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A Strategy to Minimise Ore Grade Reconciliation Problems Between the Mine and the Mill

By F F Pitard[1]

ABSTRACT

Major discrepancies between mine estimates and estimates from plant metallurgical balances are a common problem in many gold and base metals mines around the world. Many existing practices are based on practical protocols that often fall short of basic statistical requirements. Sampling tools are often flawed by design and cannot provide the needed reliability for achieving accurate ore grade and reserves. These problems are amplified by the naive application of correcting factors. An 18-point strategy is given to minimise these reconciliation problems. The strategy is based on accurate sampling capable of providing reliable data, on thorough statistical evaluations identifying the causes of variability, and on a Total Quality Management philosophy offering a platform for proactive decisions.

INTRODUCTION

The author's consulting experience with major mining corporations demonstrates that sampling, ore grade control, process control, and reconciliation problems can be solved only with the involvement of the executive team. Time invested by management to better understand integrated Sampling, Statistical Process Control (SPC), Geostatistics, and Total Quality Management (TQM) will be repaid many times over, to both the individual and the company. Executive-supported strategies founded on integrated Sampling, Statistical Process Control, Geostatistics, and Total Quality Management, and the discipline to enforce them is an unambiguous directive to engineers and operators. Invariably, this progressive and knowledgeable attitude from the executive team provides the leadership that will uncover many previously hidden problems. It will thereby permit the development of solutions with the attendant reduction or elimination of many invisible costs and risks. This leads to the following 18-point Total Quality Management strategy.

POINT ONE: CREATE A PLAN TO CAPITALISE ON EXISTING DATA

At the mine and the mill, your data has been meticulously gathered and stored at considerable expense. It has value … don't let it gather dust! Most people feed valuable data to daily or monthly production sheets to benefit only the accountant. Valuable information should be retrieved from such chronological data, providing a better understanding of the variability components it carries. This would lead to the discovery of causes of problems. For example, the grams/litre solids of a flotation plant stream are measured every hour, as illustrated in Figure 1. The questions are:

- How much random variability from sampling, subsampling, and measurement is carried by this data?
- How much non-random variability is generated by the selected sampling/measurement interval?
- How much non-random, long-range variability affects the process?

Someone must answer these questions in an unambiguous way. Yet, more often than not, no-one can. Therefore, management does not capitalise on existing data, which ultimately is translated into an invisible metal recovery loss, which does not concern the accountant. This leads to four recommendations:

1. Make a commitment to find causes of problems.
2. Carefully explain to operators what they have to do, before asking them to do their best.
3. After management realises that everything in a process is filled with variability, commit to a plan to reduce the variability of any given process parameter. Never be satisfied with the status quo on improvement.
4. Make a clear commitment to preventive maintenance. There is no way to achieve good mine/mill reconciliation with a patching philosophy on maintenance. Bring ISO standards to the rescue if necessary.

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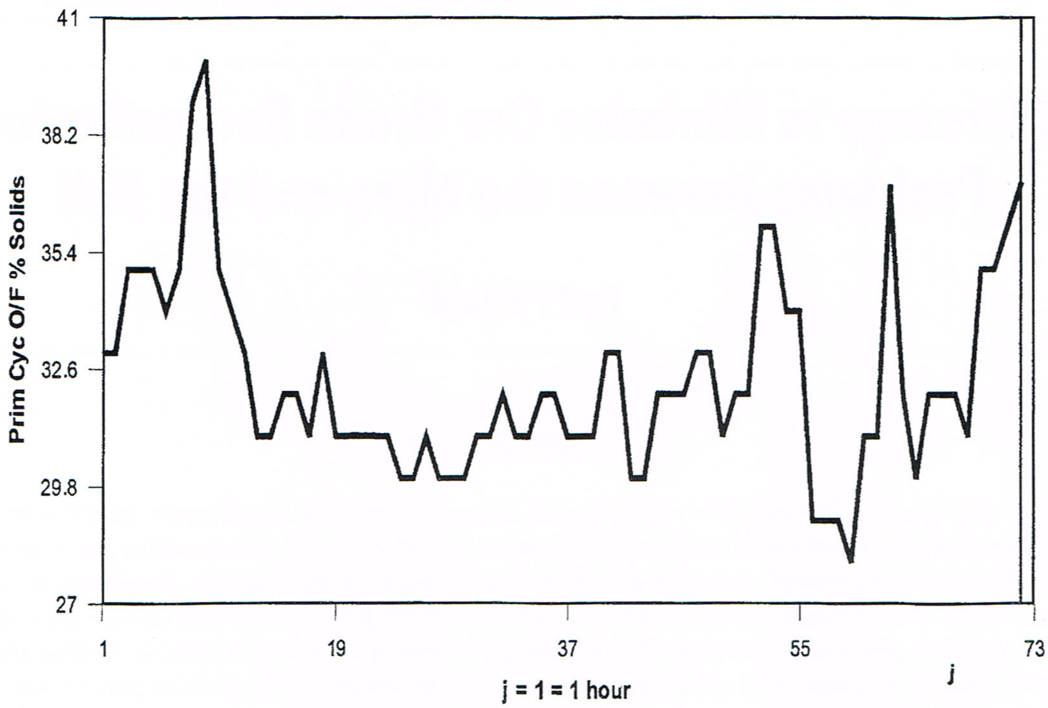


Figure 1 - Per cent solids in a primary cyclone overflow.

POINT TWO: USE ISO STANDARDS AS A STRUCTURAL FRAMEWORK FOR IMPLEMENTING PREVENTIVE MAINTENANCE

No-one can obtain an ISO certification without a clear and verified commitment to preventive maintenance. Management, as an incentive tool to improve the performance and efficiency of many areas, can use ISO. But, ISO standards are not standards for good sampling, Statistical Process Control (SPC), Geostatistics, nor standards for Total Quality Management (TQM). ISO standards are only logical, organisational guidelines. Therefore, this leads naturally to point three.

POINT THREE: DO NOT MISUSE ISO STANDARDS

A strong feature of the ISO standards is the flexibility for a company to add additional elements to the standards manual. Additional elements, such as correct Sampling, SPC, Geostatistics, and TQM should ensure that ISO standards are not misused. The symptoms of misuse are:

- status quo is the rule;
- employees loose their creativity;
- the certification agency runs the company;
- employees refer to ISO standards to protect and justify their actions, or lack of them;
- management pursues only the ISO certification; and
- the biggest achievement of ISO standards results in too much emphasis on metallurgical accounting.

It is good to pursue ISO standards certification, as long as it helps the company organise in other very important areas. This leads to the concept of the three-legged table illustrated by point four, and Figure 2.

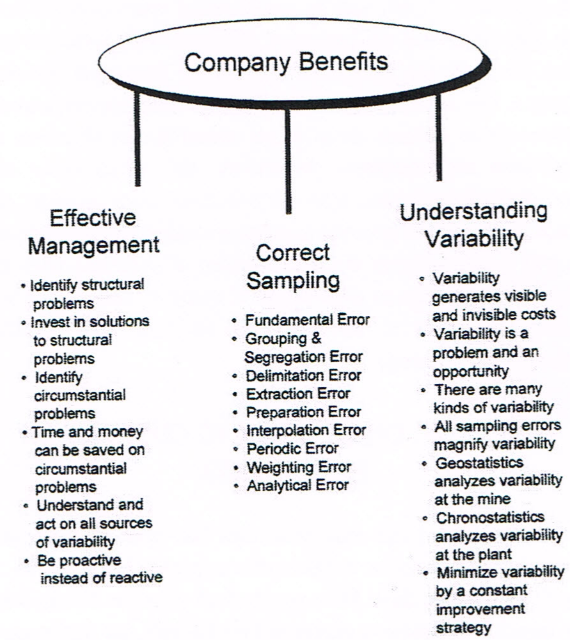


Figure 2 - The three-legged table.

POINT FOUR: INTEGRATE GOOD SAMPLING, SPC, GEOSTATISTICS, AND TQM INTO A SINGLE PROGRAM

It is convenient to compare company benefits to a three-legged table. One leg is sampling, one is SPC, and another one is TQM. These three critically important fields must be carefully integrated into one common program. Yet, more often than not, they are wrongly kept as separate programs, handled by different departments who rarely communicate. Furthermore, if one leg is broken, usually there is no table left. It is not rare that a company would be run with only one leg (eg reactive management), making it impossible to optimise the natural resources of the mine.

POINT FIVE: IMPLEMENT A PHILOSOPHY OF EQUIPROBABILISTIC SAMPLING

Ore grade control and metallurgical accounting must implement equiprobabilistic sampling, giving an equal chance to be selected to all the material to be sampled. But, it is not enough to prevent the presence of a bias. This is achieved with careful consideration to three sources of sampling errors:

1. The Delimitation Error is generated when the boundaries of the sample are not correct. The importance of a good survey in a mining project is common knowledge, and may provide a good analogy for describing the Delimitation Error. It is a survey problem at the scale of the sample. As a result, the sample may not come from the correct location.
2. The Extraction Error is generated when the sampling tool is selective on the material it is taking. For example, a drilling machine may wash away the fine, loose material located in fractures. Or, a cross-stream sampler may systematically reject coarse fragments.
3. The Preparation Error takes place when some equipment, such as the crushing and pulverising equipment, damages the integrity of the sample. Contamination, losses, and alteration of physical and chemical properties must be kept to a minimum.

As Pitard noted (1993) these three sampling errors are responsible for most sampling biases generated in ore grade control and metallurgical accounting (Pitard, 1993a; 1993b).

Equiprobabilistic sampling is achieved when the three following conditions are fulfilled:

1. All locations within the lot to be sampled have exactly the same chance of becoming part of the selected sample.
2. The sampling tool does not become selective on fragment size and mineral hardness. This implies the respect of stringent standards by the manufacturer of sampling equipment.
3. The integrity of the sample must be preserved, avoiding contamination, losses, and alteration of the physical, chemical, or mineralogical composition.

POINT SIX: DO NOT CONFUSE QUANTITY OF WORK WITH REAL PRODUCTIVITY

Geologists, metallurgists, and chemists must learn how to do the job right the first time. Quality and productivity are not incompatible. Both can be achieved at the same time if the following requirements are carefully implemented along the life time of a project:

1. Study the heterogeneity carried by constituents of interest.
2. Optimise sampling protocols according to heterogeneity facts.
3. Implement sampling protocols using correctly designed and maintained sampling systems.
4. Quantify accuracy and precision of sampling and subsampling protocols, and analytical measurements.
5. Identify and quantify the variability components carried by generated data.

Unless this inescapable sequence is thoroughly implemented, quantity of work will be unnecessarily inflated, and productivity will be poor.

POINT SEVEN: ESTABLISH A REALISTIC WISH LIST FOR EVERY PROCESS CONTROLLING PARAMETER

A wish list consists of three key values:

1. An Upper Specification (US), above which the process no longer works well.
2. A Targeted Average (TA), at which the process performs best.
3. A Lower Specification (LS), under which the process no longer works well.

Many managers and engineers are unclear what the wish list is, and what its purpose is. Furthermore, many managers do not believe in such a concept, as each parameter is dependent on many other parameters. Indeed, a wish list must be a dynamic concept that may change with time. Nevertheless, the concept of the wish list remains the same, and it is up to the manager to decide when and how the list should change, and how to co-ordinate it with other parameters. A logical wish list cannot be improvised, and it is the result of a careful variability analysis. It is the basic starting point for proactive management. See an example illustrated in Figure 3.

POINT EIGHT: WORK SMARTER, NOT HARDER

A good understanding of the various kinds of heterogeneity and the variability they generate in the process helps to implement a successful SPC program. In Figure 4, the random variability affecting the tons/hour processed through a SAG mill forces the Targeted Average (TA) to be set at 540 tons/hour in order for the mill to rarely go above a critical point. Or the random variability forces the upper specification (US) to be set at 555 tons/hour above which the performance of the mill may totally collapse. Assuming we find the cause of the random variability and minimise its effects, we may be able to move the Targeted

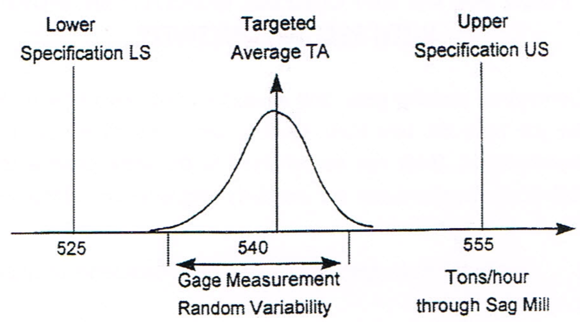


Figure 3 - A wish list for the optimisation of a SAG mill (ie semi-autogenous mill).

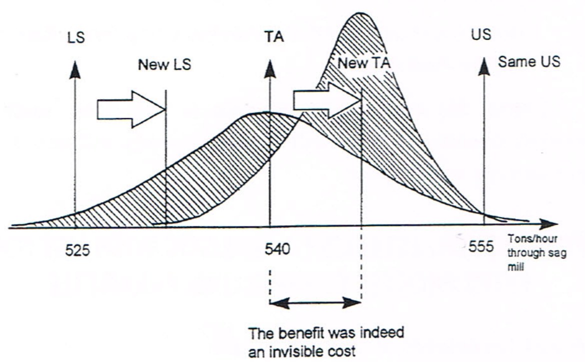


Figure 4 - Illustration of an invisible cost generated by the random variability affecting the tons per hour processed through a SAG mill.

Average higher, and still prevent the performance of the mill from collapsing. Retrospectively, the margin between the two values for the Targeted Average may be regarded as a benefit, which was previously an invisible cost.

POINT NINE: BEWARE OF ECONOMIC UNITS WITHIN THE SAME COMPANY

Today, in many companies, the mine, the mill, the smelter, and the refinery may work as independent economic units, within the same company. Management learned that independent economic units perform better as they become more responsible for a cost-effective performance. It is a good principle. But, it is not without danger, as all these units work in a logical, inescapable chronology, where the performance of one greatly affects the performance of the next one. Therefore, the by-product of economic units is the exportation of a problem to the next unit. It is no longer an incentive to correct some important details. The philosophy is 'the smelter will take care of that, the refinery will take care of this.' To become cost-effective that way, you may very well create a nightmare for smelters and refineries.

Everyone in a company must behave as a customer and a supplier of someone else. Everyone must receive feedback from customers in the next unit, and give feedback as well. Eliminate the old 'direction by objective' management philosophy where managers communicate only when they have bad news to announce to the work force.

POINT TEN: ESTABLISH A CUSTOMER AND CONTINUOUS PROCESS FEEDBACK SYSTEM

Customer and process feedback must be the object of careful statistical analysis using chronological data plots, moving averages, variograms and their derived functions, and variographic control charts (Pitard, 1993). This suggests that managers and engineers must be comfortable with basic and advanced statistical tools. This requires training and a commitment to continuing education at mine and plant sites. Simple ways must be found to prevent overcorrecting a process, which almost always results in devastating financial consequences. But, unfortunately, such over-control generates invisible costs. Who cares about invisible costs?

An example is the cost of the precision affecting blasthole samples. Precision, which may generate huge ore grade misclassification, is not taken seriously enough in most mining operations. Its effect is compounded by the desire to become over-selective through the use of unrealistic ore grade cut-offs, based on economic facts alone. The sketch shown in Figure 5 illustrates a case where management selects an economic gold grade cut-off to feed the mill with a theoretical average grade that was predetermined by a feasibility study. But, random variability affecting the database necessarily results in ore grade misclassification. If the expected grade is not obtained, management may be tempted to increase the gold grade cut-off. This is a reactive decision, does not address the causes of the problem, and drastically cuts on the Ore Reserves.

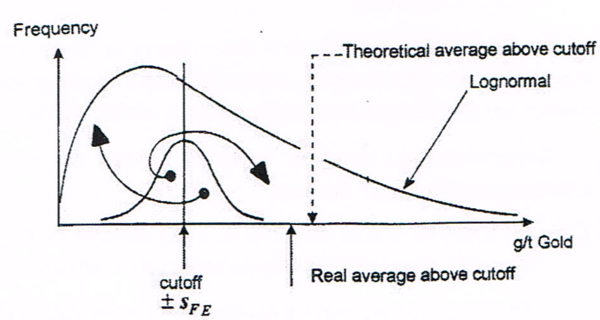


Figure 5 - Random variability (ie standard deviation SFE of the sampling fundamental error generated by the selected sample weight) affecting ore grade classification around an economical gold grade cut-off.

POINT ELEVEN: MAKE A DISTINCTION BETWEEN A NON-RANDOM PROCESS FLUCTUATION AND A RANDOM SAMPLING/MEASUREMENT FLUCTUATION

A process may be forced to drift unless the operator is properly trained not to react to sampling/measurement variability. If unsuccessful, the operator may potentially double the total variability of the process, when the best thing he could have done is to leave it alone, as illustrated in Figure 6.

POINT TWELVE: CONSTANTLY MINIMISE INVISIBLE COST

Meeting requirements provided by a wish list does not result in constant minimisation of invisible cost. Improvement is not a one-time effort. Through statistical thinking, it is important to balance visible and invisible costs. Many people believe that meeting specifications results in zero money losses, as suggested by Figure 7. The reality may be different. Even when the process is maintained within specification, as shown by another example in Figure 8, invisible cost may occur. The Fundamental Error FE referred to in Figure 8 is the sampling error generated by a selected sample weight (Pitard, 1993).

POINT THIRTEEN: BEWARE OF CORRECTING FACTORS

Incorrect sampling and poor measurement may introduce biases in a database. It is tempting to adjust biased data by using correcting factors based on observations and experiments. Unfortunately, there is no such thing as a constant bias in sampling. Therefore, filtered information, elimination of embarrassing figures, and the use of correcting factors are the symptoms of micro-management, which only succeed to increase confusion. In such a cycle of mediocrity there is no attempt to make a variability analysis of existing data, nor any attempt to quantify the heterogeneity carried by an important component. If there is a bias, the existing data are still your best data available, and it should be considered invaluable to perform any statistical study. Do not perform statistics on corrected data. Correcting factors only give a false sense of security to management. If there is a bias, learn to live with it, and see it all the time.

POINT FOURTEEN: IMPLEMENT A CREATIVE THINKING CYCLE

Mine and plant personnel must live in a system where they can talk freely about their problems. The cycle shown in Figure 9, is possible only if management implements a clear specification wish list, and uses variographic investigation charts on a routine basis to study the components of mining and processing variability.

POINT FIFTEEN: A MINE/MILL RECONCILIATION PROBLEM NEARLY ALWAYS HAS MULTIPLE CAUSES

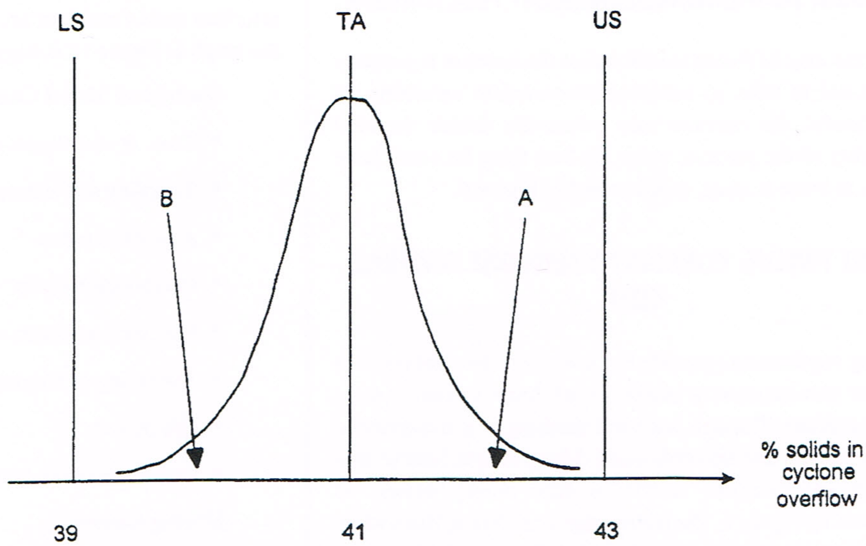
Many people are discouraged by the complexity of the idiosyncrasy of Mine/Mill reconciliation. But, the problem can be solved, or at least minimised, if a good strategy is undertaken. Divide the complex problem into its basic components, and then solve them one at a time. Of course, in such approach, priorities must come into account. To help set such priorities, the graph in Figure 10 is suggested.

1. **Geological Model Causes**
   - True, *in situ* nugget effect
   - Sampling and subsampling errors
   - Analytical errors
   - Interpolation errors
   - Excessive rejection of outliers
   - Averaging or Kriging model
   - Ore density
   - Definition of ore boundaries
2. **Mining Causes**
   - Mining model parallel to cross mineralisation in open pit
   - Drift of mineralised boundaries upon blast
   - Survey
   - Truck destination
   - Loss of fines in underground operations and open pit
   - Loss of fines in stockpiles
   - Tons estimate
   - Dilution
3. **Ore Grade Control Causes**
   - *In situ* nugget effect
   - Sampling and subsampling
   - Analytical procedure
   - Blastholes parallel to mineralisation
   - Averaging and Kriging model
   - Ore grade contouring
   - Survey
4. **Mill and Flotation Plant Causes**
   - Material balance based on non-probabilistic sampling
   - Analytical accuracy
   - Process cycles either unknown or misunderstood
   - Calibration of weightometers and flowmeters
   - Poor laboratory subsampling

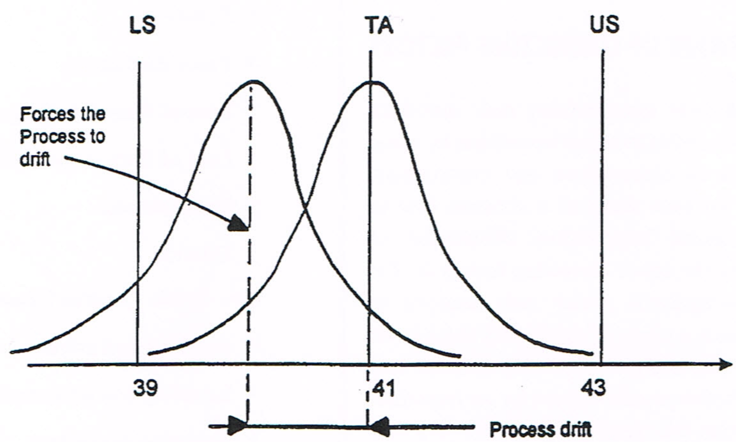
POINT SIXTEEN: A GOOD UNDERSTANDING OF VARIABILITY MUST IMPROVE METAL RECOVERY

It is the author's experience that a tighter control of the metal of interest grade ranges delivered by the mine has a deep impact

Step #1: The process is left alone.



Step #2: When reading a measurement in point A, a conscientious operator may correct A for TA.



Step #3: Panic time! Correcting new point B for TA.

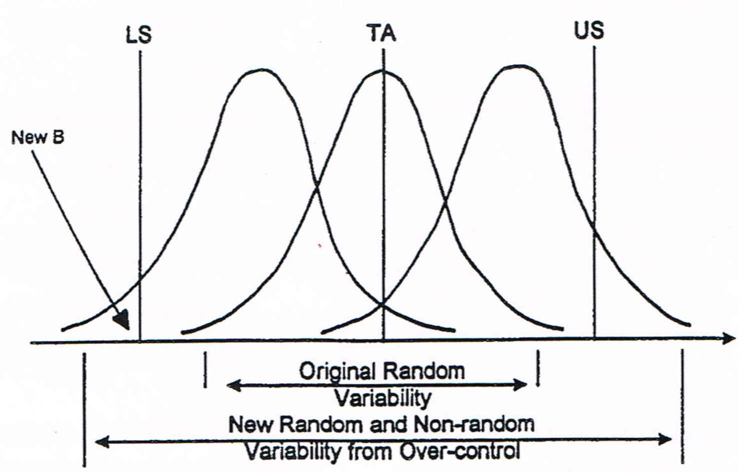
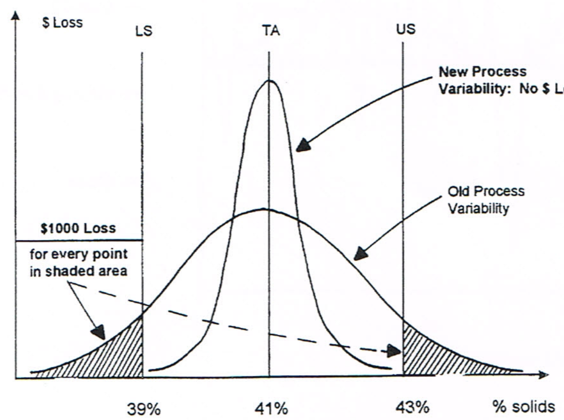


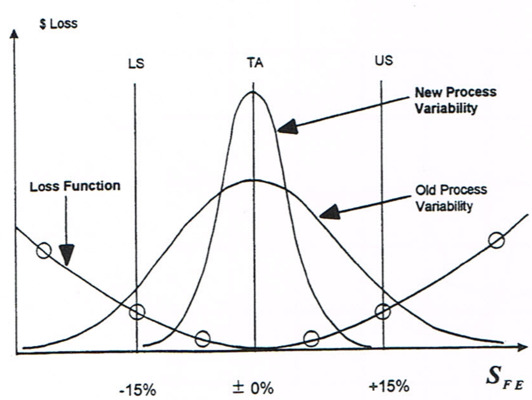
Figure 6 - Confusion between a non-random process fluctuation and a random sampling/measurement fluctuation.

Every time the cyclone overflow feeding a floatation plant does not meet **percent** solids specifications, a drop in metal recovery and productivity equivalent to $1000 takes place.



Many people believe that meeting specifications results in zero money losses.

Figure 7 - Money loss based on visible cost alone.



For ore grade control, any value for the precision of the Fundamental Error generates a money loss:

S_{FE} = ± 30% generate a huge money loss

S_{FE} = ± 15% a smaller money loss

S_{FE} = ± 5% a much smaller money loss

US and LS should be selected according to what is judged as a reasonable money loss. However, it should be clearly understood that even between US and LS, there is a money loss.

Figure 8 - Money loss based on visible and invisible cost.

on metal recoveries and also on the quality of concentrates. Every mine which had a management endorsed, ore blending policy, observed great improvement at the mill within one year.

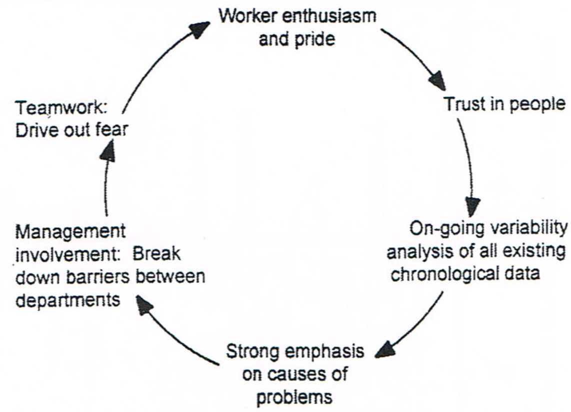


Figure 9 - Implementation of a friendly, creative thinking cycle.

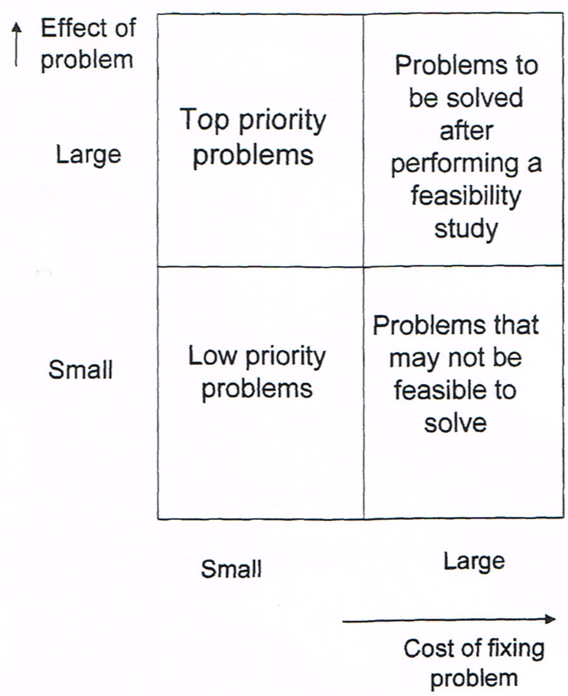
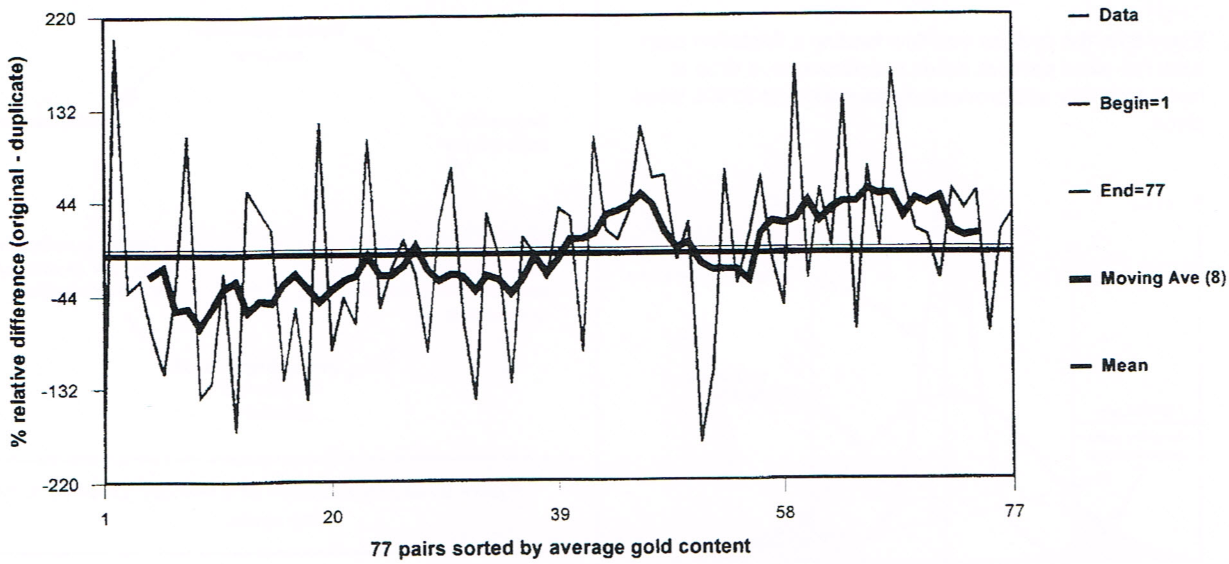


Figure 10 - Setting priorities.

POINT SEVENTEEN: USE PRAGMATIC STATISTICAL IMPROVEMENT TOOLS BASED ON GRAPHIC OBSERVATION

Complex statistical analyses often fall short of transmitting a clear message to the users at the mine and the mill. In the age of computers, I strongly suggest graphic observations must be emphasised, so management can quickly and effectively understand process variability on a daily basis. For example, correlation coefficient, significant bias tests, and other sophisticated calculations can be performed. Yet they often fall short of



Mean = -5.78 Median = 1.41 Std. = 1.48E+01

Figure 11 - Example of underground duplicate channel sampling in a gold mine.

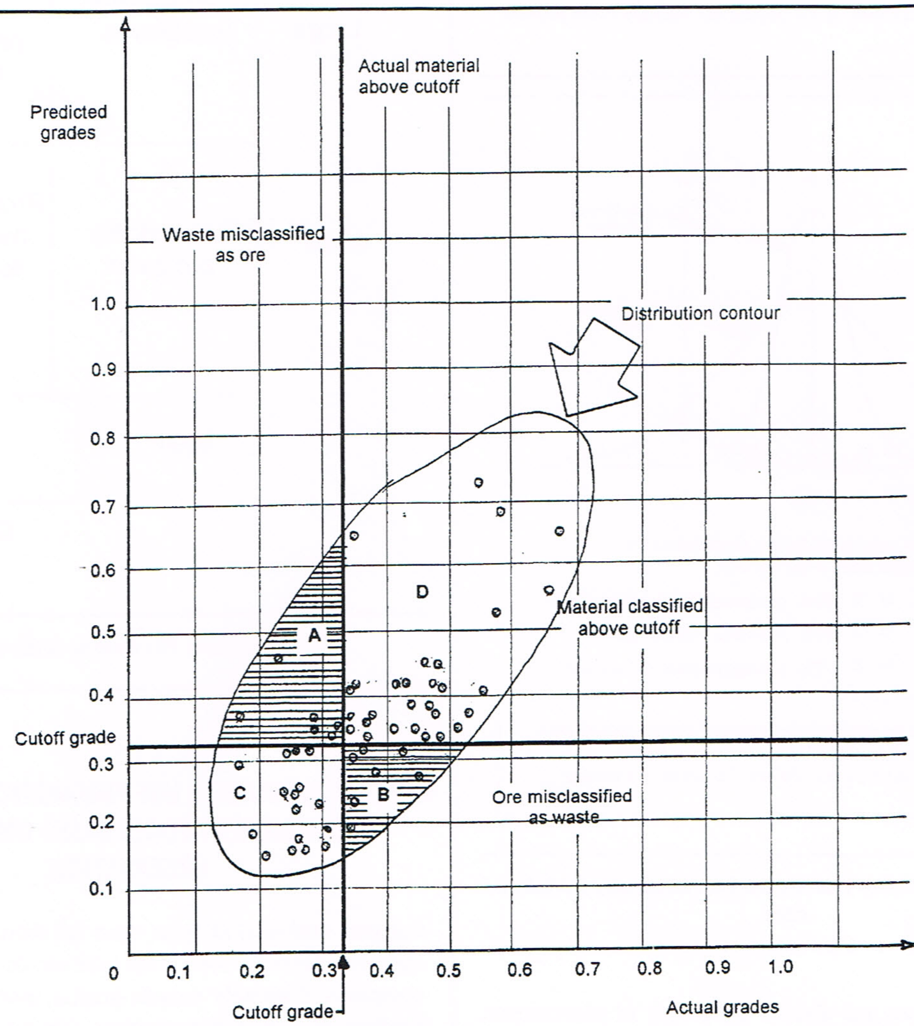


Figure 12 - Example of two-dimensional distribution of predicted copper grades versus actual copper grades in mining blocks, with a total sampling/measurement precision error about ±40 per cent: a. Waste misclassified as ore; b. Ore misclassified as waste; c. Waste properly classified as waste d. Ore properly classified as ore.

giving a concrete picture of a problem. However, a relative plot associated with a simple Moving Average as shown in Figure 11 can help a manager in a far more effective way. Not only can the magnitude of a bias be immediately quantified, but its evolution as a function of grade can also be followed. After all, in sampling, there is no such thing as a constant bias.

POINT EIGHTEEN: USE CONCRETE GRAPHIC TOOLS TO QUANTIFY INVISIBLE COST

Another pragmatic tool is the Precision graphic obtained by duplicating two to five per cent of the samples, which can be used to quantify the cost of poor sampling and analytical precision at the mine. Many people still believe that a reconciliation problem between the mine and the mill must be the result of an accuracy problem generating a bias. They are wrong, precision alone can generate a massive reconciliation problem. If a manager can see the cost of precision in a pragmatic way, as shown in Figure 12, he is more likely to invest in good sampling practices.

CONCLUSION

The elimination of significant sampling and analytical biases is possible by taking preventive actions. However, precision can never be completely eliminated. Therefore, reconciliation problems between the mine and the mill cannot be eliminated either. An operation without a reconciliation problem should alert upper management that biases may have taken place. The only thing we can do, and should do, is to identify all the causes that may generate a problem, and try hard to minimise their effects in an economical way. Therefore, a healthy operation where no biases have taken place should show slightly less metal recovery at the mill and processing plant than what was announced by the mine.

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