Hidden Cost of Poor Sampling and Reconciliation Practices – Educational Lessons Far Beyond the Mining Industry

By Dominique Francois-Bongarcon[1] & Kim H. Esbensen[2]

1. Five Mining Companies in Lots of Trouble

ABSTRACT

Behold the struggles of five fictional mining companies, the stories of which all come from real-world examples. Here are universal alarm bells of great educational significance for technical samplers and management both. We illustrate here with examples from the mining and mineral extraction world, but the implications are universal wherever professional sampling is on the agenda. Even a trivial investment in sampling training (Theory of Sampling, TOS) will be beneficial many times over. Along with honoring the founder of the Theory of Sampling (TOS), Pierre Gy (1924-2015), we highlight the important insights provided by Jan Visman (1914-2006). The presented issues do not only apply to the mining and mineral extraction/processing sectors – indeed they represent insights transgressing far beyond this demarcation.

Company A: Take mining company A: It has produced for 18 months, but the grade is nothing near what was initially expected. There had been a complete feasibility study, on which investments were based and bank loan subscribed. The production grade predicted for the first few years made it economical to build the operation, pay costs and reimburse the loans quickly. However, now a much lower grade is produced, costs are not covered in full, loan reimbursement will be longer and much more costly, shareholders will be disgruntled. The board is very concerned of course. This is a publicly traded company and a major resource write-off on the stock exchange is in the making. A classic in the fickle mining investor world! What went wrong? Could sampling be involved?

Company B – needs only little introduction. It was called Bre-X and is now completely defunct. As is well known in mining and investor communities, its demise rocked the mining industry forever, and hopefully for the better. Lack of sufficient due-diligence studies, ignoring red flags, contributed to the ultimate scandal, late detection of blatant fraud and ensuing losses. Even though it is the common belief that no amount of QA,QC will ever be able to deter fraud, a fine understanding of the data, of the story they tell us, is possible when using the right tools and models – based on the right competence (TOS). After the dust had settled, the world mining industry scrambled to show governments it could self-regulate its own affairs – to avoid scandals like this.

Thus, improved routine QA,QC procedures and better resource reporting came to the fore with much more emphasis than ever before.

Company C: Here rumor has it the plant is not adequate for the ore mined – another classic claim, sometimes triggered by biased metallurgical tests sampling. At company C, the official metal recoveries have proven to be lower than expected and planned. Plus, 'information' has leaked that millions of dollars may be dumped into the tailings dam every year, as unrecoverable metal is going through the plant without being captured by appropriate sampling devices at both the mill entrance and its exit to the tailings. The announced, disappointing recoveries are in fact still over-optimistic! What happened?

Company D: The situation is not better at company D, where bad reconciliations between mine and plant are making everyone's life difficult on site, as much unseen money is lost.

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1 Agoratek International Consultants Inc., Canada.
2 KHE Consulting, Copenhagen, Denmark

FACTBOX - The Bre-X scandal

Bre-X Minerals Ltd. was a Canadian gold exploration company, formed in 1988, that perpetrated one of the biggest scams and frauds in mining history. Commencing exploration in 1993, near the Busang river, Indonesia, with geologist Michael de Guzman as the exploration manager, Bre-X estimated the property to contain 47 million ounces of Gold (one year later even 71 million ounces) for which prospect the company's market capitalization quickly exceeded C$6 billion. The once-penny-stock climbed to more than C$275 per share on the global market! Who would not want to invest in such a prospect?

In 1997, a mysterious fire destroyed the on-site administration buildings including all geological records. A subsequent external audit reported only 'insignificant gold' at Busang, and the project manager Mike de Guzman died in a bizarre suicide (he "accidentally fell out of helicopter during flight"). The stock price dropped by 84% in a single day (see illustration), and the market cap disappeared. Losses were astronomical for investors.

A full investigation revealed that crushed drill core samples, the only hard evidence of high gold content (VERY HIGH) had in fact been 'salted' before they were sent for analysis. [For readers, not familiar with the evidence and information mandated for investors: "Salting: the process of adding a valuable metal, especially gold or silver, to a sample from a mine to change the value of the sample with intent to deceive investors or potential buyers of the mine" (Bre-X, Wikipedia,2023)

Fig. 1: Value: Now you see it – now you don't. Bre-X stock prices (1994-1997)

Indeed, to respond to executive pressure, the mine is scrambling for higher grades, so as a result, management orders to resort to mining outside of the original optimized mine plan. The cost of straying away from the optimal path is enormous, not to speak about the costs that future ore shortages will trigger. Why did this happen?

The redeeming grace for yet another **company E**, is that it doesn't even know it is dumping a lot of treatable ore on the waste dump.

The money it loses was never seen in any accounting scheme, so all seems to be fine! Instead, an additional problem company D is aware of, is that one of its concentrate buyers is defrauding big time with respect to the contract specifications, but company D will never be able to sue, since the sampling system in place at the loading port of departure could not survive even a cursory counter-audit, because management at company E has never understood, nor invested in professional sampling training. This last example relates to what is a typical double jeopardy ...

2. Double Jeopary when the Sampling Overview is Lost

Comparison of the effect of non-matching sampling procedures (especially biased vs. unbiased procedures) for two stakeholders, generically termed "buyer" and "seller". The consequences of non-representative sampling are serious for both parties – an unnecessarily inflated sampling variability (black) making it very difficult to be able to satisfy the contractual uncertainty interval (green). Things get completely out of control when both stakeholders, and even a third arbitration party, can freely choose sampling procedures at their own discretion. Resolution of the analytical result comparison quagmire is only possible when all parties and stakeholders agree only to use representative sampling procedures exclusively (red), no exceptions acceptable. TOS is the only necessary-and-sufficient framework in existence for this purpose. This scenario has recently been analysed and resolved in full detail in Esbensen & Vogel (2023).

3. What? Why?

All examples above originate from real world consulting experiences from the last 10 years. They are exclusively due to poor sampling and reconciliation practices, resulting in poor optimization of operations, which are costing tens or even sometimes hundreds of millions of dollars in unseen losses to mining companies around the world – or lead to losses that are by now well-known, but which were discovered all too late. Alas, such cases have parallel, and quite similar manifestations in many other industry sectors outside the mining realm. This malaise stems from a lack of sufficient awareness and competence of sampling theory (TOS), statistics, geostatistics, and QA,QC,QM (Quality Management), both in due-diligence and in day-to-day operational work.

4. Theory Of Sampling (TOS)

Yet, sampling theory, for example as taught by representatives from the International Pierre Gy Sampling Association (IPGSA), offers simple concepts (first and foremost sampling correctness and segregation countermeasures) that help analyse, understand and diagnose the kind of problems highlighted above.

As a major example, being able to implement procedures and equipment that complies with TOS' demand for "sampling correctness" will ensure sampling unbiasedness. TOS also offers numerical, very practical formulas, in particular those due to Pierre Gy, that will help quantify the magnitude of the errors responsible for many of these problems.
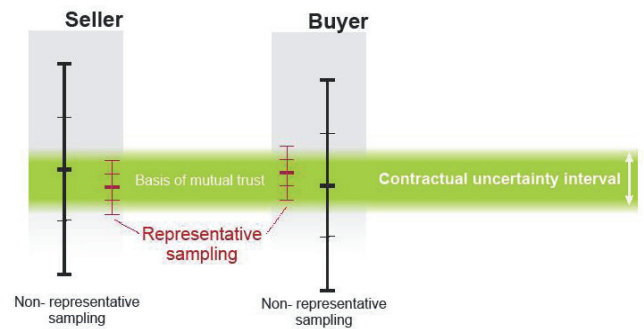
Fig. 2: Double Jeopardy when Sampling is Unmatched at Two Parties

The value of these to the full realm of relevant industries cannot be understated.

Since 2013, there has been a de facto international standard stipulating the simple universal principles behind guaranteed representative sampling, Danish Standard (DS) 3077 (2013) and the completely revised 3rd edition, forthcoming in 2024, and soon to be made into a proposal as an ISO standard. The IPGSA community is (strongly) encouraged to participate in the latter task.

5. Powerful, Yet Simple Theory to the Rescue (Jan Visman)

TOS has sometimes been perceived as cryptic or esoteric to the non-mathematically oriented practitioner, yet simple formulae can be derived with which to address ordinary, as well as less standard sampling problems, in very practical ways. Such as the little known, but very powerful "Visman's formula" concerning the relative sampling variance:

$$\text{Rel.Var.}(Visman) = \mathbf{A}/M + \mathbf{B}/N \quad (1)$$

Visman's equation relates to an easy experimental approach that allows us to control a sample assembled as a collection of N random increments, the archetype composite sample, when its sampling error (sampling variance) is due not only to its mass (M) and the heterogeneity of the material (encapsuled by the term A/M), but also to segregation manifestations that cannot be eliminated (embedded in the term B/N). Simple practical experimentation is all it takes to calibrate the two constants A and B with which to gain full control over the results of sampling, even in very adverse sampling situations tormented by segregation.

To do this, Visman advocated taking two series of 1-increment samples (grab samples in the TOS parlance): one series of very small samples, and one of very large counterparts (the large difference in masses aims at stabilising the results). Equating the variances of the two series to equation (1) yields a system of two linear equations which is easily solved, allowing for determination of the two unknown constants A and B.

In other situations, for example where a full heterogeneity characterization study has been performed, one may prefer calculating the first term A/M from the heterogeneity parameters obtained, and a single series of samples is then sufficient to elicit the value of B in (1).

JAN VISMAN

Jan Visman (2 July 1914 – 19 February 2006) was a Dutch statistician who played a key role in building a bridge between statistical sampling theory with its assumed homogeneous (iid) populations on the one hand, and practical sampling practice with well-known heterogeneous sampling units (TOS's heterogeneity contributions) and material lots on the other. Visman built an elegant theory in only a few easy-reading pages, quite independently from Pierre Gy's development of the Theory of Sampling (TOS). Upon reflection it will be appreciated that Visman's approach is but a particular, special case within TOS. Visman's formula was devised to establish the Canadian standards for the sampling of shiploads.

6. Adding in the Unavoidable Effects of Segregation

Gy's fundamental sampling variance formula for a correct sample when segregation is <u>not</u> present (very well known, and highly valued but frankly, also often misused by ill-informed practitioners) is:

$$\text{Rel.Var.}(Gy) = S_{FSE}^2 = c\, f\, g\, l\, d^3 / M \quad (2)$$

provides Visman's **A**/M term in the case where none of the parameters other than mass M can be changed, i.e. in the case of <u>fixed</u> mineralogy, concentration and comminution state.

But Gy also established the formula when segregation <u>is</u> present (the general, realistic real-world case):

$$\text{Total Rel.Var.}(Gy) \sim= [1 + ß/N]\, S_{FSE}^2 \quad (3)$$

It is not necessarily easy to appreciate that the term $[ß/N]S_{FSE}^2$ in turn provides Visman's B/N term under the same conditions, but here goes:

Indeed, the second term in (3) is $[ß/N\, S_{FSE}^2]$, for which Gy showed that $ß =\sim \xi(N_F-N) \sim \xi N_F$ where N_F is the number of fragments in the sample. As a result, $[ß/N\, S_{FSE}^2] \sim (\xi N_F/N)S_{FSE}^2$ which is of the form $\xi N_F\, K/(N\, M) = \xi\, K/[N\, (M/N_F)]$ (as S_{FSE}^2 is in inverse proportion of M for large lots). But as M/N_F is the average fragment mass in the sample, M is eliminated from the expression, which is now of the form B/N. **q.e.d.**

For the interested reader who did not find immediate comprehension relief by this compact explanation, there are more complete theoretical introductions available, e.g., Pitard (2019) and Lyman (2020).

7. Sampling in Practice

In all sampling procedures, there are two imperial demands that must be met before any other optimization details can be entertained;

1. The first demand on any sampling agenda is to respect the principle of *sampling correctness*, which is the only guarantee for unbiased sampling. This is the most fundamental requirement for professional samplers, e.g., as laid out by the educational systematics of TOS (Pitard, 2019; Lyman, 2019; Esbensen, 2020).

2. After this demand has been honored, there is now general flexibility over the sampling parameters, and the effects of segregation can be canceled out (see above), Gy's general formula (3) will now allow full control of the sampling precision.

In other cases where sampling parameters offer no flexibility, and additionally the usually devastating effects of segregation on sampling precision cannot easily be neutralized, case Visman's experimental approach will offer a powerful safe way out.

8. Visman on Sampling Segregated In-Situ Stockpiles

Of course, sampling can only be controlled for the immediately accessible (external) part of a stockpile. The Visman experiment must therefore be repeated as material collection progresses <u>into</u> the pile, unless one is willing to *assume* that segregation is *identical* throughout the complete inner volume of the stockpile as the one found on its external surficial parts – which would be an extremely risky endeavor.

Among other things, optimality of eq. (1) implies **A**/M = **B**/N, or M/N = **A**/**B**, which now appears as the optimal increment mass. Assuming this mass, eq. (1) then simplifies into: Rel.Var. = 2 **B**/N, which determines the number of increments necessary to achieve a preset precision threshold target.

Comparing the experimental first term of Visman's formula with the empirical results from a TOS heterogeneity test, or a Replication Experiment (RE) (Esbensen, 2020), can considerably improve understanding of complex, segregated mineralization cases and their corresponding optimal sampling options.

Following this line of exemplification, it is easy to see how Vismans's equation can also be used to test geological hypotheses of mineralization *randomness*, for instance in kimberlite diamond deposits.

9. Reconciliation – the Way Forward

The value of comprehensive reconciliation studies should never be undervalued. Usually triggered by one of the problems mentioned in the five cases in the introduction, they will throw light on the insufficiencies that may have triggered them. Indeed, one by one, every single potential cause for bad reconciliations can be examined and put to the test. The quality of sampling, assaying, and estimation procedures will be reviewed, and any flaws will be detected and eliminated.

In the case of a mining operation for instance, a Plan-to-Production reconciliation task will usually be broken down in the study into a series of individual part-reconciliations:
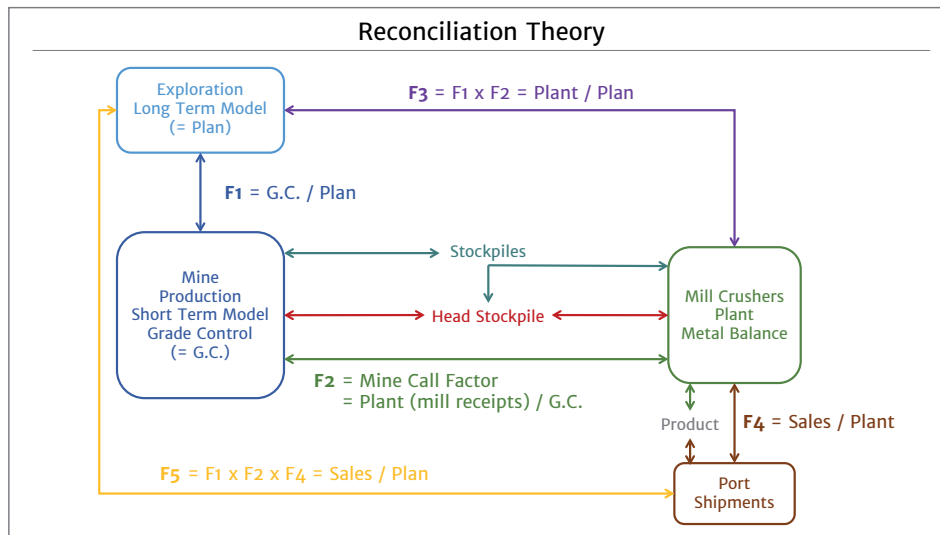
- Plan to mine-estimated mill feed (delivered) – often designated as F1 reconciliation
- Mine-estimated mill feed to Mill-estimated mill feed (e.g. head sampler) – F2 reconciliation
- Mill-estimated mill feed to balance (Production and reconciled figures)

These more focused tasks can inspect all issues in detail, as described above. Additional experimentation will help decide which steps may have triggered biases in the data used and thus identify the resulting erroneous decisions.

Courses on reconciliation techniques, drawing from all fields concerned, will help professionals sort out, and address the problems of sampling, data QA,QC,QM and, in the case of mining, ore grade models quality in turn. Underlying all of this is the foundation of representative sampling, at all locations, at all scales, for all kinds of ores – TOS to the fore!

All the above reflections do not only apply to the mining and mineral extraction/processing sectors – the presented educational insights transgress far beyond this demarcation.

2022 saw publication of a valuable compendium: "Economic Arguments for Representative sampling", containing a bonanza of educational examples and case histories from no less than 27 experts from all over the sampling world (Esbensen, 2021).

Reconciliation Theory

Exploration
Long Term Model
(= Plan)

F3 = F1 x F2 = Plant / Plan

F1 = G.C. / Plan

Mine
Production
Short Term Model
Grade Control
(= G.C.)

Stockpiles

Head Stockpile

Mill Crushers
Plant
Metal Balance

F2 = Mine Call Factor
= Plant (mill receipts) / G.C.

Product

F4 = Sales / Plant

F5 = F1 x F2 x F4 = Sales / Plan

Port
Shipments

Credit: Dominique Francois-Bongarcon; used with permission.

Fig. 3: Overview of local stage part-reconcilliations from Mine to Sales: F1, F2, F3, F4, F5

10. Conclusions

What are the main lessons from the present compendium of evergreen sampling problems and issues?

In the age of global competition, many industrial mineral extraction operations are only marginally profitable, even when well run, or when operations are extremely data quality sensitive, continuous professional sampling training is at a premium.

A small investment in training (TOS, statistics, geostastistics, QA,QC,QM) may save huge amounts of money downstream in many contemporary industries at all mining time scales and stages: development, operation, operation closure and reclamation.

Professionals will discover and learn that beyond what appears as deceptively complicated theories, lies a wealth of easy-to-understand, efficient techniques, which can be mastered in a short time with huge economic benefits when well used. Several convincing examples can be found in (Minkkinen & Esbensen, 2018).

In 2023, the Council of the International Pierre Gy Sampling Association (IPGSA) has started a drive offering new educational training options at all levels from initiating newcomers to the sampling responsibilities – to full professional continuing education. The reader may follow this drive at the IPGSA website.

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