International Journal of Mining Science and Technology 29 (2019) 239–244

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

# Proactive reconciliation as a tool for integrating mining and milling operations

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ARTICLE INFO

*Article history:*
Received 25 June 2017
Received in revised form 27 October 2017
Accepted 4 January 2019
Available online 14 January 2019

*Keywords:*
Reconciliation
Prognostication
Sampling
Gold
Copper

ABSTRACT

Historically, reconciliation has been viewed as a quality test of model estimates as well as a powerful tool for detecting and correcting problems in all stages of mine operations from resource estimation to metal production. If used correctly, reconciliation helps to better predict the life of mine (LOM), improves the adherence of production plans to the respective budget, and allows for effective control of the mining and milling processes. However, the accuracy of reconciliation results requires that all input data must be generated in accordance with the principles of sampling correctness. Furthermore, complete reconciliation systems can become extremely complex and must be carefully analyzed in order to provide realistic and helpful conclusions. Based on these concepts, this paper presents a successful proactive reconciliation system applied to a copper and gold mine in Brazil for monitoring and integrating mining and milling operations.



## 1. Introduction

Reconciliation is carried out by most of the world's mining companies and is based on the calculation of the so-called "mine call factor" (MCF). The MCF represents the ratio between the grade, contained metal or mass of produced ore with the grade, contained metal or mass of ore estimated by the resource models. In order to more accurately predict what the processing plant will be able to produce, the MCF can be applied to future estimates in a practice called "reactive reconciliation". However, such an approach is disadvantageous because it does not resolve the reconciliation problems. The main objective of any reconciliation system should not be to correct estimates but rather to allow for timely adjustments within production processes so that results are consistently within acceptable uncertainty limits.

Holtham et al. state "reconciliation compares what has been achieved with what was expected to be achieved so that both planning and production processes can be continually refined and improved" [1]. Thus, adequate practices of reconciliation should be able to detect the causes of discrepancies between model estimates and observed production. By eliminating the major causes of such errors, estimates become sufficiently accurate to form a basis for more reliable decision-making and ensure that what happens in the future better corresponds to that which is planned. Good reconciliation results that are based on a reliable reconciliation system are the key for mining companies to demonstrate that information provided regarding resources, reserves and operation performance are precise, accurate and auditable.

Following the previously presented logic and aiming to extract from the practice of reconciliation more useful information other than calculating and applying the MCF, several authors have conducted reconciliation studies and proposed new reconciliation practices and models. Thomas and Snowden presented a case study from an open pit gold mine and proposed statistical and geostatistical analysis to improve reconciliation between exploration estimates and grade control estimates, and between exploration estimates and true head grades and production tonnages [2]. Schofield presented an important flaw in the assumptions underlying the use of reconciliation in evaluating the performance of resource and ore selection models, and discusses several problems which may cause poor reconciliation in mines [3]. Crawford proposed a complete reconciliation flowscheme where each step of the operation is examined sequentially from model to mine, mine to mill, mill to smelter or refiner or to final sales, showing that reconciliation can be used as a powerful tool for determining if a production problem exists at an operation, and often provides diagnostics for resolution of those problems [4]. Morley and Thompson demon-

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https://doi.org/10.1016/j.ijmst.2019.01.001
2095-2686/© 2019 Published by Elsevier B.V. on behalf of China University of Mining & Technology.

strated how a reconciliation software implemented in a diamond mine facilitates the process of reconciling geological models, mine plans, production data and plant results, showing the benefits gained by closing the loop between reconciliation and ongoing process improvement [5]. Chieregati and Pitard proposed a strategy for sampling improvement in two low-grade and erratic gold deposits to increase reliability in the reconciliation results between the long-term and the short-term models, and between the mine and the plant [6]. Chieregati and Pignatari proposed dividing a reconciliation system into its basic components and presented a new reconciliation model with six reconciliation indicators for a gold mine, aimed to highlight the critical stages of the operation and solve each detected problem separately [7]. Jang et al. developed an artificial neuron network model to predict uneven break (unplanned dilution and ore loss) in underground mines and improve reconciliation [8].

Even though many reconciliation studies were carried out all over the world, it was Morley [9] who introduced and established the concept of 'prognostication' or 'proactive reconciliation', which is an iterative process that allows for the correction of sampling and estimation procedures in a way that improves the model predictability [9,10] and on which some of the cited studies were based.

This paper presents the results of proactive reconciliation practices carried out in a copper and gold mine in Brazil with the goal to integrate its mining and milling operations. The objectives of this study are as follows: (1) increase the reliability of resources and reserves reported by the company; (2) improve the adherence of the short-term plans in relation to the budget; and (3) increase the reliability of the predicted quality of the ore fed to the plant.

## 2. Methodology

Reconciliation problems are very common in the mining industry, especially when dealing with precious metals or deposits with high nugget effect or heterogeneity. It turns out that these problems very often occur as a result of improper sampling practices and/or resource modelling. Therefore, special attention must be given to the procedures of data collection and processing.

According to Morrison [11], "the essence of reconciliation is to track products back to source with as much knowledge as possible about how well the various components of that path are known". Proactive reconciliation was developed for detecting the causes of reconciliation problems at each process stage and can be used as a tool for integrating mining and milling operations in an effective and reliable way, as presented by Morley [9] and Chieregati and Pignatari [12]. Following the authors' recommendations, the reconciliation model was customized for application in a copper and gold mine in Brazil (Fig. 1).

Instead of using the common names found in the literature – F1, F2, F3, and so on –, which suggest that these numbers are to be used as 'factors', the proposed model defines five reconciliation 'indicators' instead, which are named as: Model Indicator (MI), Planning Indicator (PI), Operation Indicator (OI), Mine Reconciliation (MR) and Plant Reconciliation (PR), in addition to the well-known MCF. These factors work as performance indicators of each individual stage, which allows for the detection and correction of the causes of reconciliation problems along the mining chain. Fig. 2 shows the calculation of each indicator using results of contained gold over a production period of six months (see Table 1). The adopted units are in accordance with industry practices, whose equivalents in SI are: (1) oz = $3.11 \times 10^{-2}$ kg and (2) lb = $4.54 \times 10^{-1}$ kg.

Based on the calculations presented in Fig. 2, values above and below 100% indicate an underestimation and overestimation, respectively. For example, if one assumes no sampling or mass measurement errors, a MR value of 87% means that only 87% of the predicted gold was fed to the plant. In other words, the long-term model overestimates the mine reserve by 15.5%: Au overestimation$_{\text{LONG-TERM MODEL}}$ = (119910–103803)/103803 = 15.5%.

It is important to emphasize that MR is often called 'mine-to-mill reconciliation' because it reconciles the plant feed with model estimates. Some operations do not include a sampling stage at the plant feed or, as in the case of the mine selected in this study, fragments may be so large that they preclude the installation of a sampler. This often happens when the first comminution stage is carried out using a semi-autogenous (SAG) mill at the plant. In these cases, the company back-calculates the ore fed to the plant using metal contained in the concentrate and tailings and, as a consequence, PR will always be 100%. Another important consideration is that the indicator PR should not be misused as 'plant recovery' (64% in the example of Fig. 2), which does not include the tailings in its calculation. A reconciliation system must take into account all input and output data including inventory changes (2775 oz Au in Fig. 2). The MCF value in Fig. 2 (56% or 0.56) does not consider the amount of gold sent to the tailings, and represents the ratio between the produced metal with the contained metal estimated by the long-term model. Although the MCF used in this example is useful for understanding the adherence of the long-term plans in relation to the budget, which the company deemed necessary, in order to validate the long-term model estimates it is more appropriate to calculate MCF based on both products, concentrate and tailings, as follows: MCF = (106578–2775)/119910 = 86.6%.

Since 2011, the proactive reconciliation model described above has been used in the Brazilian copper and gold mine. We present and discuss the results in the following sections.

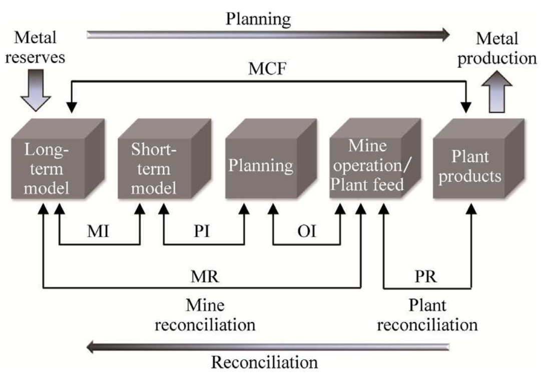


**Fig. 1.** The proactive reconciliation model adapted from Chieregati et al. [12,13].

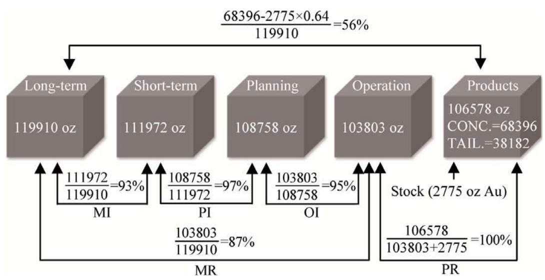


**Fig. 2.** Calculation of the proactive reconciliation indicators for contained gold.

**Table 1**
Reconciliation matrix for the copper and gold mine (January–June 2011).

| Variable | Metal | Reserves | | Mine | | Plant | |
|---|---|---|---|---|---|---|---|
| | | Long-term | Short-term | Planning | Mine operation | Stock | Plant feed |
| Grade | Cu (%) | 0.444 | 0.447 | 0.424 | 0.411 | 0.411 | 0.411 |
| | Au (g/t) | 0.332 | 0.332 | 0.308 | 0.299 | 0.299 | 0.299 |
| Mass (t) | | 11,219,673 | 10,505,422 | 10,989,127 | 10,797,920 | 288,654 | 11,086,574 |
| Contained metal | Cu ($\times10^3$ lb) | 109,852 | 103,471 | 102,625 | 97,840 | 2616 | 100,456 |
| | Au (oz) | 119,910 | 111,972 | 108,758 | 103,803 | 2775 | 106,578 |
| Reconciliation indicators (%) | Cu | MR = 89% | MI = 94% | PI = 99% | OI = 95% | | PR = 100% |
| | Au | MR = 87% | MI = 93% | PI = 97% | OI = 95% | | PR = 100% |
| Produced metal | Cu ($\times10^3$ lb) | 83,669 | | | | | |
| | Au (oz) | 68,396 | | | | | |
| Plant recovery (%) | Cu | Plant recovery = 83% | | | | | |
| | Au | Plant recovery = 64% | | | | | |
| MCF (%) | Cu | MCF = 74% | | | | | |
| | Au | MCF = 56% | | | | | |

## 3. Results

The reconciliation matrix presented in Table 1 shows an overview of the operation performance and highlights its critical stages. The indicators were calculated based on the contained metal accumulated from January to June of 2011.

Over a period of six months, the company noticed that all indicators were repeatedly below 100%, which means that each stage overestimates the next. Each individual monthly matrix, as well as the accumulated matrix (Table 1), were analyzed to allow for changes to be made in order to bring the indicators as close to 100% as possible. In other words, the estimates would become prognoses that could then be used with confidence in decision-making processes and the development of annual budgets of the company.

It's worth emphasizing that indicators close to 100% do not necessarily mean good reconciliation. Successful reconciliation can be illusory when errors generated at one point of the process are offset by errors generated at other points, resulting in apparently excellent reconciliation [14]. Illusory reconciliation leads to an erroneous appreciation of the process as a whole, which results in serious consequences for the mine operation, especially when reaching poorer or more heterogeneous areas of the deposit.

Estimate reliability depends, among other things, on correct use of geostatistical methods for grades and tonnes estimates, minimization of mining losses, correct short-term geology estimation, correct ore delineation and correct sampling practices. According to Pitard [15], reconciliation results have been shown to be deceptive unless all parties involved are in compliance with the principles of sampling correctness, therefore, the reliability in reconciliation results depends critically on the representativeness of the samples from which they were generated.

To prevent an illusory reconciliation from taking place, ensuring reliability in reconciliation results, a complete diagnosis of geostatistical modelling and of sampling equipment and procedures was carried out for three years at this copper and gold mine, and improvements were made with regard to sampling and geological modelling.

For example, in a study comparing twin holes drilled by a rotary drilling rig and by a diamond drilling rig, El Hajj et al. [16] showed that the rotary drilling rig used for short-term sampling was highly inadequate for sampling purposes and overestimated gold and copper contents by 75.5% and 34.8%, respectively. The authors also found that these errors were partially compensated by incorrect manual sampling practices such that only the front pile formed by the drilling rig (composed mainly of coarse material) was sampled, while the rear pile (composed mainly of fine material) was discarded.

Changes were then introduced to the sampling procedures in order to achieve more reliable mass and metal content data, resulting in the reconciliation matrix presented in Table 2.

The main improvements were as follows: (1) purchase of a reverse circulation (RC) drilling rig with automatic sampling system to increase the quality of short-term samples; (2) reduction

**Table 2**
Reconciliation matrix for the copper and gold mine (January–December 2014).

| Variable | Metal | Reserves | | Mine | | Plant | |
|---|---|---|---|---|---|---|---|
| | | Long-term | Short-term | Planning | Mine operation | Stock | Plant feed |
| Grade | Cu (%) | 0.366 | 0.389 | 0.384 | 0.380 | 0.296 | 0.374 |
| | Au (g/t) | 0.246 | 0.279 | 0.273 | 0.281 | 0.260 | 0.279 |
| Mass (t) | | 21,807,483 | 19,258,634 | 18,880,614 | 18,828,710 | 1,531,949 | 20,360,659 |
| Contained metal | Cu ($\times10^3$ lb) | 175,926 | 165,140 | 159,749 | 157,903 | 9978 | 167,880 |
| | Au (oz) | 172,289 | 172,992 | 165,577 | 169,848 | 12,791 | 182,639 |
| Reconciliation indicators (%) | Cu | MR = 90% | MI = 94% | PI = 97% | OI = 99% | | PR = 100% |
| | Au | MR = 99% | MI = 100% | PI = 96% | OI = 103% | | PR = 100% |
| Produced metal | Cu ($\times10^3$ lb) | 133,452 | | | | | |
| | Au (oz) | 107,447 | | | | | |
| Plant recovery (%) | Cu | Plant recovery = 79% | | | | | |
| | Au | Plant recovery = 59% | | | | | |
| MCF (%) | Cu | MCF = 71% | | | | | |
| | Au | MCF = 58% | | | | | |

of the short-term sampling grid generating more data for the short-term model to reach the accuracy and precision needed; (3) calculation of minimum sample masses and optimization of sample preparation protocols based on heterogeneity tests for copper and gold to minimize the fundamental sampling error.

Further sampling studies were conducted at the mine over the next three years. In order to estimate the representativeness of the samples generated by the old and new drilling rigs, three 10 m holes were drilled using each rig. Average size distributions of the recovered material are presented in Fig. 3 for the old rotary drilling rig and in Fig. 4 for the new reverse circulation drilling rig. The graphs, where the screen openings are given in mm, compare the sample particle size distributions with the total (sample plus rejects) particle size distributions.

The first graph presents very different distributions, which suggests that manual sampling using the old rotary drilling rig generates biased samples. El Hajj [17] verified that sampling biases (average relative errors) were −12.6% and −7.1% for gold and copper grades, respectively, indicating that the samples were inaccurate and tended to underestimate the grades of both gold and copper.

The second graph shows that the RC drilling rig distributions are very similar and that there is no selection of a particular size fraction at the expense of others, which suggests that the new RC rig generates unbiased samples. El Hajj [17] also confirmed the absence of any systematic errors or biases for data obtained using the RC sampling system (i.e. samples do not underestimate or overestimate the grades). Furthermore, it is known that the complete particle size distribution must be represented in order for the sample to represent the grades. It can therefore be stated that the RC drilling rig with the automatic sampling system generates samples that are fully representative of the original lot.

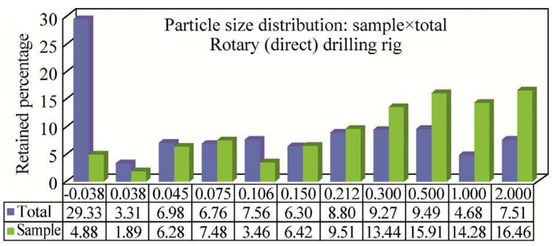


**Fig. 3.** Average particle size distributions comparing samples with all material recovered by the old rotary drilling rig.

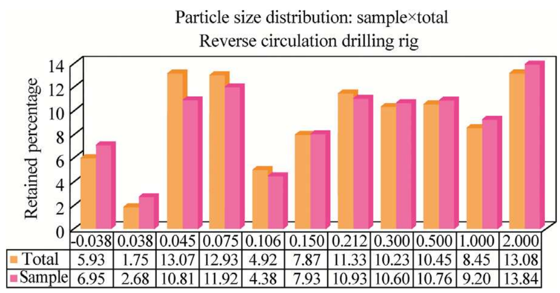


**Fig. 4.** Average particle size distributions comparing samples with all material recovered by the new reverse circulation drilling rig.

## 4. Discussion

The MR (or 'mine-to-mill reconciliation') indicator contains information about the metals in the reserves and in the plant feed. In essence, it relates that which was planned to feed the plant to that which was actually fed to the plant but provides no information about plant recoveries. As previously stated, the main goal of the proactive reconciliation practice is to bring MR as close to 100% as possible, indicating a complete use of the declared reserves that generated the production plan and allowing the company to present a reliable annual budget. Obviously, for this statement to be valid, all possible error-generating operations must be previously optimized in a way that illusory reconciliation is avoided. The plant recovery should also be treated and optimized separately from reconciliation.

Table 1 indicates low MR values for both copper and gold (89% and 87%, respectively). This situation resulted from loss of contained metal in the short-term model (5.8% and 6.6% for copper and gold, respectively). These losses are significant and, in this case, contradict the historical data obtained from the previous three years that had been used for the current budget. The mine geologist therefore investigated whether this was an isolated situation due to an overestimated portion of the deposit or a recurring problem for all regions. The mine also presented a loss of reserves of 6.4% mass (from 11219673 t estimated by the long-term model to 10505422 t estimated by the short-term model), which led to the reduction of contained metal. However, this apparently small percentage is actually significant if one considers the mass of low-grade ore and waste that needed to be extracted in order to compensate for such losses, evidencing a critical situation for this mine in 2011.

The consistent overestimation trend in the 2011 reconciliation matrix (Table 1) drew attention to the short-term stage. Among the three indicators (MI, PI and OI), MI performed the worst (94% and 93% for copper and gold, respectively). Therefore, the first change was applied to the short-term data collection. The replacement of the sampling rig was one of the process changes that improved the reliability of reconciliation indicators as it increased the accuracy of input data. However, a complete diagnosis was carried out that generated more realistic reconciliations and brought indicators closer to 100% with no trend of overestimation or underestimation for the duration of the year. The individual monthly indicators from January to December of 2014 are presented in Table 3.

As a consequence, Table 2 (accumulated in 2014) presents a considerably more balanced operation with excellent results for

**Table 3**
Individual indicators from January to December of 2014.

| Indicator | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MI (%) | Cu | 100 | 103 | 91 | 95 | 98 | 81 | 92 | 91 | 103 | 98 | 81 | 94 |
| | Au | 104 | 96 | 90 | 96 | 116 | 101 | 103 | 102 | 108 | 103 | 87 | 93 |
| PI (%) | Cu | 92 | 91 | 98 | 96 | 100 | 100 | 88 | 94 | 103 | 101 | 96 | 98 |
| | Au | 90 | 89 | 96 | 96 | 101 | 95 | 83 | 94 | 101 | 101 | 95 | 99 |
| OI (%) | Cu | 101 | 91 | 106 | 98 | 98 | 93 | 101 | 96 | 109 | 99 | 98 | 91 |
| | Au | 97 | 95 | 108 | 109 | 107 | 103 | 102 | 91 | 118 | 99 | 99 | 100 |

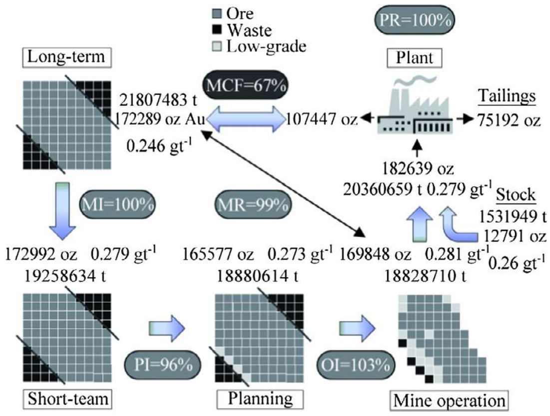


**Fig. 5.** The 2014 reconciliation system for contained gold.

all indicators, especially considering that this deposit is low-grade and geologically complex. Since the first application of the proactive reconciliation model in 2011, a complete analysis and restructuring of the long-term model was carried out by the mine geologist, which improved the estimate reliability. Furthermore, a detailed analysis of this process, including measurement of gold in solutions, was required to establish a strategy that resulted in more consistent mass and metallurgical balance. Sampling for short-term planning was also modified after the purchase of the RC drilling rig with automatic sampling system, which generated more representative samples for inclusion in the short-term model. Therefore, the reliability of all reconciliation indicators was improved, resulting in an effective 1-year reconciliation system as presented for contained gold in Fig. 5.

The reconciliation system for contained gold shows the following:

(1) High adherence between the geological models (MI = 100%).
(2) Low planned dilution (PI = 96%).
(3) No operational dilution and high mining recovery (OI = 103%).
(4) Excellent reconciliation between the mine and the mill (MR = 99%).

The same analysis can be done for copper, based on the results in Table 2. Thus, the reconciliation system for contained copper shows:

(1) High adherence between the geological models (MI = 94%).
(2) Low planned dilution (PI = 97%).
(3) Very low operational dilution and high mining recovery (OI = 99%).
(4) Good reconciliation between the mine and the mill (MR = 90%).

This example demonstrates that successful reconciliation is based on the integration of geology, mining and milling operations. Even though plant recoveries were kept low after process changes, the improvements in reconciliation results show that proactive reconciliation is an effective tool for the company to demonstrate that the information provided on resources, reserves and operation performance are reliable and auditable.

Following Pitard [18], the mining company benefits can be compared to a three-legged table: one leg is representative sampling; the second is statistical process control; and the third is total quality management. These critically important fields must be fully integrated and serve as prerequisites for the company to optimize the recovery of its natural resources. The authors therefore recommend the following suggestions for diagnosing the causes of reconciliation problems: (1) ensure that geological models are suitable for the deposit; (2) evaluate the selectivity of mining operations so as to estimate ore dilution and loss; (3) guarantee that all samples are unbiased and representative of the original lots; (4) constantly calibrate weightometers and flow meters so as to quantify mass measurement errors; (5) estimate the constitutional heterogeneity and in situ nugget effect of the deposit; (6) guarantee that the physical laboratory preserves the quality of the primary sample; (7) optimize sampling protocols from the primary stage to the chemical analysis; (8) avoid loss of fines in every sampling and sample preparation stage; (9) calculate the fundamental sampling error for the optimized protocol as precision cannot be higher than the standard deviation of the fundamental sampling error; and (10) implement a QA-QC (quality assurance-quality control) system for all sampling and sample preparation stages.

## 5. Conclusions

Reconciliation problems will always exist in mining operations but the most important aspect for assessment is to identify their causes and minimize their effects. A separation of the reconciliation problem into its basic components and resolution of each aspect individually is the key for understanding and controlling mine operations. This is the basic concept of proactive reconciliation practices that have been applied to a copper and gold mine in Brazil and proven to be a useful tool for integrating and controlling mining and milling operations.

The analysis of the reconciliation matrices and its indicators was of utmost importance to correctly diagnose errors that were masking the operation results and preventing the company from reaching its annual budget. In order to correct these errors, consistent action plans were drafted for the following themes: geological and grade modelling; mine and plant sampling; geometallurgical modelling; selectivity of mining operations; management of mining operations; reliability of mass measurement systems; and reliability of sampling preparation and chemical analysis. All of these actions converged for the fulfilment of the annual budget related to the metal production and operating costs, which established a reliable life of mine (LOM) plan and execution.

As part of a new monthly routine, the company now monitors reconciliation indicators as key performance indicators (KPI), and evaluates reconciliation matrices every quarter in order to develop more reliable forecasts for future quarters. Every year, such matrices are used to evaluate the review of the LOM and the reconciliation of resources and reserves.

Mine-to-mill reconciliation problems often have multiple causes but the problems can be solved, or at least minimized, if a good strategy is undertaken. Verification of the ten suggestions for diagnosing the causes of reconciliation problems and separation of the complex problem into its basic components so as to individually solve each problem at a time are the keys for correct use of proactive reconciliation as a tool for effective control of mining and milling processes.

## Acknowledgments

The first author gratefully acknowledges the support of Yamana Gold Inc., Brazil. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## References


[1] Holtham P, Scott A, Sanders D. Measurement and reconciliation of the coal production chain. In: An introduction to metal balance and reconciliation. Indooroopilly. p. 517–68.

[2] Thomas N, Snowden V. Improving reconciliation and grade control by statistical and geostatistical analysis. In: Strategies for grade control, Bulletin 10. Perth. p. 49–59.

[3] Schofield NA. The myth of mine reconciliation. In: Mineral resource and ore reserve estimation: the AusIMM guide to good practice. Melbourne. p. 601–10.

[4] Crawford GD. Reconciliation of reserves. In: Pincock perspectives No 49. Colorado; 2003.

[5] Morley C, Thompson K. Extreme reconciliation - a case study from Diavik Diamond Mine, Canada. In: Proceedings of the 6th international mining geology conference. Darwin: AusIMM; 2004. p. 313–21.

[6] Chieregati AC, Pitard FF. The challenge of sampling gold. In: Proceedings of the 4th World Conference on Sampling and Blending (WCSB4). Cape Town: SAIMM; 2009. p. 107–12.

[7] Chieregati AC, Pignatari LEC. New reconciliation model for gold industry. In: Proceedings of the 5th World Conference on Sampling and Blending (WCSB5). Santiago: GECAMIN; 2011. p. 235–42.

[8] Jang H, Topal E, Kawamura Y. Illumination of parameter contributions on uneven break phenomenon in underground stoping mines. Int J Min Sci Technol 2016;26:1095–100.

[9] Morley C. Beyond reconciliation: a proactive approach to using mining data. In: Proceedings of the 5th large open pit mining conference. Kalgoorlie: AusIMM; 2003. p. 185–92.

[10] Chieregati AC, Delboni Jr H, Costa JFCL. Sampling for proactive reconciliation practices. Min. Tech. (Trans. Inst. Min. Metall. A) 2008;117(3):136–41.

[11] Morrison R. Data analysis for reconciliation. In: An introduction to metal balance and reconciliation. Indooroopilly. p. 273–305.

[12] Chieregati AC, Pignatari LEC, Pitard FF, Esbensen KH. A segmented reconciliation matrix approach to monitor gold operations and reserve estimation. In: Proceedings of COM 2011: 50th conference of metallurgists. Montreal: MetSoc of CIM; 2011. p. 749–58.

[13] Chieregati AC. The many facets of mine reconciliation. In: Proceedings of the 6th World Conference on Sampling and Blending (WCSB6). Lima: GECAMIN; 2013. p. 207–16.

[14] El Hajj TM, Chieregati AC, Pignatari LEC. Illusory reconciliation: compensation of manual sampling erros. TOS Forum 2014;3:7–9.

[15] Pitard FF. Pierre Gy's theory of sampling and C.O. Ingamell's poisson process approach: pathways to representative sampling and appropriate industrial standards. Esbjerg: Aalborg University; 2009.

[16] El Hajj TM, Chieregati AC, Pignatari LEC. Illusory reconciliation: compensation of errors by manual sampling. In: Proceedings of the 6th World Conference on Sampling and Blending (WCSB6). Lima: GECAMIN; 2013. p. 227–37.

[17] El Hajj TM. Reconciliação ilusória: compensação de erros por amostragem manual. Sao Paulo: University of Sao Paulo; 2013.

[18] Pitard FF. A strategy to minimise ore grade reconciliation problems between the mine and the mill. In: Mineral resource and ore reserve estimation: the AusIMM guide to good practice, Melbourne. p. 557–66.