The many facets of mine reconciliation

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Reconciliation is routinely carried out by most mining companies worldwide and can be defined as the comparison between observed production and estimated production. Providing the sampling errors have been minimized, the practice of reconciliation generates a group of factors which provide a good indication of operation performance. The complexity of reconciliation systems is enormous. Many approaches, practices and models have been created over the years, but still some questions remain. What is the real meaning of poor reconciliation: Sampling problems, modeling problems or operation problems? What to reconcile: Tonnage, grade, geometry or contained metal? The calculation of the reconciliation factors based on contained metal provides no indication about dilution or the mass processed in the plant, therefore, one can conclude that the best practice is to calculate the factors based on grade. For the gold industry, however, what really matters is the produced gold ounces and, in this case, the grade is not as relevant. In fact, all variables must be considered in an integrated reconciliation system, allowing an effective control of all operations. The analysis of the reconciliation system must allow for operational improvements in order to keep the reconciliation factors as close to one as possible, which means that the estimates become prognosis and can be used with confidence in decision making and for annual budgeting. This paper analyzes and discusses the many variables of reconciliation, drawing attention to the importance of good sampling practices for reliable reconciliation results.

INTRODUCTION

The practice of mine reconciliation is usual for most mining companies and was historically based on calculating the so-called 'Mine Call Factor' (MCF). The MCF is obtained dividing the grade, contained metal or tonnage of produced ore by the grade, contained metal or tonnage of ore estimated by the geological models, and can be applied to future estimates to better predict what the operation will produce. The practice of applying factors to estimates was called by Morley (2003) 'reactive reconciliation' and is not the best reconciliation practice. The main objective of any reconciliation system should be to allow timely adjustments in the processes so that the results are always within acceptable uncertainty limits.

According to Chieregati *et al.* (2011), adequate practices of reconciliation should detect the causes of the errors observed between estimates and real production. By eliminating the major causes of these errors, the estimates become accurate enough to form a basis for more reliable decision making, ensuring that what happens in the future corresponds to what was planned at the present. According to Morley (2003), this is the concept of 'proactive reconciliation', an iterative process which allows the correction of sampling and estimation procedures in a way to improve the predictability of the models.

Proactive reconciliation is the key for the company to show that the information provided on resources, reserves and operation performance are precise, accurate and auditable. However, the limited knowledge of (1) what reconciliation really is, (2) when to rely on its results, and (3) how to interpret its factors, makes it difficult to develop an advantageous and effective reconciliation system in most mining companies in the world.

This paper presents a detailed description of reconciliation and its factors, emphasising the importance of good sampling practices in the development of a reliable reconciliation system. A hypothetic case study, based on real facts in the gold industry, shows how illusory reconciliation can hide biases in the system and make companies believe they are operating well, while loss and dilution takes place.

METHODOLOGY

According to Morrison (2008), the Australian Code of Practice defines reconciliation as "a metallurgical balance which relates production of sealable and reject or waste materials from a process back to its source as ore or other feed material. It should be provided with defined and stated errors as for any other metallurgical balance". Hence, 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. Holtham *et al.* (2008) simplifies this definition, stating that "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".

The easiest way to track products back to its source and to improve the production processes is to divide reconciliation into stages, defining factors or indicators capable of detecting the critical operations in the mining chain.

Defining the terms of the reconciliation system

Aiming to visualise the critical stages of mining operations as well as to improve each process individually, Chieregati *et al.* (2011) developed a new reconciliation model based on Morley's proactive reconciliation practices. In order to define the terms of the reconciliation system, a similar model will be taken as an example and is presented in Figure 1.

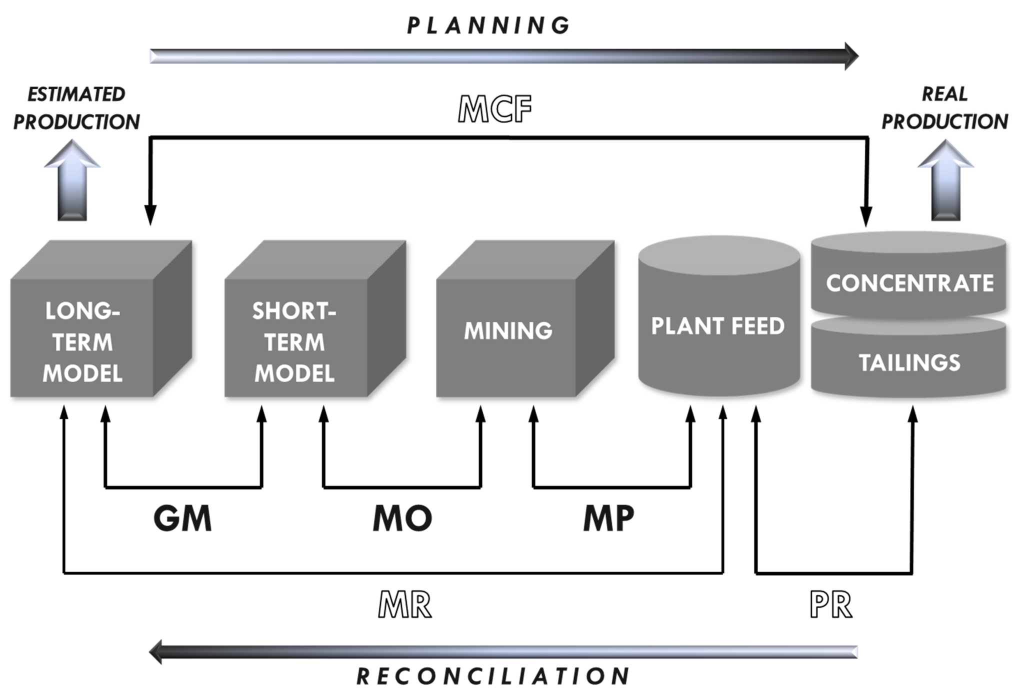

Figure 1 The model of a complete reconciliation system

The model presented in Figure 1 consists of five reconciliation factors besides the well-known MCF. These 'factors' will be called 'indicators' since they work as performance indicators of each individual process, allowing the detection and correction of the causes of reconciliation problems along the mining chain. These problems often result from improper sampling practices, as will be explained further on.

It can be easily seen that the forward direction in the reconciliation system represents 'planning' or 'forecast', while the back direction represents 'reconciliation'. In this way, each indicator is calculated by dividing the value of the variable being studied (tonnage, contained metal, or grade) of the subsequent operation by the previous operation:

- MCF or *Mine Call Factor* = plant production ÷ long-term model estimate
- GM or *Geological Model* = short-term model estimate ÷ long-term model estimate
- MO or *Mine Operation* = mining operation estimate ÷ short-term model estimate
- MP or *Mine to Plant* = plant feed estimate ÷ mining operation estimate

- MR or *Mine Reconciliation* = plant feed estimate ÷ long-term model estimate
- PR or *Plant Reconciliation* = plant concentrate + tailings ÷ plant feed estimate

The meaning of each indicator is presented as follows:

- MCF or *Mine Call Factor*: indicates the predictability of the long-term model of what will be produced by the plant.
- GM or *Geological Model*: indicates the consistency of the long-term model compared to the short-term model.
- MO or *Mine Operation*: indicates the consistency of the short-term model compared to the actual mined ore.
- MP or *Mine to Plant*: connects the last sampling stage at the mine to the plant feed; may indicate the quality of grade control samples (when MO exists) or the predictability of the short-term model (when MO doesn't exist).
- MR or *Mine Reconciliation*: indicates the predictability of the long-term model of what will feed the plant.
- PR or *Plant Reconciliation*: indicates the control efficiency of plant operations.

It's important to note that, when no sampling is performed before the plant feed (e.g. sampling the trucks or the stockpiles after blasting), MO no longer exists and MP connects the short-term model with the plant feed. The poor quality of truck/pile grab sampling practices makes the usefulness of MO doubtful. Nevertheless, mining operations with homogenization piles may have a sampling stage while forming the piles and, in this case, MO will be helpful. It is up to the company to choose the most appropriate indicators for its operation or set new performance indicators according to their needs for control.

Another important observation refers to the definition of the indicator PR. When PR is calculated in relation to the plant production (concentrate), its meaning is restricted to the plant recovery and, in this case, the indicator would be called 'Plant Recovery'. When PR is calculated in relation to the plant products (concentrate plus tailings), the indicator refers to the plant reconciliation and this is the one that should be used in any reconciliation system. The plant reconciliation indicates effective control provided the plant feed is not back-calculated based on its products. Plant feed sampling is a must for a complete and realistic reconciliation system.

RESULTS AND DISCUSSION

Grade, tonnage and contained metal reconciliation

Consider an underground gold mine in which an ore mass of 5,000 t at an average grade of 3 g/t represents a 150 m in length and 4 m × 4 m section gallery. In order to design the complete reconciliation system, the company provides sampling data at every stage of the system. Next, it should be determined which variable will be reconciled, whether contained metal (oz of gold), grade or tonnage. Provided all sampling procedures have been optimised and all sampling equipment have been correctly designed, the systems presented in Figures 2, 3 and 4 show the critical stage (highlighted with an exclamation mark) when reconciling contained metal, tonnage and grade. Table 1 summarises the calculation of the indicators in Figures 2, 3 and 4. The critical stages are shown in grey cells.

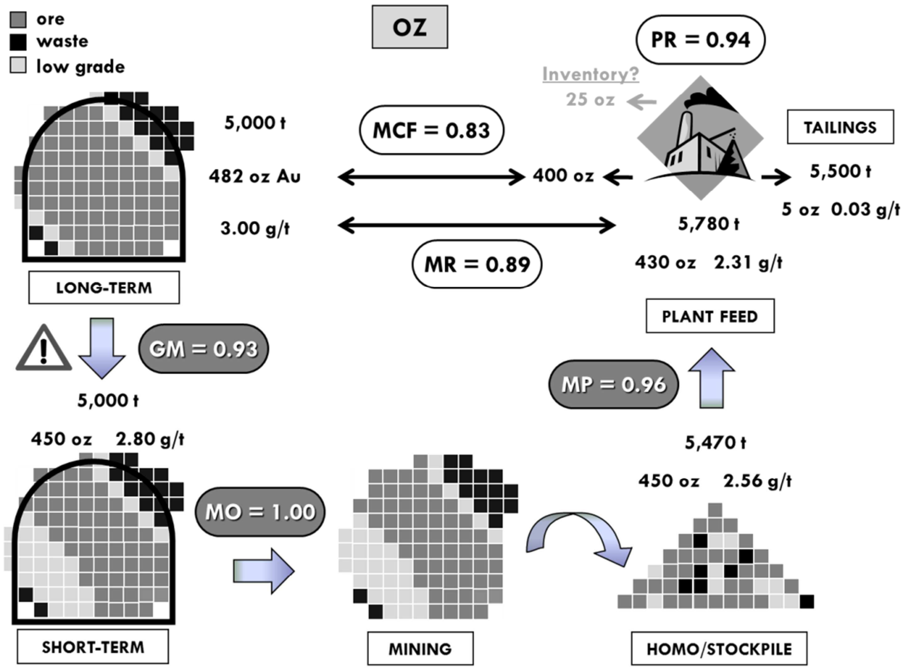

Figure 2 Reconciling contained gold

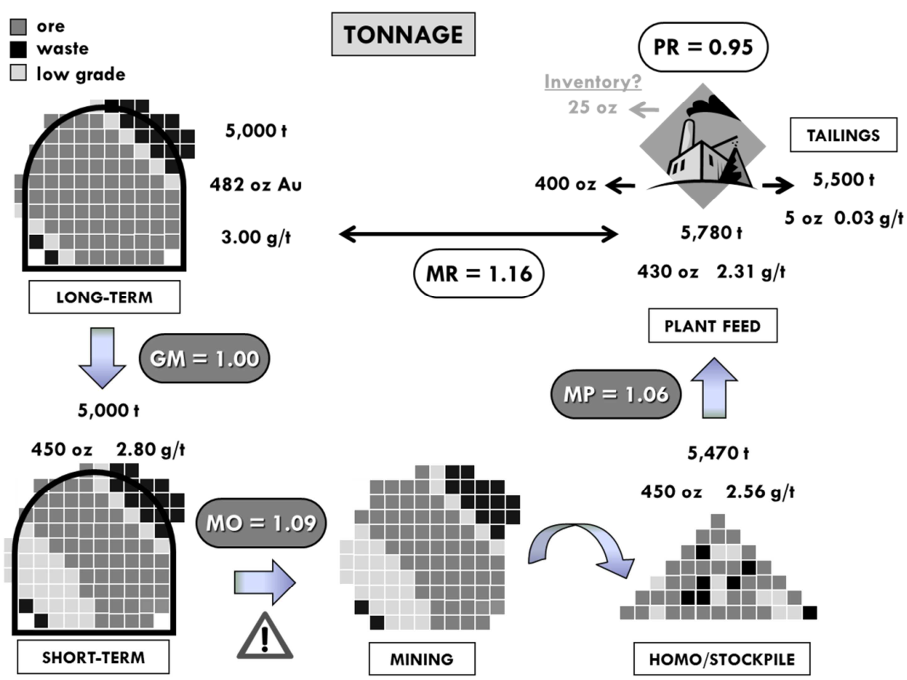

Figure 3 Reconciling ore tonnage

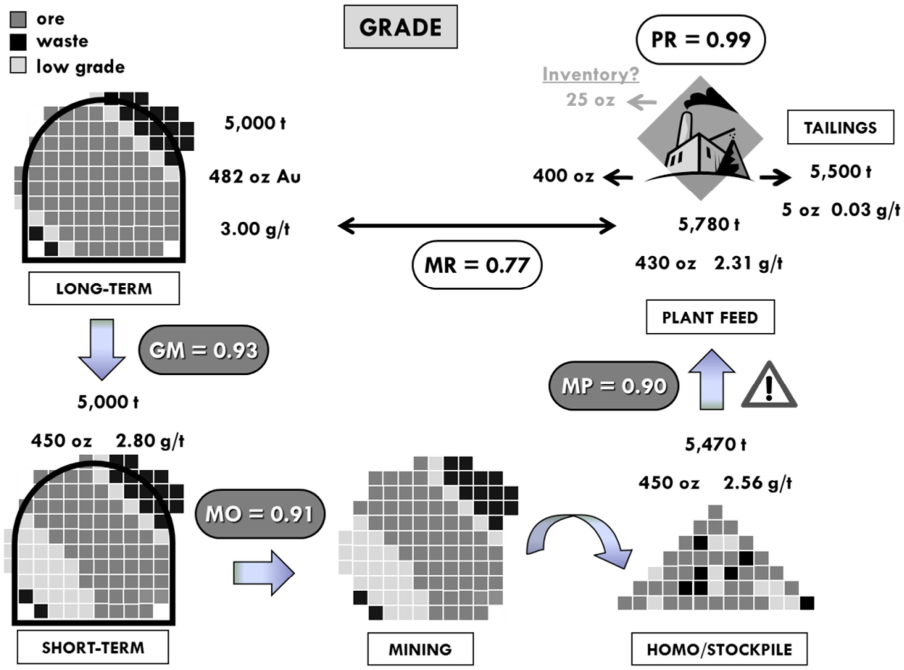

Figure 4 Reconciling ore grade

Note that the factor MR is often called MCF and this step is often called 'mine-to-mill reconciliation', since it reconciles the plant feed with the model estimates. Despite having different concepts, both can be used for the same purpose of establishing the models predictability.

$$\mathrm{MCF} = \mathrm{GM} \times \mathrm{MO} \times \mathrm{MP} \times \mathrm{PR} = \mathrm{MR} \times \mathrm{PR} \quad (1)$$

$$\mathrm{MR} = \mathrm{GM} \times \mathrm{MO} \times \mathrm{MP} \quad (2)$$

Table 1 Calculation of the performance indicators using the variables oz., tonnage and grade

Indicator	Oz of Au	Ore tonnage	Ore grade
GM	$\mathrm{GM} = \frac{450}{482} = 0.93$	$\mathrm{GM} = \frac{5{,}000}{5{,}000} = 1.00$	$\mathrm{GM} = \frac{2.80}{3.00} = 0.93$
MO	$\mathrm{MO} = \frac{450}{450} = 1.00$	$\mathrm{MO} = \frac{5470}{5000} = 1.09$	$\mathrm{MO} = \frac{2.56}{2.80} = 0.91$
MP	$\mathrm{MP} = \frac{430}{450} = 0.96$	$\mathrm{MP} = \frac{5780}{5470} = 1.06$	$\mathrm{MP} = \frac{2.31}{2.56} = 0.90$
PR	$\mathrm{PR} = \frac{400 + 5}{430} = 0.94$	$\mathrm{PR} = \frac{5500}{5780} = 0.95$	$\mathrm{PR} = \frac{2.29}{2.31} = 0.99$
MR	$\mathrm{MR} = \frac{430}{482} = 0.89$	$\mathrm{MR} = \frac{5780}{5000} = 1.16$	$\mathrm{MR} = \frac{2.31}{3.00} = 0.77$
MCF	$\mathrm{MCF} = \frac{400}{482} = 0.83$		

Table 1 shows that the critical stage may differ when reconciling contained metal, tonnage and grade. This example highlights the importance of building a complete reconciliation system for effective control of all operations.

It's important to emphasise that MR must be calculated using data generated by head samples at the plant feed. The fact is that many operations don't sample the plant feed, or the fragments are so large (SAG and AG mills) that they hamper the installation of a sampler at the mill feed. In those cases the company may consider the ore fed into the plant as the ore extracted at the mine. However, one should never back-calculate the plant feed from the metal production, because it would mask the errors generated during the mineral processing stage. If the company decides to back-calculate grade and tonnage, it must keep in mind that part of the control of its processes may be lost.

Geometry reconciliation

Another consideration to be made is about geometry. What should be reconciled, the planned or the executed geometry? As previously stated, the meaning of reconciliation is to track products back to the source. Therefore, the executed geometry relates to 'reconciliation' and the planned geometry relates to 'planning' (Figure 5). When reconciling, one should consider overbreaks and underbreaks and use the real mined volume in the long-term and the short-term models when calculating the reconciliation factors.

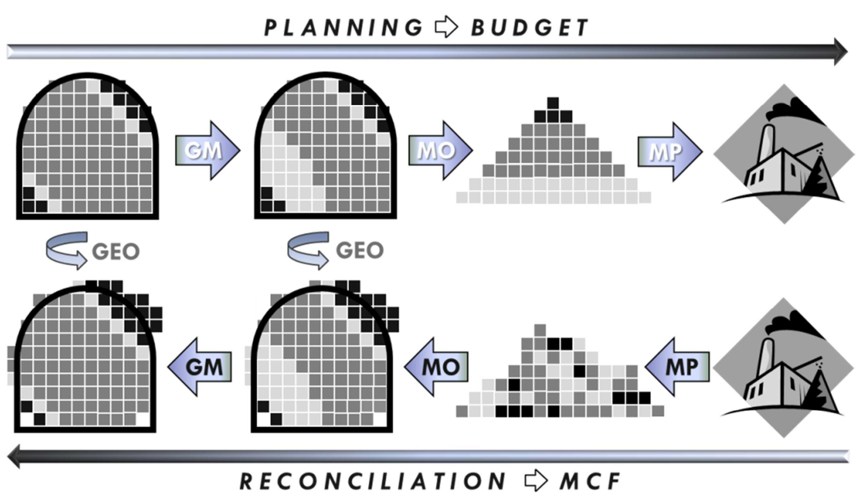

Figure 5 Planned vs. executed geometry reconciliation

It's still possible to reconcile planned geometry (or tonnage, or grade, or contained metal) with executed geometry. In this case, one extra indicator is created for each variable (GEO for geometry) and will indicate the performance of the mining operation, i.e. how mining operation is capable of reproducing the mining plan.

Illusory reconciliation

The next example is based on the author's experience in what commonly happens in the mining industry when it comes to sampling and reconciliation. Consider an open pit gold mine in which an ore mass of 300,000 t at an average grade of 3 g/t represents a 50 m × 50 m × 50 m block. The mined volume can be tracked back to the models for estimation of grade, tonnage and contained metal. The complete system is shown in Figure 6 and presents an apparently excellent reconciliation, with a MCF of 1.01 for contained metal and 1.06 for processed tonnage. The indicator indices 't', 'c' and 'g' represent 'tonnage', 'contained metal' and 'grade' respectively, and 'RV' is 'reconciled volume'.

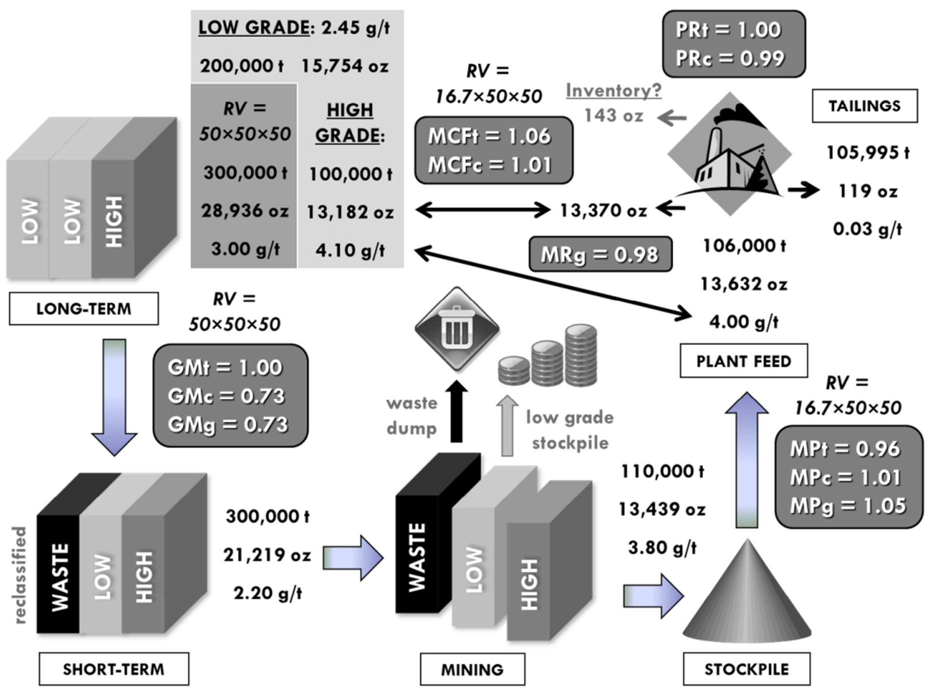

Figure 6 A complete reconciliation system for a 50 m × 50 m × 50 m mined block

According to Figure 6, the long-term model estimates that 2/3 of the block is low grade ore and 1/3 is high grade ore. In this case, GM indicates the reconciliation between the models for a reconciled volume (RV) of 50 m × 50 m × 50 m.

Additional data for short-term planning comes from blasthole samples. The short-term model, enriched with the blasthole sampling results, reclassifies 1/3 of the block as waste. After blasting, 1/3 of the block is sent to the waste dump, 1/3 of the block is sent to the low grade stockpile and the last 1/3 is sent to the plant. It's worth emphasising that, from this point on, the reconciled volume decreases to 16.7 m × 50 m × 50 m, as this is the only volume that continues to be part of the process. Therefore, MP, PR, MR and MCF relate solely to the high grade ore.

Analysing the reconciliation system, it's clear that something wrong happened between the long-term and the short-term models. The short-term model's estimates of grade and contained metal are

27% lower than the long-term model's estimates (GMg and GMc = 0.73). Since the sampling grid for the short-term model is much denser than the one used for the long-term model, there is a tendency of considering the short-term model as the most reliable. But how representative are the samples that generated each model? Is the reclassified material really waste?

This example shows a misclassification of ore as waste due to the sampling procedure. In an attempt to avoid contamination between blastholes and the exposure of operators by fine particulates as well, the sampling team decided not to collect the fines, composing the grade control samples with ¼ of the medium and coarse material discharged by the underflow of the driller's cyclone. This decision introduced a bias to all short-term samples, underestimating its grades by not collecting the fines, where gold grades are higher. The bias is confirmed by MPg, which shows, for the same material, a higher grade at the plant feed.

The final reconciliation results seem excellent; however, part of the low grade ore is being lost as waste and probably will never be recovered, since no sampling is performed in the waste dump. In this case, if only the MCF is calculated, an illusory reconciliation takes place, hiding biases caused by poor sampling and making the company believe it's operating perfectly, while losing gold in its waste dump.

CONCLUSION

This paper was essentially meant to describe the terms of a complete reconciliation system, emphasising the importance of sampling in developing a reliable system. The subtleties of reconciliation are many and many are the ways to build a reconciliation model suitable to each mining operation. However, one condition is a must for all operations: to provide as many sampling points as possible to develop a helpful and effective reconciliation system.

Sampling plays the most important role in this system. Reconciliation results can be deceptive unless all parties involved have been in compliance with the principles of sampling correctness (Pitard, 2009). In order to avoid illusory reconciliation, all sampling procedures must be optimised and all sampling equipment must be correctly designed. Only by guaranteeing the representativeness of the samples, the estimates become prognosis and can be used with confidence in decision making and annual budgets of mining companies.

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REFERENCES

Chieregati, A.C., Pignatari, L.E.C. & Delboni Jr., H. (2011) 'Novo modelo de reconciliação para a indústria do ouro', *Revista Escola de Minas*, REM, Ouro Preto, Brazil, vol. 64, no. 2, pp. 237–243.

Holtham, P., Scott, A. & Sanders, D. (2008) 'Measurement and reconciliation of the coal production chain', *An introduction to metal balance and reconciliation*, JKMRC, Queensland, Australia, pp. 517–568.

Morley, C. (2003) *'Beyond reconciliation: a proactive approach to using mining data'*, *Fifth Large Open Pit Mining Conference*, AusIMM, Kalgoorlie, Australia, 3–5 November, pp. 185–192.

Morrison, R. (2008) 'Data analysis for reconciliation', *An introduction to metal balance and reconciliation,* JKMRC, Queensland, Australia, pp. 273–306.

Pitard, F. F. (2009) *Pierre Gy's theory of sampling and C.O. Ingamell's poisson process approach, PhD thesis*, Aalborg University, Esbjerg, 309 p.