Comminution 2019

II INTERNATIONAL CONGRESS ON MINERAL CRUSHING, GRINDING, HPGR & CLASSIFICATION

“New Drives for Better Geometallurgy Practices”

Authors:

Jorge M. Menacho, De Re Metallica Ingeniería SpA, DRM Tech

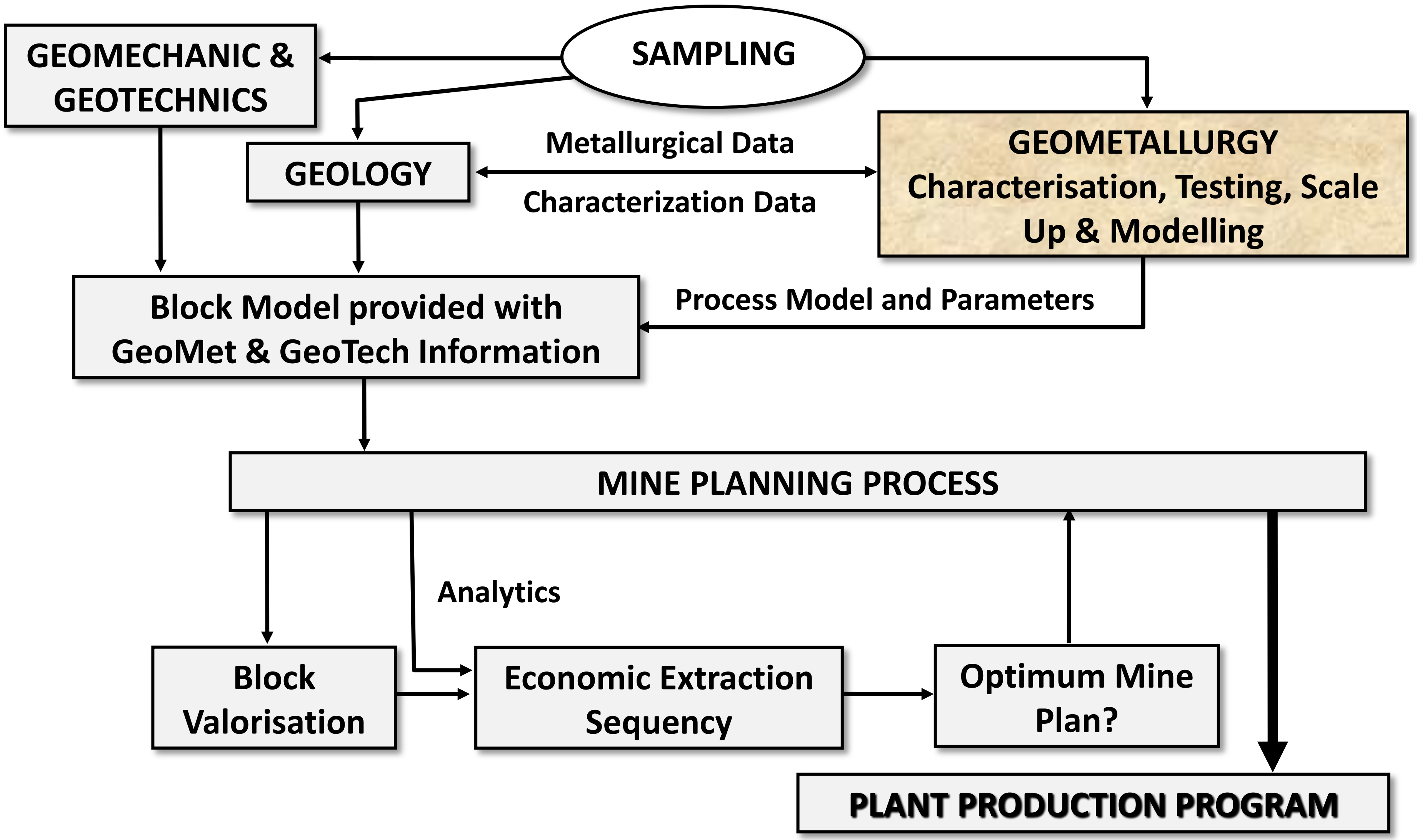
Guillermo E. Vega, De Re Metallica ingeniería SpA

Organized by: InterMet

Agenda

- ✓ Introduction
- ✓ Multiple domains and variable hierarchy
- ✓ Non Linearity and uncertainty
- ✓ Modelling tools
- ✓ Case Studies
- ✓ Remarks

Geomet Environment



Multiple Domain System – Attribute Hierarchy

Attribute Xi	Variance
Grade	S_1^2
Lithology	S_2^2
Alteration	S_3^2
Mineralogy	S_4^2
Blastability	S_5^2
Crushability	S_6^2
Copper Recovery	S_7^2
Acid Consumption	S_8^2

$$\begin{bmatrix} Sample \\ Amount \\ for\ X_1 \end{bmatrix} = f\left(\begin{bmatrix} Variability \\ of\ \ Attribute \\ X_1 \end{bmatrix}, \begin{bmatrix} Accepted \\ Confidence \\ Level \end{bmatrix}\right)$$

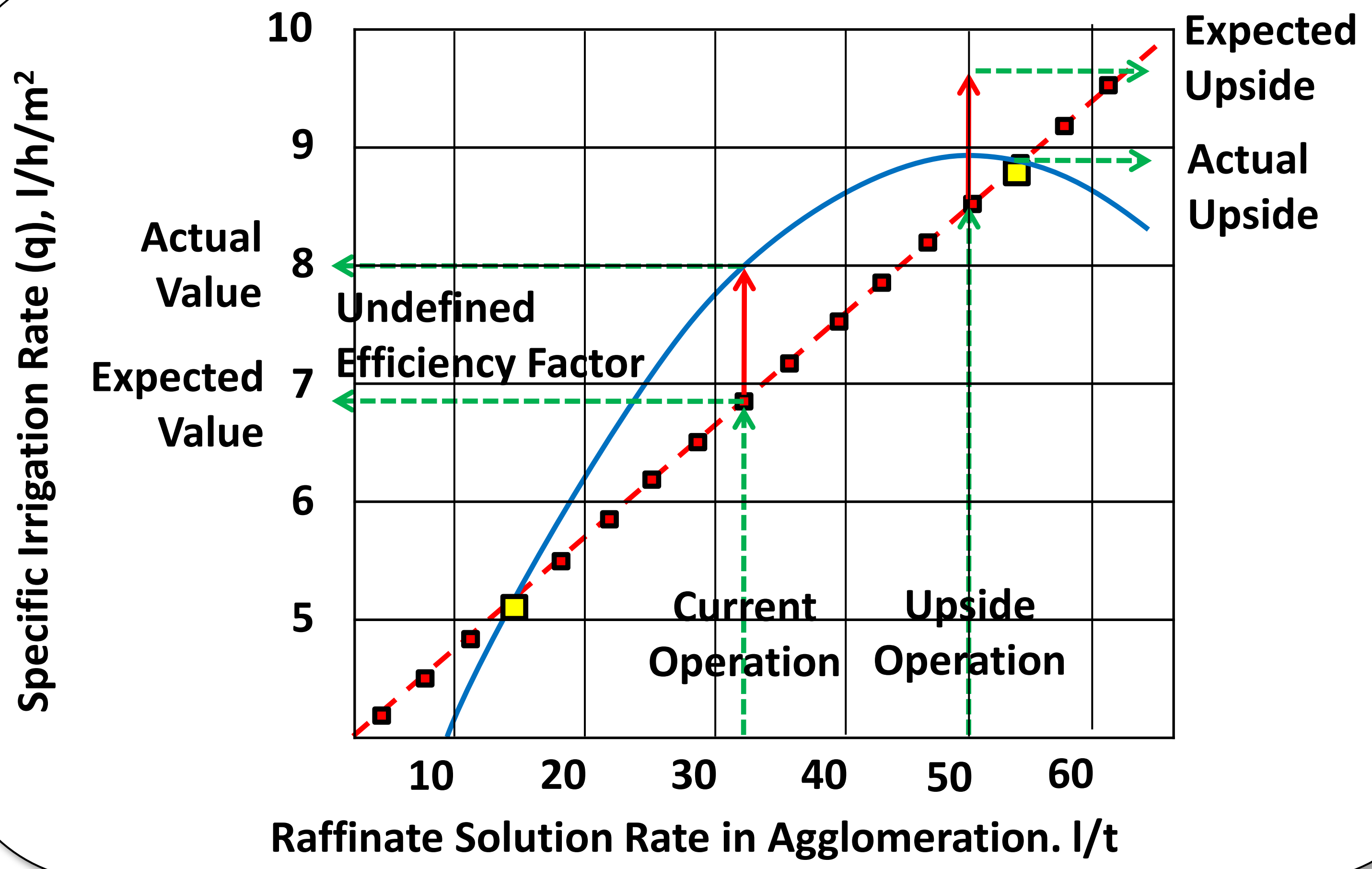
$$\begin{bmatrix} Sample \\ Amount \\ for\ X_2 \end{bmatrix} = f\left(\begin{bmatrix} Variability \\ of\ \ Attribute \\ X_2 \end{bmatrix}, \begin{bmatrix} Accepted \\ Confidence \\ Level \end{bmatrix}\right)$$

...

$$\begin{bmatrix} Sample \\ Amount \\ for\ X_8 \end{bmatrix} = f\left(\begin{bmatrix} Variability \\ of\ \ Attribute \\ X_8 \end{bmatrix}, \begin{bmatrix} Accepted \\ Confidence \\ Level \end{bmatrix}\right)$$

<u>COPPER GRADE</u> is unequivocally defined, but <u>COPPER RECOVERY</u> depends on process conditions

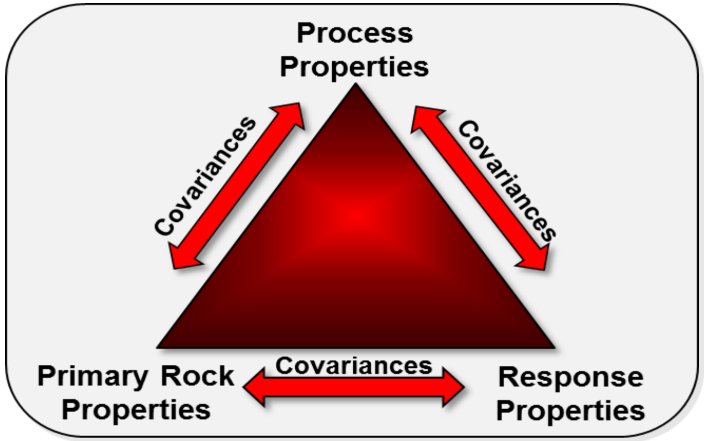
Non –Linear Responses



After Coward et al., 2009.

Most Geomet Processes are Non-Linear…

Mining processes are multi variate systems with strong covariances often leading to critical points: (L) Limit; (F) Failure; (B) Bifurcation



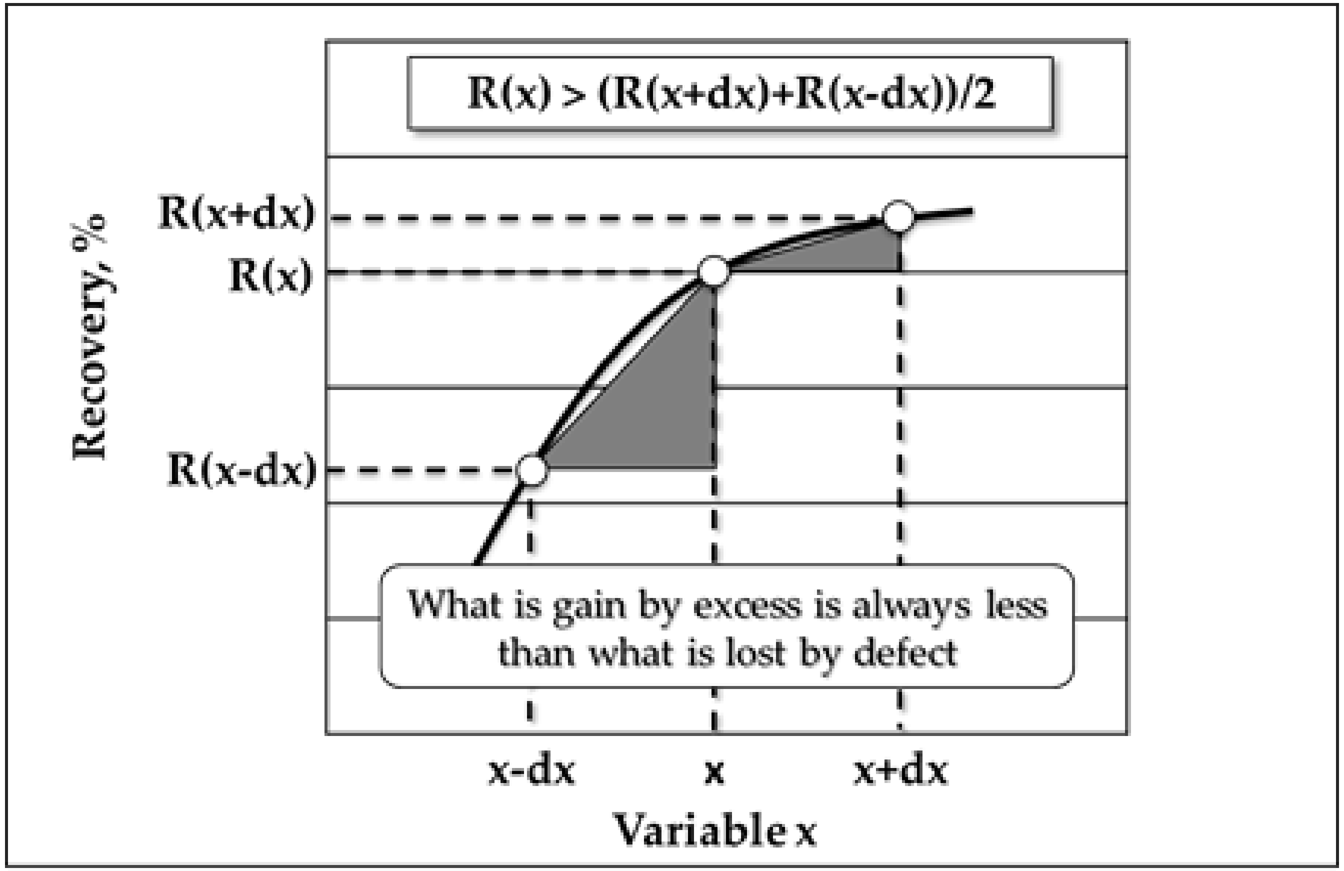
- *__Nil__* Cl in electrolyte, *__lower__* EW-Cu grain cristallinity
- *__Low__* Cl in electrolyte, *__higher__* EW-Cu grain cristallinity
- *__High__* Cl in electrolyte, *__Lower__* EW-Cu grain cristallinity

Do you still think in Linear Processes?

Deterministic or Stochastic Planning?

Normally, the production plan is computed in deterministic mode. Asymmetry of the non-linear response, drives to biased estimate.

Random variability of input variables can be measured, then this can be included to estimate the production plan, using stochastic simulation, to find more realistic estimate of the production plan.



Some Current Grindability Tests

Test	Mill Dia.	Top Size	Core	Database
	m	mm		Y/N
Bond Low-energy Impact	N/A	76.2	PQ/HQ	Y
Media Competency	1.83	175		Y
MacPherson Autogenous	0.46	32	NQ	Y
JK Drop-weight	N/A	63	PQ/HQ	Y
SMC Test®	N/A	31.5	Any	Y
JK Rotary Breakage Test®	0.45	53	HQ	Y
SAGDesign	0.49	38.1	NQ	Y
SPI®	0.305	38.1	NQ	Y
AG Pilot Plant	1.75	200		Y
Lab-scale HPGR	0.25	12.7	BQ	Y
SPT	N/A	19.1	BQ	Y
HPGR Pilot Plant	0.90	50		Y
Bond Rod Mill	0.305	12.7	Any	Y
Bond Ball Mill	0.305	3.35	Any	Y

after F.O. Verret et al., 2011

Grindability Test Performance

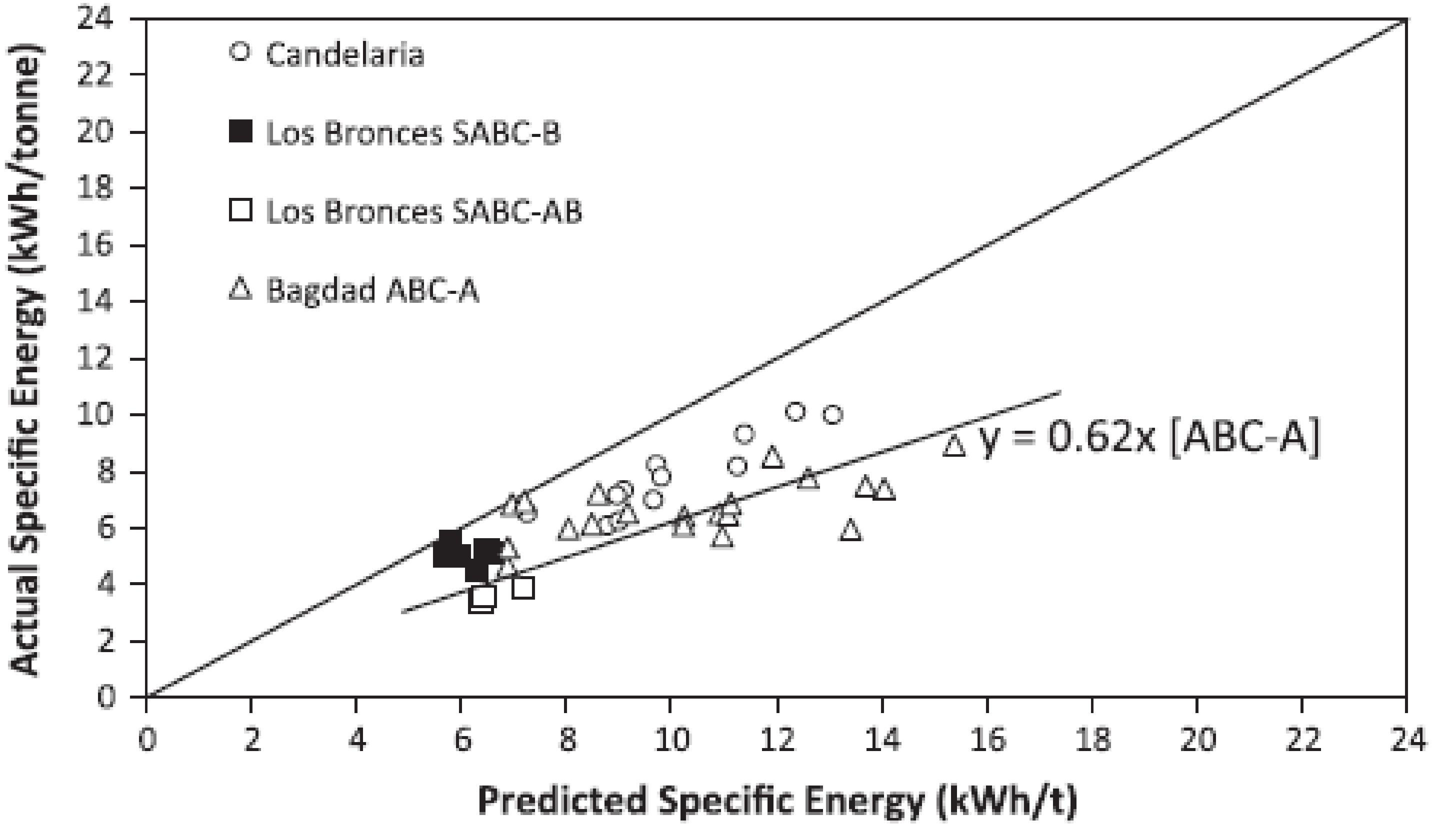
"Recommendations to reduce the error (SGI determination) as it ranges 25%…"

"To reduce error, the feed size distribution…"

"The grinding curve should be modelled using a variant of the Swebrec equation and…"

……………………

"A shorter, *lower cost/lower precision* version of the test has been recommended…"



Taken from: P. Amelunxen et al. / Minerals Engineering 55 (2014) 42–51

A Better Approach: Physical Quality Units

Attribute \ Ore	Ox-03	Ox-04	Ox-01	Ox-02	SS-02	SS-03	Mix-01	Mix-02	SS-01
Alteration Ser.+Argíl.	18.4	14.3	14.1	13.9	12.1	12.0	0.6	0.5	0.7
Unit Weight., t/m^3	2.55	2.53	2.58	2.53	2.62	2.56	2.66	2.67	2.62
UCS, MPa	42.98	50.62	57.21	58.79	56.43	71.67	72.33	91.21	91.57
TR, MPa	5.74	6.72	6.34	7.45	8.22	7.85	9.68	10.19	8.10
Young Index, GPa	29.8	32.2	33.0	35.1	39.3	38.1	42.3	44.1	46.6
RQD, %	80.16	80.51	73.40	75.47	94.38	91.26	92.93	92.93	94.84
FF, f/m	7.70	7.75	9.84	9.06	3.25	4.32	3.65	3.77	2.88
LRS, cm	163.15	166.37	153.29	155.92	190.68	186.12	189.13	189.13	191.70
GSI, %	43.78	45.88	42.96	44.91	55.37	53.73	53.94	54.72	54.82
RRD, %	3.09	3.43	3.35	3.41	3.97	3.94	3.86	3.89	3.92
BWI, kWh/t	7.8	10.8	10.5	11.3	12.5	12.9	15.8	16.1	16.4
SPI, min	38	65	54	67	97	102	130	126	140
Physical Quality Index	1	2			**3**		**4**		

The physical quality component naturally arise from the ranking of attributes.

Scale Up of Continuous Comminution Machines

Continuous Comminution Machine

Fracture Phenomena

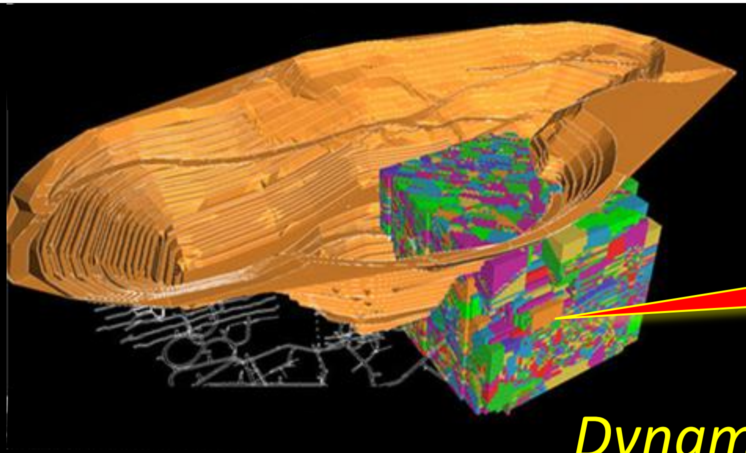
Test (mass, energy, PSD):	Batch Comminution test
Equation:	PBM Model
Scale Up Parameter:	Selection Function

Transport Phenomena

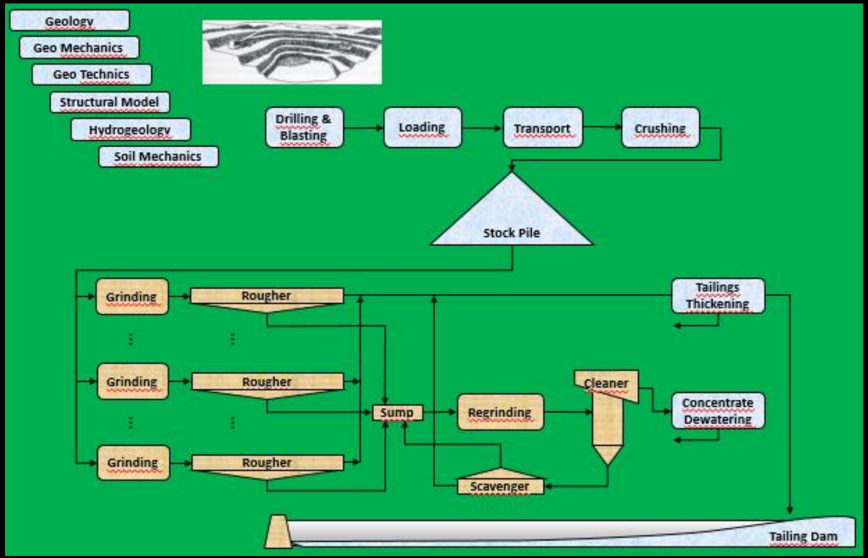
Test (Flowrate/Holdup):	Continuous Comminution tests
	Rheological tests
Equation:	Transport with Comminution
Scale Up Parameter:	Transport parameters

- Most current methods consider only fracture phenomena
- Often severe simplification of the PBM approach is used
- Test scale is generally too small; geo structural features are missed

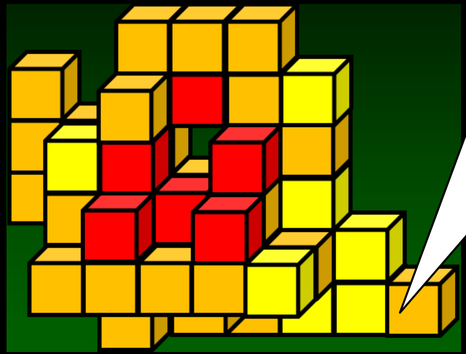
Simulate Instead of Estimate



Dynamic Phenomenological Simulator



Block Model Linear Estimator



Tonnage
Grades
Density
Lithology
Mineralogy
…
Recovery
Acid Cons.

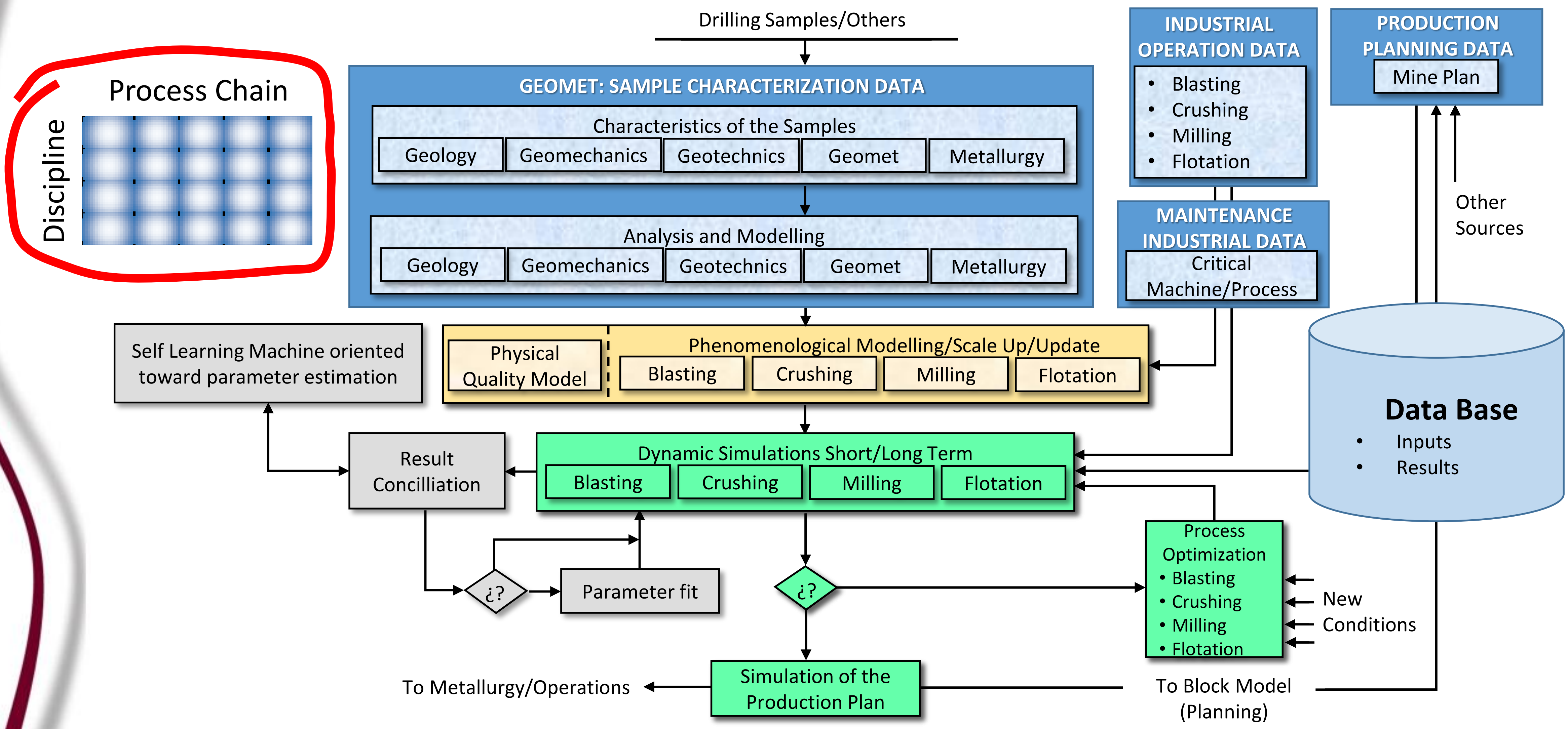
Draw taken from Geometallurgy – Optimising the resource, R. Baumgartner, Geneva, 2012.

Modelling Approach for Planning

- All characteristics of the orebody are *SPATIALLY VARIABLES*
- Once extraction start all processes are *TIME DEPENDENT*
- *NON LINEARITY is everwhere*
- Metallurgical results are highly dependent on *PROCESS VARIABILITY*

"Dynamic" modelling is appropriate and preferently in a phenomenological framework

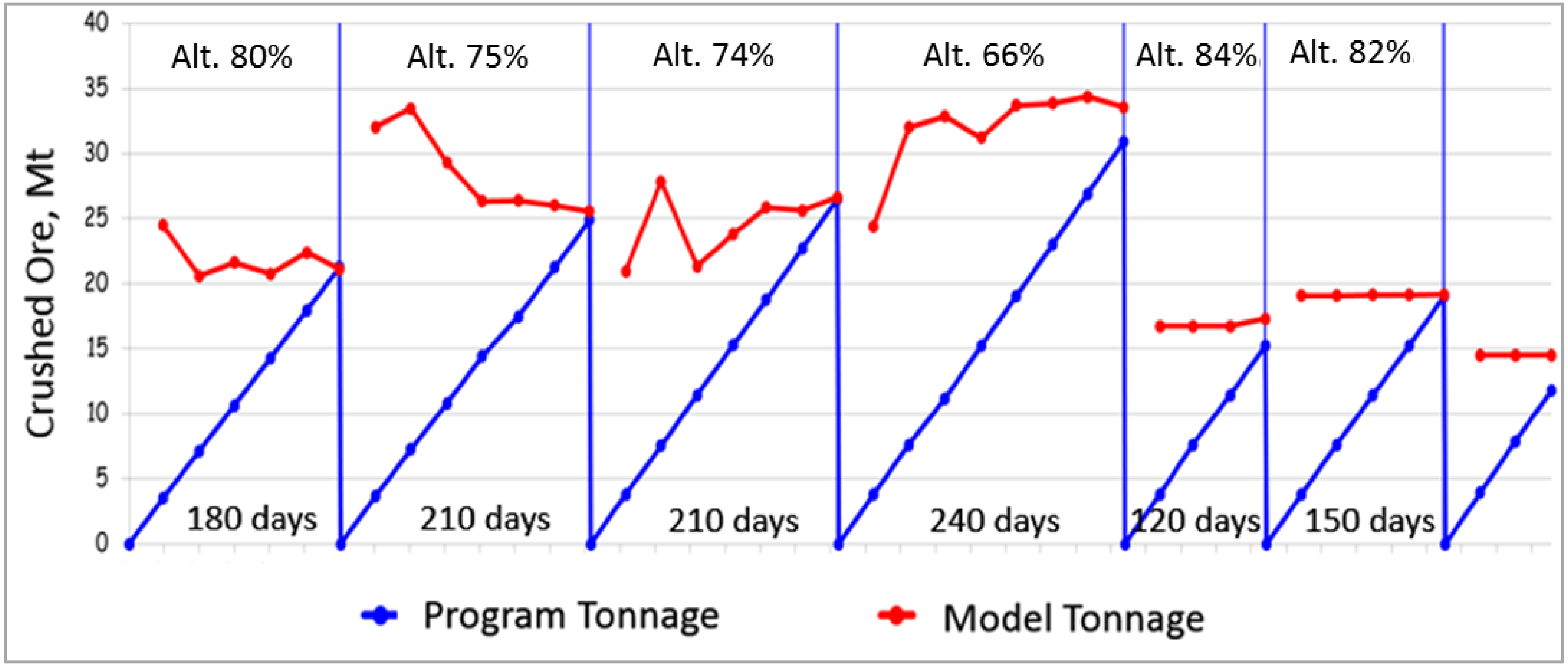
Planning with "Matrix Modelling"

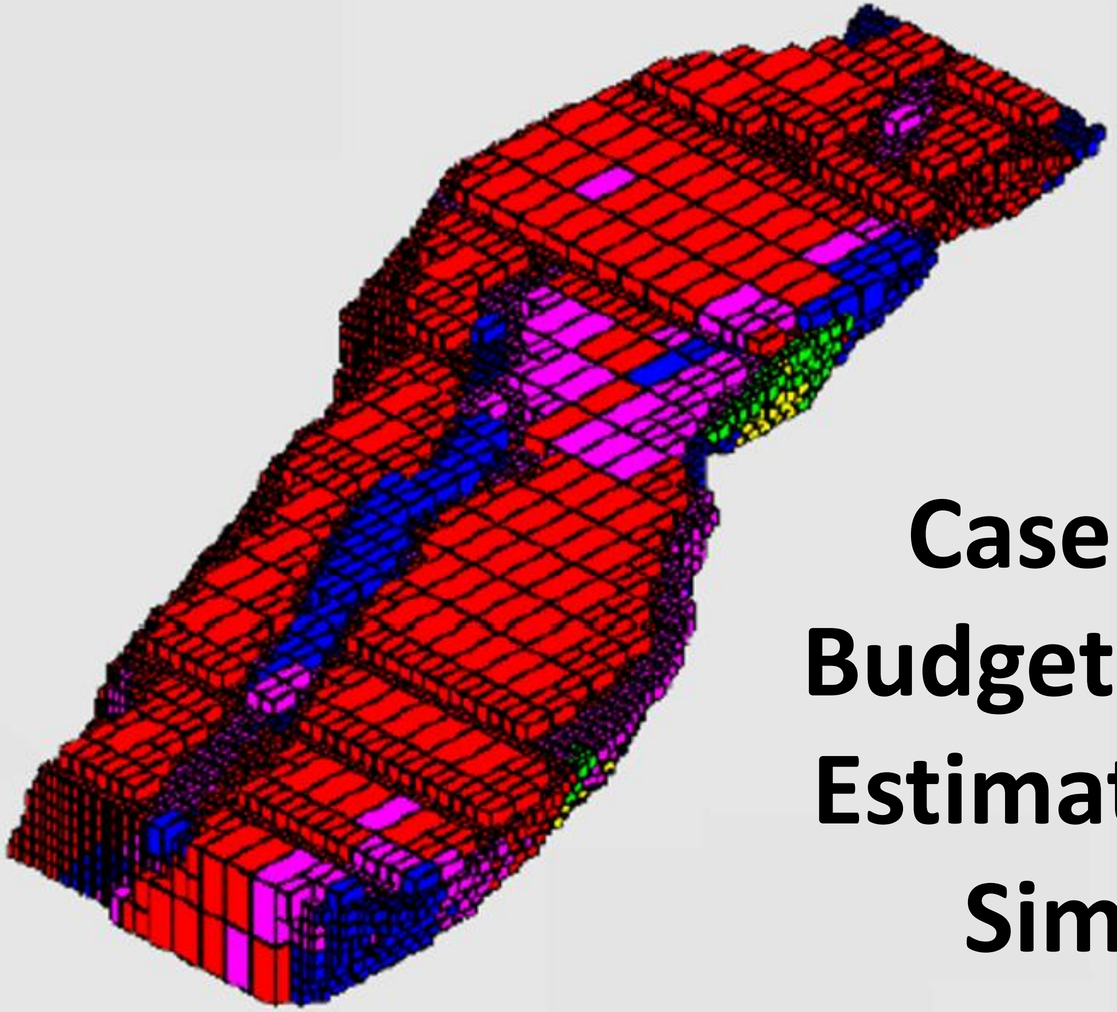


Comminution 2019

Planning with "Matrix Modelling"

Example: Prediction of concave change in the primary crusher from geological data and process modelling.





Case Study 2: Budget Planning – Estimation versus Simulation

Draw taken from Geometallurgy – What, why and how, P. Lamberg, Levi, Finland, 2011

"The Operator Inequality at the Concentrator"

$$\underbrace{P_{Plan} = \bar{m}\,\bar{L}\,\bar{R}}_{\text{Planned Yr. Production, Block Model}} \geq \underbrace{\int_0^{365} Q_P(t)\,\rho_P(t)\,S_P(t)\,L(t)\,R_F(t)\,dt}_{\text{Real Yr. Production, Dynamic Process}} = P_{Real}$$

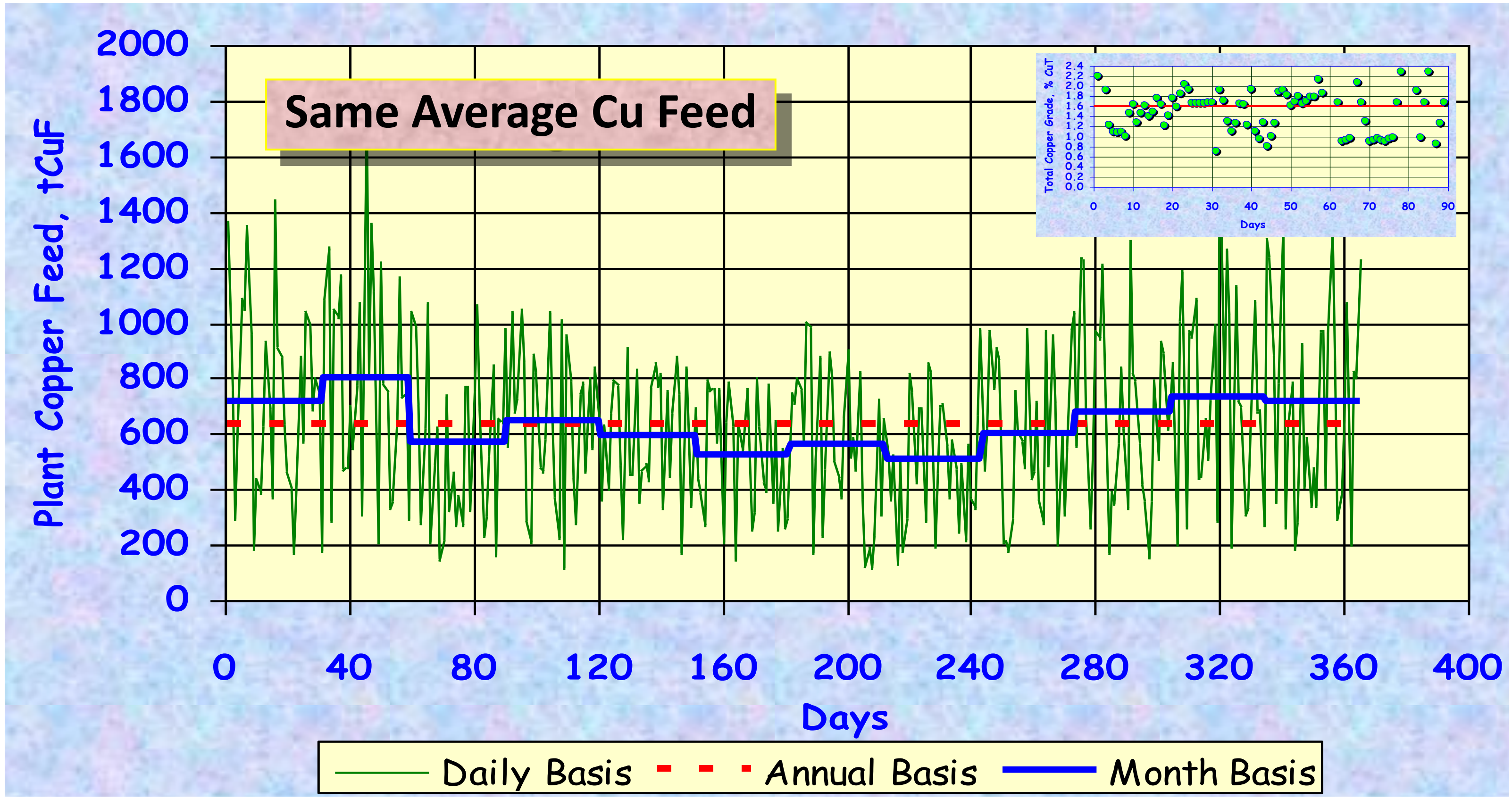
WON BY EXCESS IS LESS THAN LOST BY DEFFICIENCY IN ANY ASYMPTOTIC NON LINEAR PROCESS

This inequality is a permanent paradigm for the Concentrator plant operator, always trying to reconcilliate planned and operational results.

This is often due to an *incorrect planning* which ignores dynamic variability linked to process non-linearities and operational constrains.

Study Case: Simulate versus Estimate

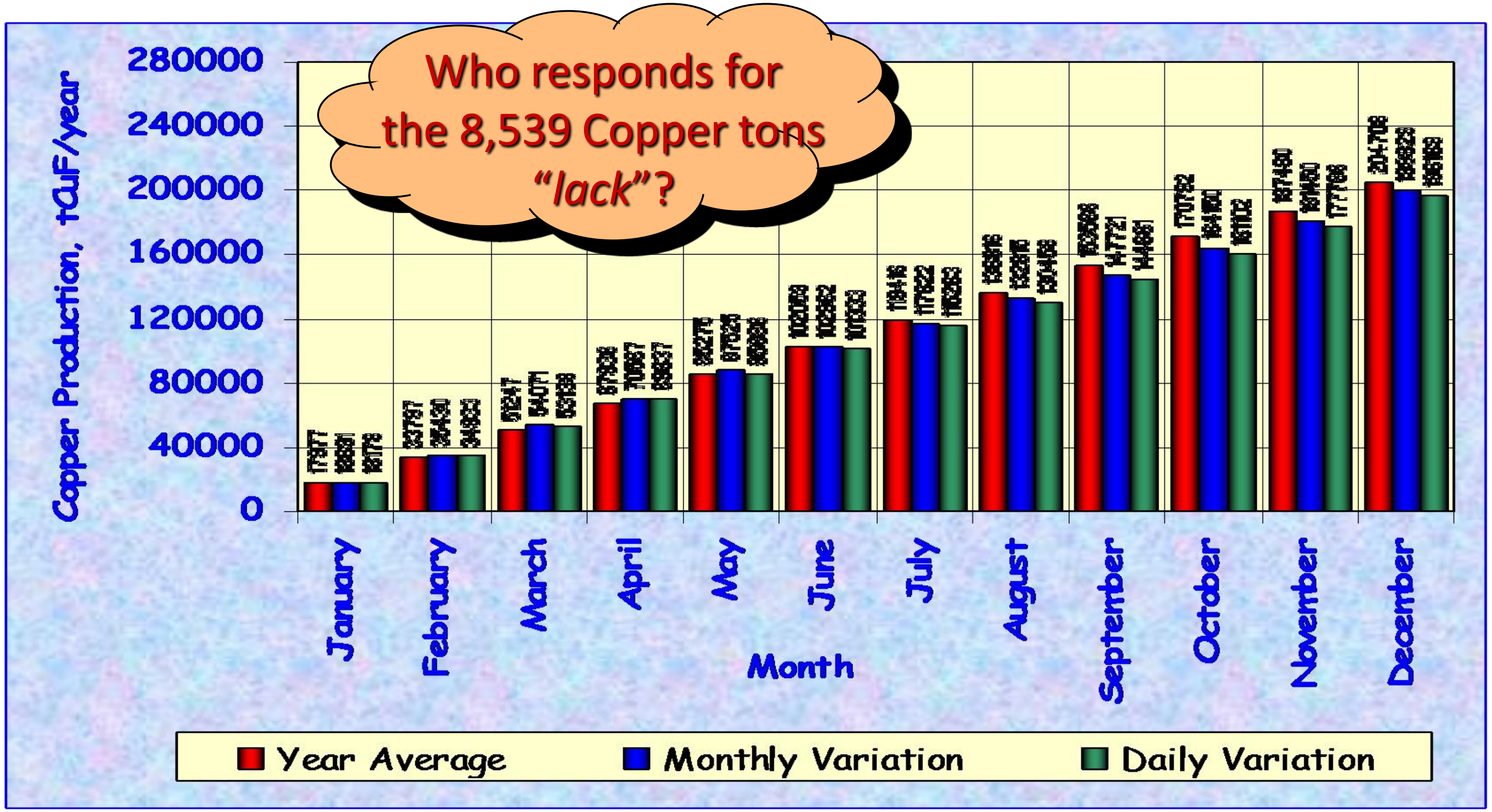
Three mine programs: (i) *year*-basis, (ii) *monthly*-basis and (iii) *daily*-basis. The first two provided by the mine. The third one obtained by *Stochastic Simulation*.



Study Case: Simulate versus Estimate

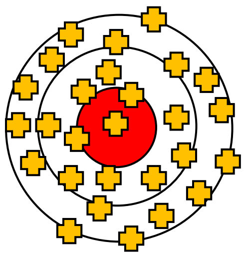
Year average	: 204,708 t Cu/year
Monthly variation	: 199,828 t Cu/year
Daily variation	: 196,169 t Cu/year

INCREASING BIAS…

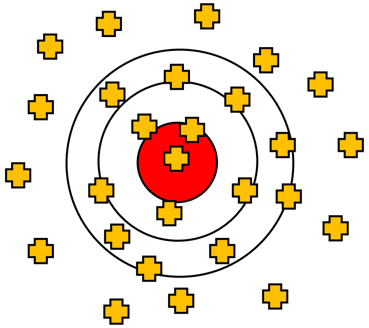


Managing the Operational Variability…

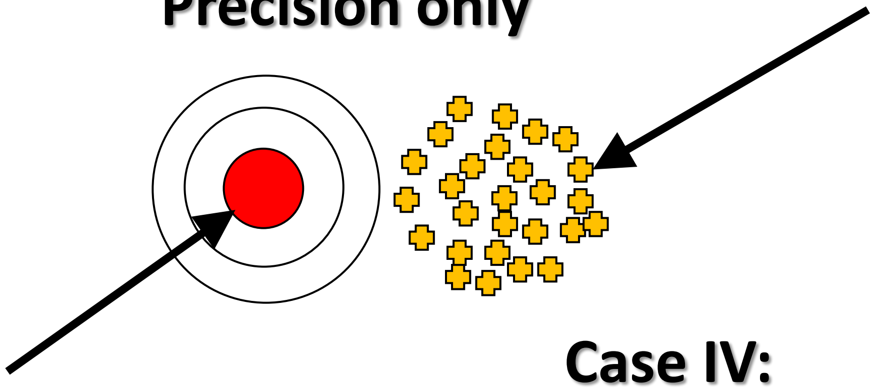
Case I:
Both accuracy and precision



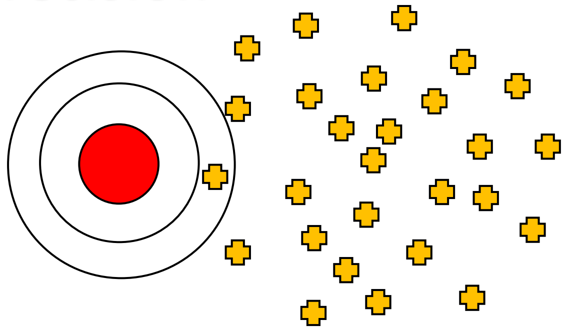
Case II:
Accuracy only



Case III:
Precision only



Case IV:
Neither accuracy nor precision



Planning and real results are compared and differences drive to optimization opportunities

Remarks

- It must be distinguished between *fundamental attributes* like Copper Grade and *responses* like Copper Recovery as the first one is an absolute independent quantity and the last one is a relative dependent quantity.
- Using linear estimation approach, such as *Kriging*, is not valid for non-linear and non-additive variables such as recovery of elements.
- It is hard to believe that current comminution tests and related interpretation methods may drive to accurate production estimates due to structural flaws.
- Most of the sizing equations are simplified versions of the PBM approach. *Generally speaking, none considers transport aspects.*
- For planning subjects we suggest to manage the "*Physical Quality*" concept properly included within the invariant transfer functions.

Remarks

- For design and sizing of any industrial continuous comminution machine, we need to consider: (i) Comminution tests (mass-power-PSD), (ii) Rheological tests (yield stress, Bingham fluid), (iii) Validation continuous test to measure transport parameters and set scale up criteria.
- The experimental data must be fed to a phenomenological comminution model with two invariant transfer functions:
  - ✓ The reduced selection function.
  - ✓ The transport function.
- Next generation of comminution models (matrix models) will consider ***explicitly***: Process, Operational and Maintenance aspects, among others.
- Variability not only intrinsic to the orebody but also related to actual operation in the mine and the plant, leads to ***overestimate Production***. Better estimates of real results are obtained by ***Random simulation***.