# Met Accounting and Reconciliation

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## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Balance</td>
<td>2</td>
</tr>
<tr>
<td>Sampling</td>
<td>3</td>
</tr>
<tr>
<td>Equipment</td>
<td>5</td>
</tr>
<tr>
<td>Moisture measurement</td>
<td>6</td>
</tr>
<tr>
<td>Containers</td>
<td>7</td>
</tr>
<tr>
<td>Assaying</td>
<td>7</td>
</tr>
<tr>
<td>Flow Measurement</td>
<td>8</td>
</tr>
<tr>
<td>Weigh Feeders, Weightometers</td>
<td>8</td>
</tr>
<tr>
<td>Flowmeters</td>
<td>8</td>
</tr>
<tr>
<td>Certification</td>
<td>9</td>
</tr>
<tr>
<td>Inventory Measurement</td>
<td>9</td>
</tr>
<tr>
<td>Tanks</td>
<td>10</td>
</tr>
<tr>
<td>Thickeners</td>
<td>10</td>
</tr>
<tr>
<td>Stockpiles</td>
<td>10</td>
</tr>
<tr>
<td>Goldroom/ Product Stockpiles</td>
<td>10</td>
</tr>
<tr>
<td>Reconciliation</td>
<td>11</td>
</tr>
<tr>
<td>Plant Losses</td>
<td>11</td>
</tr>
<tr>
<td>Common Met accounting systems</td>
<td>12</td>
</tr>
<tr>
<td>References</td>
<td>13</td>
</tr>
</tbody>
</table>
Met Accounting and Reconciliation

Metallurgical accounting involves the monitoring of the valuable components present in a metallurgical circuit. The task of met accounting then, is essentially performing a simple in and out mass balance over the processing operation. With one primary input to the plant and generally no more than a handful of exit streams, the balance might be perceived to be relatively straight-forward. Anyone tasked with performing this balance would understand this is not the reality.

In recent years AMIRA International conducted a project to develop the P754 Metal Accounting Code of Practice. The push to produce a code of practice came from within the mining industry, driven by increased demand for corporate governance and a need to improve practices and processes. Mining companies are endeavouring to improve their met accounting reporting in order to comply with this Code. This paper was not written with specific consideration of the Code of Practice but reflects some of the key targets presented therein.

Accurate and reliable met accounting relies on obtaining several key sets of data but difficulties and potential errors exist with each measurement. Numerous traps exist for processing operations attempting to reconcile their metal accounting over daily, weekly, monthly or annual periods. It is hoped this paper will help to identify those traps and assist readers in identifying and rectifying such issues.

Primary Balance
As mentioned, the met accounting process is essentially a mass balance over the processing plant. This will be conducted over a specified time period, usually monthly.

![Figure 1. Simple process plant balance](image)

For a relatively simple processing operation, depicted in Figure 1, the Primary mass balance is relatively straight forward. The overall rates are defined by

\[ F = P + T \]

Where \( F \) is the Feed rate, \( P \) the Product flow rate and \( T \), the Tails flow rate.

For the individual component(s)

\[ F \times f = (P \times p) + (T \times t) \]

Where \( f, p \) and \( t \) are the concentration (or grade) of the component in question.
When more streams are involved as depicted in Figure 2, such as several product streams, or additional waste streams, the equations increase in complexity. It follows that the met accounting process will become more involved.

![Figure 2. Process plant with increasing complexity](image)

Naturally throughout this process, water addition and stream moisture composition is also a critical and influential factor that needs to be included and accounted for. The water balance for a mine is generally a critical aspect of its operation in any case.

These primary equations omit a key consideration. That is, the change in inventory held within the plant over the period, which must also be taken into account. Assuming that the inventory of metal within the plant remains the same from beginning to end of month is oversimplifying even for a modest operation. Changes in tank levels, stream concentrations, solids density (i.e. % solids) or intermediate stockpiles will influence the met accounting calculations.

Measurement of these variables is thus critical. Measurement of flow rates and component grades are discussed broadly next.

**Sampling**

Correct sampling is critical in order to get samples that accurately represent the component concentration or metal grades in the chosen material stream and produce accurate metallurgical accounts. Sampling in mineral processing should be based upon sound elements of applied statistics and probability.

Pierre Gy produced a theory regarding how best to sample particulate materials and what size the sample should be in order to minimise the error induced by the sampling process itself, in the late 1940’s – early 1950’s.

The focus of that theory is that as long as every particle has an equal chance of selection and nothing happens to change the sample or the process your samples will be representative. With respect to the sampling error, the following variables are important:

- particle size
- the liberation size of the target component
- mineralogy/ composition
• grade/ true value
• mass of the lot
• sample mass
• particle shape
• density of the components
• variability of the particle size.

If you have an understanding of these characteristics you can estimate the likely error, as long as you are sampling correctly.

Sampling error will be cumulative, thus each component of the sampling process will increase the likely sampling error. Listed below are the ten sources of sampling error (Pitard, 2005) that contribute to the non-representativeness of samples. They include:

- In situ Nugget Effect – especially with materials such as gold where nuggets of native metal can occur, a given sample may contain a very high grade of metal or none at all. This nugget effect makes it difficult to obtain consistent, representative samples.
- Fundamental sampling error – loss of precision due to chemical and physical composition, including particle size distribution. Fundamental error can be reduced by decreasing the particle size or increasing the sample mass.
- Grouping and segregation errors – error due to non-random distribution of particles, e.g. by gravity. This can be minimised by compositing a sample from several samples and homogenising that composite before splitting it to get the final sample.
- Long-range heterogeneity (quality) fluctuation error (shifts and trends) – error that fluctuates and is non-random. This can be reduced by taking many increments to form the sample.
- Long-range periodic heterogeneity (quality) fluctuation error (cycles) – fluctuation based on time or distance. This also can be minimised by correct compositing of samples.
- Increment delimitation error – error caused by inappropriate sampling design and/or use of wrong equipment.
- Incremental extraction error – occurs when the sampling procedure fails to precisely extract the intended increment. Well designed sampling equipment and good procedures will assist to minimise this error component.
- Weighing error – errors associated with reading or operation of weighing equipment during sample processing.
- Preparation error - refers to the loss, contamination or alteration of a sample or sub-sample. Good field and laboratory techniques are required to minimise this.
- Analytical error – errors associated with the analytical procedures involved in processing the sample.

Much work has been done to explain and further develop the work that he did but for our purposes an essential point is that smaller samples can be used and expected to provide good results, when finer material is sampled. It seems logical that if one takes a sample of finely ground material it is more likely to be representative than if we take a similar quantity of material from a coarse material, with other factors being equal.
Also, the expected grade is critical to the sampling process. Economic precious metal head grade is usually measured in the grams per tonne range, while base metals head grades are usually measured in percentages. It is logically more difficult to achieve a reliable, representative sample of feed ore to a gold plant than to a copper processing plant.

Minnit, Rice and Spangenberg (2007) present a thorough breakdown of the components of the fundamental sampling error and how it ultimately affects the quantities of material required for reliable sampling. Rather than re-hash this material, the reader is recommended to read this paper.

It should always be kept in mind that the reliability of the results and thus the usefulness of the data, relies on the reliability of the samples. Best practice sampling and handling procedures need to be followed in order to minimise each area where potential error could be introduced.

**Equipment**

Good sampling devices are important to good sampling protocol. A range of online samplers are available for liquid/slurry streams and for solids.

Solid sampling will often be done by grab samples which do not provide representative samples. The representivity can be improved by taking a number of samples to produce a composite.

Mechanical samplers are used extensively because they are more efficient than hand sampling techniques and the human factor is eliminated. Two different approaches are followed—part of a moving stream of material is continuously removed, or the whole stream of material is diverted at regular intervals. This may be done with rotary cutters, cross belt samplers, screw samplers or chain bucket samplers. Stopping a belt and taking the entire contents over a length of the belt can also be used to provide a relatively good sample but is not favoured as it interrupts production and is quite labour intensive.

A range of samplers, often incorporating 2 or 3 levels of sample splitting are also available for online slurry or liquid measurement. Importantly also, the stream diversion should capture the whole stream so that no bias is introduced. Figure 3 illustrates a sampler which incorporates an online analyser.
Manual slurry sampling of stream flows can be problematic in terms of cutting the entire stream flow as well as introducing potential safety hazards, especially with fast moving flows or even more-so with corrosive or otherwise hazardous materials.

Valve style sample points in a line are common but can be subject to a misrepresentative sample if the flow is not perfectly homogeneous throughout the cross-section of the pipe. Ideally valve sample points should be positioned in vertical lines. Also the flow should be allowed to run for a short period to flush the pipe associated with the sample valve, to remove any build-up of material that has collected.

Manually sampling tanks with a bucket or other sample container will produce samples with relatively low confidence but this method is rife within the industry. As with the solid grab samples, combining several samples into a composite can improve the reliability of the sample if no automated option is possible. Gaylard et al (2009) recommend a mechanical auger system to take representative samples across the surface of a solid pile and through its depth as a minimum for piles of solid material.

**Moisture measurement**

Samples obtained for moisture measurement pose a unique challenge on a mineral processing plant. While it is not necessarily a difficult task, it is vital that samples taken automatically or manually are not compromised by the elements. Samples need to be diligently taken and sample containers well sealed in order to prevent loss of moisture, especially in warm climates, or collecting more moisture from rain or condensation. A small error in evaluating the moisture of a particular stream can have significant impact in the met accounting.
**Containers**
Sample containers are usually re-used in any operation. It goes without saying that these need to be properly cleaned before re-use, but another precaution is to use the container for the same sample point. At least any error will be minimised if the container has not been well cleaned. In the worst case, a poorly cleaned concentrate container, used to sample the tails stream may contaminate the sample with high grade material, giving an inordinately high reading which will send alarm bells ringing (hopefully!) and greatly distort met accounting figures. Similar alarm bells may ring if high levels of deleterious elements were detected in the concentrate sample because the wrong, dirty sample container was used.

**Assaying**
The assaying process is also one in which the met accounting relies heavily. Numerous assay techniques are available to the metallurgical industry and the particular method used will depend upon the material being assayed, the expected grade of the target elements, level of accuracy required and cost restraints, among other factors.

Stages of processing the sample material that can influence the results include size reduction, digestion, dilution and reaction to produce detectable components. If any of these are conducted improperly or differently from one sample to the next, inconsistency in the final assay results can result.

In order to produce reliable results to feed into operational data and to the met accounting, the suitability of each method used for each sample point should be discussed with experienced laboratory personnel. The method can be selected with the various constraints in mind to give optimum results. Most methods are well established but certain components are still difficult to assay.

Beyond that point, laboratory supervision must ensure best practice laboratory procedures are always carried out. This should include regular testing with reference samples to assess any bias and regular calibration of equipment.

Sample contamination is also a potential risk during the sample preparation for assay. Containers and utensils must be thoroughly cleaned after use and care taken not to contaminate samples. High value products such as gold or platinum group elements (PGE) are particularly susceptible to such contamination, as the measured grades are usually so low, as mentioned previously.

It is important that lab procedures ensure that samples are retained to allow proper investigative processes to be undertaken should an issue be identified later. If issue with an assay result or series of results is found after the fact, say, in reconciling metallurgical accounts, it is beneficial to be able to check the results by repeat assays. Each plant and laboratory should agree their policies for labelling, logging and retention of samples.

Ensuring best possible assay results will assist in ensuring reliable met accounting for the plant and smoother operation for all involved.
Flow Measurement

Weigh Feeders, Weightometers
Belt Weighers are also known as conveyor scales, weightometers or continuous weighers and are designed to weigh solids product moving along a conveyor belt. A belt weigher consists of a weigh frame fitted with load cells mounted in the conveyor frame and connected to a digitiser to translate the weight readings into a flow rate and total weight. There are various classes of belt weigher with the attained accuracy being dependent on many factors.

Installation, maintenance and calibration of these items are crucial to their operation. To achieve the best possible results from a weightometer a number of issues must be addressed in respect of its mechanical installation. The major factors are (Viatech, 2013):

- Vertical Alignment
- Horizontal Idler Spacing
- Horizontal Alignment
- Idler Frame and Roller Selection
- Weigh frame Location.

Incorrect installation that results in appreciable vertical misalignment will result in the device reading in a non-linear fashion.

The horizontal spacing naturally includes the need to have the idler frames parallel. The sensing idlers and frames on either side should be considered the most important and effort made to install and maintain these as close to the ideal as possible with diagonals a closely matched as possible.

Where the conveyor load is consistent and lump sizes relatively constant and well distributed the horizontal alignment will be relatively tolerant of errors. If the conveyor load varies significantly and has irregular or cyclic load distribution, horizontal alignment becomes more of an issue. In general, an accuracy of +/- 5mm per metre should be considered an acceptable target in practice.

As discussed with all plant equipment, regular maintenance and calibration are vital to maintaining accuracy and accurate met accounting. Further with weightometers, housekeeping is also important. It is important to keep weigh frames clean to avoid high readings caused by dust build-up.

A recent unexplained variance of about 2% between a load-out weightometer measurement and the shipping survey was resulting in quantities of material being written off at the rate of a shipload per month. At the time of writing the cause of the discrepancy had not been identified but such an error can have major implications for the business.

Flowmeters
Flowmeter selection can be a difficult task, complicated by the number of designs and technologies and also the factors affecting the choice. Several hundred designs are available, based up the following 10 general principles:
Differential pressure (DP) meters
• Other DP meters
• Displacement meters
• Turbine meters
• Vortex meters
• Electromagnetic meters
• Ultrasonic meters
• Coriolis mass meters
• Thermal meters
• Miscellaneous meter types.

Selection of the correct flowmeter to provide the most accurate flow for a specific duty will be critical in ensuring accurate data and reliable metallurgical accounts.

Installation of the meters is also important to ensure correct flow conditions such that the meter then reads correctly. Generally flowmeters are calibrated by manufacturers under controlled conditions. Actual operating conditions are rarely ideal for operation of the meters which may be sensitive to external influences such as electrical interference, vibration and ambient temperature change. Errors can be induced by such installation effects. In order to minimise errors it is important to follow manufacturers’ guidelines regarding installation, maintenance and calibration. Their optimal operation will be critical to reliable met accounting and can be an important area to check if regular discrepancies are being noted.

Certification
Further to the need for regular calibration of weightometers, independent certification is required for weighing instruments used to measure quantities at points of sale or transfer of custody. Suitable procedures and record-keeping are also important to conform to best practice.

Inventory Measurement
Proper measurement of material grades and the stream flows for the necessary streams completes the required inputs for the Primary mass balance over the plant. Importantly, this omits the accumulation (or reduction) of material within the plant. Measurement of the inventory contained within the plant and comparison from the beginning and end of the time period provides a vital input to the reconciliation process.

Key points in the process where significant inventories of material are held should be included when plant inventories are considered. Large tanks such as leach tanks or concentrate filter feed tanks, SX or EW feed tanks and vessels, barren solution tanks, stockpiles of intermediate material such as clinker for cement production, or concentrate destined for a leaching process and thickeners will all contain substantial quantities of material which will change from month to month, by virtue of changes in concentration and/or volume.

Sampling of each of these inventory stocks involve issues already discussed, in most cases requiring grab samples, so the representivity is often less than ideal. Every effort should be taken to follow
consistent procedures and take composite samples to improve the reliability of the results if the optimum equipment cannot be used.

The omission of certain small items consistently, is unlikely to have a significant impact upon inventory changes although the overall accuracy of the balance is reduced slightly. It would not be uncommon to take a considered decision to overlook certain smaller vessels in order to simplify the met accounting process. A consistent approach from month to month is most important here.

**Tanks**

The volume of tanks containing liquids are relatively simple to sample and to evaluate contained metal. However as soon as solids are introduced and we have slurries to assess, the task becomes more difficult. Sampling to assess the solids density can be hit-and-miss and can result in large discrepancies when measuring metal in circuit. Sampling needs to identify solids percentage in the slurry and metal grades in solution and solid in order to assess the overall metal content. For CIL leach tanks, a third component, the carbon must also be assessed in terms of carbon dosage and the gold loaded. This further complicates the inventory calculation and the need for good sampling procedures.

Enclosed vessels need reliable instrumentation to measure levels and or pressure to evaluate the vessel contents. With reliable instrumentation in terms of pressure, level or weight sensing, good accuracy is expected.

**Thickeners**

Thickeners’ bed depth are measured automatically in more modern plants, so a good estimate of the quantities of solids and solution can usually be made in a thickener. Assays of the solution and solids then complete the picture when assessing the metal inventory of the vessel.

If instruments are not available to give the bed depth, then a manual depth needs to be taken, with care, and according to consistent procedures to ensure consistent results over subsequent periods.

**Stockpiles**

Materials stored in 1 tonne Bulka Bags such as concentrate, fertiliser or reagents pose fairly low risk of error. A discrepancy in the order of 10 or 20 kg in a bulka bag represents 1-2% error, generally over a small total quantity. Further, with small quantities, it would not be an inhibitive task to actually weigh the product. However, with large stockpiles of product or ore, quantities are difficult to measure. Errors are introduced from the estimate of bulk density which is unlikely to be completely uniform throughout a large pile and the error in estimating the volume. Pacing out a stockpile and estimating height and shape provides an interesting challenge. This can be somewhat easier in an enclosed shed or bund!! Regular surveys are required by best practice operations but add a reasonable cost to the operation.

**Goldroom/ Product Stockpiles**

Often gold stored in the gold room will be treated as shipped for met accounting purposes. Similarly, concentrate or cathode of stockpiled final product could be treated as sold. If this is the case, then consistency of treatment is the key to dealing with these quantities. Product considered shipped at the end of one month cannot be double counted if it is subsequently actually/physically shipped off
Reconciliation
The reconciliation process seeks to take several measurements from different sources, over the chosen time period and compare the results. The objective is realising the ‘true’ figures, based upon that input information. Hence, the reconciled head grade fed to the plant will be calculated based upon the tonnes fed to the plant and the quantity of metal produced by the plant - once produced metal is tallied, adjustments made for changes in inventory over the period, and any necessary adjustments made for the period (such as corrections for mint receipt for gold production).

This figure will inevitably be compared to the measured head grade fed to the plant, albeit in coarse feed material.

Ultimately, the most important result is to consistently and accurately represent the path of the metal in the circuit. If we can consistently get the measured grade and reconciled grade to closely match, great confidence will follow in the met accounting system.

Plant Losses
Plant losses will inevitably cause discrepancies within met accounting reports. Whenever identified an effort should be made to quantify such losses. Alternatively, the met accounting process may in fact be the means of identifying significant losses, by highlighting discrepancies - be they one-off events or regular significant losses.

Significant losses would usually be more noticeable in the accounts if large quantities of material or high concentration products or streams are lost. Some examples of losses are mentioned below. This list is far from comprehensive. Connelly (2009) discusses plant losses from a gold plant in more detail.

- Major spillage events are unlikely to be missed but it may be difficult to accurately quantify metal losses. It is important to account for these losses as best as possible so as not to sacrifice the accuracy of the metal accounts.
- Theft is usually a greater issue or risk in gold, precious metals or diamond plants. Measures must be employed to limit opportunity and temptation so such product losses do not eventuate.
- Fine carbon losses from a gold plant obviously take gold with it out to tails. It is critical that carbon fines are removed from the circuit after stripping.
- It is important to minimise re-precipitation of metal in leach circuits as although this should be measureable in assays and hence accountable, the loss of metal is undesirable.
- Crud removed from a solvent extraction circuit will usually contain some metal. The quantity of crud removed and its metal content should be measured to allow the loss to be quantified and accounted for.
Losses naturally need to be minimised in order to optimise the plant operation and productivity, but when they do occur, best effort must be made to quantify them, for the benefit of the overall accounts.

**Common Met accounting systems**

Perhaps the most common means for metallurgists or process engineers to conduct their met accounting, or monthly balances is with one or more spreadsheets. These may be linked to combine data from various sources or points in the process. They are used and filled out by several people leading to issues of maintaining the integrity of the data. Changes to feed blends or processing paths can require changes to the spreadsheets which can lead to confusion at the changeover point and then in subsequent months when attempting to interrogate or compare data. Gaylard et al (2009) suggest that the use of spreadsheets to conduct met accounting operations should be avoided.

The use of powerful database tools can assist in removing such problems and providing a structured, time effective approach to daily and monthly met accounting procedures.

Cubility’s MPXDS is a metallurgical accounting tool designed to streamline production reporting at a processing plant, reduce dependence on a variety of spreadsheets and paper log sheets and increase productivity.

Use of the package assists operators seeking to adhere to the 10 principles of metal accounting agreed in AMIRA’s P754 Code of Practice. ‘The basic philosophy behind the Code is that it prescribes standards and best practices for mass measurement, sampling, sample preparation, analysis, data management and metal balancing to enable compliance with the basic principles.’ (Gaylard et al, 2009).

Advantages of this system include:

- Minimal data entry and re-entry. Data can be imported from existing systems
- Simple entry of Blend information or process variants
- MPXDS incorporates downtime event logging in the same system
- Centralised recording of reagents and monitoring of unit consumptions and costs
- Restrictions on who can enter and see various data
- No cutting and pasting of spreadsheets and debugging altered sheets
- No adjustments to spreadsheets to fit to different accounting or reporting periods
- Storage of data in one central database, accessible from anywhere on the mine network
- Automated reporting and metal reconciliation
- Ease of interrogating data
- Consistent, configurable reports and graphs, no matter which team is on site
Ease of distributing and publishing reports and confidence they will be received on time

These factors combine to limit introduction of error, improve confidence in the operation and to save considerable amounts of time... Time better spent by metallurgists and shift supervisors out on the plant making a difference.

References


