and assay measurement errors. In such an absence of data redundancy, measured values must be taken at their face value without any possibility of validation (except, of course, for the obvious cases where the method leads to negative computed mass flow rates). Clearly, this situation was not satisfying BMAP Principle #7 about data validation.

Another caveat of the 4-product formula is that a bias may hide inside the data set without being detected. Detecting and, above all, locating a bias is not always an easy task but it can and should be eliminated (or at least minimised) because its effect accumulates in any cumulative measure of production or process performance. This situation was not satisfying BMAP Principle #10 about data accuracy either.

Data Handling and Reporting

Common Excel™ spreadsheets were used to collect, store and process metallurgical accounting data. Daily and month-end reports were generated by copying-and-pasting data into different worksheets or were channelled through dynamic linking to other Excel workbooks. Although such spreadsheets were considered fine at the time, they raised security and auditability issues in the multiple-user environment. Information could be changed at any time, without a trace and anonymously. Because multiple copies of the metallurgical accounting dataset could be made and modified independently, the system could not protect the integrity of reported data. The spreadsheet-based metallurgical accounting system was not integrated with management information systems and therefore, was not satisfying BMAP Principle #1.

MAIN DRIVERS FOR IMPROVING METAL ACCOUNTING PRACTICES

The Xstrata Nickel corporate-wide adoption of SAP business management software was probably the main agent of change for metal accounting practices at the Strathcona mill. This was driven by a corporate ambition to increase the accuracy of key performance indicators across the whole business unit. As illustrated in Figure 4 sales contract negotiations and production planning are both based on achieved metal balances. Improving trading reactivity needed improvements in production planning which strongly relied on improved metallurgical accounting. This improvement wind has also generated a need for increasing production report quality as more frequent internal audits were being conducted.

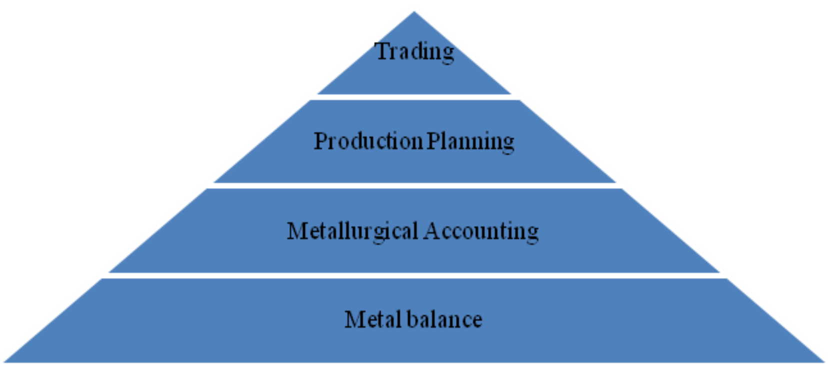

Figure 4 – The metallurgical trading pyramid (Castro, 2009)

A SAP module integrating the entire production chain was put in place thereby imposing production numbers to be declared on a daily basis. However, due to unavoidable laboratory turn-around delays, the daily declaration has to be done on a differed basis. As providing provisional numbers to the SAP system was not an option, the Strathcona mill had to speed up and enhance its metallurgical accounting procedures. PGM production could no longer be accounted only on a monthly basis. The need for shorter assaying delays triggered the search for faster analytical techniques.

It was also rapidly identified that an automated, secured and auditable system that makes use of relational database technology would allow the Strathcona mill to timely and rigorously issue the production numbers required by the SAP system.

Another driver for change was the need for better understanding the flotation response of non-Xstrata Nickel ores. With Xstrata Nickel ores, achieved production results could always be compared to historical performance datasets. However, given the very limited operating experience and knowledge of Strathcona with some non-Xstrata Nickel ores, data redundancy and statistical reconciliation would provide the metallurgists with a powerful means to validate the metallurgical balances to report to their customers. There were also metallurgical accounting issues related to metal ownership when blending ores from multiple stockpiles prior to feeding the mill. These situations, even when the reported feed tonnage split was acknowledged by the owners, were challenging because each feed type has different ore properties, grades, contaminants and therefore, different expected recovery.

FIRST PHASE OF BMAP IMPLEMENTATION (2008-2010)

The status of the Strathcona metallurgical accounting system after the first phase of BMAP implementation is summarized in Table 4. For the first time, the metallurgical accounting practices were formalized in a commercial system (Metallurgical Accountant^{TM}) application which was able to provide the data required by the SAP system.

Table 4 – Status of the of Strathcona metallurgical accounting system after the first phase of BMAP implementation

Component	Description
Mass flow rate measurement	Plant feed only Humidity level was measured for this stream
Sampling, sampling management and analysis	Four base metals assays (Ni, Cu, S, Co) were used on a daily basis for each stream.
Mass balancing and reconciliation	Data reconciliation through mass balance PGM balances of Xstrata Nickel feeds were determined on a monthly basis PGM balances of non-Xstrata Nickel feeds were determined on a daily basis
Data handling and reporting	Relational database Daily reports Month-To-Date (MTD) reports Year-To-Date (YTD) reports Integrated with management information systems

Mass Flow Rate Measurement and Sampling

The initial (primary accounting) metal balance diagram (Figure 3) was maintained. The feed stream was still the only stream on which the mass flow rate is measured. A fourth chemical analysis (for cobalt) was made on each stream sample.

Mass Balancing and Reconciliation

The additional Co analysis provided data redundancy and the previously used 4-product formula was no longer appropriate for optimally solving the associated mass balance problem. An advanced data reconciliation through mass balance algorithm (Bilmat^{TM}) was introduced to simultaneously handle all the measurements available.

This new data redundancy allowed systematic data validation, precision estimation and gross error detection therefore fulfilling BMAP Principles #7 and #10. This change has also introduced a new category of process data, i.e. the adjusted data which needed to be approved and stored adequately from this point on.

Data Handling and Reporting

This first phase included also the migration from the spreadsheet based system to a relational database based system. Such a transition was needed for achieving best practices in metallurgical accounting by meeting BMAP principles #2, #4 and #5.

Professional programmers have long learned the benefits of strict development disciplines to eliminate errors. In contrast, surveys of spreadsheet developers (Panko, 2008) indicate that typical spreadsheet creation is informal and that few organizations have comprehensive policies for spreadsheet development.

Experience with BMAP implementation has shown that in complex spreadsheet applications (such as for metal accounting purposes) it is often difficult to distinguish original data (entered manually) from computed data. Since the footsteps of the source data to reported production numbers can hardly be followed, the auditing of such a system by a Qualified Person (to meet BMAP principle #4) is very challenging.

SECOND PHASE OF BMAP IMPLEMENTATION (2010-2011)

Towards the end of 2008, following the global economic crisis, Strathcona operations started to process ores from multiple external sources, sometimes in relatively small quantities. Along the way, the mill needed to be upgraded to become more flexible. This has prompted the metallurgical accounting system to increase its ability to cope with different ore sources from different customers. The status of the Strathcona metallurgical accounting system after the second phase of BMAP implementation is summarized in Table 5.

Table 5 – Status of the of Strathcona metallurgical accounting system after the second phase of BMAP implementation

Component	Description
Mass flow rate measurement	Plant feed only Humidity level is measured for this stream
Sampling, sampling management and analysis	13 assays are used on each stream (Ni, Cu, S, Co, Fe, MgO, SiO_2, Pb, Zn, Au, Ag, Pt, Pd)
Mass balancing and reconciliation	Data reconciliation through mass balance
Data handling and reporting	Relational database Daily reports Month-To-Date (MTD) reports Year-To-Date (YTD) reports OLAP Cube / Reporting service Integrated with management information systems

Mass Flow Rate Measurement and Sampling

Although difficult to prove earlier, a retrospective analysis of metallurgical accounting data has shown that, for Xstrata Nickel ore blends, the quality of base metal assays (Cu, Ni, S) was high and led to precise estimates of product mass flow rates. This was observable, despite the fact that concentrate flow rates are relatively low and sensitive to sampling and assaying errors. It was also discovered that the sole addition of Co to the metal balance (along with Cu, Ni and S), although providing data redundancy, brought insignificant gain of precision to the estimated product stream mass flow rates. The fact that Co and Ni split factors are almost identical was the main explanation.

Initially, it was considered to add three more chemical assays, Fe, MgO and SiO_2, to the mass balance. Although studies showed that only Fe brought a significant contribution, all three new chemical assays were kept in the balance. Pb, Zn and PGM assays were ultimately added to the list for maximizing data redundancy.

Mass Balancing and Reconciliation

The thirteen chemical assays determined on each stream provide a high degree of data redundancy. They feed a data reconciliation engine that produces a coherent mass balance of all thirteen chemical elements. This high redundancy is particularly useful for determining the composition of new ore blends. Without data redundancy and previous experience with the ore, the calculated composition blend can hardly be validated.

Data Handling and Reporting

An essential component of the entire metal accounting system is the automatic generation of reports that summarize metal accounting results and other plant performance indicators. Key reporting features were implemented that greatly enhanced flexibility and speed of the system. For example, a new reporting service was installed to allow plant personnel to modify the report structure by themselves. The OLAP cube technology was also embedded in the system to speed up data handling within the database.

CONCLUSIONS

The overall purpose of metallurgical accounting is to provide managers with the reliable knowledge they need for monitoring mining and metallurgical operation performance. The information provided by state-of-the-art metal accounting systems can be trusted to minimize risk of process optimization and capital intensive projects and maximize the profitability of the operation.

The Strathcona mill has implemented all the necessary hardware and technology for complying with AMIRA principles of best metallurgical accounting practices (BMAP) and generating the most accurate production reports. These include a metal accounting system that is truly state of the art. It is reliable and user friendly yet flexible enough to suit the characteristics of each plant operating mode while providing the best possible report of plant performance.

The main differences between the previous and the new systems are two key elements: (1) the generation and appropriate use of data redundancy and (2) the replacement of spreadsheets by a commercial relational database system. Utilizing a unique, secure and traceable database for metallurgical accounting protects the integrity of plant data while keeping a trace of all modifications made.

As demonstrated at Strathcona, detailed metallurgical accounting systems greatly facilitate the evaluation of plant performance of custom milling operations. A rigorous metal accounting system, short delays at the assay laboratory and a tight campaign tracking are amongst the most important ingredients of a professional and reliable reporting system.

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REFERENCES

Anonymous. (2007). *P754 : Metal Accounting*.

Castro, A. (2009). Connected Mining. *Escenario Actual de la Minería y Soluciones Innovadoras*. Lima, Peru.

Gaylard, P. G., Morrison, R. D., Randolph, N. G., Wortley, C. M. G., & Beck, R. D. (2009). Extending the application of the AMIRA P754 code of practice for metal accounting. *The Southern African Institute of Mining and Metallurgy* (pp. 15-38).

Hodouin, D., Lachance, L., & Poulin, É. (2011). Suboptimal flowrate estimators and their application to the design of measurement strategies. *Journal of Process Control*, *21*(2), 235-245. doi:10.1016/j.jprocont.2010.10.017

Holmes, R. J. (2004). Correct sampling and measurement -- the foundation of accurate metallurgical accounting. *Chemometrics and Intelligent Laboratory Systems*, *74*(1), 71-83. doi:10.1016/j.chemolab.2004.03.019

Lachance, L., & Flament, F. (2011). A New ERA Tool for State of the Art Metallurgical Balance Calculations. *43th Annual Meeting of the Canadian Mineral Processors*. Ottawa, ON.: Canadian Institute of Mining, Metallurgy and Petroleum.

Morrison, R. D. (Ed.). (2008). *An Introduction to metal balancing and reconciliation* (p. 618). Indooroopilly, Qld: Julius Kruttschnitt Mineral Research Centre.

Panko, R. R. (2008). What We Know About Spreadsheet Errors. *Journal of End User Computing's*. Retrieved from http://panko.shidler.hawaii.edu/ssr/Mypapers/whatknow.htm

Wortley, C. M. G. (2009). Mass measurement for metal accounting — principles , practice ,. *Fourth World Conference on Sampling & Blending* (pp. 121-128). Cape Town, South Africa. Retrieved from http://www.saimm.co.za/Conferences/SamplingBlending2009/121-128_Wortley.pdf