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Integral Planning of the Process-Chain Performance

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Introduction

- Estimate of Copper Production Plans today is often imprecise
- Current tools to predict throughput and recovery are not enough fine to assure realistic results along the process chain and the time.
- The block model is quite approximate and it normally calculates under static process conditions.
- Dynamic phenomenological models properly complemented with predictive maintenance models, sensitive to characteristics of the ore, actual operational conditions and "random" process variability are needed to approach the reality.
- Also a cost/benefit algorithm is convenient to include in order to provide an economical viewpoint to take business decisions.

Framework

Dynamic Database: Geology, Geomechanics, Geotechnics, Structural Geology, Soil Mechanics, Hydrogeology, Operational Conditions, Maintenance, Metallurgy and Cost

Other Uses

3D Physical Quality Model (Mine and Plant Attributes)

3D Grades Model (Valuable Metals and Contaminants)

3D Mineralogy Model (Metals and Gangue)

INTEGRATED DYNAMIC SIMULATOR

Process and Operation
- Drilling and Blast
- Primary Crushing
- SAG/Ball Milling
- Flotation

Maintenance
- Drilling and Blast
- Primary Crushing
- SAG/Ball Milling
- Flotation

Cost
- Drilling and Blast
- Primary Crushing
- SAG/Ball Milling
- Flotation

{ Recovery, grades, throughput, operational conditions }

{ Reliability, availability, utilisation, downtime, net throughput }

{ Prices, cost, incomes, benefit }

PLANNING WITH VARIABILITY: $(\text{Variability})^2 = (\text{Maintenance Issues})^2 + (\text{Random Variability})^2$

Models Description

Blasting: Population balance approach (fully described in a separated paper Procemin 2018)

Crushing: Population balance approach for the crushers and Tromp curve for the screen classifiers

SAG milling: It has 4 submodels: (i) Population balance, (ii) Power consumption, (iii) Mass transport and (iv) Slurry evacuation

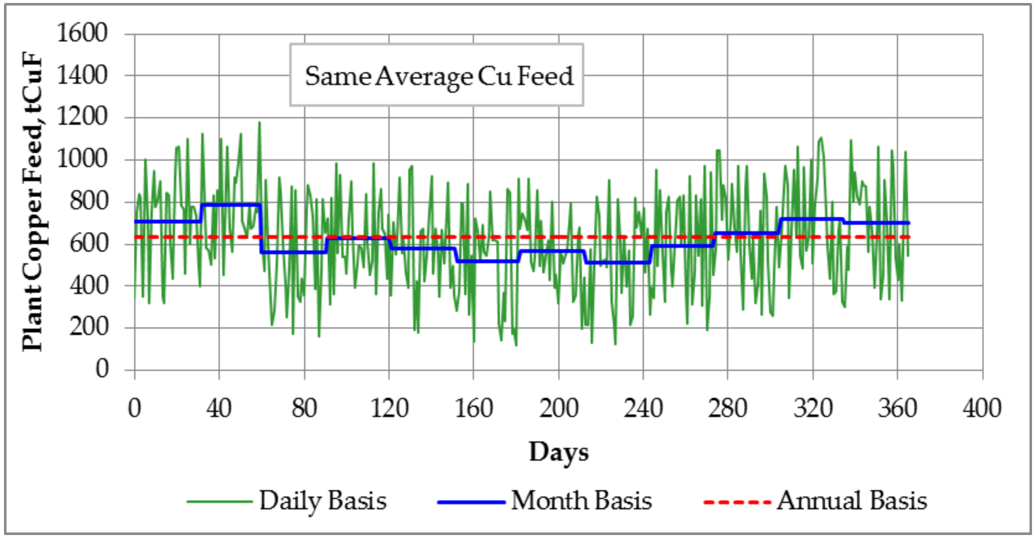
Ball milling: It includes 3 submodels: (i) Population balance, (ii) Power consumption and (iii) Grate classifier when applies

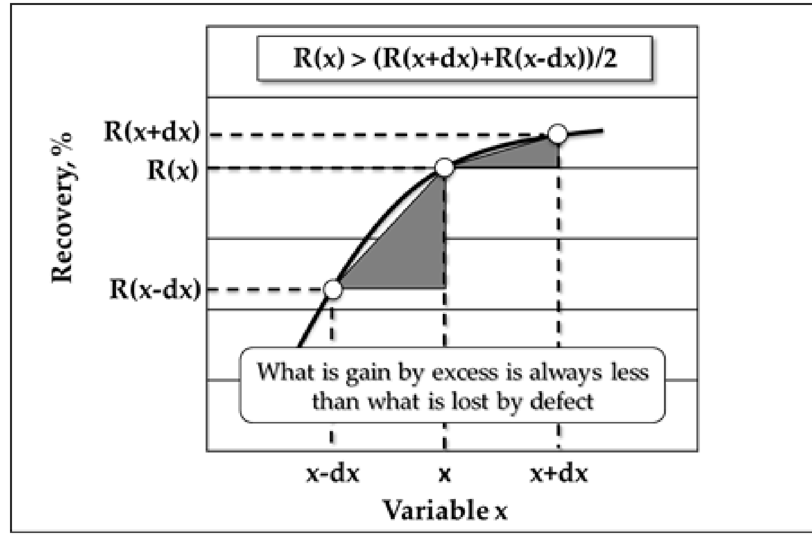
Flotation plant: 2-phase kinetic flotation model. Parameter sensitive to particle size profile, mineralogy, liberation, bubble size profile and operational conditions

Maintenance model: Historical maintenance matrix, characteristics of the ores and operational condition. It predicts availability, downtime and troughput

Cost/Benefit model: Cost distribution matrix, it estimates net benefit per period.

Impact of Variability on Planning Issues





Production according the year average plan is 231,775 t Cu while the monthly plan estimates 229,366 t Cu. The daily plan which is the most realistic, indicates just 228,683 t Cu, that is, over 3,000 tons difference between the extremes.

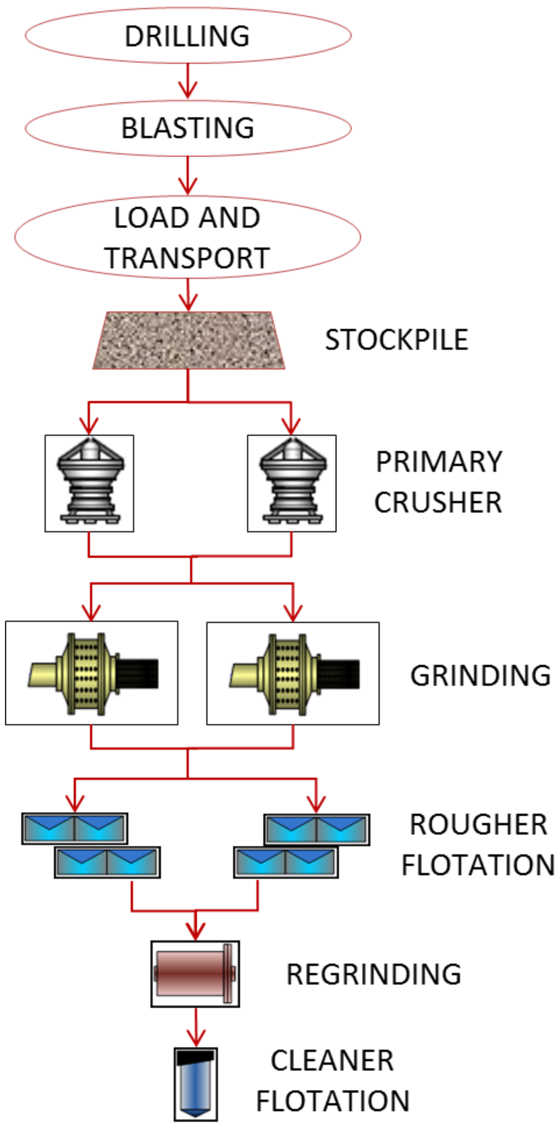
Linear estimation approaches such as Kriging and similar are not valid to set continuity for non-linear and non-additive variables such recovery, because what is gain by over recovery is in most cases lower that what is lost by under recovery.

Physical Quality Model

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
Physical Quality Index	1	2			**3**		**4**		

The physical quality groups naturally arise from the ranking of attributes. Four groups are here identified.

Study Case: Current Condition



DRILLING AND BLASTING	
Burden, m	8.0
Spacing, m	9.0
Powder Factor FC, g/t	650
Drilling Diameter, in	12.25
ORE IN STOCKPILE	
CuT, %	1.20
FeT, %	1.71
Cpy, %	1.21
Cc, %	0.78
Cv, %	0.25
CRUSHING	
Throughput, t/h	4,580
CSS Primary Crusher, mm	178
Crusher Power, kW	167
GRINDING	
Retained on 100#, %	25.2
Product P80, mm	0.22
Ball Mill Fractional Ball Filling, %	35
Grinding Total Power, kW	50,973
FLOTATION	
Rougher Flotation Time, min	28.13
Collector Dose, g/t	14.68
Rougher Mean Froth Height, cm	68
Cleaner Mean Froth Height, cm	90

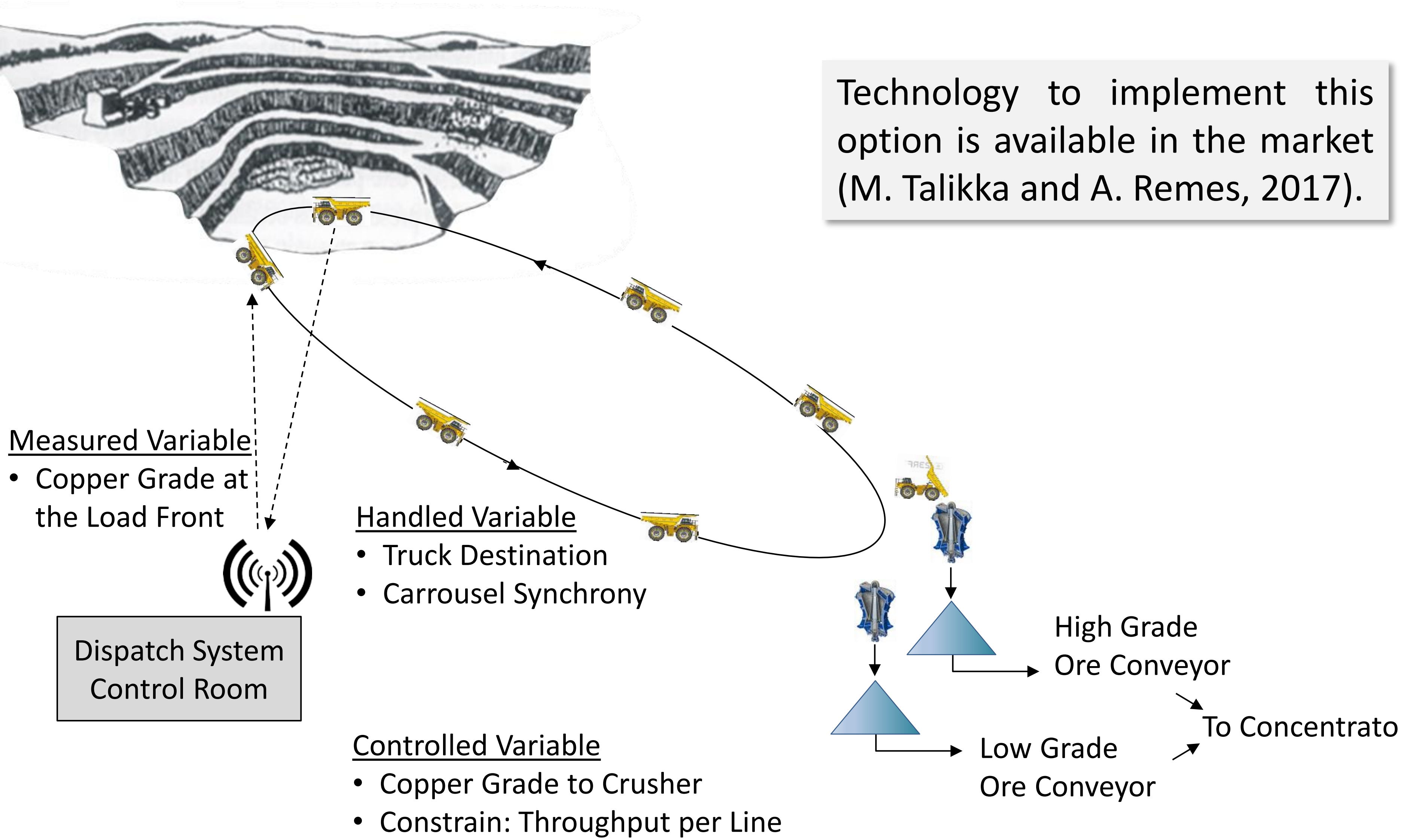
Study Case: OPEX Distribution

Open-Pit Mine Cost Distribution	
Mine Processes	Cost Matrix, %
Drilling	0.5
Water	0.6
Truck Hopper Expense	0.9
Others	1.1
Electric Energy	1.1
Blasting	6.1
Tires	7.2
Wages	11.2
Fuel (Oil and Lubricants)	28.6
Maintenance and Repair	42.7

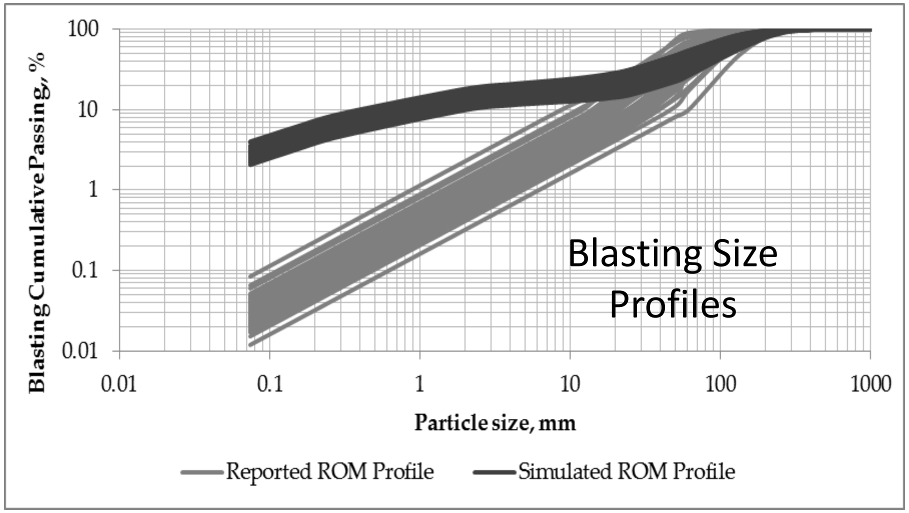
Concentrator Plant Cost Distribution	
Concentrator	Cost Matrix, %
Crushing	4.0
Grinding	49.0
Collective Flotation	11.0
Selective Flotation	4.0
Tailings	3.0
Desalinated Water	21.0
Auxiliaries	5.0
Others	3.0

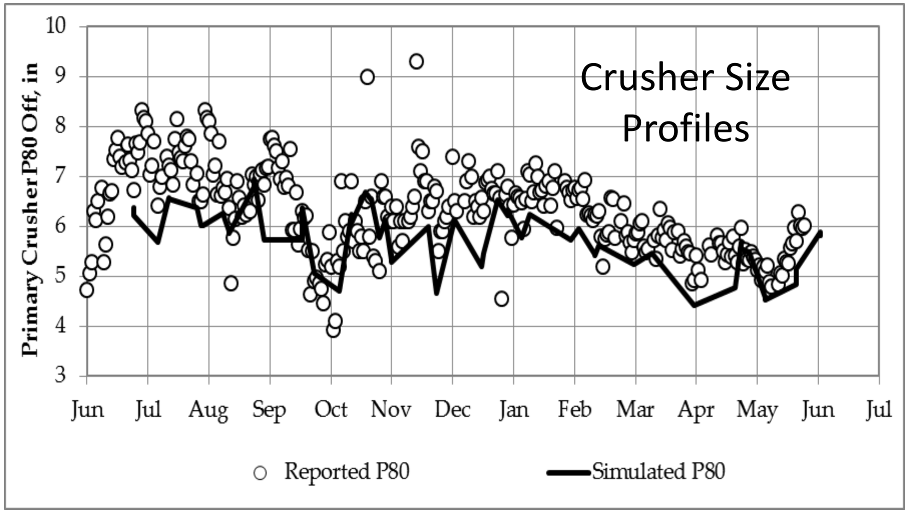
The Challenge

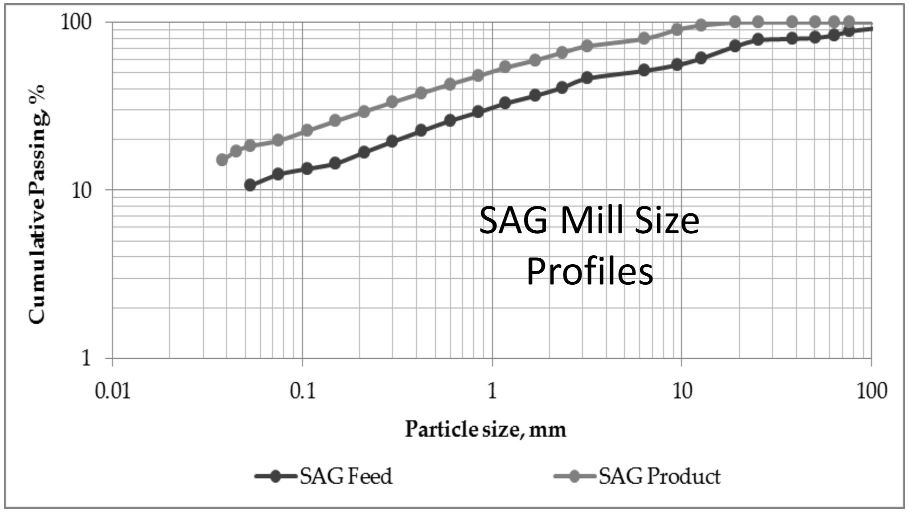
Technology to implement this option is available in the market (M. Talikka and A. Remes, 2017).

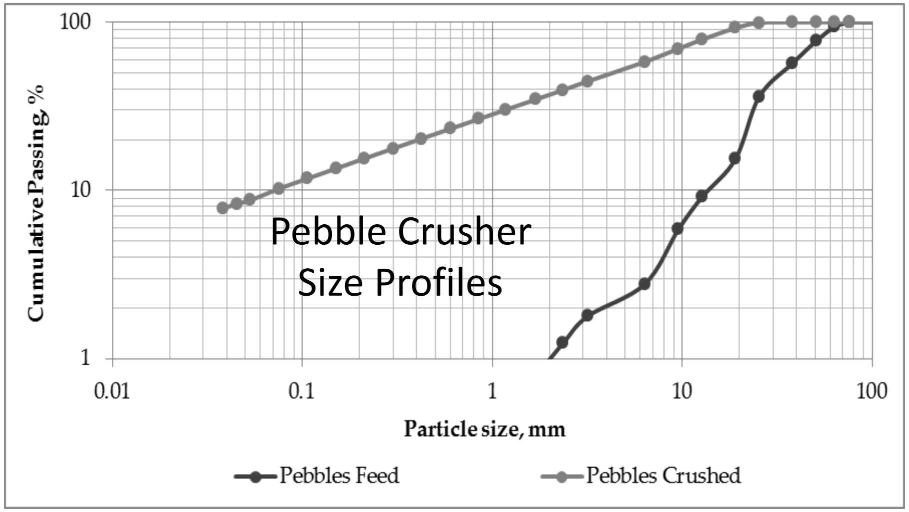


Models Fit

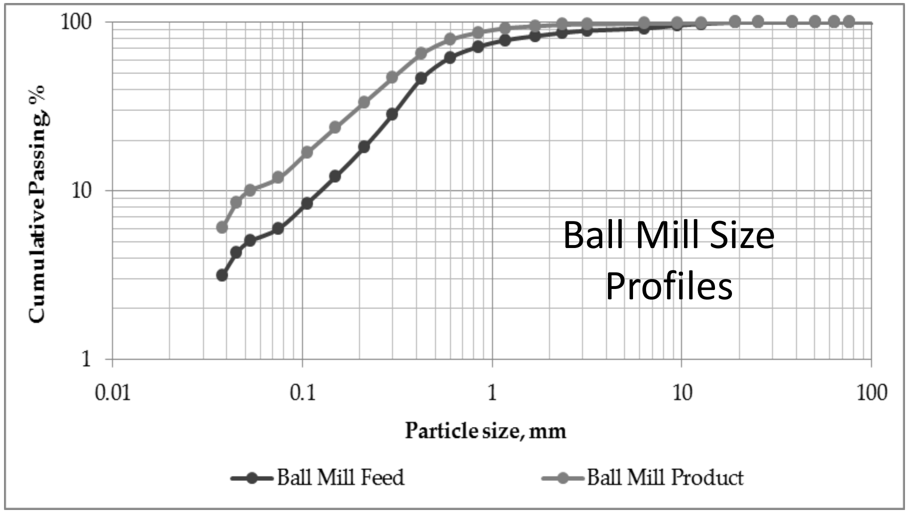

Blasting Size Profiles
Blasting Cumulative Passing, %
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000
Particle size, mm
Reported ROM Profile
Simulated ROM Profile

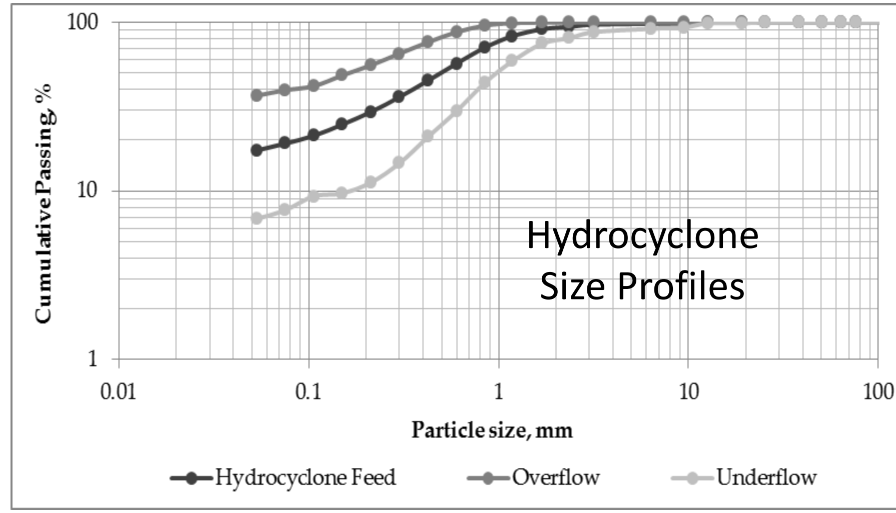

Crusher Size Profiles
Primary Crusher P80 Off, in
10
9
8
7
6
5
4
3
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Reported P80
Simulated P80

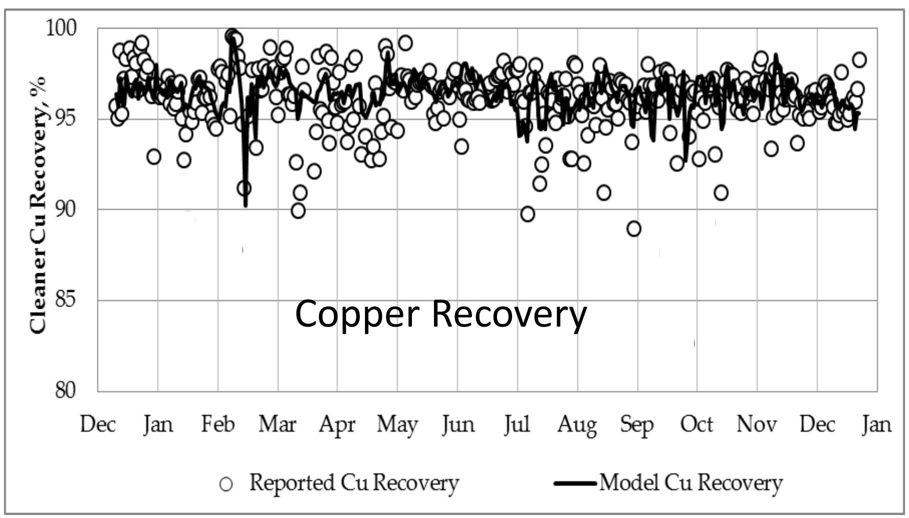

SAG Mill Size Profiles
Cumulative Passing %
100
10
1
0.01
0.1
1
10
100
Particle size, mm
SAG Feed
SAG Product

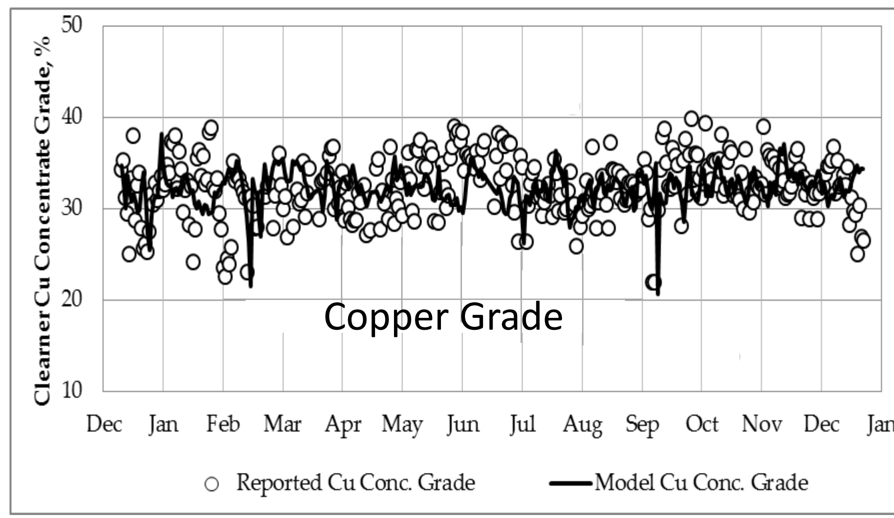

Pebble Crusher Size Profiles
Cumulative Passing %
100
10
1
0.01
0.1
1
10
100
Particle size, mm
Pebbles Feed
Pebbles Crushed

Models Fit


100
10
1
Cumulative Passing, %
0.01
0.1
1
10
100
Particle size, mm
Ball Mill Size Profiles
Ball Mill Feed
Ball Mill Product


100
10
1
Cumulative Passing, %
0.01
0.1
1
10
100
Particle size, mm
Hydrocyclone Size Profiles
Hydrocyclone Feed
Overflow
Underflow


100
95
90
85
80
Cleaner Cu Recovery, %
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Copper Recovery
Reported Cu Recovery
Model Cu Recovery


50
40
30
20
10
Cleaner Cu Concentrate Grade, %
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Copper Grade
Reported Cu Conc. Grade
Model Cu Conc. Grade

Results: Single Feed vs Double Feed

Parameter Single feed	Single Feed	Double feed		Delta Benefit
		High Grade	Low Grade	
Throughput, %	100	50	50	
Head Copper Grade, %	1.19	1.41	0.98	
Powder Factor FC, g/t	650	800	500	
Ball Filling JB, %	35	38	32	
Collector Dose, g/t	14.68	17.36	12.00	
Rougher Mean Froth Height, cm	68	60	75	
Cleaner Mean Froth Height, cm	90	80	100	
Overall Cu Recovery, %	78.59	93.07	70.69	
Cu Grade in Final Concentrate, %	34.18	34.08	34.37	
Cost, USM$/year	1,225	637	618	
Incomes, USM$/year, 317 ¢/lb Cu	2,640	1,829	959	
Benefit, USM$/year	1,415	1,534		119
Incomes, USM$/year, 250 ¢/lb Cu	2,082	1,442	756	
Benefit, USM$/year	857	944		87

Final Remarks

- Decreasing grades and cyclic metal prices demand different ways to get better results: Sorting technology, automated remote dispatch and better management of stockpiles is a main route. Selective optimization practices demonstrate significant benefit as shown in the Study Case here presented.
- Today more than never the integrated view of the production chain is a “must”. Planning tasks should be assisted by Process/ Maintenance/Economical simulators.
- Well-settled phenomenological models can be enpowered with learning machine tools to reach optimal results. This is the next model generation.