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Sampling and Weighing of Mineral Concentrates

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Summary

Between source and final destination the wet weight of each consignment of mineral concentrate and its quality parameters are measured as the basis for settlement between trading partners. The risk to lose in this commercial transaction depends on the magnitude of uncertainties in the chain of measurements that determine the value of each consignment. Uncertainties in measurements can be divided into random variations that cancel as a function of time, and systematic errors that cause a loss to one of the trading partners. If the value of a consignment is high, even the cumulative effect of all random variations in the chain of measurements may cause too high a risk.

Accuracy is an abstract concept that cannot be defined in mathematical terms but the lack of accuracy for a measurement, and its precision, are clearly defined and can be quantified in different ways. While the variance is the most basic measure for precision, more transparent measures such as coefficients of variation, and confidence intervals and ranges, are frequently applied. Statistical tests differentiate between random variations that are intrinsic to a measurement process, and systematic errors that should be avoided if at all possible.

Loss prevention and control is a logical approach to assessing the risk to lose due to systematic errors that should be eliminated, and due to random variations that can be reduced at a cost. The accuracy and precision characteristics of wet weights, moisture contents and metal grades for consignments of mineral concentrates will be discussed, and their impact on the risk to lose will be addressed.

1. Introduction

The contract between the trading partners specifies when and where to determine the wet weight of a consigment and how to measure its quality parameters. Contracts often specify terms and conditions for inspection and supervision during weighing, sampling, preparation of gross samples, determination of moisture contents, and preparation of exchange samples. Wet weights and quality parameters that form the basis for settlements between buyers and sellers are usually determined at discharge. Some smelters discharge vessels at their own docks while others receive concentrates in barges, rail cars, or trucks, either directly from a mine or after discharge from a vessel at a port. Every transfer causes some mechanical loss which translates into an element of risk. Careful handling will limit losses to less than 0.05% for a single transfer but under adverse conditions higher losses may be incurred.

Intermediate storage at bulk handling terminals may also result in contamination, oxidation and mechanical loss. Another disadvantage of intermediate storage is that random variations in weights that are added to or deducted from an inventory accumulate until a zero adjustment is made. Weights that are measured with a static scale and added to the inventory contribute little to this uncertainty but weights that are measured by draft survey and deducted from the inventory contribute a large measure of uncertainty to the remaining inventory. Hence, the degree of uncertainty for an inventory at a bulk handling terminal, and thus its precision in terms of a confidence interval and range, is a function of the number of consignments that were loaded aboard vessels and measured by draft survey between zero adjustments. Eventually the uncertainty for an inventory becomes so high that its book value is just a random number.

High grade precious metal concentrates are often shipped in drums or bulk bags that are weighed and sampled at the smelter which virtually eliminates mechanical losses to the detriment of the seller. Wet weights that are determined with a static scale contribute significantly less to the uncertainty for the metal contents than sampling, preparation and analysis for metal grades. As a result, the risk to lose due to random variations in the weighing process is small.

For many bulk solids wet weights of consignments are measured by draft surveys but this technique is rarely used for concentrates. Freight and insurance charges are generally based on wet weights that are measured by draft survey at loading. Only provisional payments for concentrates are based on draft surveys at loading.

Draft surveys are much less precise than static scales such as truck, track, hopper and grab scales. The difference in

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precision between wet weights that are determined by draft survey and with a static scale impacts only marginally on costs for insurance and freight. However, the low degree of precision for draft surveys virtually determines the risk to lose and the probability to gain in the final settlement.

Weighing and sampling for total moisture should be closely spaced in time to eliminate systematic errors due to either loss or gain of moisture in the interim. The variance of sampling, preparation and analysis for moisture contents can be used to compute the composite variance for the dry weight of a sampling unit, and for the cumulative dry weight of any number of sampling units. Similarly, the variance of sampling, preparation and analysis for metal grades can be used to compute composite variances for the metal contents of each sampling unit, and for the cumulative metal contents of any number of sampling units.

Metrology, the science of measurement, provides tools and techniques to check the absolute or relative accuracy of a chain of measurements, to estimate the precision of each measurement, and to monitor precision as a function of time. Accuracy and precision characteristics of various measurements can easily be monitored on appropriate control charts. Literature on applied statistics, and on sampling and weighing, and international standards (ISO) and national standards (ASTM, BSS, DIN), are useful sources of information. NBS Handbook 44 defines the tolerance as a measure for the precision of a scale. Tolerances, unlike variances, do not add up so that this measure cannot be translated into useful precision parameters.

Technical Committee 183 of the International Standards Organization (ISO TC183) is presently in the process of developing sampling methods and regimes, preparation procedures, and test methods for moisture contents and metal grades of ores and concentrates. This Committee is investigating possible integration of weighing and sampling such that precision parameters in terms of confidence intervals and ranges for wet weights and dry weights of consignments, and their metal contents, can be reported on a routine basis.

2. Weighing

Wet weights of mineral concentrates on which settlements are based should be measured with a static scale. Draft surveys should only be used to determine wet weights for provisional payments, freight charges and insurance premiums. The difference between the precision of these mass measurement techniques impacts significantly on the uncertainty in wet and dry weights of consignments of mineral concentrates and their metal contents.

The precision of draft surveys and static scales will be addressed in separate sections. A consignment of a mineral concentrate with a wet weight of 25,000 t, a moisture content of 8.0%, and a metal grade of 50.0%, will be used to demonstrate how precision parameters for wet weights, moisture contents and metal grades interact, and how precision statements for metal contents in terms of 95% confidence intervals and ranges provide a clear and concise measure for the risk to lose and the probability to gain.

2.1 Draft Surveys

The precision of draft surveys may well be marginally acceptable for bulk solids such as coal and iron ore but is unacceptable for valuable mineral concentrates. An unbiased estimate for the precision of a draft survey would be obtained if two marine surveyors were to measure, completely independently, the draft of a vessel in light and loaded condition while accounting for changes in ballast and supplies during loading of a consignment.

Conditions that impact on the precision of a draft survey are stratified salinity, wind velocity, and stress deformation of a vessel, in particular of a partially loaded vessel. Marine surveyors tend to be optimistic about the precision of draft surveys but the evidence does not support the common claim that a precision of ± 1% in terms of a 95% confidence interval can be routinely achieved. For this precision can only be obtained under optimum conditions.

Draft surveys are often measured by consensus between an officer of the ship, a marine surveyor that acts on behalf of the seller, and, at times, another surveyor that represents the buyer. This approach does not generate any data to estimate the precision of a single draft survey in an unbiased manner. In the case that the wet weights at loading and at discharge are both determined by independent draft surveys, the differences between such paired data would become a measure for the precision between draft surveys in different ports.

Statistical comparisons of draft surveys at loading and discharge often display the déjà vu effect, a remarkable phenomenon that appears to defy the laws of mathematical probability. Such comparisons are based on the premise that the variance of differences between loaded and discharged wet weights is a measure for the precision between draft surveys. If the draft surveys at loading and discharge were equally precise, then each would contribute a similar variance component to the variance of differences. In practice, the conditions at loading and discharge often vary significantly so that the precision of loaded and discharged weights also varies.

Comparisons of draft surveys, either at loading or at discharge, with wet weights that were measured with a static scale showed that the variance of differences between paired draft surveys was significantly lower than the variance of differences between pairs of draft surveys and static weights. The most plausible explanation for this phenomenon is the déjà vu effect which dictates that knowledge of the vessel's B/L makes it impossible to measure the wet weight of a consignment by draft survey at discharge in an unbiased manner.

The large number of variables that interact during draft surveys causes the precision for the same vessel to vary between voyages and between ports. Under optimum conditions a coefficient of variation of 0.5% (CV in %) is possible but under adverse conditions a precision of 2.5% for draft surveys on partially loaded vessels have been observed. For all practical purposes a CV of 0.5% is equal to 95% confidence interval of ± 1% while a CV of 2.5% is equal to a 95% confidence interval of ± 5%. Hence, the precision for this mass measurement technique ranges from ± 1% for draft surveys on a light and completely loaded vessel under ideal conditions to ± 5% for draft surveys of a partially loaded vessel under poor conditions.

Based on these considerations the CV for a draft survey during loading of a consignment of concentrate with an unknown true wet weight of 25,000 t aboard a 65,000 t bulk carrier under acceptable conditions is expected to range from a low of 0.75% up to a high of 1.5%. In Table 1 are listed 95% confidence intervals and ranges for these low and high precision estimates.

The risk to lose, and, of course, the probability to gain, in monetary terms, is quantified by multiplying each 95% confidence interval with the value of the mineral concentrate. This amount is estimated to range from a low of $100,000 to a high of $400,000 for a single consignment. Unless the wet weight of a consignment is biased trading partners run identical risks to lose, and have identical chances to win. It is obvious that imprecise wet weights leave a wide margin for commercially significant systematic errors that are difficult to detect.

Table 1: Precision of draft surveys for 25,000 t

Parameter	Symbol	Low	High
95% Confidence Interval	95% CI		
in t		± 375	± 750
in percent		± 1.5	± 3
95% Confidence Range	95% CR		
LOW in t	wM − 95% CI	24,625	24,250
HIGH in t	wM + 95% CI	25,375	25,750

2.2 Static Scales

The wet weight of a consignment of concentrate is absolutely accurate if it is determined with a properly calibrated static scale. The criterion is that the certified weights which were used to calibrate the scale can be traced to the International Unit of Mass through National Prototypes. Static scales at bulk handling terminals are calibrated once or twice per year, and often by a government agency in the receiving country that administers weights and measures, or that deals with metrology as applied to weighing of bulk solids.

Sets of certified weights are usually available at smelters, and should preferably be available at terminals where wet weights of consignments are measured for settlement purposes. Precision parameters for hopper scales are difficult to obtain under routine conditions but calibration data can be used to estimate the variance for a single weighing cycle. Hopper scales are calibrated by adding certified weights in increments of 1–2 t so that linearity and sensitivity can be checked over its working range. Grab scales are simple to calibrate if a certified mass that matches the average load is available on the site. Their precision is simple to measure and monitor on the basis of no less than five checks during the discharge of each consignment.

Certified weights for truck and track scales are generally the property of government agencies. The precision of static truck and track scales is easy to measure under routine conditions. However, their precision is a function of load so that the monitor program should be based on gross weights.

Control charts for absolute accuracy require a suitable set of certified weights on the site. Control charts for precision are a useful tool to monitor the performance of static scales. An effective monitor program would be to weigh in duplicate five rail cars or five trucks in loaded condition during the discharge of a consignment. The mean of absolute differences between duplicates is a measure for the variance of a gross weight which, in turn, can be used to compute the variance for a single net wet weight. The total variance for the cumulative wet weight of a consignment is the variance of the net wet weight of a unit load multiplied by the number of unit loads, or rather by the number of hopper or grab loads, rail cars or trucks.

In terms of a CV the precision for single weighing cycles ranges from a low of 0.1% for a hopper scale to a high of 0.5% for a track scale. Anomalous conditions that result in a lower degree of precision have been observed but the range from 0.1% to 0.5% is realistic for static scales that are commonly used to determine the wet weight of mineral concentrates for settlement purposes.

If the wet weight for a consignment of 25,000 t of mineral concentrate were measured in average unit loads of 12.5 t with a hopper scale that has a precision of 0.1% for a single unit load, then the variance for the cumulative wet weight is 0.31 t^2 for a 95% confidence interval of ± 1.1 t. However, if this weight were determined in average unit loads of 50 t with a track scale that has a precision of 0.5% for the net wet weight of a single rail car, then the variance for the cumulative wet weight is 31.25 t^2 for a 95% confidence interval of ± 11.2 t.

In Table 2 are listed precision parameters in terms of 95% confidence intervals and ranges for each type of scale, and for a draft survey of a consignment of 25,000 t that was measured with a precision of 0.75% in terms of a coefficient of variation.

The probability to lose less than 0.1% for a consignment of concentrate is a commercially acceptable risk. If wet weights at loading and at discharge were determined with the same high degree of precision, then a difference of 0.1% could possibly be identified as a systematic error.

Table 2: Precision of static scales for 25,000 t

Parameter	Symbol	Hopper	Track	Draft
95% Confidence Interval	95% CI			
in t		± 1.1	± 11.2	± 375
in percent		± 0.004	± 0.04	± 1.5
95% Confidence Range	95% CR			
LOW in t	M − 95% CI	24,999	24,989	24,625
HIGH in t	M + 95% CI	25,001	25,011	25,375

3. Sampling

Settlements between trading partners are based on metal contents of consignments. Moisture contents are used to convert wet weights into dry weights which are then converted into metal contents on the basis of metal grades on dry basis. Random variations and systematic errors in the measurement of wet weights, moisture contents and metal grades propagate in the uncertainties for the metal contents of a consignment.

Quality parameters are determined in gross samples that are collected manually during transfer of a consignment. For mineral concentrates mechanical sampling systems are used much less frequently than manual sampling regimes. Sampling systems that collect primary increments with one or more probes, or that divide the entire consignment into a sample and reject flow with a pair of continuous dividers in series, have found limited application. At times consignments of precious metal concentrates are divided into a small number of sampling units that are first homogenized and then divided with continuous dividers.

A consignment of concentrate is usually divided into sampling units with a mass of 250 t up to 1,000 t. At times a set of sampling units for moisture is combined into a single sampling unit for metal grades upon completion of drying.

Adjectives such as moisture lot or assay lot are used to describe such sampling units. Manual sampling methods for mineral concentrates can be divided into two basic categories:

1. sampling under static conditions from stockpiles, barges, rail cars, trucks, or containers,
2. sampling under dynamic conditions from the stratum on a moving belt, the flux at a transfer point in a conveyor belt system, or the contents of a grab during discharge.

Collecting primary increments manually from sampling units under static conditions conforms to a three-dimensional model. Unless all elementary cells in a sampling unit can be accessed with the sampling device, the method does not comply with an equiprobable sampling model. Moisture migration, and oxidation to a lesser extent, may cause systematic errors in samples that are collected from three-dimensional sampling units after prolonged storage.

Collecting primary increments manually from the concentrate stratum on a conveyor belt, or from the particle flux at a transfer point, conforms to a two-dimensional sampling model. Under such conditions differences between moisture contents and metal grades of upper and lower strata on conveyor belts are randomly distributed so that primary increments are unbiased for all quality parameters. During transportation and storage moisture migrates so that moisture contents of upper and lower strata in holds of vessels and barges, and in rail cars, may differ significantly. Moisture migration in rail cars that are processed in a thaw shed may also cause large differentials.

In the case of grab discharge too upper strata in grabs are a random exposure for all quality parameters so that gross samples that are collected manually from a grab, either with a scoop or with a probe, are unbiased. Primary increments that are collected with a sample probe represent a much thicker particle stratum than those collected with a scoop. Hence, gross samples that are collected with probes are intrinsically more precise than those collected with scoops. A slotted probe is the most suitable device for manual sampling of concentrates.

For each sampling unit the number of primary increments, their average mass, and the interval between increments either in time or in mass, are defined. Such a sampling regime determines the variance of each gross sample, and thus the intrinsic precision of all quality parameters. Primary increments are usually collected at constant intervals of time or mass, and then stored in plastic bags, or in sample containers with tight-fitting lids.

The intrinsic precision of a gross sample can be estimated by measuring quality parameters in each primary increment. Such a data set can be used to calculate the sampling variance and the terms of the time series variances on which sampling variograms are based. Fig. 1 shows a typical sampling variogram for the metal grade of a mineral concentrate which displays the effect of a serial correlation at intervals of a constant mass of 5 t. Moisture contents of closely spaced primary increments too display a serial correlation.

A much more efficient method to determine the sampling variance is to collect pairs of interpenetrating samples from each sampling unit, albeit that it does not provide time series variances. In the case that a serial correlation between moisture contents and metal grades of consecutive primary increments exists, the sampling variance is determined by the second term of the time series variances.

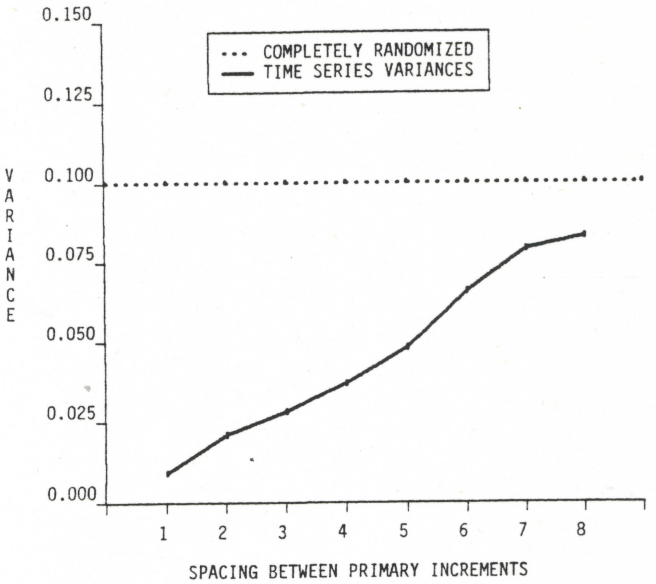

Fig. 1: Sampling variogram

Although the first term of the time series variances is marginally lower than the second term, both are significantly lower than the variance between completely randomized primary increments.

Due to the particle size of mineral concentrates the mass of a primary increment need not exceed 0.25 kg. For the number of particles in the average primary increment is so large that the composition variance component of the sampling variance is much lower than its distribution variance component. As a rule, the variance of sampling, preparation and analysis for moisture contributes significantly less to the variance of metal contents than the variance of sampling, sample preparation and analysis for metal grades. In fact, if the wet weight of a consignment is measured with a static scale, the variances for its metal contents is determined by the variance of analysis for each metal grade.

Generally, the variance of sampling, preparation and analysis for total moisture contributes significantly less to the composite variance for metal contents than the variance of sampling, preparation and analysis for metal grades. As a result, the precision for the moisture factor of $(100 - \%H_2O)/100$ is perfectly acceptable for the calculation of the dry weight of a consignment.

For a properly designed sampling regime the variance of analysis is significantly higher than the sum of the variances for sampling and preparation. Under those conditions the question whether the variances of analysis for metal grades are acceptable for settlement purposes no longer depends on the sampling regime but only on the variance of differences between the exchange laboratories.

The sampling method that is most commonly applied to bulk solids is based on collecting primary increments in sequence, and either storing each set in a suitable container, or processing it with a mechanical sampling system. The disadvantage of this method is that the intrinsic precision of a gross sample cannot be estimated on a routine basis. An effective method to determine this precision is to collect a pair of interpenetrating gross samples from each sampling unit. The mean of absolute differences is a measure for the variance of sampling, sample preparation and analysis. Fig. 2 shows a flow chart for a sampling regime that is based on collection of interpenetrating gross samples.

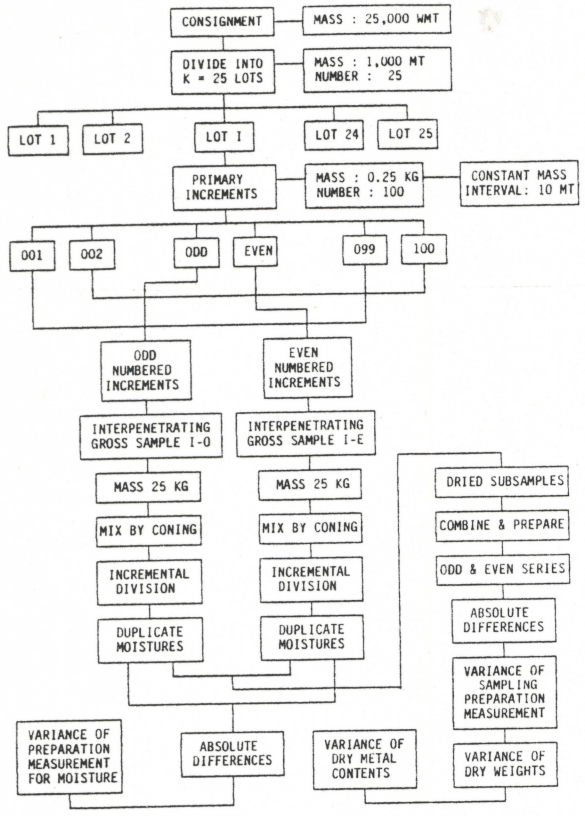

Fig. 2: Flow chart for interpenetrating gross samples

A sampling regime that is based on collecting interpenetrating gross samples generates a reliable estimate for the variance of sampling, preparation and analysis of moisture contents and metal grades for each consignment. Despite the obvious advantages of a sampling regime that is based on collecting pairs of interpenetrating gross samples from each sampling unit, a sampling regime that is based on combining the set of primary increments for each lot into a single gross sample is commonly applied. Yet, the variances between quality parameters in the set of lots hardly form the basis for realistic precision parameters for the average moisture content and metal grades of the consignment. If the consignment of 25,000 t were divided into sampling units for moisture and quality of 500 t each, a set of fifty gross samples would be obtained. If a pair of interpenetrating gross samples were collected from each lot of 1,000 t, a set of fifty gross samples would also be generated.

It is obvious then that it would not be more costly to collect from each lot a pair of interpenetrating gross samples that does provide realistic precision parameters for the metal contents of a consignment. After all, this set of twenty-five pairs of interpenetrating gross samples not only provides estimates for the variance of sampling, preparation and analysis for moisture contents and metal grades but also takes into account the effect of a serial correlation on the sampling variance. For composite variances for the dry weight of a consignment and its metal contents cannot be calculated without unbiased and precise variance estimates for the average moisture content and metal grades.

The set of fifty gross samples that each consists of a series of consecutive primary increments, provides a measure for the variability of quality parameters between lots. This variance is hardly a measure for the precision of sampling, preparation and analysis. After all, such precision estimates are based on the premise that differences between quality parameters in lots are due to random variations only, and not to true differences between quality parameters. Fisher's F-ratio of the variance between lots and the variance of sampling, preparation and analysis is invariably significant to the extreme so that the latter provides the most reliable precision estimates.

The mass of a gross sample for moisture and quality generally ranges from 10 kg up to 25 kg. Each gross sample should be mixed four times, either with a Gilson SP1 divider or with a pair of large stainless steel mixing trays. Next, single or duplicate test samples with a mass of 0.5–1 kg each should be collected by incremental division with a No. 5 incremental division scoop. The process of incremental division or increment reduction is described in Japanese Industrial Standard M8100 as a high precision alternative to the riffle divider.

Test samples should be dried at 105°C, and reweighed while hot to avoid reabsorption of moisture during cooling. Differences between duplicates are a measure for the precision of collecting test samples and determining moisture contents. Differences between each set of paired interpenetrating samples are a measure for the precision of sampling, preparation and analysis.

Duplicate moisture samples for a lot are recombined into a composite from which a set of exchange samples is prepared. Many smelters use mechanical blenders and dividers to mix dried subsamples and to collect a set of exchange samples. Mixing by coning with medium size stainless steel trays followed by increment reduction is more effective than rolling on rubber or vinyl sheets and randomized division with a spatula.

3.1 Precision of Dry Weights

Variances propagate in a predictable manner. How variances of single measurements such as wet weights, moisture contents and metal grades propagate in composite measurements such as dry weights and metal contents depends on the underlying formula and its partial derivatives. For the variance of a composite measurement is equal to the sum of the products of squared partial derivatives and the variances for single measurements. If the precision for moisture were 2.0% in terms of a coefficient of variation for the process of sampling, preparation and analysis for each sampling unit of 1,000 t, then the variance for the average moisture content of 8.0% for the consignment would be 0.0010.

Coefficients of variation of 0.75% for a draft survey, 0.5% for a loaded rail car, and 0.1% for a hopper load, were earlier used to calculate the variance for wet weights. In Table 3 are summarized the variances for the measurement of wet weights and for sampling, preparation and analysis of total moisture.

Table 3: Variance components for dry weight of 23,000 t

Parameter	Symbol	Hopper	Track	Draft
Variance Component				
Wet Weight	var(wM)	0.26	26.45	29,755
Total Moisture	var(H_2O)	64.00	64.00	64
Dry Weight	var(dM)	64.26	90.45	29,820

Variances for wet weights that are measured with either static scale contribute less to the variance for a dry weight of 23,000 t than the variance of sampling, preparation and analysis for total moisture. In the case of draft surveys, however, the variance for the wet weight dominates the variance for the dry weight.

These different variances for the dry weight of 23,000 t can also be expressed in terms of 95% confidence intervals and ranges, and the results of this calculation are summarized in Table 4.

Table 4: Precision for dry weight of 23,000 t

Parameter	Symbol	Hopper	Track	Draft
95% Confidence Interval	95% CI			
in t		± 16.0	± 19.0	± 345
in percent		± 0.07	± 0.08	± 1.5
95% Confidence Range	95% CR			
LOW in t	dM − 95% CI	22,984	22,981	22,655
HIGH in t	dM + 95% CI	23,016	23,019	23,345

The risk to lose due to random variations in weighing a consignment of concentrate with a static scale, and in sampling, sample preparation and analysis for total moisture is less than 0.1%. For a consignment of concentrate such a risk is acceptable but a risk of ± 1.5% for the draft survey is unacceptable. For draft surveys the risks for wet weights and dry weights are both ± 1.5% which indicates that the variance of sampling, preparation and analysis for total moisture did not contribute much to the variance for the dry weight.

3.2 Precision of Metal Contents

During preparation exchange samples reabsorb moisture from ambient air which results in moisture contents that usually range from 0.2% up to 1%. Drying each exchange sample, or a part of it, prior to collecting test samples for metal grades, is a poor alternative to determining residual moisture in 5 gram test samples that are collected simultaneously with the set of test samples for metal grades.

Exchange of assays between trading partners takes place on a pre-arranged date. If the difference between exchange assays exceeds the splitting limit, a reserve sample is submitted to the umpire. A new approach to the exchange of assays should be considered. Buyer and seller should submit exchange assays in duplicate to a referee who would then apply statistical techniques to assess compatibility, and who would advise the trading partners which samples should be reassayed without releasing to either partner the first set of exchange assays of the other partner.

Exchange through an independent referee ensures that the second set of assays is not biased due to familiarity with the first set. Application of a variable splitting limit that is essentially a function of the variance of differences between exchange assays also forms part of the pursuit of fair and equitable settlements between trading partners.

Variances for a wet weight of 25,000 t, an average moisture content of 8.0%, and a metal grade of 50.0% propagate in the composite variance of metal contents. If the precision for the metal grade were 1.0% in terms of a coefficient of variation for the process of sampling, preparation and analysis for each sampling unit of 1,000 t, the variance for the average metal grade of 50.0% would be 0.010.

CVs of 0.75% for a draft survey, 0.5% for a loaded rail car, and 0.1% for a hopper load, were earlier used to calculate the variance for wet weights. The variance of 0.0010 for an average moisture content of 8.0% will also be used again to calculate the composite variance for the metal contents of the consignment. In Table 5 are listed variances for wet weights, for sampling, preparation and analysis of moisture contents and metal grades, and for metal contents.

Table 5: Variance components for metal content of 11,500 t

Parameter	Symbol	Hopper	Track	Draft
Variance Component				
Wet Weight	var(wM)	0.07	6.6	7,439
Total Moisture	var(H_2O)	16.00	16.0	16
Metal Grades	var(MG)	529.0	529.0	529
Metal Contents	var(Me)	545.1	551.6	7.984

The variance for the draft survey contributes most to the composite variance for a metal content of 11,500 t. The variance of 529 for sampling, preparation and analysis for the metal grade is the second highest variance. Variance components for single measurements can be converted into percentages of the composite variance to show how much each measurement contributes to the variance of metal contents. In Table 6 are summarized variance components as a percentage of the composite variance.

Fig. 3 shows variance contributions that are based on measurement of 25,000 t with a hopper scale, with static

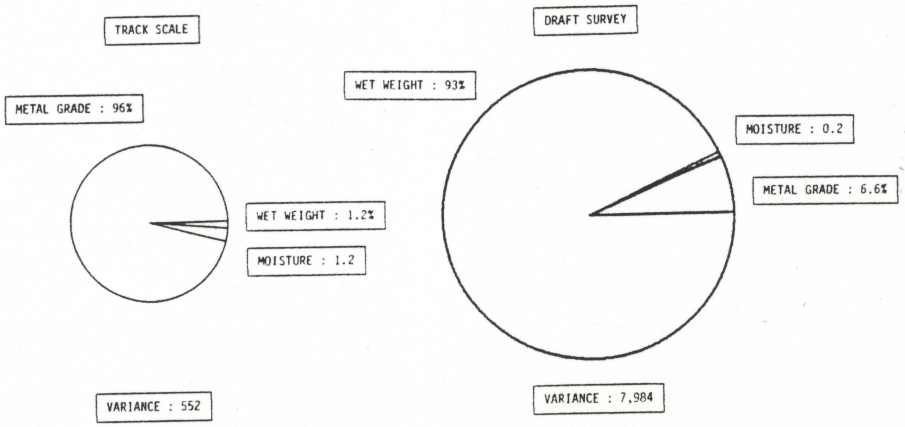

Fig. 3: Distribution of variance components

Table 6: Variance contributions in percent

Parameter	Hopper	Track	Draft
Contribution of Wet Weight	0.01	1.2	93
Moisture	2.9	2.9	0.2
Metal Grades	97	96	6.6

track scale and by draft survey. The ratio between surfaces of these pie charts is identical to the F-ratio of: 7,984/551.6 = 14.74 which is, of course, statistically significant to the extreme.

The variances for the metal content of 11,500 t can also be expressed in terms of 95% confidence intervals and ranges, and the results are summarized in Table 7.

Table 7: Precision for metal content of 11,500 t

Parameter	Symbol	Hopper	Track	Draft
95% Confidence Interval	95% CI			
in t		± 46.7	± 47.0	± 179
in percent		± 0.41	± 0.41	± 1.55
95% Confidence Range	95% CR			
LOW in t	Me − 95% CI	11,453	11,453	11,321
HIGH in t	Me + 95% CI	11,547	11,547	11,679

The risk to lose due to random variations in weighing a consignment of concentrate with a static scale, and in sampling, sample preparation and analysis for moisture contents and metal grades is ± 0.4%. A risk of this magnitude appears high for concentrates. The risk of ± 1.55% for a wet weight that is determined by draft survey is too high. For a consignment with a value of $ 10,000,000 the risk to lose would be equivalent to $ 155,000.

If the risk of ± 0.4%, or $ 40,000 in this numerical example, were unacceptable, then it can be reduced most effectively by improving the precision of analysis for metal grades. In this case the variance of sampling, preparation and analysis was not partitioned into variance components for the collection of primary increments, for the preparation of gross samples, and for the analysis of exchange samples.

Practical experiences with different types of concentrates have indicated that the variance of analysis is the dominant component. If a sampling regime that is based on collecting pairs of interpenetrating samples from each sampling unit, were applied, and if the trading partners were to report exchange assays in duplicate, the 95% confidence intervals and ranges for all metal contents in each consignment of mineral concentrate can be calculated.

Similar precision statements can be estimated from wet weights and quality parameters that were measured during loading at the mine for comparison with those on which final settlements between the trading partners are based. A systematic comparison of loading and discharge data is the key to effective loss prevention and control between source and final destination.

References

[1] Merks, J.W.: Sampling and Weighing of Bulk Solids; Series on Bulk Materials Handling, Vol. 4 (1985), 420 pp., Clausthal-Zellerfeld, Trans Tech Publications.