



HEATH & SHERWOOD

HARD ROCK SOLUTIONS SINCE 1927

The Value of Good
Sampling

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The legend continues

Introduction – Topics To Cover

- Review of Sampler Design
- How is sampling inaccurate – bias / random
- Detrimental effect to operations
- Effect on Mass Balancing (example)
- Combined OSA and Sampler Errors (Assay)
- Assay errors and Grade / Recovery curve
- Intro to SPC
- *Estimating* Assay Error Effects on NSR
- *Estimating* where your process operates
- Review



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SHOULDER TO SHOULDER, SOLVING PROBLEMS

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Review of Good Sampler Design

- **Sampling**, by definition, is the **removal of a small representative portion** from a total consignment or flow for the **purpose of accounting or process control**.
 - A sample can only be considered representative, if each and every increment collected, in each of the sampling stages, is representative
 - Each particle of the sampling lot must have same probability of being included in the final sample
 - If both above conditions are met, then the final sample will be representative of the complete sampling lot
- **The theory of sampling indicates that in order to collect a representative sample:**
 - The **total stream** should be sampled
 - The sample **cutter** should intersect the sample at **right angles to the flow**
 - The sample **cutter** should travel through the stream at a **linear and constant speed** (speed deviations < max +/- 5%).

Review of Good Sampling Design

- **AMIRA's P754 Code of Practice for Metal Accounting states:**
 - The metal accounting system must be based on **accurate measurements of mass and metal content**
 - Sampling systems must be **correctly designed, installed and maintained** to ensure unbiased sampling and an acceptable level of precision
 - It is vital that samplers are **inspected and cleaned at least every shift**. This requires that the complete cutter can be viewed. **Submerged or encased cutters or nozzles cannot meet this requirement.**

Cutter Inspection Port



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How is sampling inaccurate

- **Problem with samplers which do not adhere to sampling theory:**
 - These kinds of samplers contain errors, which can be **constant (biased) or fluctuating (random)**. The portion of **fine to coarse or light to heavy particles can vary** in going into the cutter or nozzle.
 - **Segregation by particle size, density**, etc. is usually **present in the transport method** as there is seldom any guarantee that the slurry flow to be sampled is consistent or homogenous
 - This **errors change over time** due to changes in feed tonnages, particle size, densities, flow rates, pressure, etc.
 - **Segregation effects at pipe bends or intersections**, etc.



How is sampling inaccurate

- **Launder Sampler (shark fin) with static cutters:**
 - The portion of **fine to course or light to heavy particles** are effected
 - Designed to **work within certain flow rates**, the **bigger the particle the tighter the limits**.
 - Samplers are **often flooded or have back pressure** at exits if sample system is not designed correctly

How is sampling inaccurate - Example

TAILS STREAM

		Cu	Fe
Final Tls	wt.%	%	%
+150	10.858	0.120	1.640
+106	10.678	0.070	2.030
+75	11.013	0.050	3.160
+38	17.649	0.040	3.920
+15	17.727	0.020	4.350
+6	20.025	0.020	4.080
+2	12.049	0.050	4.460
tail (calc)	100.000	0.047	3.560

Weight g/100g

Cu
Fe

0.01303 0.17806

0.00747 0.21677

0.00551 0.34802

0.00706 0.69185

0.00355 0.77113

0.00400 0.81702

0.00602 0.53740

0.04665 3.56026

 % Change1 (+150) **2.5000**

Weight g/100g

Cu
Fe

150 0.01335 0.18252

106 0.00747 0.21677

75 0.00551 0.34802

38 0.00706 0.69185

15 0.00354 0.76945

6 0.00399 0.81385

2 0.00595 0.53048

0.04687 3.55294

0.48224 -0.20552
Change%
14.3
28.6
57.1
%Change Assay

% Change2 (+150)

5.0000

Weight g/100g

Cu
Fe

0.01368 0.18697

0.00747 0.21677

0.00551 0.34802

0.00706 0.69185

0.00353 0.76776

0.00397 0.81068

0.00587 0.52357

0.04710 3.54562

0.96447 -0.41103



Detrimental effects to operations

- The assays from samples are used for control and accounting purposes
- **Planning**
 - Production targets
 - Plant need to make a certain amount of money to pay its bills and make a profit. This effects how much tonnage to push through a mill.
- **Plant control**
 - Grade / Recoveries
 - Target values for these are set and accurate assays are required to achieve this.
- **Metallurgical Accounting**
 - Unbalanced results (poor sampling, assaying or weighing of stream)
 - Unaccounted loss (lack of measurement accuracy)

Effect on Mass Balancing – Constant Bias

- Data from composite samples
- Can be seen as **revenues short of expectations (\$18.8M/yr)**
- Productions forecasts were incorrect
- Additional production losses likely because recovery would have been seen as higher than it really was – operators were happy!

Real Assays%

Feed%	Conc%	Tail%
1.75	13.50	0.25

Real Metallurgical Balance Results - Based on Assays

	Weight t	Assays %	Weight Metal t	Distribution Metal %
Feed	2,102,400	1.75	36,792	100
Conc	238,008	13.50	32,131	87.33
Tail	1,864,392	0.25	4,661	14.51

Sampler Errors%

Feed%	Conc%	Tail%
3.50	0.00	0.00

Biased Metallurgical Balance Results - Based on Assays

	Weight t	Assays %	Weight Metal t	Distribution Metal %
Feed	2,102,400	1.81	38,080	100
Conc	247,726	13.50	33,443	87.82
Tail	1,854,674	0.25	4,637	13.86

Biased Assays%

Feed%	Conc%	Tail%
1.81	13.50	0.25

Conc Difference (t)	-1,312
Conc Difference (lb)	-2,892,501
\$Price / lb of Metal	6.5

Expectation Difference(\$)

-18,801,259

Effect on Mass Balancing – Random Error

- Data from composite samples
- 1-SD errors in mass balance calculations
- Additional errors **comparing 1% and 1.5%** sampling error
- Additional accounting uncertainty **error of \$2.7M/yr**

Metalurgical Balance Results - Based on Assays

Item	Weight t	1-SD			Assays %	1-SD			Wt Metal t	1-SD			Distr Metal %	1-SD		
		Err-1	Err-2	Diff		Err-1	Err-2	Diff		Err-1	Err-2	Diff		Err-1	Err-2	Diff
Feed	2,102,400	0	0	0	1.75	0.026	0.018	0.009	36,792	552	368	184	100	0	0	0
Conc	238,008	5,555	3,703	1,852	13.50	0.203	0.135	0.068	32,131	567	378	189	87.33	0.29	0.20	0.10
Tail	1,864,392	5,555	3,703	1,852	0.25	0.004	0.003	0.001	4,661	73	48	24	12.67	0.29	0.20	0.10

Assays%

Feed% Conc% Tail%

1.75 13.50 0.25

Sampler Errors%

	Err-1	Err-2
Feed	1.500	1.000
Conc	1.500	1.000
Tails	1.500	1.000

Additional Uncertainties

Conc Difference (t)	189
Conc Difference (lb)	416,571
\$Price / lb of Metal	6.50

Uncertainty Difference(\$) **2,707,710**

OSA and Sampler Errors (On-line Assays)

- OSA only analyzes the sample it is presented
- Normal OSA accuracies, as 1-SD (depends on application)
 - Feed ~ 4-6% (Aver 5%), Conc ~ 2-4% (Aver 3%), Tails ~ 7-9% (Aver 8%)
- Measurement result error (1-SD):

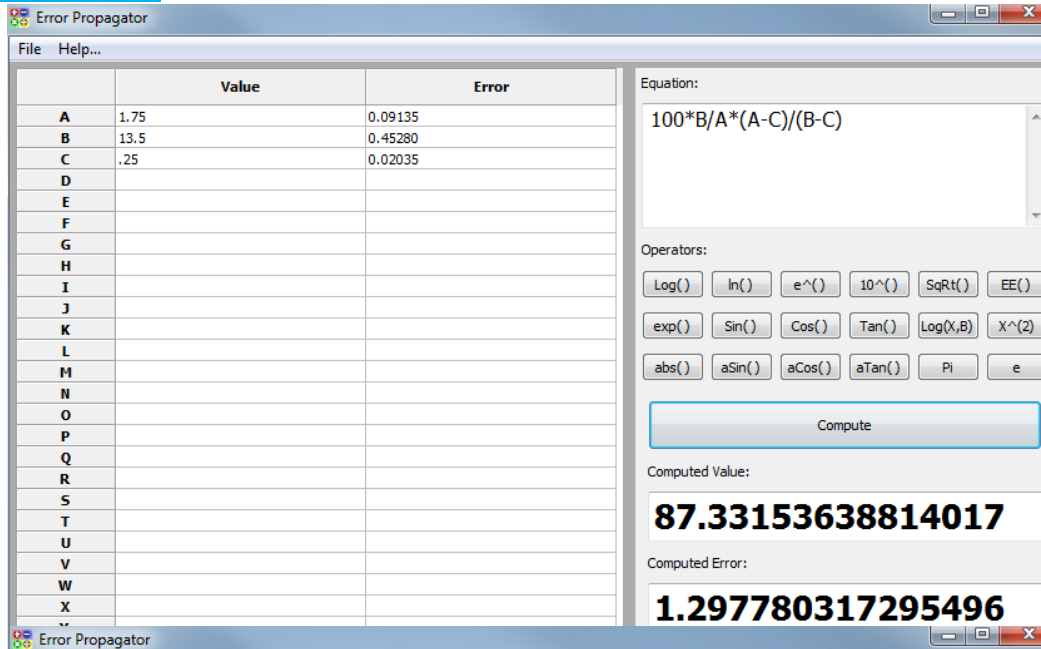
$$- : \quad s_{meas}^2 = s_{sampling}^2 + s_{analytical}^2$$

$$- : \quad s_{meas} = \sqrt{s_{sampling}^2 + s_{analytical}^2}$$

- **POINT OF INTEREST**

- There was a paper (Measurement Issues In Quality “Control”) presented by Brian Flintoff in 1992 at a CMP conference which stated: “Clearly, no bias can be accepted” as it pertains to the composition of OSA measurements.
- If the *sample feed to the OSA is biased, the results are biased!!!*

Error Propagation - Recovery



CASE1

Feed%	Conc%	Tail%	Rec%
1.75	13.50	0.25	87.33

Errors % (1-SD)	Case1	OSA	ABSTotal
Feed	1.50	5	0.09135
Conc	1.50	3	0.45280
Tails	1.50	8	0.02035

Recovery error 1.2978

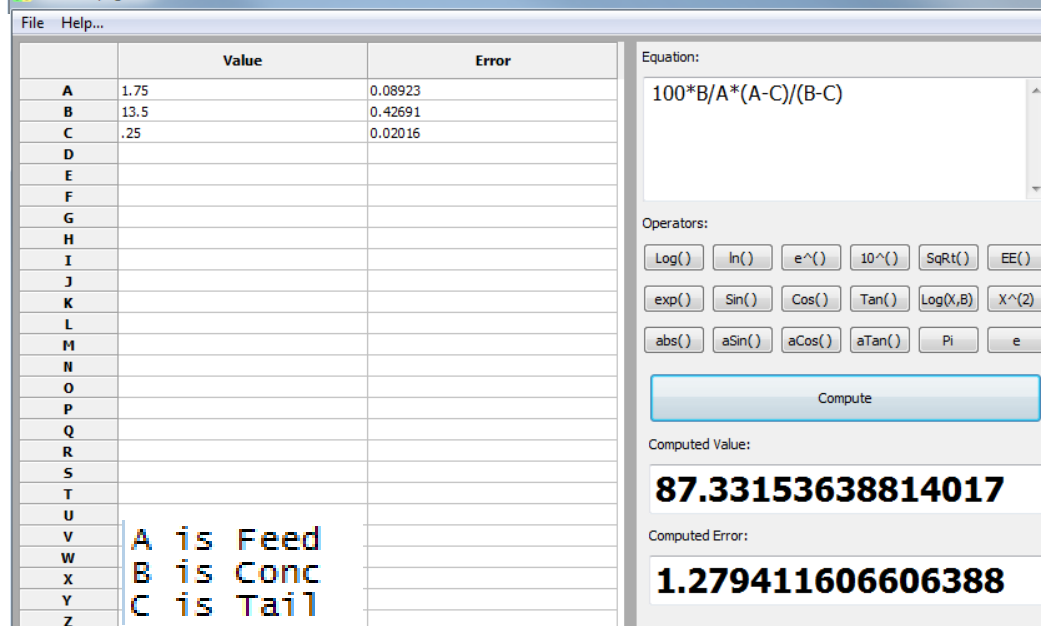
CASE2

Feed%	Conc%	Tail%	Rec%
1.75	13.50	0.25	87.33

Errors % (1-SD)	Case2	OSA	ABSTotal
Feed	1.00	5	0.08923
Conc	1.00	3	0.42691
Tails	1.00	8	0.02016

Recovery error 1.2794

Recovery Error Difference 0.0184 (1-SD)



Grade / Recovery

- This statement can be found in the Will's Mineral Processing Technology book:

*“The aim (of a flotation control system) should be to improve the metallurgical efficiency, i.e. to produce the best possible grade-recovery curve, and to **stabilize the process at the concentrate grade** which will produce the most economic return from the throughput.”*

- This statement has a few key points:
 - A **concentrate grade is decided** upon (could be by planer, metallurgist, control system or other and depends on feed grade)
 - Keep the **process stable** (upsets are not good)
 - **Increase the recovery as close as possible, to the best grade-recovery curve**, without de-stabilizing (upsetting) the circuit
 - Maximize recovery at a target grade

Assay errors and Grade / Recovery curve

- Points by Monte Carlo type simulation
- Ellipse 1-SD – Error propagation
- Centre point from OSA measurement, real result somewhere in cloud

Feed%	Conc%	Tail%	Rec%
1.75	13.50	0.25	87.33

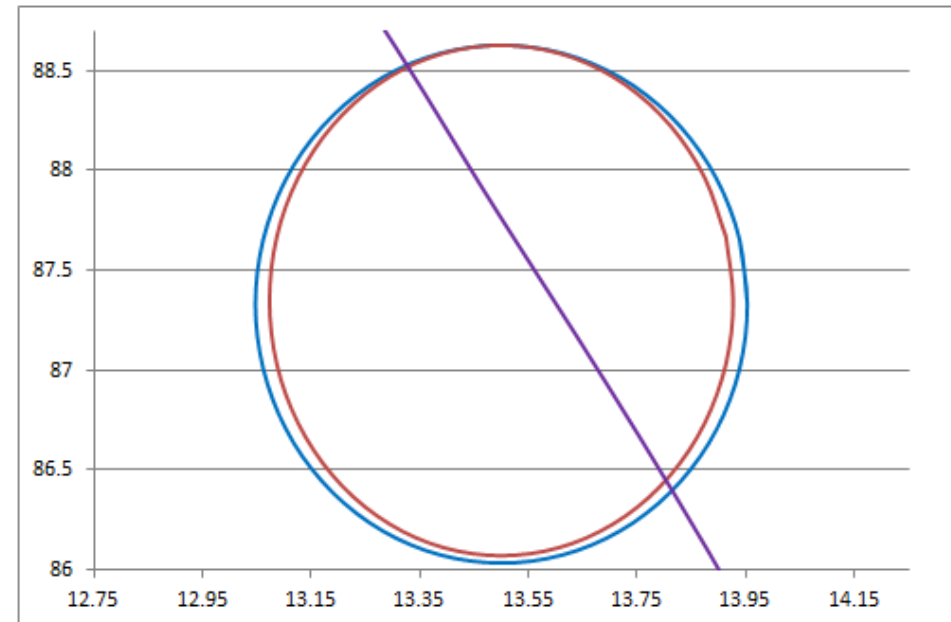
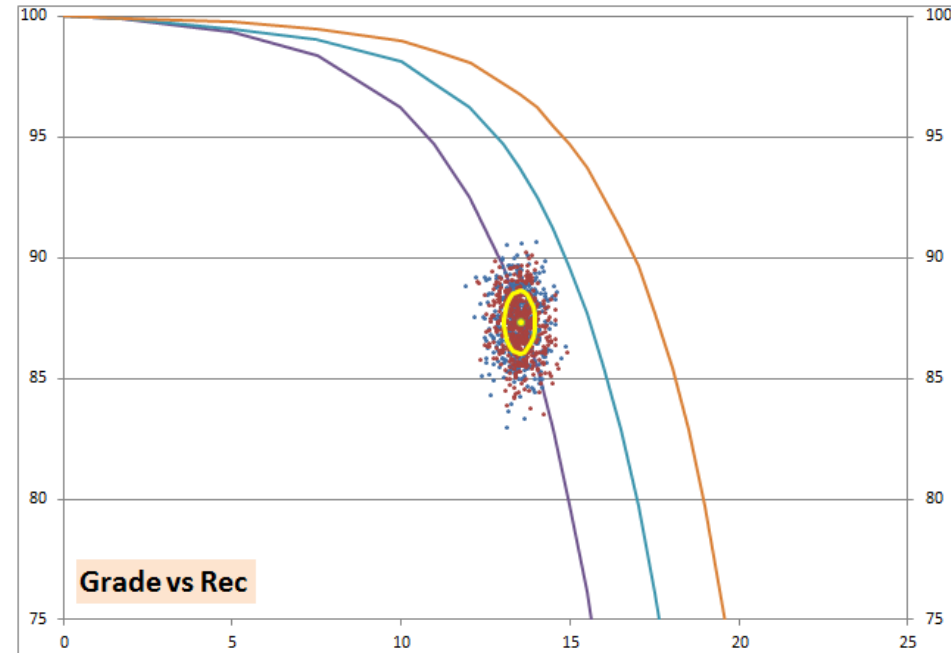
	Case 1	Case 2
Recovery error	1.2978	1.2794
Recovery Error Difference (1-SD)	0.0184	

Uncertainty Ellipse Area

%Grade x %Rec	Case 1	Case 2
%Grade x %Rec	1.85	1.72
Control Area Improvement %	7.06	

COMMENTS

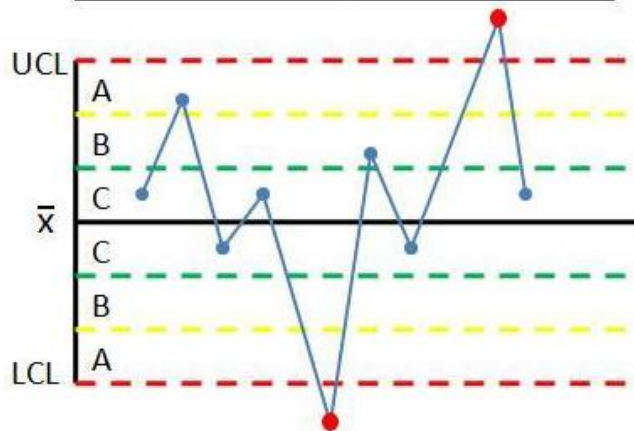
- At a given feed grade and ore type the conc grade is held constant and recovery is optimized
- If conc grade goes up above the optimum recovery curve, recovery suffers
- If recovery goes up above the optimum recovery curve, conc grade suffers
- With the slightly better samplers in Case 2, the recovery target can be moved upwards the 0.0184% (or 0.0368% with 2-SD) error difference with the same likelihood of upsetting the circuit as in Case1
- As the target for grade / recovery changes, due to feed changes, the error difference changes only slightly (~10%).



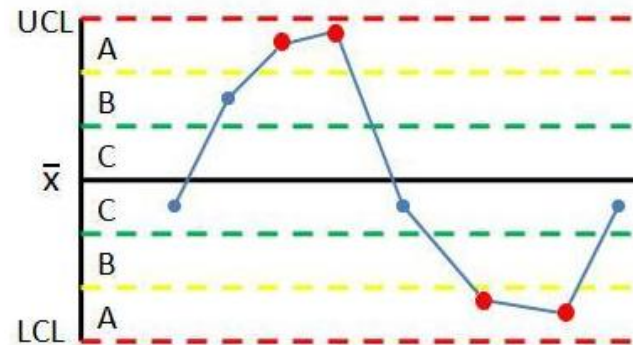
Introduction to SPC

*“All control starts with measurement and the **quality of control can be no better than the quality of the measurement input.**” (Connell [1988])*

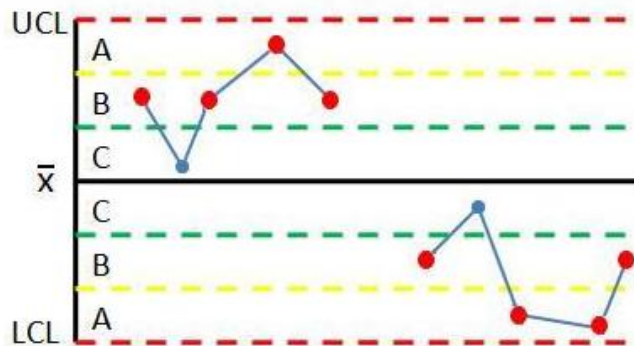
Rule 1: Any point falls beyond 3σ from the centerline (this is represented by the upper and lower control limits).



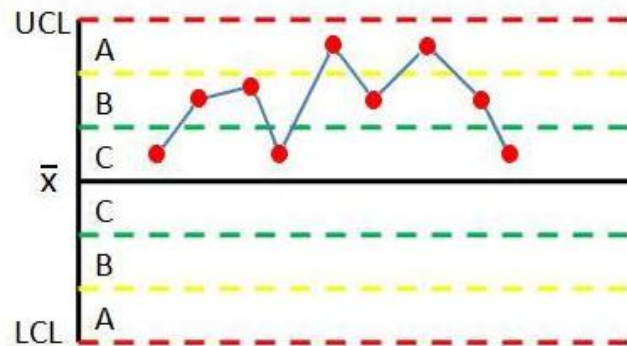
Rule 2: Two out of three consecutive points fall beyond 2σ on the same side of the centerline.



Rule 3: Four out of five consecutive points fall beyond 1σ on the same side of the centerline.



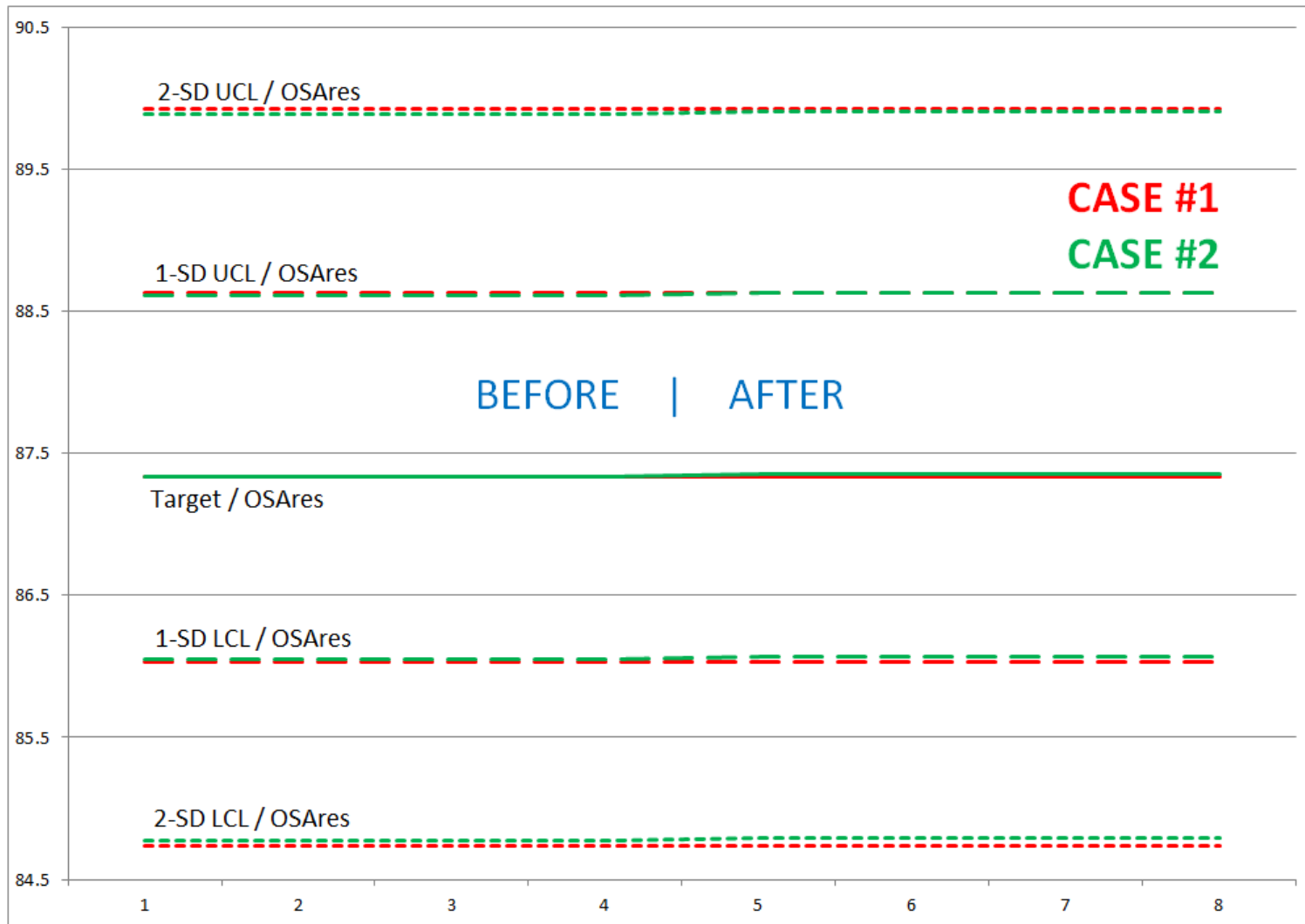
Rule 4: Nine or more consecutive points fall on the same side of the centerline.



Rule #4 most likely can not be followed as the measuring cycle of an OSA is to long (10-15 min times 9, 1.5 to 2.25hr). However, it is possible if feed is reasonably stable.

Introduction to SPC

- Control limits for grade / recovery depend upon the accuracy of the analyzer / samplers
- Example chart of recovery control, target shifted up 1-SD difference, 0.0184%



Probability of error detection over 2-SD UCL is the still better than in Case #1

Probability of error detection over 1-SD UCL is the same in both cases

Target moved up 1-SD difference (0.0184)

Tighter control limits at 1-SD LCL and 2-SD LCL

Error Propagation - \$NSR/t

	Value	Error
A	1.75	0.09135
B	13.5	0.45280
C	.25	0.02035
D	14330	0
E	87	0
F	350	0
G	10	0
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		

	Value	Error
A	1.75	0.08923
B	13.5	0.42691
C	.25	0.02016
D	14330	0
E	87	0
F	350	0
G	10	0
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S	A is Feed	
T	B is Conc	
U	C is Tail	
V		
W	D is Price/Ton	
X	E is Smelter Payment (% of Conc)	
Y	F is Smelter Treatment cost (price/t)	
Z	G is Transport cost (price/t)	

CASE1

Feed%	Conc%	Tail%	\$NSR/t
1.75	13.50	0.25	149.78

Errors % (1-SD)	Case1	OSA	ABSTotal
Feed	1.50	5	0.09135
Conc	1.50	3	0.45280
Tails	1.50	8	0.02035

\$NSR/t error 9.3845

CASE2

Feed%	Conc%	Tail%	\$NSR/t
1.75	13.50	0.25	149.78

Errors % (1-SD)	Case2	OSA	ABSTotal
Feed	1.00	5	0.08923
Conc	1.00	3	0.42691
Tails	1.00	8	0.02016

\$NSR/t error 9.1658

\$NSR/t Error Difference 0.2187 (1-SD)

Estimating Assay Error Effects on NSR

- Points by Monte Carlo type simulation
- Ellipse 1-SD - Error propagation
- Centre point from OSA measurement, real result somewhere in cloud

Feed%	Conc%	Tail%	\$NSR/t
1.75	13.50	0.25	149.78

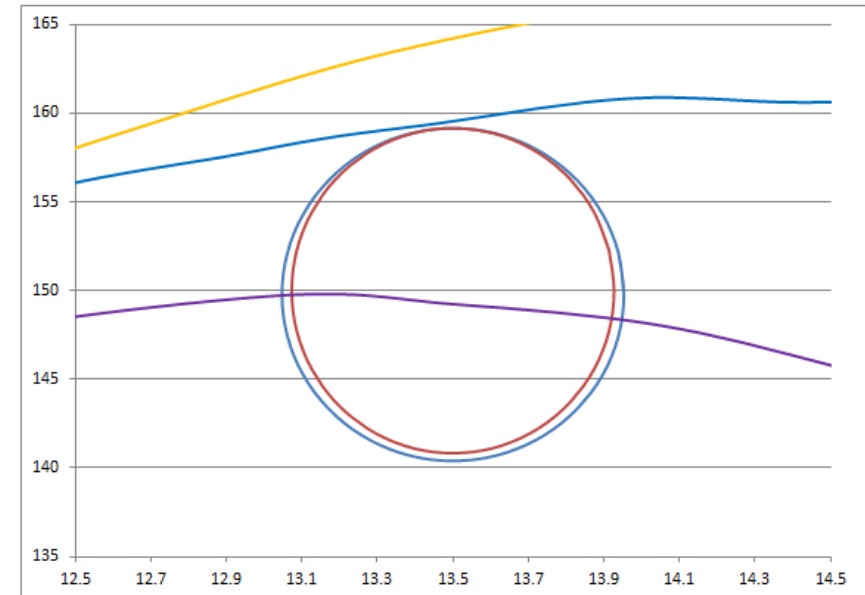
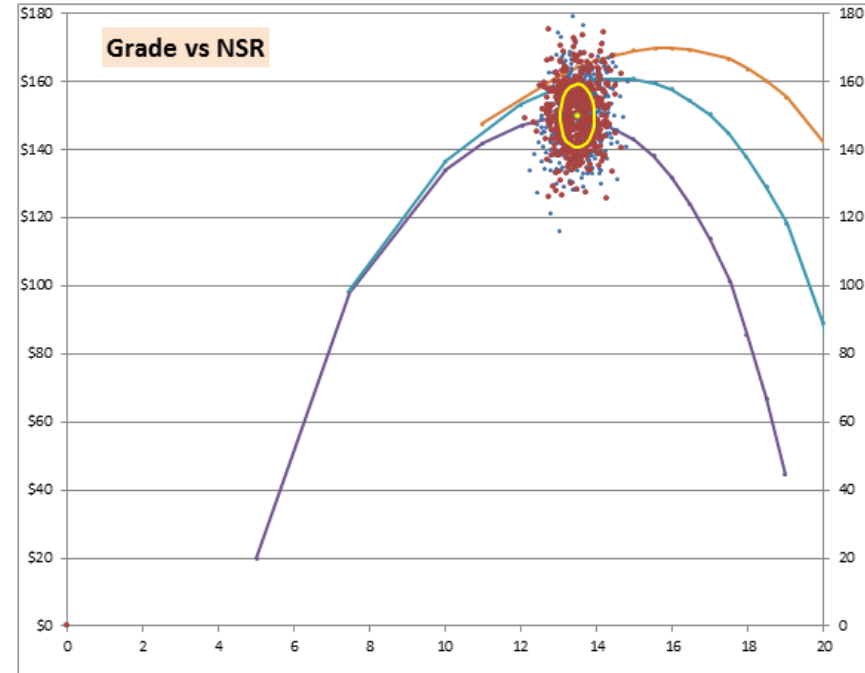
	Case 1	Case 2
\$NSR/t error	9.3845	9.1658
\$NSR/t Difference	0.2187 (1-SD)	

Uncertainty Ellipse Area

%Grade x \$NSR/t	13.35	12.29
Control Area Improvement %	7.92	

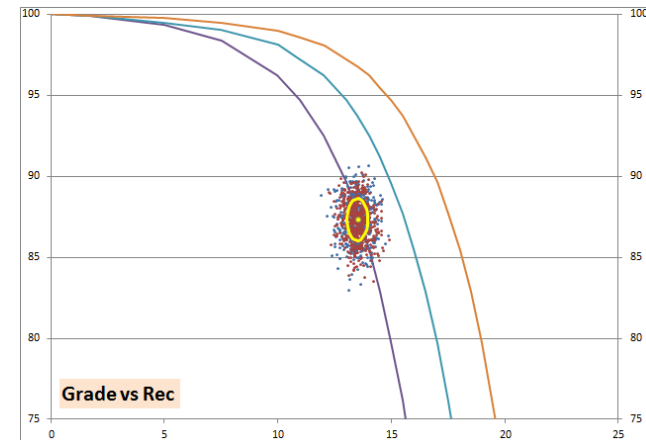
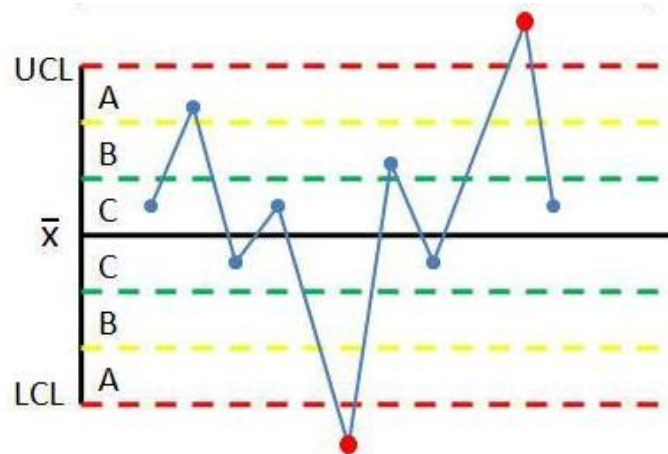
COMMENTS

- With the slightly better samplers in Case 2, the \$NSR/t can be moved upwards the \$0.2187 (or \$0.4374 with 2-SD) error difference with the same likelihood of upsetting the circuit as in Case1. This is done by the recovery control.
- At 2,000,000 t/year this is:
 - \$437,400.00 @ 1-SD Error Diff
 - \$874,800.00 @ 2-SD Error Diff



Estimating where your process operates

- 1-SD is 68%, 2-SD is 95.5%, 3-SD is 99.7%
- Probability of result error over 1-SD is 32%, 2-SD is 4.5%, 3-SD is 0.3%
- At UCL these numbers are halved, 1-SD is 16%, 2-SD is 2.25%, 3-SD is 0.15%. This where you process gets noticeably upset (concentrate grade drops while recovery increases)
- Your OSA has about 100 cycles a day , roughly a 15 minute cycle time (4/hr x 24hr ~ 100)
- How often a day does you process get upset?
 - At 8/shift (16/day) your SD is about 1 (x)
 - At 2-3/shift (5-6/day) your SD is somewhere around 1.5 (x)
 - At 1-2/shift (2-4/day) your SD is somewhere around 2 (x)
 - Once every several days, your SD is somewhere around 3
- This gives you an idea of how much you can increase your recovery / NSR target ($x * 1\text{-SDdiff}$)



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Another example (1/2)

- Low grade Cu mine with large tonnages (140,000t/day)
- Comparing **1% and 2%** sampler errors
- **\$2.19M/yr** estimated improvement

Assays%

Feed%	Conc%	Tail%
0.28	41.00	0.022

Errors% (1-SD)

	Case1	Case2	OSA
Feed	2.0000	1.0000	5
Conc	2.0000	1.0000	3
Tails	2.0000	1.0000	8

Total Errors ABS (1-SD)

	Case1	Case2
Feed	0.0151	0.0143
Conc	1.4783	1.2965
Tails	0.0018	0.0018

Metal

Metal Price(\$/lb)	3
Metal Price(\$/t)	6614
Smelter Payment (% of conc)	92
Smelter Treatment Cost (\$/t)	125
Transportation Cost (\$/t)	70
Tons /yr	48,545,000

\$NSR/yr **\$702,893,337**

Re - Calculate

Metalurgical Balance Results - Based on Assays

Item	Weight t	SD-C1	SD-C2	Diff	Assays %	SD-C1	SD-C2	Diff	Wt Metal t	SD-C1	SD-C2	Diff	Distr Metal %	SD-C1	SD-C2	Diff
Feed	48,545,000	0	0	0	0.28	0.015	0.014	0.001	135,926	7,320	6,931	389	100	0	0	0
Conc	305,642	21,100	19,595	1,505	41.00	1.478	1.297	0.182	125,313	7,376	6,987	389	92.19	0.77	0.75	0.02
Tail	48,239,358	21,100	19,595	1,505	0.02	0.002	0.002	0.000	10,613	876	856	20	7.81	0.77	0.75	0.02

Case 1

REC%	err-ABS
92.19	0.771

\$NSR/ton	err-\$/ton
\$14.48	\$0.853

NSR 1-SD-err
\$41,427,274

Case 2

REC%	err-ABS
92.19	0.747

\$NSR/ton	err-\$/ton
\$14.48	\$0.808

NSR 1-SD-err
\$39,236,841

Rec ABS - Difference
0.0243

NSR/t - Difference
0.0451

NSR - Difference
\$2,190,433

Uncertainty Ellipse Size

%Grade x %Rec	3.58	3.04	15.06
%Grade x \$NSR	3.96	3.29	16.93

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Another example (2/2)

- Low grade Cu mine with large tonnages (140,000t/day)
- Comparing **1% and 3%** sampler errors
- **\$5.60M/yr** estimated improvement

Assays%

Feed%	Conc%	Tail%
0.28	41.00	0.022

Errors% (1-SD)

	Case1	Case2	OSA
Feed	3.0000	1.0000	5
Conc	3.0000	1.0000	3
Tails	3.0000	1.0000	8

Total Errors ABS (1-SD)

	Case1	Case2
Feed	0.0163	0.0143
Conc	1.7395	1.2965
Tails	0.0019	0.0018

Metal

Metal Price(\$/lb)	3
Metal Price(\$/t)	6614
Smelter Payment (% of conc)	92
Smelter Treatment Cost (\$/t)	125
Transportation Cost (\$/t)	70
Tons /yr	48,545,000

\$NSR/yr **\$702,893,337**

Re - Calculate

Metalurgical Balance Results - Based on Assays

Item	Weight t	SD-C1	SD-C2	Diff	Assays %	SD-C1	SD-C2	Diff	Wt Metal t	SD-C1	SD-C2	Diff	Distr Metal %	SD-C1	SD-C2	Diff
Feed	48,545,000	0	0	0	0.28	0.016	0.014	0.002	135,926	7,926	6,931	995	100	0	0	0
Conc	305,642	23,395	19,595	3,800	41.00	1.739	1.297	0.443	125,313	7,982	6,987	995	92.19	0.81	0.75	0.06
Tail	48,239,358	23,395	19,595	3,800	0.02	0.002	0.002	0.000	10,613	907	856	51	7.81	0.81	0.75	0.06

Case 1

REC%	err-ABS
92.19	0.810

\$NSR/ton	err-\$/ton
\$14.48	\$0.924

NSR 1-SD-err
\$44,840,842

Case 2

REC%	err-ABS
92.19	0.747

\$NSR/ton	err-\$/ton
\$14.48	\$0.808

NSR 1-SD-err
\$39,236,841

Rec ABS - Difference
0.0631

NSR/t - Difference
0.1154

NSR - Difference
\$5,604,001

Uncertainty Ellipse Size

%Grade x %Rec	4.42	3.04	31.28
%Grade x \$NSR	5.05	3.29	34.78

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Review

- With **smaller errors** in online assays, you can get **better grade / recovery control**.
- With **small errors** improvements in online assays, you can get **better \$NSR/t returns**.
- With **smaller errors** in online assays recovery targets can **get closer to the optimal grade / recovery curve**
- Good **representative sampling requires cross cut samplers** which sample the complete stream
- International Sampling Standard and **AMIRA Code requires good sampling practices**.
- Sampling errors can be biased or random
- Sampling errors effect production plans, your control system and metallurgical accounting processes

“THIS IS THE VALUE OF GOOD SAMPLING”

- With tools available online “Error Propagation” can be done by anyone. You don’t need to know how to partially differentiate (calculus).

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Thank-you
from
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Presentation Link

http://heathandsherwood64.com/products/sampling/linear_samplers

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