IMPROVING THE ACCURACY OF STOCKPILE INVENTORY ESTIMATES

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ABSTRACT

Stockpiles can be found on almost every mining and mineral processing plant properties around the globe. Whether they are made of crushed ore, concentrate, iron ore pellets or other valuable-metal bearing material, stockpiles always hold significant value. Consequently, rigorously tracking the inventory of metal within these stockpiles is of paramount importance to every mining company. Assessing the metal inventory of stockpiles is a well-known metal accounting challenge. Unless they are built upon a well-calibrated weigh-scale, which is seldom the case, stockpile inventories can never be determined exactly. Because all measurements and sample analyses that are used for characterizing a stockpile carry unavoidable errors, inventories are always estimated with a certain level of uncertainty. In statistical terms, stockpile inventory assessments are stochastic variables with non-null variances. Different techniques are used in the mining industry for assessing the inventory of stockpiles. Interestingly, the variance (level of uncertainty) of the assessed inventory much depends on the technique that is being applied for calculation. Some are more accurate than others. By carefully selecting the assessment technique, it is therefore possible to improve the accuracy of a stockpile inventory estimate and consequently, to reduce the magnitude of the corrections that have to be made from time to time to reported stockpile inventories.

KEYWORDS: stockpile; inventory; metal; accounting; mineral; processing.

1. INTRODUCTION

Substantial metal values are often locked in aggregates stockpiles (ore, concentrates, iron ore pellets, heap leach pads, slags, etc.). Both from a financial accounting and operations management standpoint, this is more than enough to justify rigorous and accurate tracking of metal inventory within these stockpiles. However, accurately determining a stockpile inventory has always been a technical challenge (Morrison, 2008).

Unless they are built upon a well-calibrated weigh-scale, which is seldom the case, stockpile inventories can never be determined exactly. Given that industrial measurements and sample analyses always carry errors, stockpile inventory estimates calculated from this information always have an unavoidable level of uncertainty (as the stockpile on Figure 1 clearly has). Stockpile inventory assessments truly are stochastic variables with non-null variances.

Figure 1. Concentrate stockpile at a Peruvian mining operation.

Luckily, of the different techniques that are used in the mining industry for assessing stockpile inventories, some are more accurate than others. By carefully selecting the assessment technique or combining them, it is possible to maximize the accuracy (minimize the variance) of a stockpile inventory estimate and consequently, to reduce the magnitude of the corrections (write-in or write-off) that have to be made from time to time to the reported stockpile inventories within metal balances.

The inventory management techniques that will be discussed are applicable to different material storage processes (including bins, storage tanks and thickeners). However, this discussion will primarily focus on their application to aggregate stockpiles, which are very common in the mining industry.

2. DEFINING STOCKPILES

The stockpile is probably the easiest and cheapest process for storing solids. In the mining industry, it is applied for storing different kinds of aggregates (ore, concentrate, iron ore pellets, slags, etc). They are built by accumulating aggregates within a delimited area.

There are essentially two main stockpile types: dynamic and static stockpiles. In dynamic stockpiles, aggregates have a finite (or short) residence time. Aggregates get into the stockpile (through belt conveyors, dump trucks, etc.) and remains in it until they get reclaimed (through front-end loaders, draw points underneath the stockpile, etc).

In static stockpiles, aggregates have an infinite (or very long) residence time. Aggregates are accumulated in but never withdrawn from static stockpiles.

Crushed ore, concentrates and iron ore pellets are typically stored in dynamic stockpiles. Waste rocks, dry tailings and leach heap ore are often stored in static stockpiles.

3. BASE CASE: TRACKING INVENTORY THROUGH THE INDIRECT METHOD

The most common problem is the estimation of a dynamic stockpile inventory on a daily basis. From an known opening inventory I(i-1), the challenge is to assess the closing inventory I(i) at the end of the day i.

The information that is often available for solving this problem is the cumulative tonnage of aggregates that fed the stockpile during the day F(i) and the cumulative tonnage of aggregates that were reclaimed R(i) from the same stockpile. The closing inventory is then calculated by applying mass conservation principles. This method is called the 'Indirect method' (Gariépy *et al*., 2012) because it does not require any physical measurements of the actual stockpile.

$$I(i) = I(i-1) + F(i) - R(i) \tag{1}$$

When the technique is repeated over N successive days, the closing inventory of day N is obtained through the following summation.

$$I(N) = I(0) + \sum_{k=1}^{N} F(k) - \sum_{k=1}^{N} R(k) \tag{2}$$

The equation of the indirect method does respect the principles of mass conservation and should, in theory, provide the exact closing stockpile inventory. In practice, however, all feed and reclaim transactions (F(k) and R(k)) carry non-negligible errors (by their nature, belt conveyor and/or dump-truck weigh-scales are imperfect instruments). These measurement errors turn the closing inventory I(N) into a stochastic variable with a non-null variance. Therefore, closing inventories that are calculated through the indirect method also have a non-null variance, i.e. that they carry a certain level of uncertainty.

Gariépy *et al*. (2012) demonstrated that the level of uncertainly (or variance) of the estimated closing inventory I(N) essentially depends on the uncertainty of the mass measurements of stockpile feed and reclaim. More importantly however, they also showed that the variance of the estimated closing inventory grows from one estimation to the next. In other words, when the stockpile inventory is updated every day using the indirect method, the accuracy of the stockpile inventory estimate decreases from day to day.

Gariépy *et al*. (2012) ran Monte-Carlo simulations of a (gold ore) stockpile inventory tracking process where the 'true' feed and reclaim daily tonnages were kept steady for 6 months. For demonstrating the propagation of errors, they added uncertainty to the measurements (as shown in Table I). They assumed that stockpile inventory was updated every day for the 180 days of the

simulation. Eight distinct simulations were conducted (each using a different random number generator seed) and the results were gathered in Figure 2. From the graph, it can be seen that after 180 days, the estimated gold inventory within the stockpile could be anywhere between 5000 and 10000 ounces of gold at a 95% confidence interval (square root bold lines) while the true gold inventory (horizontal bold line) remains steady at 7500 ounces!

Table I. Simulation parameters of the gold ore stockpile inventory.

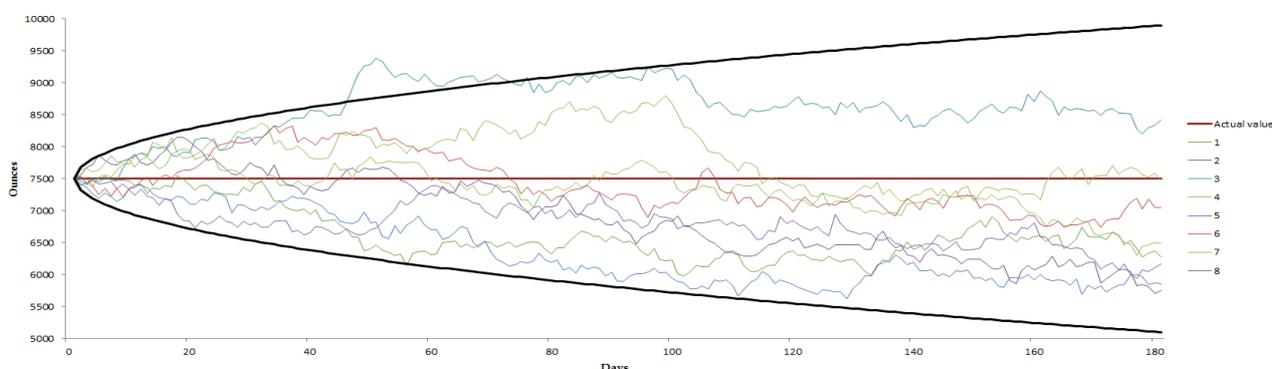|	Ore inventory	Ore grade	Gold inventory	Relative standard deviation
	Tonnes	ounces/tonnes	ounces	%
Feed	40 000	0.025	1000	8
Reclaim	40 000	0.025	1000	4
In-process inventory	300 000	0.025	7500	0

Figure 2. Simulations of indirect estimation of a stockpile inventory (expressed in ounces of gold).

4. ALTERNATIVE: DIRECT (IN-SITU) EVALUATION METHOD

By far, the best in-situ method of obtaining a very accurate estimate of a stockpile inventory is to build the stockpile directly on a heavy-weight measuring system. This is of course hardly practical and rarely applied in the mining industry.

The in-situ inventory evaluation method that is most often used in the mining industry is based on a volumetric evaluation where optical surveying instruments are used for characterizing the shape and the size of the stockpile. Specific gravity and void fraction parameters are then applied to the estimated volume for evaluating the mass of the stockpile.

Of course, stockpile inventory estimations calculated from optical volumetric evaluations also carry errors. Even though lasers can be very precise, the heterogeneity of stockpile surface and the imprecision of the aggregates bulk density (specific gravity and void fraction) reduce the accuracy of the calculated stockpile inventory. However, as opposed to the indirect method, the variance of the results (accuracy level) remains constant from one inventory estimations to the next. As shown on Figure 3, which represents Monte-Carlo simulations of inventory estimations calculated through optical volume determinations (using the gold ore stockpile case described in the previous section), the reported inventory would often differ from the actual value and would change from one day to the next. The variance however (5% in this case) would always be the same.
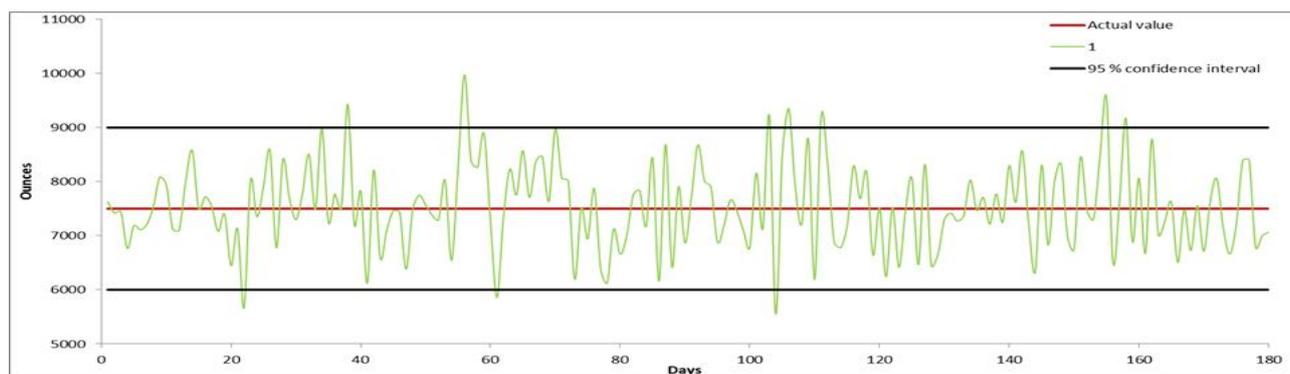
Figure 3. Simulations of in-situ estimation (through volumetric evalauiton) of a stockpile inventory (expressed in ounces of gold).

Determining the inventory of a large and irregular stockpile inventory through optical means can be time-consuming and therefore, may not always be practical to apply on a daily basis. However, it is fairly common in the industry to have stockpile inventories be determined through volumetric evaluations made on a monthly or fortnightly basis.

5. BEST OF BOTH WORLDS: REDUNDANT EVALUATION METHOD

Many mining companies make use of the two stockpile inventory evaluation methods. They use the indirect method for estimating stockpile inventories at high frequency (on a daily basis, for example) and they carry a volumetric evaluation of stockpiles at lower frequency (on a monthly basis, for example).

Of course, if all measurements were exact, both methods would provide the exact same inventory estimations (of a given stockpile over a given time period). However, due to the errors carried by the measurements, the methods often produce different results with also, different levels of accuracy.

Even though, the two methods have different levels of accuracy, determining which of the two is the most accurate requires a thorough analysis. Essentially, the answer depends on (a) the accuracy of the measurements taken and (b) on the time between two stockpile inventory estimations. Figure 4 shows the confidence intervals of the two methods (using arbitrary parameters) as applied to the gold ore stockpile example. For this example, the graph indicates that the indirect method provides a better estimate of the stockpile inventory in the first days following the commissioning of the stockpile (the conversion to dynamic operation of the static stockpile occurs at time 0). Interestingly, even if the variance of the indirect method grows with time, it is initially the most accurate of the two methods. As time goes by, however, the variance of the indirect method grows to the point of exceeding the variance of the volumetric evaluation method.
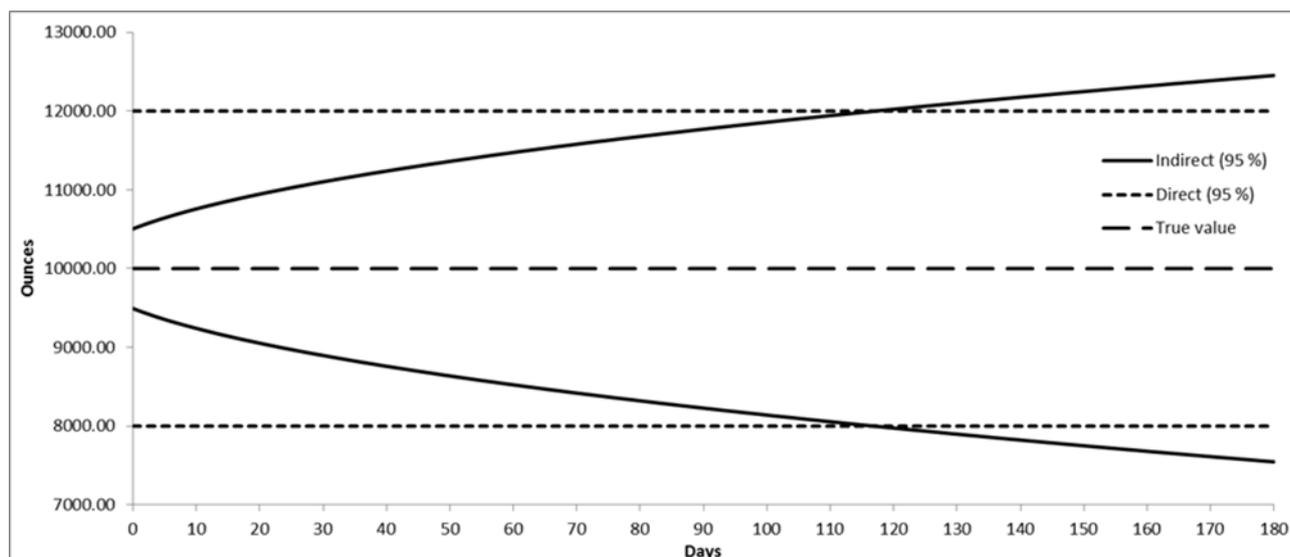
Figure 4. Confidence intervals (95%) of the two stockpile inventory evaluation methods over time (expressed in ounces of gold).

Very simplistically, Figure 4 suggests that the indirect method should be used only during the commissioning of the stockpile. Once the variance of the indirect method has grown to the point of exceeding the variance of volumetric evaluations (after about 115 days in this case), it should be completely abandoned. From this point on, the graph suggests that only volumetric evaluations of the stockpile (direct method) should be conducted. Consequently, all the information generated through the indirect method after the crossover point, still very informative, would be totally ignored. This would really be a waste.

The redundant inventory estimation method, as proposed by Lachance *et al*. (2012), is the most productive approach to exploiting the information that both 'primary' methods provide. In a nutshell, the redundant method consists in applying the principles of statistical data reconciliation (Hodouin 2011) every time two stockpile inventory estimates are available. The technique exploits all the information provided by both primary methods, including their respective accuracy levels, to compute the optimal (or statistically best) inventory estimate along with its variance. Interestingly, the accuracy level of the optimal estimate is always lower than the lowest variance of the estimates provided by the two primary methods. In other words, the optimal estimate (obtained through data reconciliation) is always more accurate than any of the two primary estimates.

The gold ore stockpile inventory case was used for illustrating the advantages of the redundant method. Here, it was assumed that the mining company wanted to get the most accurate stockpile inventory estimates (of course) but did not want the inaccuracy to exceed the variance of the volumetric evaluation method (relative σ = 10% in this case). They then adopted a strategy where they would rely on the indirect method until the inventory estimate inaccuracy exceeds this threshold. The results are shown on Figure 5.

From the time the stockpile is made dynamic (time = 0), the company relied on the indirect method for about 115 days before the first volumetric evaluation is conducted. On the same day, the inventory estimates provided by both methods are reconciled and the accuracy of the optimal estimate is calculated (which, again, is always better than the variance of the two primary estimates). The stockpile inventory would then be monitored using the indirect method until the accuracy drop below the tolerance of the company (about 14 days later in this case) and another volumetric estimate is carried out. In this case, the company requirements would be met by

continuously provided inventory estimates through the indirect method and by conduction volumetric evaluation of the stockpile every fortnight.
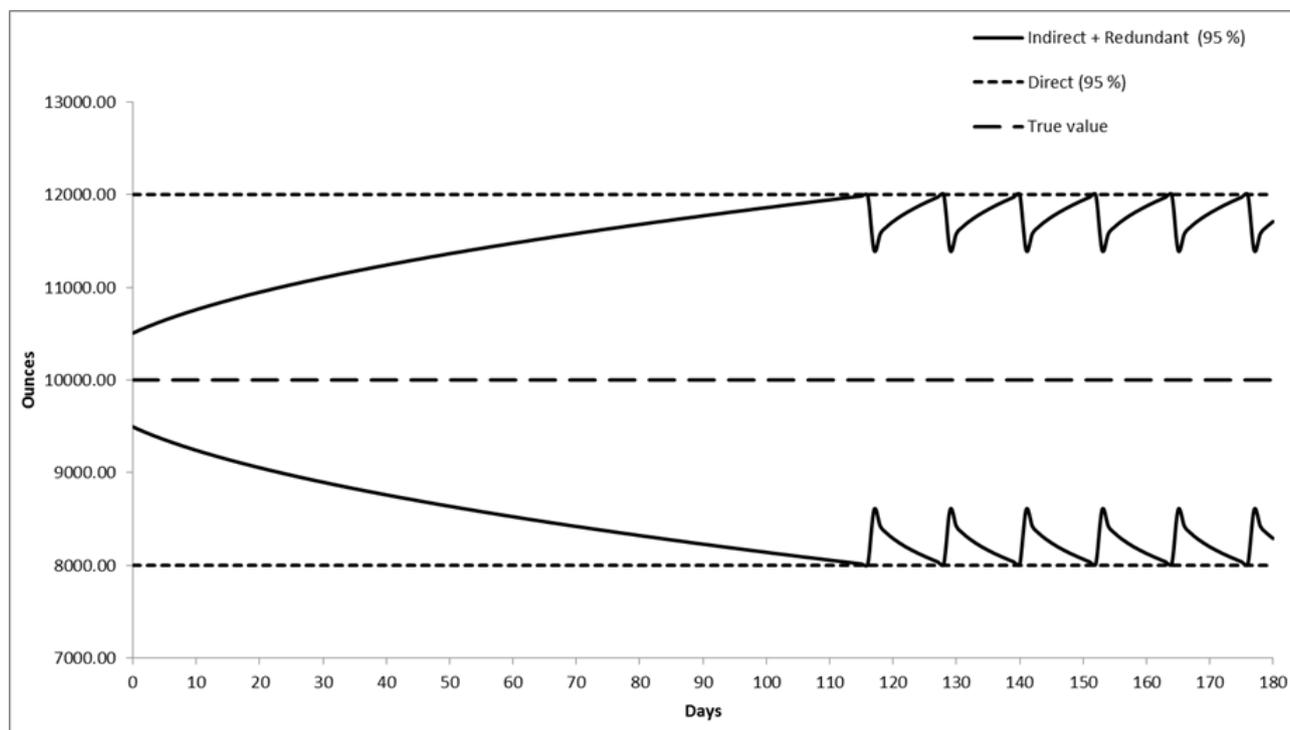

Figure 5. Confidence interval (95%) of the redundant inventory evaluation methods over time (expressed in ounces of gold).

6. CONCLUSIONS

From a metal accounting perspective, the fundamental issue with aggregate stockpile inventory estimation is the feasibility of direct (or in-situ) measurements at an affordable degree of accuracy. If this could be easily achieved, the inclusion of stockpiles in metal balance would be greatly facilitated.

Different methods are used in the mining industry for estimating stockpile inventories. Two methods are the most common. The indirect method is the most often used at high frequency (for day-to-day inventory estimations) but exhibits an accumulation of estimation error over time. Inventory estimates obtained through a volumetric evaluation of the stockpile (a.k.a. the direct method) are labor-intensive and are therefore typically conducted at a lower frequency (fortnightly monthly or lower) but they also carry significant errors.

When redundant stockpile inventory estimates are available, the principles of statistical data reconciliation can be applied to extract the optimal, most accurate stockpile inventory level from the primary estimates. Along with a thorough analysis of the errors carried by the field instruments, the application reconciliation technique cannot only lead to optimal design of any stockpile inventory monitoring strategy.

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