Challenges in Quality Assurance and Quality Control Systems Development

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Quality Assurance and Quality Control (QA/QC) is of critical interest in the mining industry. Over the years, Anglo American Platinum has adopted a sound strategy of Best Practice Principles (BPP) for mass measurement, sampling, sample preparation, analysis, and metal accounting. Often, much effort is focused on implementation and maintenance of quality control systems to provide quality assurance. Within the Anglo American Platinum business units, QA/QC data are deemed of significant value on a day-to-day basis and on a higher level also provides a means to prove or disprove evaluation and metal accounting disputes between various sites and/or opposing members of the Joint Evaluation Committee (JEC). Unfortunately, QA/QC data and associated QA/QC systems alone do not always provide the technical or tangible reasons to supplement explanations around anomalies in performance. It is sometimes necessary to go beyond monitoring and focus on interpreting the QA/QC data to comprehend the underlying issues. This paper aims to showcase a multitude of actual case studies pertaining to troubleshooting of challenges encountered throughout the Platinum processing pipeline (i.e., Concentrator to Smelter to Refinery). These challenges range from areas of mass measurement to sampling, to sample preparation and analytical as well as plant performance. Observations and learnings from these instances indicated that even though stringent QA/QC was adhered to, it was evident that complying to first principles of mass measurement and sampling theory, minimum sample mass and an ongoing understanding of individual material characteristics was crucial. It was also highlighted that the re-assessment of designs, methods and protocols are necessary per material stream and that a standardization approach across all Anglo American Platinum business units is perhaps sensible at one time but may not always be appropriate and/or relevant.

Introduction

Anglo American Platinum operations are divided into mining and process respectively. The mining end comprises of open pit and underground mining, while the process end comprises of Concentrator Plants (fully owned and joint ventures), four Smelters, one Base Metal Refinery (BMR) and one Precious Metal Refinery (PMR). UG2, Merensky, Platreef and Great Dyke ore reefs are mined and processed to produce final products including precious metals as well as base metals. The Group Evaluation, Metal Accounting and Analytical (GEMA) team reside within the Anglo American Platinum corporate function and high-level responsibilities include ensuring that risk is mitigated through governance of the evaluation, analytical and metal accounting entities with strict adherence to the AMIRA Code of Practice P754[1]. Frequent evaluation meetings are held between site personnel and GEMA to discuss the trended quality control data and maintain quality assurance.

With current economic pressures, Lomberg[2] succinctly emphasizes the challenges with exploration and exploitation of Platinum Group Element (PGE) deposits since the very low ore grades hover around the detection limits of analytical techniques and factors such as the nugget effect. Bhattacharya, Islam, Kumar & Santosh[3] further mentions that the practice of statistical quality control in the minerals industry is very limited and variable but can be a somewhat promising technique in terms of quality assurance. According to Simon & Gosson[4] quality assurance and quality control are the two major components of any quality management system. Consistent with the ISO definition, quality assurance is 'the assembly of all planned and systematic actions necessary to provide adequate confidence that a product, process, or service will satisfy given quality requirements,' and quality control refers to 'the operational techniques and activities that are used to satisfy quality requirements.'

Quality control plays a significant role in ensuring quality assurance; however, in certain instances quality control systems provide only a means to consolidate important information in a concise manner without really detecting the problem or non-conformance. This paper focuses on actual case studies within the Anglo American Platinum Concentrator Plants and Smelters.

Case Study A: Weighbridge mass reconciliation

Wet filtered concentrate material is transported by flexi-side tipper trucks from various Concentrator Plants to the Smelters within the Platinum Group. In this instance, multiple concentrate streams were directed to one particular Smelter in question. The wet mass comparison on gross mass was performed between the Sender and Receiver sites to reconcile masses for metal accounting purposes. The relative difference between the gross masses were calculated and trended as per norm. Figure 1 below illustrates the gross mass comparison for Stream A over a period.

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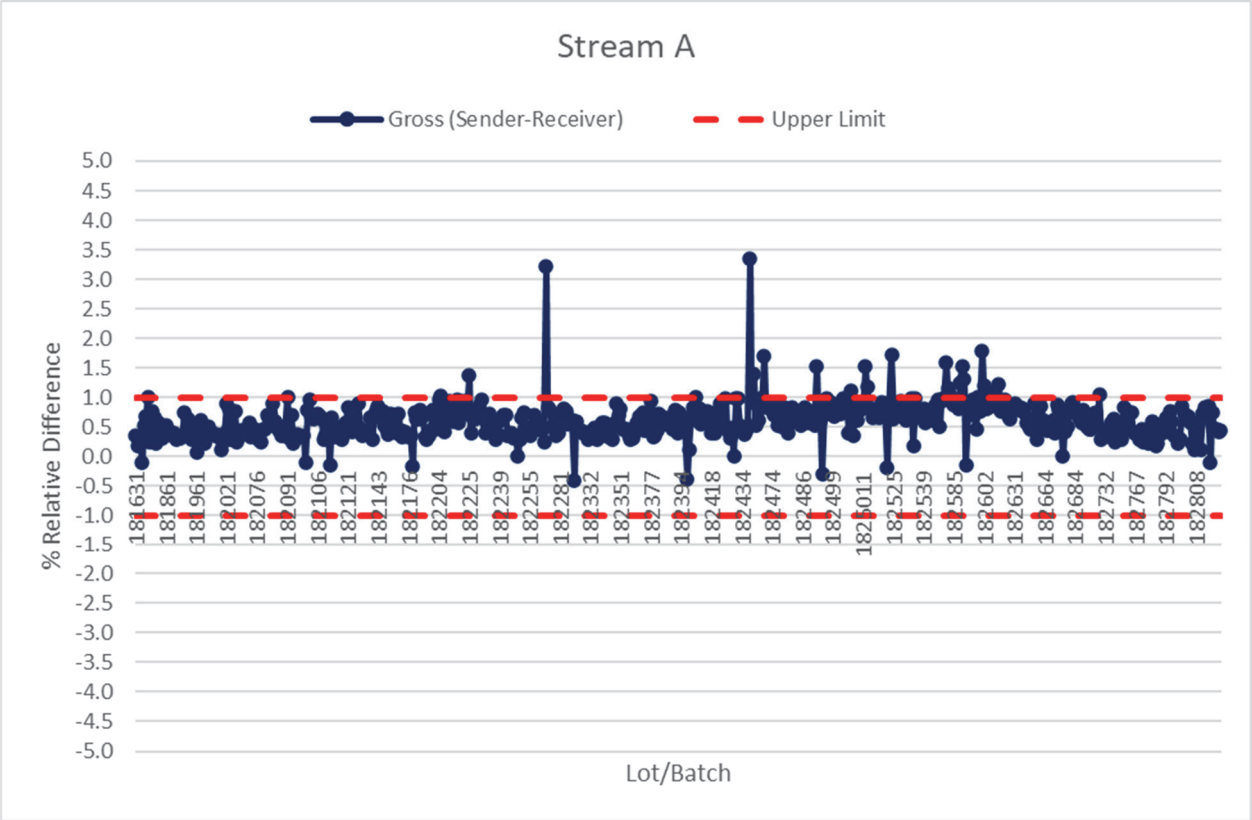

Figure 1. Gross Mass Comparison for Stream A.

The % relative difference between the Sender and Receiver was generally within the control limit of ±1% set by Group Metal Accounting and thus the site metal accountant did not immediately raise any concerns. However, after further discussion at an evaluation meeting, it was agreed that a bias clearly existed with the Sender site weighbridge consistently reading higher masses than that of the Receiver site. Even though a quality control system was in place, this did not ensure that the problem was identified, investigated, and resolved immediately. In addition to this, the Receiver site also consolidates weighbridge mass data via an automated system. The system is setup to pre-calculate the % relative difference and if exceeded, security personnel and the site super user need to investigate further. Upon discussion with site personnel, it was clear that a gap existed between the amount of these occurrences and the implication thereof.

Bi-monthly weighbridge checks using certified weights is a Group Standard and this site had deviated from this and therefore there was no way of confirming if the Receiver's weighbridge was accurate or not. Further mass comparisons were performed for other incoming and outgoing streams at the Receiver site and the same pattern emerged. A full weighbridge re-calibration was then initiated, and the original equipment manufacturer conducted the calibration. Prior to calibration, the weighbridge and associated parts were inspected. It was found that one of the load cells which contribute to the overall truck gross mass value was defective. The defective load cell was subsequently replaced, and the data post calibration was trended. Figure 2 below illustrates the mass comparison for Stream A before and after the weighbridge load cell replacement and re-calibration.

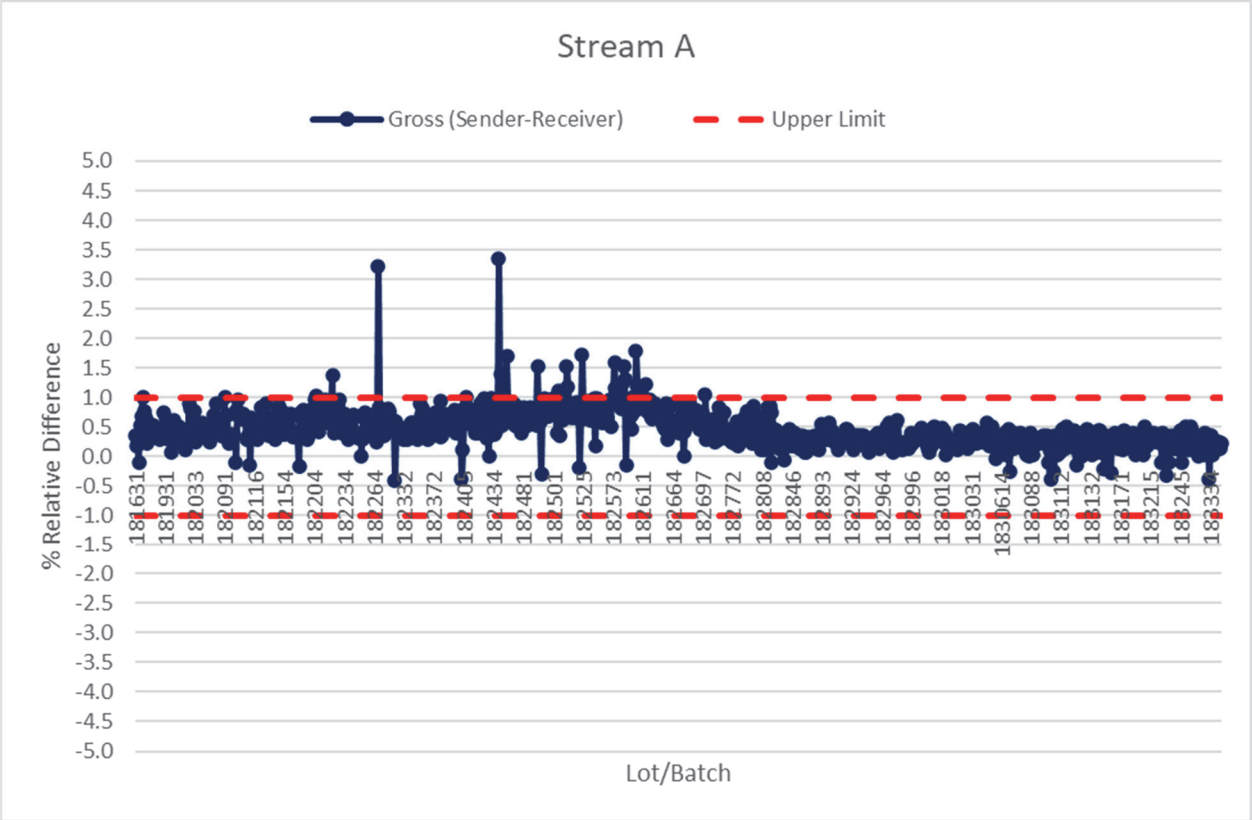

Figure 2. Gross Mass Comparison for Stream A after Re-calibration.

Having replaced one load cell and re-calibrating the weighbridge lowered the % relative difference values to be unbiased and well within the control limits. Furthermore, if the bi-monthly weighbridge checks using certified test weights were done, this would have possibly outlined the problem earlier rather later. In this case study, it is observed that systems are in place to minimize risk by monitoring and controlling certain variables however, if the highlighted warning signs through quality control systems are not acknowledged and actioned then one can go on without realizing the implication thereof. The possible outcome of this scenario has a domino effect. The Smelter accountability could be skewed because of under estimation of inputs, and in-situ stock comparison with theoretical stock would not tie up. In addition, since the Smelter is deemed the Receiver and the Concentrator Plants are deemed the Sender, and the Receiver mass is the official mass used for metal accounting purposes, the Concentrator plant would also have an inflated recovery and over-accountability.

Case Study B: Specific gravity comparison

An Anglo American Platinum Smelter receives two independent, PGM enriched concentrate streams from two Concentrator Plants respectively. The respective concentrate streams are transported by pipe to the concentrate handling area located at the Smelter. Each concentrate stream is sampled by means of a vezin-vezin sampler combination. The primary increment is sub-sampled by the secondary vezin and the sample is then deposited into two stationery openings 180° apart. The vezin-vezin combination is designed and operated according to the principles of Theory of Sampling and as such representative samples are always ensured. The density of the respective concentrate streams is reported in terms of Specific Gravity (SG). An A and B sample results per daily LOT. The SG of the A sample collected during sub-sampling of the day tank is determined during sample preparation done at the Evaluation Laboratory within the Smelter. The B sample is reserved for backup purposes. In addition, an SG determining instrument is installed on the concentrate weigh tanks of both Concentrator Plant 1 and Concentrator Plant 2. The SG from the instrument is a calculated value based on differential pressure. To date, both the sample SG and instrument SG have been trended and compared together with the % solids of the samples collected.

The contractual agreement between the Smelter and the Concentrator Plants states that a penalty may be invoked (at the discretion of the Smelter) should the average of the individual monthly SG readings obtained from the instrument SG be less than a value of 1.600. Furthermore, the instrument SG is the official SG to be reported with the % solids being the input for metal accounting purposes. Concerns were raised around the reliability and accuracy of the instrument SG data being reported. To address these concerns and assist the Smelter with a methodology to follow, sample SG and instrument SG data from November 2016 to February 2018 was analysed.

Monthly Weighted SG – Difference between Sample and Instrument SG

A monthly weighted SG for the Plant 1 and Plant 2 streams were calculated for the Sample and Instrument, and the difference between these values was then determined. All raw data was used as part of this analysis and no data was removed as possible

outliers to give an overall indication of worst case scenario. Table 1 and Table 2 below provide a summary of the monthly weighted SG data for Plant 1 and Plant 2 respectively.

Table 1. Plant 1 Monthly Weighted SG Data.

Month	SG – Sample (Lot)	SG - Instrument	Difference (Sample - Instrument)
Nov-16	1.560	1.529	0.031
Dec-16	1.581	1.562	0.019
Jan-17	1.609	1.584	0.025
Feb-17	1.622	1.597	0.025
Mar-17	1.628	1.609	0.019
Apr-17	1.651	1.623	0.028
May-17	1.613	1.610	0.003
Jun-17	1.622	1.607	0.015
Jul-17	1.616	1.598	0.018
Aug-17	1.569	1.571	-0.002
Sep-17	1.597	1.573	0.024
Oct-17	1.614	1.586	0.028
Nov-17	1.623	1.581	0.042
Dec-17	1.553	1.568	-0.015
Jan-18	1.570	1.521	0.049
Feb-18	1.577	1.623	-0.046

Data has been factorized and site details omitted for confidentiality purposes.

Table 2. Plant 2 Monthly Weighted SG Data.

Month	SG – Sample (Lot)	SG - Instrument	Difference (Sample - Instrument)
Nov-16	1.564	1.605	-0.041
Dec-16	1.667	1.627	0.040
Jan-17	1.637	1.606	0.031
Feb-17	1.635	1.594	0.041
Mar-17	1.685	1.652	0.033
Apr-17	1.672	1.640	0.032
May-17	1.639	1.620	0.019
Jun-17	1.696	1.650	0.046
Jul-17	1.661	1.637	0.024
Aug-17	1.633	1.620	0.014
Sep-17	1.661	1.636	0.024
Oct-17	1.609	1.632	-0.024
Nov-17	1.623	1.581	0.042
Dec-17	1.553	1.568	-0.015
Jan-18	1.634	1.645	-0.011
Feb-18	1.621	1.637	-0.016

Data has been factorized and site details omitted for confidentiality purposes.

From Table 1, the calculated monthly weighted Plant 1 SG for the Instrument was less than 1.600 for November and December 2016, January, February, July – December 2017 and January 2018.

From Table 2 previously, the calculated monthly weighted Plant 2 SG for the Sample was less than 1.600 for February, November and December 2017. It appears from the data in Table 1 and Table 2, that the Plant 2 stream delivers a higher and more consistent SG than that of the Plant 1 stream. It is also notable that the Instrument for intermittent periods generally reports a lower SG than that of the Sample SG for both Plant 1 and Plant 2 streams. A possible reason for this may be that settling of solids is present in the weigh tanks and therefore the solids present in the area below the bottom pressure probe is not accounted for. Having said this, for other time periods, the difference between the Sample SG and Instrument SG for both streams is positive and negative which indicates that a consistent bias is not present since introduction of the Instrument. One might argue however that there are consecutive periods where the difference between the Sample SG and the Instrument SG is one sided and is therefore bias. Using the monthly SG data for both methods, the Standard Deviation (SD) on the difference between the Sample SG and Instrument SG was determined for both streams. Applying the standard deviation on the difference between the Sample SG and Instrument SG resulted in the following summary as per Table 3 and 4:

Table 3. Plant 1 Monthly Weighted SG Data – Standard Deviation on Difference of SG's.

Month	Volume – Sample (Lot)	Instru-ment	Difference (Sample - Instrument)	1sd (calcu-lated for each month data)	+1sd	-1sd	+2sd	-2sd	+3sd	-3sd
Nov-16	1.560	1.529	0.031	0.060	PASS	PASS	PASS	PASS	PASS	PASS
Dec-16	1.581	1.562	0.019	0.090	PASS	PASS	PASS	PASS	PASS	PASS
Jan-17	1.609	1.584	0.025	0.065	PASS	PASS	PASS	PASS	PASS	PASS
Feb-17	1.622	1.597	0.025	0.082	PASS	PASS	PASS	PASS	PASS	PASS
Mar-17	1.628	1.609	0.019	0.027	PASS	PASS	PASS	PASS	PASS	PASS
Apr-17	1.651	1.623	0.028	0.074	PASS	PASS	PASS	PASS	PASS	PASS
May-17	1.613	1.610	0.003	0.074	PASS	PASS	PASS	PASS	PASS	PASS
Jun-17	1.622	1.607	0.015	0.052	PASS	PASS	PASS	PASS	PASS	PASS
Jul-17	1.616	1.598	0.018	0.029	PASS	PASS	PASS	PASS	PASS	PASS
Aug-17	1.569	1.571	-0.002	0.034	PASS	PASS	PASS	PASS	PASS	PASS
Sep-17	1.597	1.573	0.024	0.045	PASS	PASS	PASS	PASS	PASS	PASS
Oct-17	1.614	1.586	0.028	0.038	PASS	PASS	PASS	PASS	PASS	PASS
Nov-17	1.623	1.581	0.042	0.145	PASS	PASS	PASS	PASS	PASS	PASS
Dec-17	1.553	1.568	-0.015	0.135	PASS	PASS	PASS	PASS	PASS	PASS
Jan-18	1.570	1.521	0.049	0.045	FAIL	PASS	PASS	PASS	PASS	PASS
Feb-18	1.577	1.623	-0.046	0.060	PASS	PASS	PASS	PASS	PASS	PASS

Table 4. Plant 2 Monthly Weighted SG Data – Standard Deviation on Difference of SG's.

Month	Volume – Sample (Lot)	Instru-ment	Difference (Sample - Instrument)	1sd (calcu-lated for each month data)	+1sd	-1sd	+2sd	-2sd	+3sd	-3sd
Nov-16	1.564	1.605	-0.041	0.042	PASS	PASS	PASS	PASS	PASS	PASS
Dec-16	1.667	1.627	0.040	0.081	PASS	PASS	PASS	PASS	PASS	PASS
Jan-17	1.637	1.606	0.031	0.110	PASS	PASS	PASS	PASS	PASS	PASS
Feb-17	1.635	1.594	0.041	0.044	PASS	PASS	PASS	PASS	PASS	PASS
Mar-17	1.685	1.652	0.033	0.059	PASS	PASS	PASS	PASS	PASS	PASS
Apr-17	1.672	1.640	0.032	0.115	PASS	PASS	PASS	PASS	PASS	PASS
May-17	1.639	1.620	0.019	0.055	PASS	PASS	PASS	PASS	PASS	PASS
Jun-17	1.696	1.650	0.046	0.042	FAIL	PASS	PASS	PASS	PASS	PASS
Jul-17	1.661	1.637	0.024	0.034	PASS	PASS	PASS	PASS	PASS	PASS
Aug-17	1.633	1.620	0.014	0.039	PASS	PASS	PASS	PASS	PASS	PASS
Sep-17	1.661	1.636	0.024	0.058	PASS	PASS	PASS	PASS	PASS	PASS
Oct-17	1.609	1.632	-0.024	0.076	PASS	PASS	PASS	PASS	PASS	PASS
Nov-17	1.623	1.581	0.042	0.145	PASS	PASS	PASS	PASS	PASS	PASS
Dec-17	1.553	1.568	-0.015	0.135	PASS	PASS	PASS	PASS	PASS	PASS
Jan-18	1.634	1.645	-0.011	0.050	PASS	PASS	PASS	PASS	PASS	PASS
Feb-18	1.621	1.637	-0.016	0.026	PASS	PASS	PASS	PASS	PASS	PASS

From Table 3 and 4 respectively, only one failure is noted for Plant 1 and Plant 2 on the 1SD limit for the difference between the Sample SG and Instrument SG.

% Co-efficient of Variation –Sample SG and Instrument SG

The % Co-efficient of Variation (COV) was calculated for the period November 2016 to February 2018, taking into account the Sample SG data and the Instrument SG data. In general, a % COV below 5% indicates an acceptable performance. For Plant 1 and Plant 2, the % COV (with any possible outliers) were calculated as follows in Table 5:

Table 5. %COV with Possible Outliers.

	Plant 1	Plant 2	Target
% COV for Sample SG	5.04	5.13	5.00
% COV for Instrument SG	2.89	2.73	5.00
% COV for SG Difference (Sample SG – Instrument SG)	3.65	3.77	5.00

The Instrument SG data resulted in a lower % COV of 2.89 compared to the Sample SG % COV of 5.04% for Plant 1. Similarly, for Plant 2, the Instrument SG data resulted in a lower % COV of 2.73 compared to the Sample SG % COV of 5.13% This indicates that the instrument performance is consistent (precise but not necessarily accurate) over a long period of time. Furthermore, the % COV for the SG difference between the Sample SG and Instrument SG was calculated to be below 5% for both streams.

For Plant 1 and Plant 2, the % COV (without outliers) were calculated as follows in Table 6:

Table 6. %COV without Possible Outliers.

	Plant 1	Plant 2	Target
% COV for Sample SG	3.09	3.91	5.00
% COV for Instrument SG	2.60	2.63	5.00
% COV for SG Difference (Sample SG – Instrument SG)	2.04	2.30	5.00

The SG outliers were determined by plotting a histogram of the historical data and removing the values which did not appear for more than 0.6% (frequency of less than 5 times in an excess of 400 data points) of the total data points. Again, the same conclusion around the Instrument SG performance was noted as per above.

Variograms: Sample SG vs. Instrument SG

Variograms were also produced using the Sample SG data and Instrument SG data for period November 2016 to February 2018.

For Plant 1, the V0 value was 0.729 and 0.251 for the Sample and Instrument respectively indicating that the error associated with the Sample SG data is almost three times that of the Instrument SG data. Figure 3 and 4 indicates the Plant 1 variogram for the Sample and Instrument respectively.

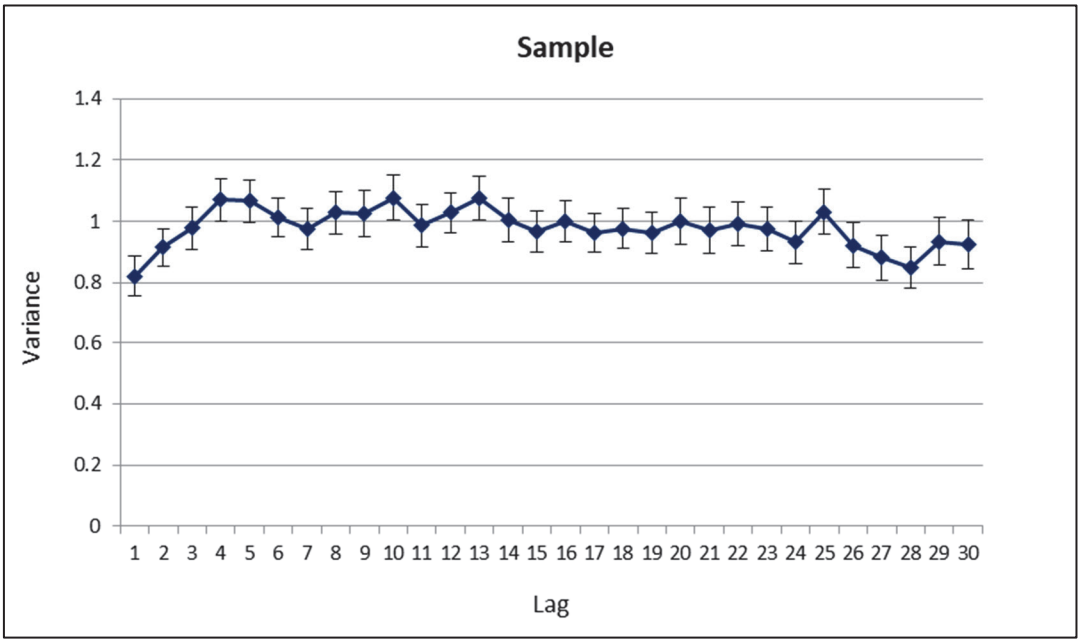

Figure 3. Variogram for Sample SG data – Plant 1.

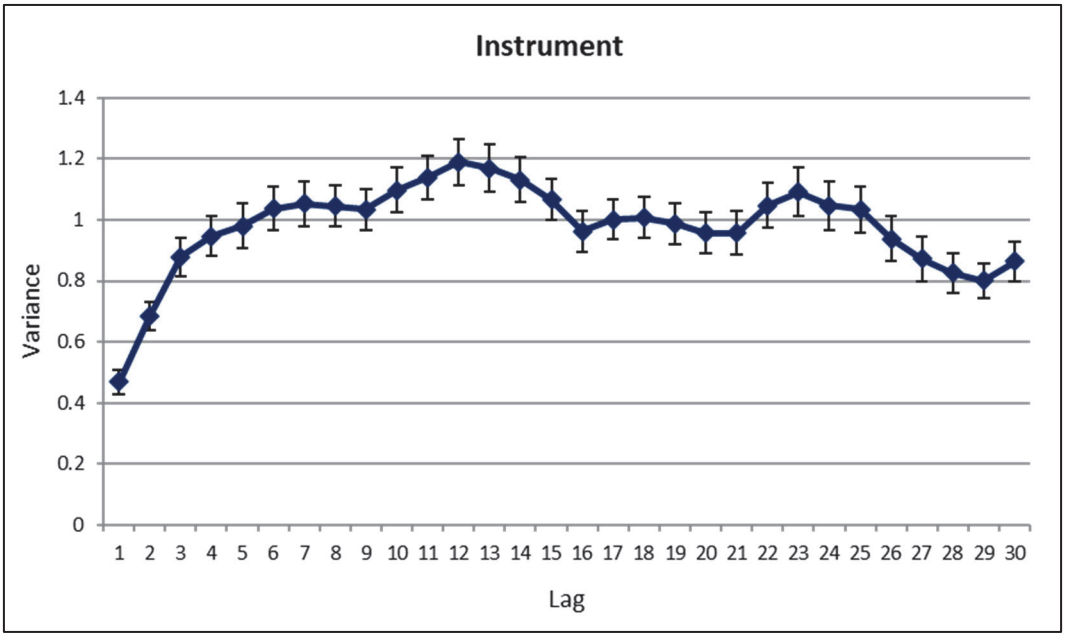

Figure 4. Variogram for Instrument SG data – Plant 1.

For Plant 2, the V0 value was 0.875 and 0.309 for the Sample and Instrument respectively indicating that the error associated with the Sample SG data is again almost three times that of the Instrument SG data. Figure 5 and 6 indicates the Plant 2 variogram for the Sample and Instrument respectively.

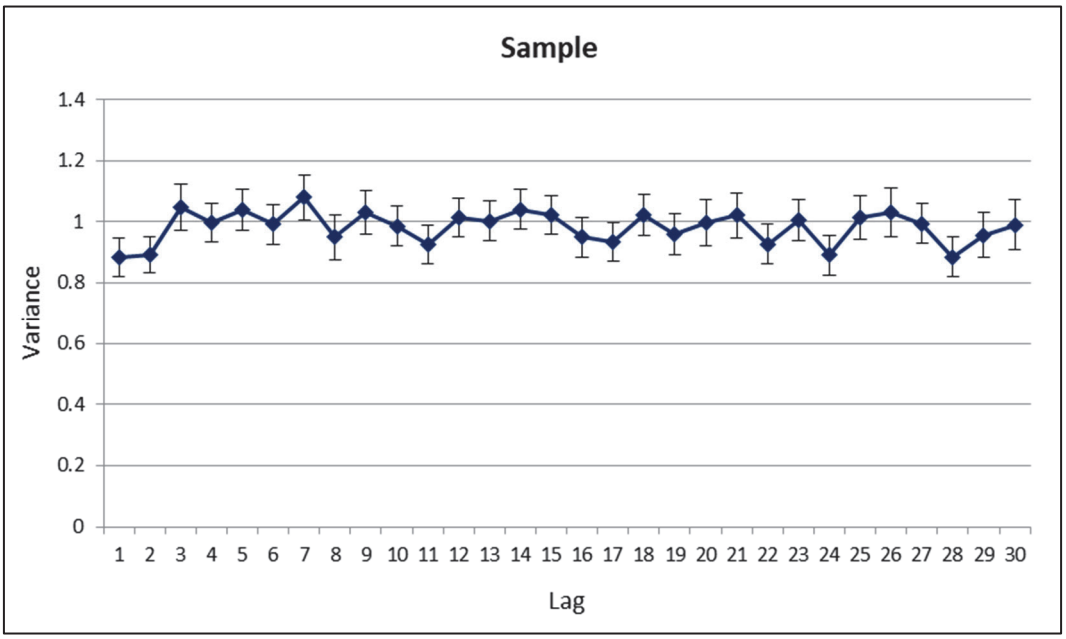

Figure 5. Variogram for Sample SG data – Plant 2.

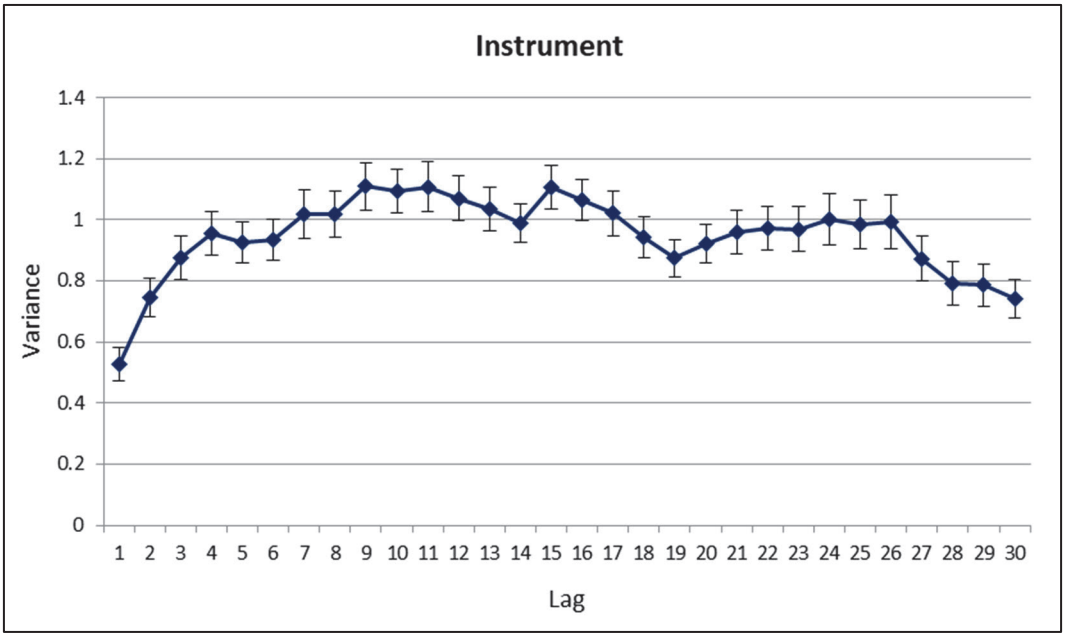

Figure 6. Variogram for Instrument SG data – Plant 2.

In both cases, the Instrument gave a better correlation (indicated by the longer lag periods) than that of the Sample. This provides confidence that the instrument can provide a more consistent and reliable SG value than that of the Sample which is prone to human errors.

Control Limits – Difference between Sample SG and Instrument SG

Control limits (±1SD, ±2SD & ±3SD) for the difference between Sample SG and Instrument SG was determined using the data from December 2017 to February 2018 – refer to Figure 7 and 8.

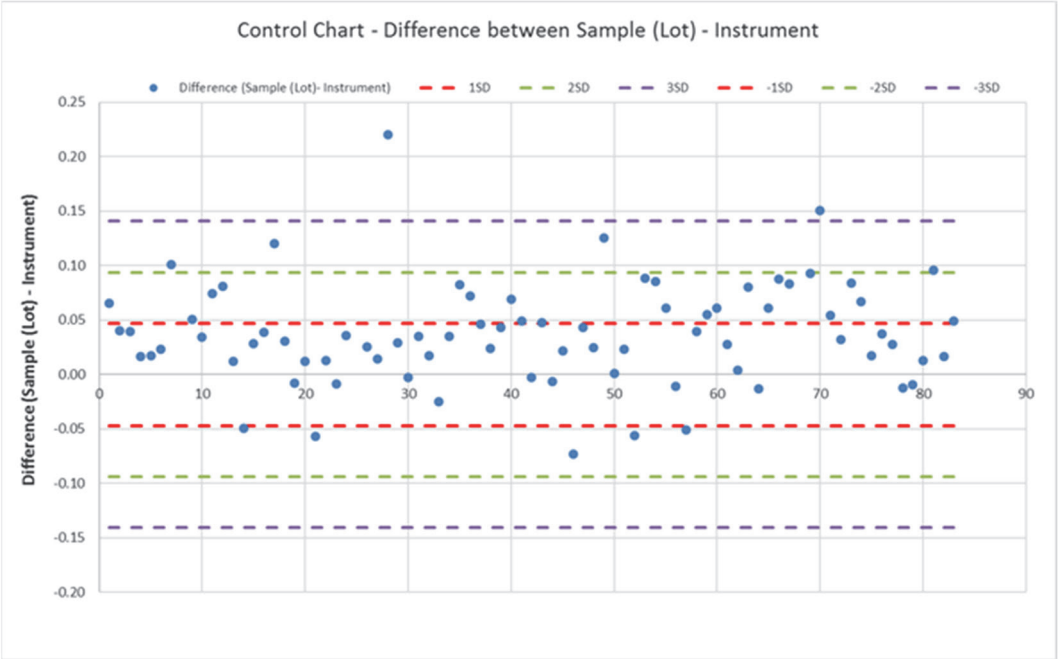

Figure 7. Control Chart – Plant 1.

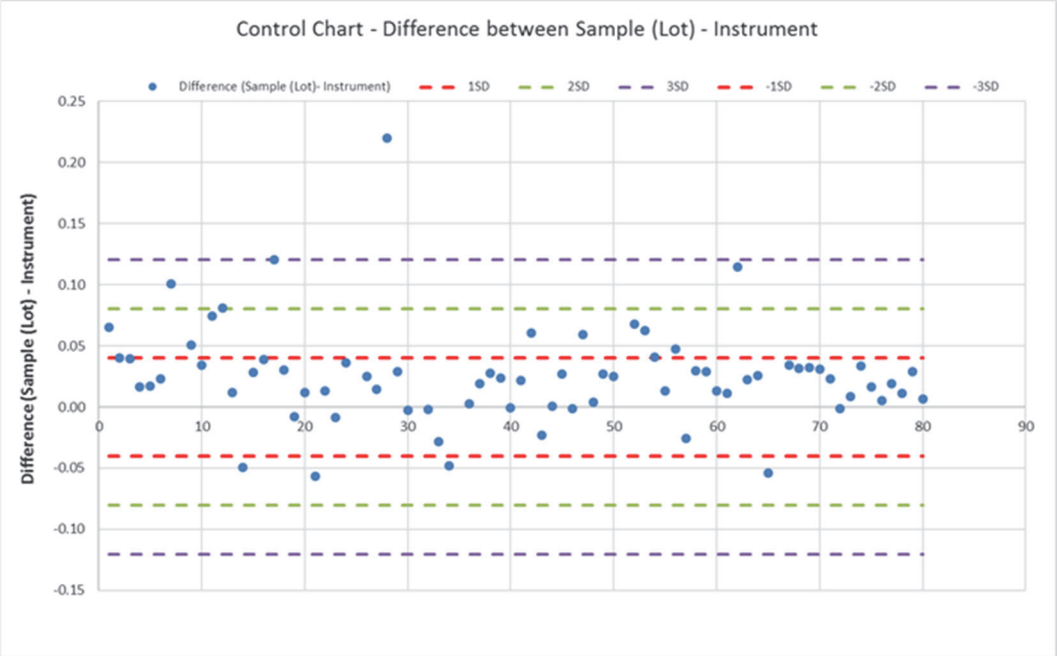

Figure 8. Control Chart – Plant 2.

The number of data points failing the respective SD limits are summarized in Table 7 and 8 below.

Table 7. Failures corresponding to Control Limits – Plant 1.

Plant 1	**+1SD (PASS/FAIL)**	**-1SD (PASS/FAIL)**	**+2SD (PASS/FAIL)**	**-2SD (PASS/FAIL)**	**+3SD (PASS/FAIL)**	**-3SD (PASS/FAIL)**
Number of Data Points - FAIL	29	5	7	0	2	0
Number of Data Points - PASS	54	78	76	83	81	83
% FAIL	34.94	6.02	8.43	0.00	2.41	0.00
% FAIL	6.83		1.41		0.40	

Table 8. Failures corresponding to Control Limits – Plant 2.

Plant 2	**+1SD (PASS/FAIL)**	**-1SD (PASS/FAIL)**	**+2SD (PASS/FAIL)**	**-2SD (PASS/FAIL)**	**+3SD (PASS/FAIL)**	**-3SD (PASS/FAIL)**
Number of Data Points - FAIL	11	1	3	0	1	0
Number of Data Points - PASS	74	84	82	85	84	85
% FAIL	12.94	1.18	3.53	0.00	1.18	0.00
% FAIL	2.35		0.59		0.20	

From analysing the % failure, it is recommended that a control limit of ±2SD be implemented for decision making around how to proceed when differences between the Sample SG and Instrument SG result.

% Solids vs. Sample SG/Instrument SG

The % solids is determined from the daily sample and is highly dependent on how the sample is retrieved from the sampling point and handled in the Evaluation Laboratory. A Pearson correlation was done between the % solids and Sample SG as well as between the % solids and the Instrument SG for both streams. It both instances, the Pearson correlation co-efficient was slightly better for the Sample than the Instrument. This is due to the % solids being determined from the physical sample itself. In addition, the Pearson correlation co-efficient calculated indicated a poor correlation between % solids and the SG data.

A theoretical calculation was then done to determine what the % solids calculated would be compared to the % solids measured during sample preparation. From theory, the solid ore SG for Plant 1 and Plant 2 is approximately 3.2 and 4.0 respectively. It is assumed here the blending of ore types or treating of waste does not occur.

Parity charts were plotted to compare the % solids measured and the % solids calculated values for Plant 1 and Plant 2 respectively – refer to Figure 9 and 10.

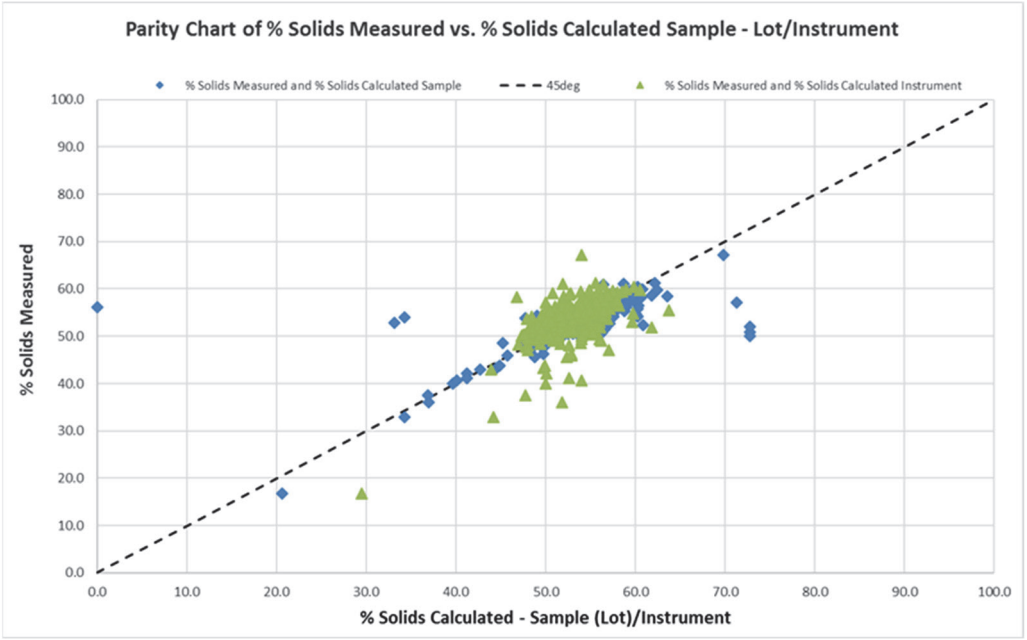

Figure 9. Parity Chart – Plant 1.

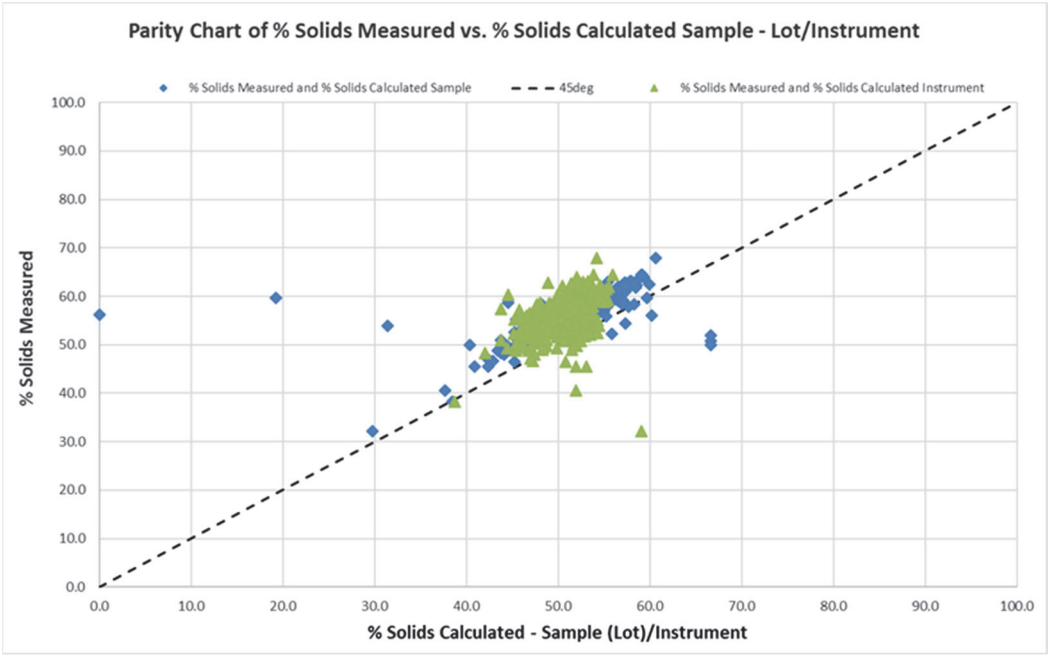

Figure 10. Parity Chart – Plant 2.

As expected, in both cases, the % solids calculated from the Sample SG compares better with the % solids measured as they are inherently related whereas the Instrument SG is not. This tool however can be used to quickly assess if the % solids measured is within range or not.

Through this exercise of analysing the actual data, a quality control methodology was derived. As per previous illustrations, a control limit of ±1SD and ±2SD should be implemented for decision making around how to proceed when differences between the Sample SG and Instrument SG result:

- If the difference is greater or smaller than the 1SD limit of 0.047 for Plant 1 and 0.040 for Plant 2 respectively, then the SG and % solids on the B sample may be done.
- If the difference is greater or smaller than the 2SD limit of 0.094 for Plant 1 and 0.080 for Plant 2 respectively, then the SG and % solids on the B sample must be done.
- If the SG of the B sample compares well with the SG of the A sample but the % solids of the A and B sample differ, then determine the % solids calculated and compare with the % solids measured to get an indication if something went wrong with the sample preparation of sample A, sample B or both samples A and B;
- The control limits must be reviewed every six months with assistance from Group Evaluation Metal Accounting and should be implemented by the Smelter thereafter.

This case study highlights the statement made by Bhattacharya et al.[3], in that statistical quality control is a promising technique with regards to quality assurance. There is also a need to re-assess upper and lower control limits from time to time and to determine what is an appropriate limit based on the expectations and instrument capability.

Case Study C: Poor 4T accountability

The importance of sampling in the mining industry cannot be over-emphasized, whether in exploration, in mining or in mineral processing[5]. The conventional wisdom suggests that when the rules and procedures for representative sampling are well defined and followed and the sampling equipment is in good order, unbiased samples will be obtained. In sampling, there are two major areas where bias can exist, namely, sampling and sample preparation. Sampling bias generally occur when (i) increments coincide with cyclic events (ii) when only a portion of the stream is being sampled (iii) where cutter specifications are not being adhered to (iv) when sample containers are overfilled[6]. Therefore, the best defence against any sampling bias is the correct sampling protocol, correct mechanical design of the sampling rig and adequate control and maintenance during its operation[5,10].

The 4T (individual elemental analysis comprising of elements: Platinum, Palladium, Rhodium and Gold) accountability for all Concentrator Plants within Anglo American Platinum is calculated, charted and is used as a risk management tool to rapidly determine metal content discrepancies between input and output streams. A UG2 Concentrator Plant was historically under-accounting in terms of Platinum Group Metals (Platinum, Palladium, Rhodium and Gold). The current practice at this Concentrator Plant is that crushed run-of-mine UG2 ore is milled in a semi-autogenous (SAG) mill and the mill product is classified using a screen to produce undersize and oversize material streams respectively. The oversize classification screen material is sent back to the SAG mill for further grinding. The undersize material is gravity fed to a surge tank and this material is then pumped to the primary rougher flotation circuit. Prior to being fed to the primary rougher flotation circuit, the material is sampled by an automatic, two-stage, vezin-vezin sampler as seen in Figure 11.

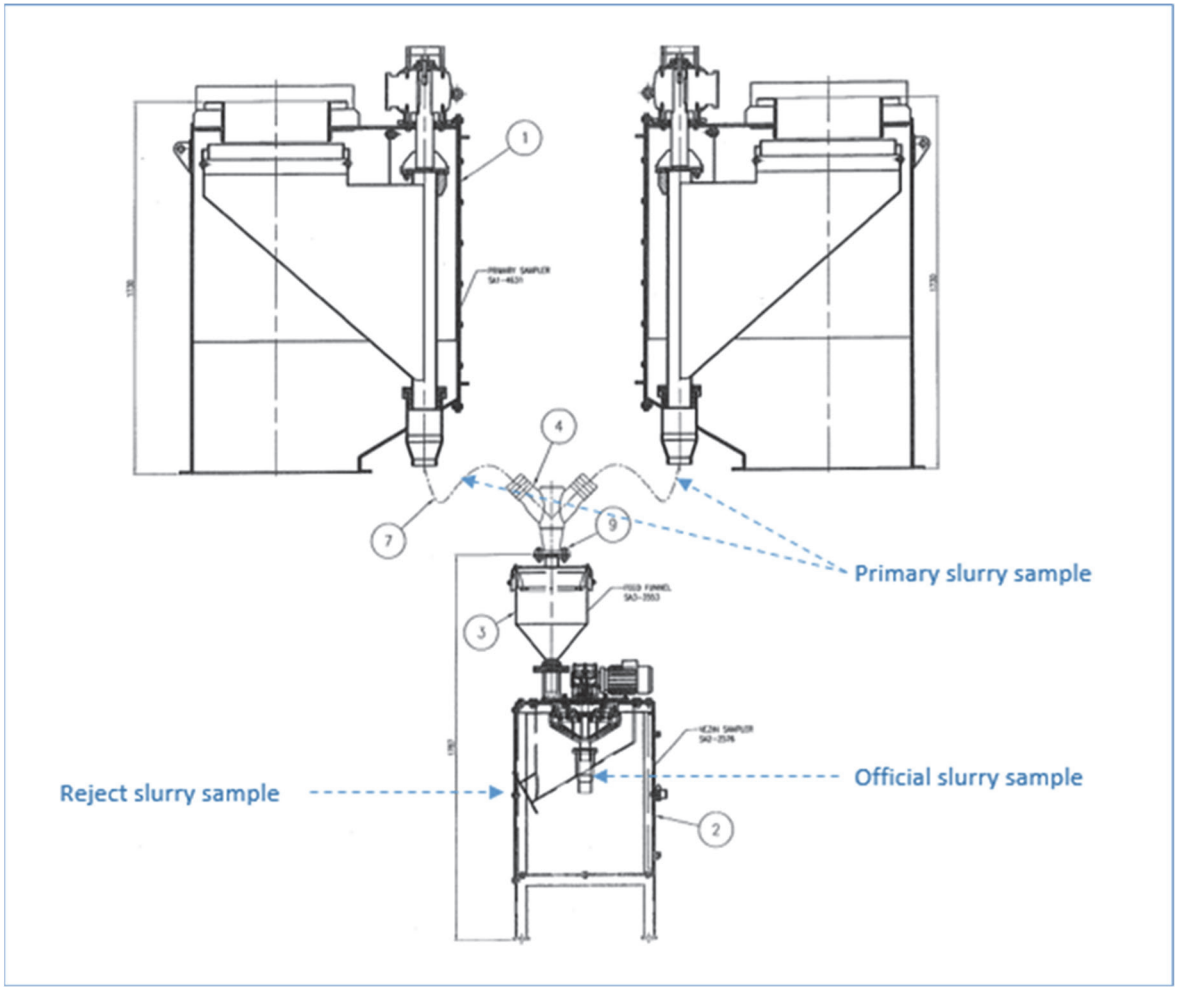

Figure 11. Vezin-Vezin Sampler Combination[8].

The debate on the source of under-accounting pointed towards possible non-representative sampling or biased sampling occurring in the Concentrator Plant feed sampling system. There were numerous indications that pointed in the direction of the feed sampling system being the problem. Process related challenges such as poor classification screening efficiency and missing classification screen panels led to unnecessary chokes in the feed to the vezin-vezin sampling system. These chokes only heightened the poor accountability trend further. Internal and external audits conducted indicated that all the other parameters contributing to the determination of the accountability value were not to be questioned. There were also no obvious or noted changes in

ore blend ratios and primary mill grind. A sensitivity analysis done using the plant accountability model also indicated that the likely contributor to the poor accountability was the feed grade as opposed to the other parameters. It was hypothesized that the main reason for the consistent under-accounting may be due to over sub-sampling of finer material into the official samples and consequently under sub-sampling of the coarser material present in the feed slurry streams. UG2 feed material size by assay analyses indicate that higher platinum and palladium grades are associated with the sub 75µm size fractions as opposed to the coarser size fractions above 75µm[7]. Indications are that because of the under sub-sampling of coarse material, the head grade of the feed into the plant is overstated leading to an under accountability of metal content.

Conventionally, a primary vezin or linear cross stream sampler is used to take a minimum number of primary increments per sampling campaign. For larger increments the flow through the secondary vezin, could be restricted by means of a conical hopper with regulated compressed air at the reduced hopper outlet to agitate the primary slurry increment until sub-sampling is complete. The air agitation alone did not keep all particles, of varying size and density in “equal” suspension throughout the sub-sampling duration of the primary increment. The finer, high-grade particles were suspended for much longer compared to the coarser and heavier, low grade particles resulting in a final sample that was biased low in coarse, low grade particles. This was established through a series of vezin credibility tests. To combat the resulting segregation error, a re-design of the intermediate hopper system was considered, and this included (i) retrofitting the design of the discharge nozzle on the original hopper (ii) use of a new hopper design, that mechanically agitates the slurry with an original discharge nozzle design (iii) use of a new hopper design with the new discharge nozzle design. Replica vezin credibility and chronological sub-sampling tests were done using all the intermediate hopper configurations to measure the evident bias. The results obtained using the original hopper and new nozzle design showed the best improvement in the bias related to particle size distribution in the sub-sample and reject, indicating that particle segregation had been significantly reduced to give more credible sampling results.

From Figure 12 below, a notable improvement in plant accountability was realized with an unbiased relationship between build-up (calculated) and measured feed grade[8].

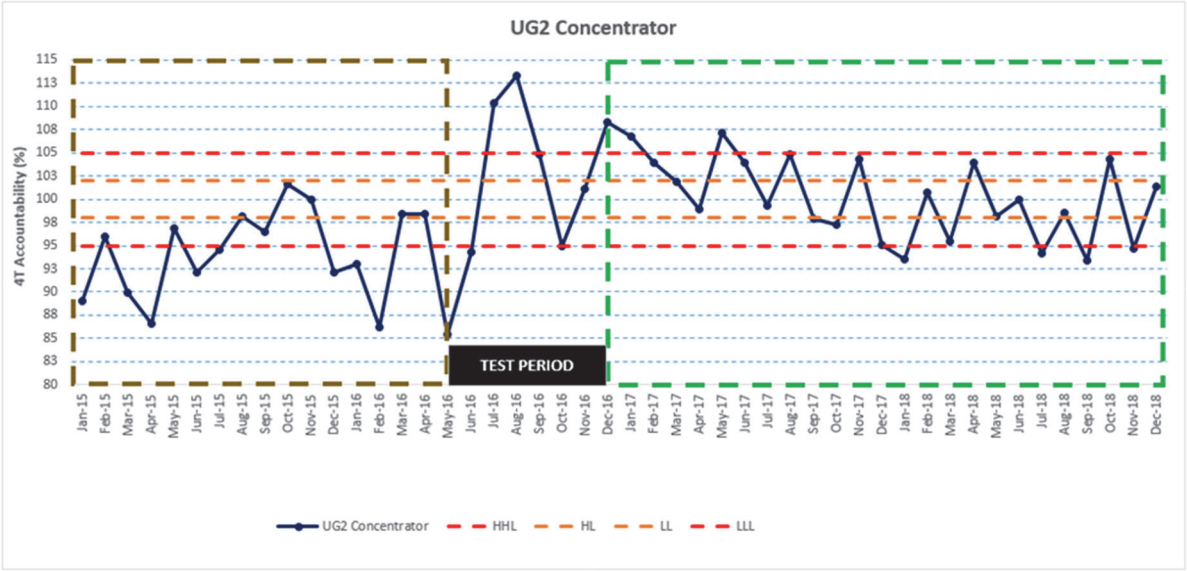

Figure 12. 4T Accountability.

The nozzle re-design, although effective in significantly reducing the bias between the official sub-sample and reject sample, was still limiting in that only a certain number of primary increments could be taken per shift or per sampling campaign. The nozzle re-design did not cater for any process variability. By producing a variogram, the time interval that a sample needs to be taken to overcome process variability can be determined. This comment is further supported by Esbensen[9] statement that “Variographic analysis of the specific lot heterogeneity is demonstrated to furnish a reliable basis upon which to estimate a minimum number of increments needed to suppress total sampling error below a regulatory threshold”. The mechanically agitated hopper (MAH) design of 60L capacity together with the nozzle re-design allows for superior benefits including additional flexibility to increase the number of primary increments taken per campaign, agitating and circulating the collected increments and sub-sampling thereafter to produce a more representative sample. This will be applicable in all sampling scenarios but more specifically in scenarios where the process variability in the feed (such as mill grind) is high and increments need to be taken over shorter but regular time intervals. It is envisaged that the MAH will eventually replace all conventional intermediate hoppers in the Platinum division. The initial cost or capital outlay for the mechanically agitated hopper is estimated to be in the region of 200 000 ZAR per sampling point. As an illustration, given that two metal accounting points exist, the risk of a parameter such of recovery being inaccurate by ±1% over a 12-month period for five years amounts to a Net Present Value (NPV) of ±244 million ZAR with a payback period of 2 days. In this case study, mere trending of relevant data was not enough to pinpoint the actual issue and it was highlighted once again that understanding and evaluating ones’ material characteristics is indeed not a once off task.

Case Study D: Poor analytical precision

Crushed dry material sub 3mm is the final product from the Anglo Converter Plant (ACP) and is sent to the BMR for further refining. This material is rich in platinum group metals as well as base metals with Platinum grades ranging between 1000g/t and 2000g/t. The material is sampled via a vezin sampler, and the resulting sample is further processed at the Evaluation Laboratory. Sample splits from the final laboratory purpose splitting method are sent to two internal analytical laboratories and the analytical precision is then determined. The particle size required for assaying this material and any other material in the Platinum Group has historically been 90% (by mass) passing 75µm. This requirement is necessary to have a properly mixed sample that is relatively homogeneous before sampling for fluxing and subsequent analysis. A sample containing precious metals that is not properly mixed for homogeneity will always result in twin stream analysis discrepancies due to the nugget effect.

Over the years, much focus has been placed on evaluating this material stream. The paper by Kruger & van Tonder[10] showcases, in much detail, the process that took place to explain poor accountabilities between the ACP and BMR. An audit and physical inspection as well as a change in the sampling protocol and sampler itself was introduced to eliminate the confirmed sampling bias. Following all these interventions, the accounting between the ACP and BMR had been restored to be within statistical limits with the difference between physical and theoretical stock being below 5% relative to the cumulative input.

For some time, however, the inter-laboratories precision have been outside the relative standard deviation limits of ±5%, indicating poor precision and thus prompting further investigation. After much test work, it was observed that during the final splitting method of the sample, the presence of platelets following rod milling was the main contributor to the variability in grade between the sample splits sent to the two internal laboratories. It is believed that during rod milling, heat is generated and may cause smearing which in turn creates platelets being higher in grade than the remaining particles within the sample. Kobe & Kruger[11] outlines the details pertaining to the history behind the need for wet rod milling of the crushed dry material prior to assaying. This case study supplements all the observations and comments made in the previous case studies in that assigning a sampling protocol is a continuous process. Even through the material characteristics were well understood and the minimum sample mass was implemented and adhered to, other factors such as sampling and sample preparation errors/non-conformances could easily negate that impact and create further issues downstream. In this case study, the devil was in the detail and looking beyond the quality control was necessary to alleviate the problem. It was essential to re-visit the development of the knowledge base for this material type and emphasize the need to assess materials individually on a chemical and physical basis and assign control limits specific to the material type. The understanding and importance of rod milling was only the beginning and further investigation was needed for overall optimization.

Conclusion

The case study examples collectively highlights one common question: How does one bridge the gap between having QA/QC systems in place, realizing that there may be an area of concern, and subsequently resolving the concern. For now, the answer remains with continuous, real-time trending of QA/QC data using data analytics in conjunction with equipment inspection and audits. In addition, it ultimately amounts to following basic principles and fully understanding one's material characteristics. QA/QC systems are the key to supplementing further investigation and should be treated as such.

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