FLOTATION 2018

III Minerals Flotation International Congress

Lima, June 07 - 08

"A New Approach to Flotation Plants"

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De Re Metallica Ingeniería SpA, DRM-Tech

InterMet
Consultores Metalúrgicos

Did You Know That…?

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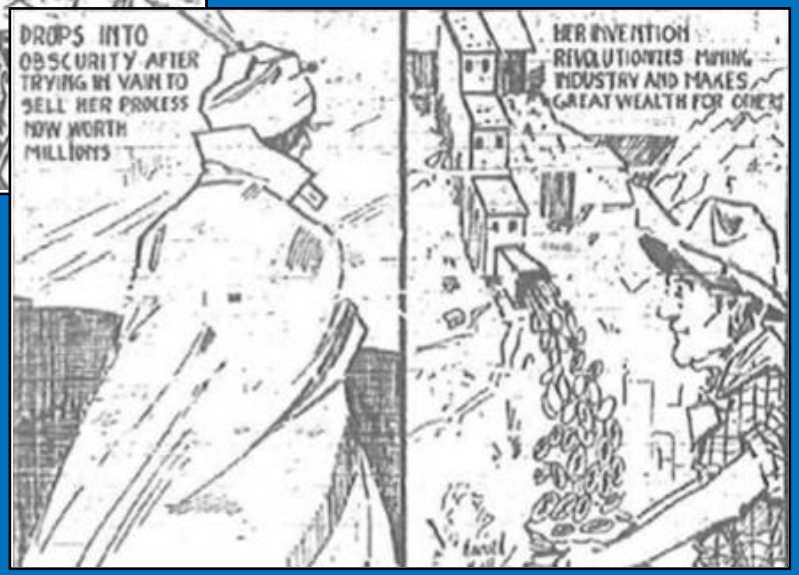
US Patent 348,157, (1886) "Process of Concentrating Ores".



Carrie Jane Billings Everson (1843 – 1911).

Mrs. Everson discovered and proved a method for bulk oil flotation concentration of mineral ores, the precursor to modern froth flotation methods of minerals concentration. She patented her process in 1886 and ran a demonstration plant in the early 1890´s.

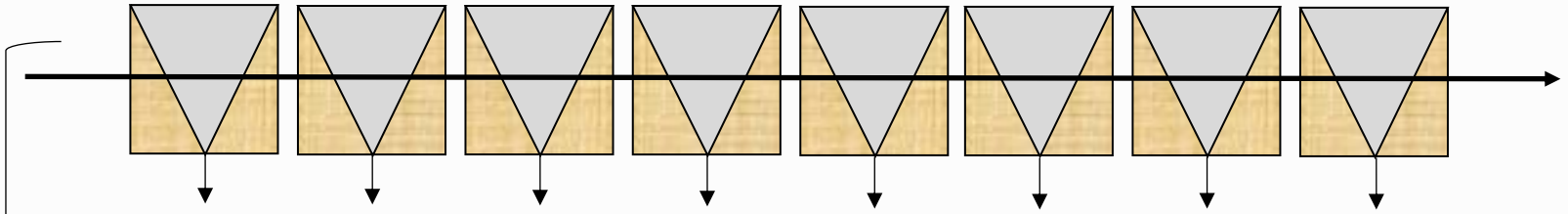
The 12 November 1915 Denver Times ran this interpretation of Carrie Everson´s process Discovery and life.

https://www.mininghistoryassociation.org/Journal/MHJ-v12-2005-Bunyak.pdf

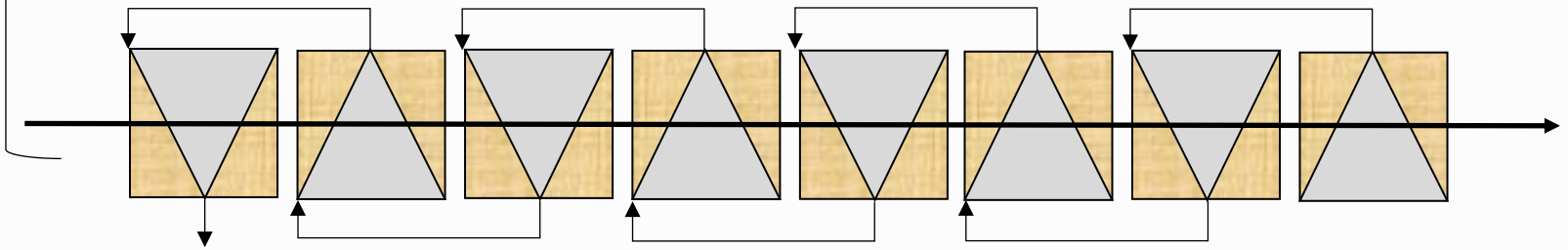
Basics on Flotation Circuit

"Recovery" Circuit

Highest Recovery/Low Grade Circuit → Open-Circuit Concentrate

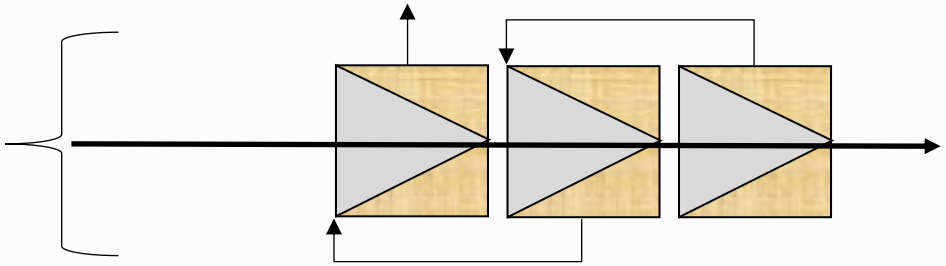


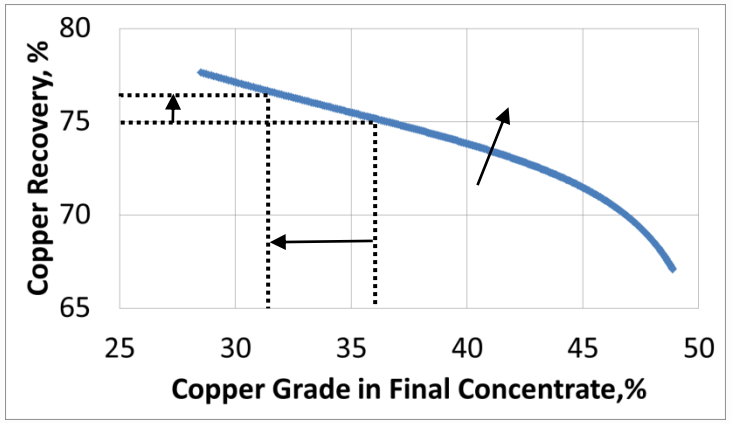
Less Recovery but Higher Grade Circuit → Counter-Current of Concentrate



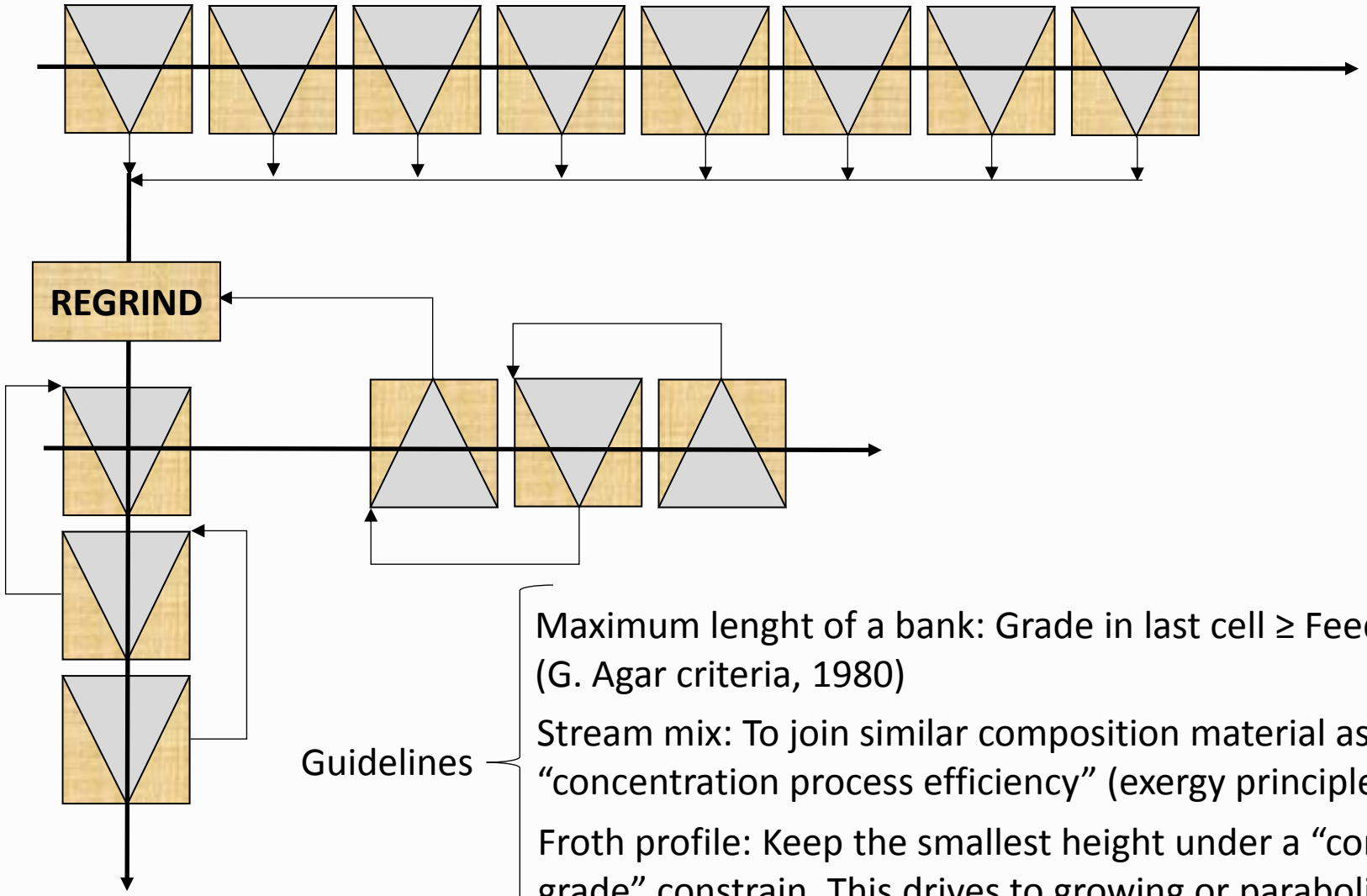
"Cleaning" Circuit

High Grade Circuit → Counter-Current of Tailings





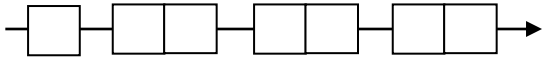
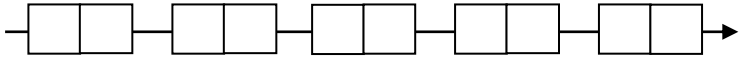
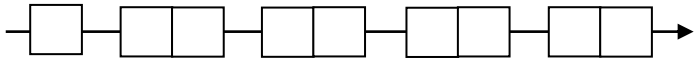
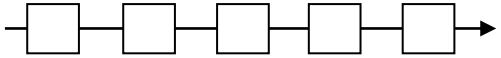
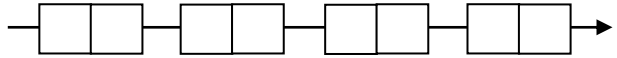
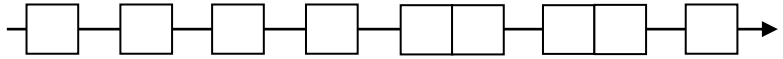
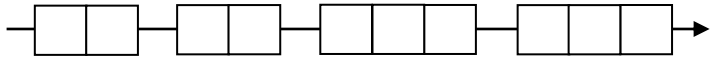
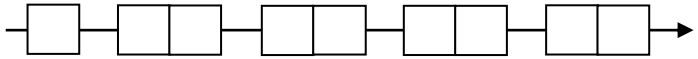
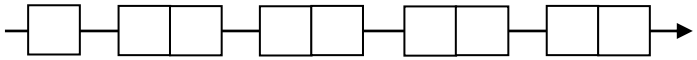
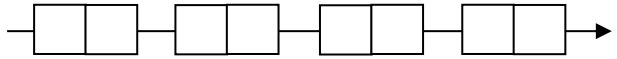
Common Arrangement



Guidelines

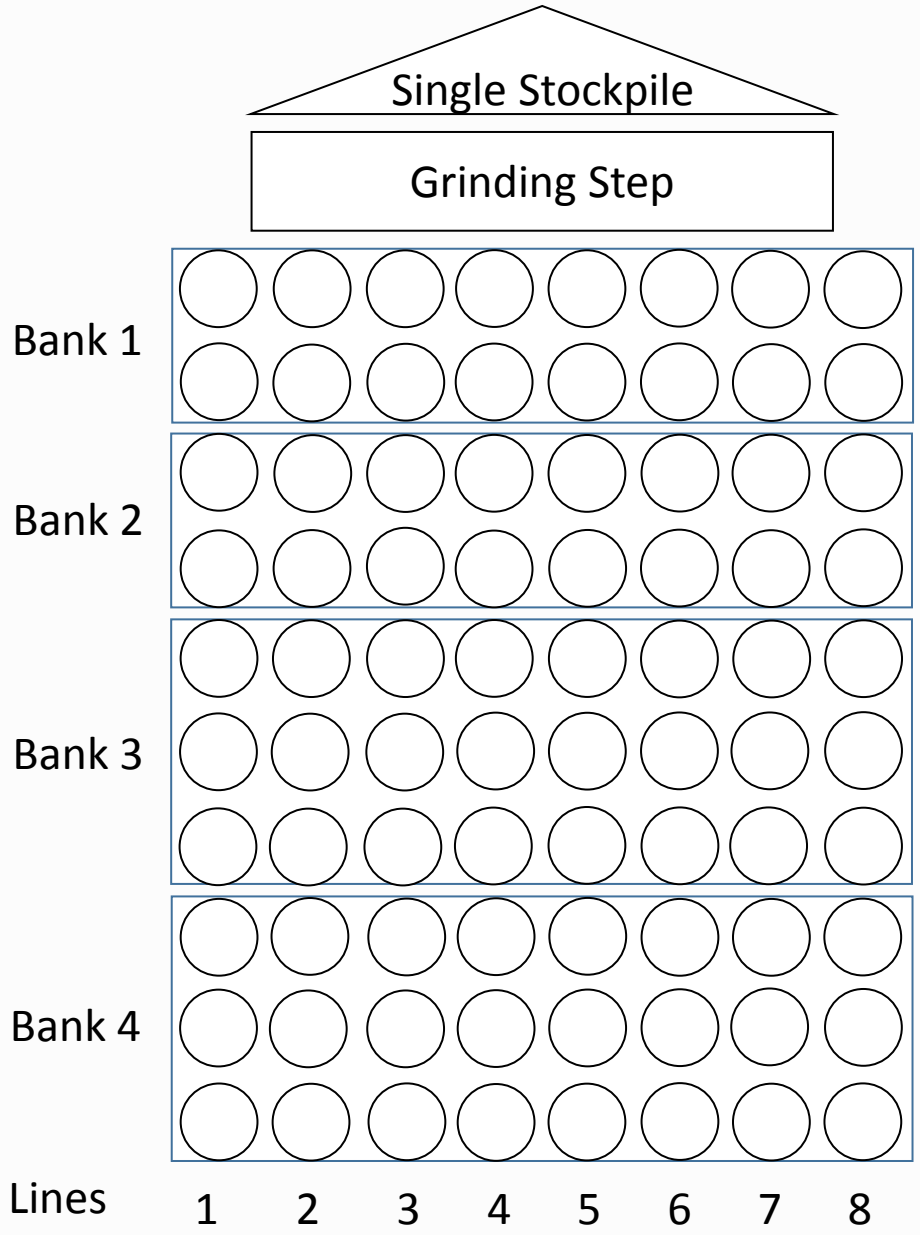
- Maximum lenght of a bank: Grade in last cell ≥ Feed grade (G. Agar criteria, 1980)
- Stream mix: To join similar composition material assures the “concentration process efficiency” (exergy principle)
- Froth profile: Keep the smallest height under a “concentrate grade” constrain. This drives to growing or parabolic profile

Banks and Lines

CONCENTRATOR	CELL VOLUME,m^3	NUMBER OF CELLS	BANK ARRANGEMENT	DIAGRAM
Esperanza	300	7	1-2-2-2	
Candelaria	130	10	2-2-2-2-2	
Pelambres	130	9	1-2-2-2-2	
	250	5	1-1-1-1-1	
Chuquicamata	160	8	2-2-2-2	
Escondida	160	9	1-1-1-1-2-2-1	
	100	10	2-2-3-3	
Collahuasi	130	9	1-2-2-2-2	
	160	8	1-2-2-2-2	
Andina	100	8	2-2-2-2	

http://www.iimp.org.pe/pptjm/jm20140508_Yianatos.pdf

Parallel Line Arrangement…



The Rougher Scavenger Step

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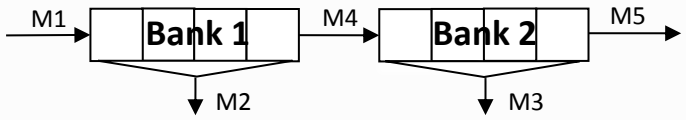
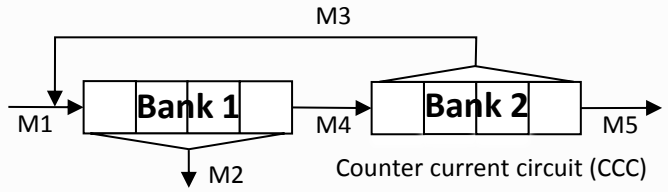
Direct Open circuit (DOC)

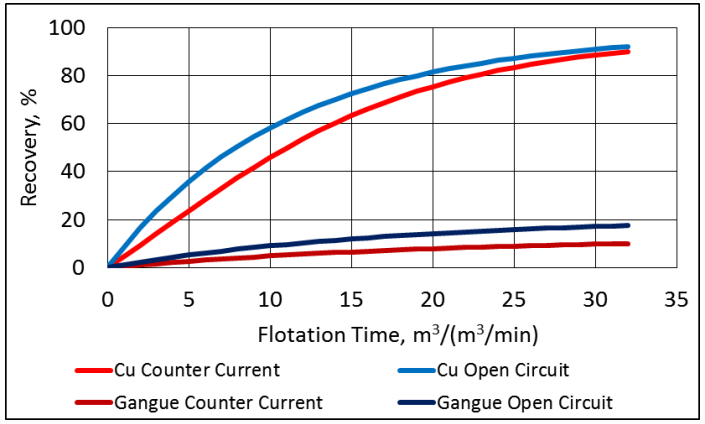


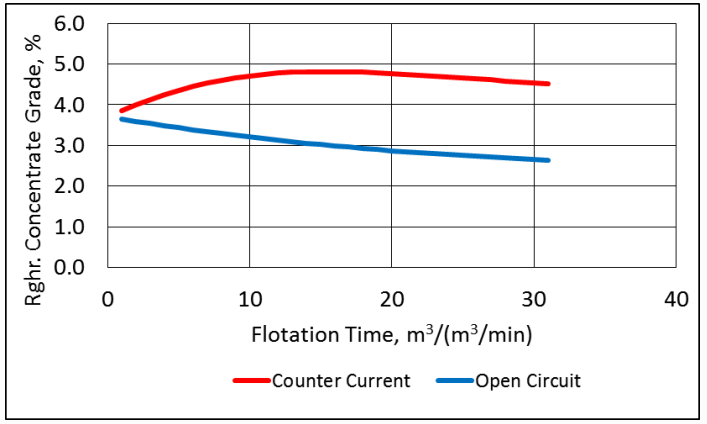


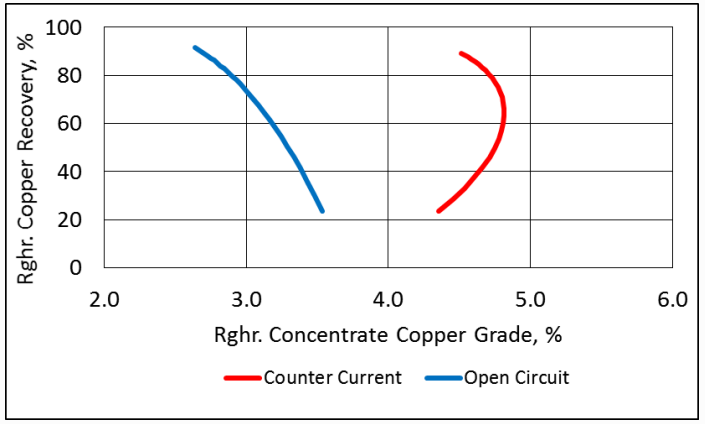
Counter current circuit (CCC)

$R_{Cu} = R_{1Cu} + R_{2Cu}\left(1 - R_{1Cu}\right)$	Copper Recovery	$R_{Cu} = \dfrac{R_{1Cu}}{1 - R_{2Cu} + R_{1Cu}R_{2Cu}}$
$R_{Gn} = R_{1Gn} + R_{2Gn}\left(1 - R_{1Gn}\right)$	Gangue Recovery	$R_{Gn} = \dfrac{R_{1Gn}}{1 - R_{2Gn} + R_{1Gn}R_{2Gn}}$
$Cu_{Conc} = Cu_{Feed}\dfrac{R_{1Cu} + R_{2Cu}\left(1 - R_{1Cu}\right)}{R_{1Gn} + R_{2Gn}\left(1 - R_{1Gn}\right)}$	Concentrate Grade	$Cu_{Conc} = Cu_{Feed}\dfrac{R_{1Cu}}{R_{1Gn}}\dfrac{1 - R_{2Gn} + R_{1Gn}R_{2Gn}}{1 - R_{2Cu} + R_{1Cu}R_{2Cu}}$

Example $R_{1Cu} = R_{2Cu}$:





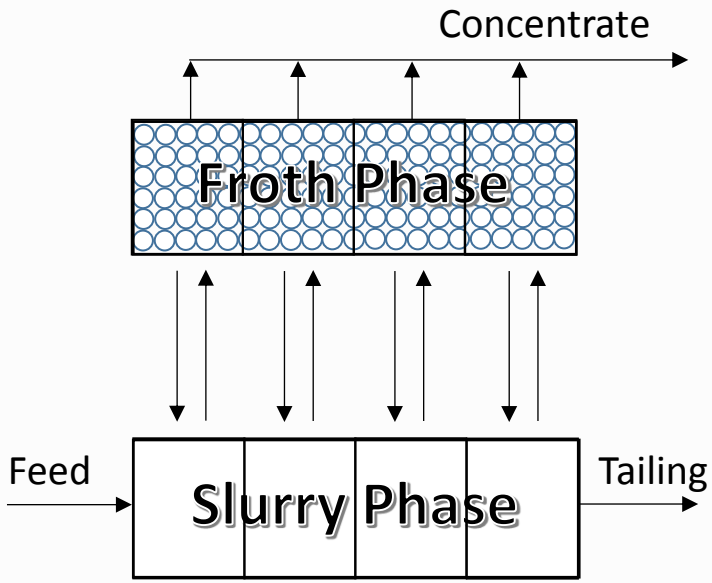


CCC is the most efficient way to concentrate, but not the highest capacity way. Recovery becomes the same in the plateau region, with the higher grade advantage. It always reduces requirement in the cleaning step.

The Outstanding Role of the Froth

Froth control is a key aspect to optimize the flotation results. Consequently, any optimization model must have explicit dependency with the froth height and velocity in order to be realistic.

Bank flotation model: N well-mixed reactor connected in-series; first order kinetics, Cu and gangue components; Slurry and froth phases



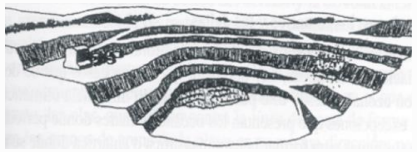
$$R_{Cu} = \frac{R_{Cu,\infty}\left(1-\left(1+\frac{k_{Cu}\,\tau_S}{N}\right)^{-N}\right)\exp\left(-k_{Cu,F}\,\tau_F\right)}{1-R_{Cu,\infty}\left(1-\left(1+\frac{k_{Cu}\,\tau_S}{N}\right)^{-N}\right)\left(1-\exp\left(-k_{Cu,F}\,\tau_F\right)\right)}$$

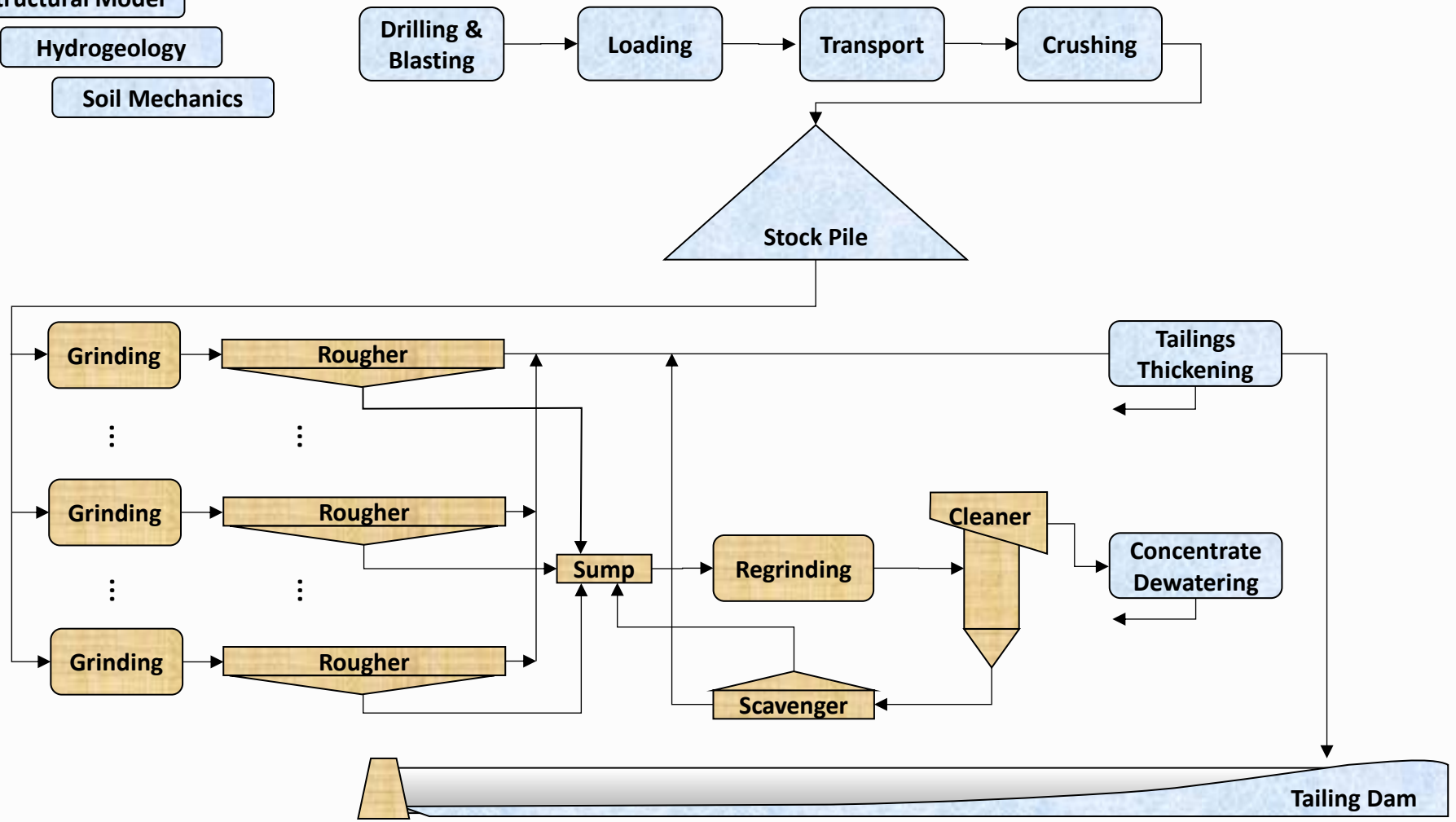
$$R_{Gn} = \frac{R_{Gn,\infty}\left(1-\left(1+\frac{k_{Gn}\,\tau_S}{N}\right)^{-N}\right)\exp\left(-k_{Gn,F}\,\tau_F\right)}{1-R_{Gn,\infty}\left(1-\left(1+\frac{k_{Gn}\,\tau_S}{N}\right)^{-N}\right)\left(1-\exp\left(-k_{Gn,F}\,\tau_F\right)\right)}$$

Ref.: Client DRM Report 350-01-2011

The Flotation Plant is Part of a Major System…

- Geology
- Geo Mechanics
- Geo Technics
- Structural Model
- Hydrogeology
- Soil Mechanics





Business Strategies

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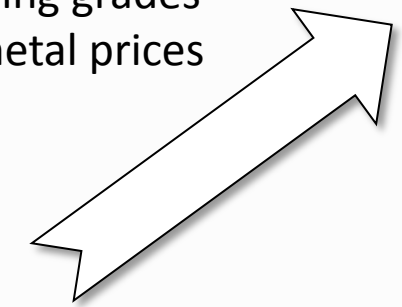
Main Driving Forces

- ✓ Decreasing grades
- ✓ Cyclic metal prices



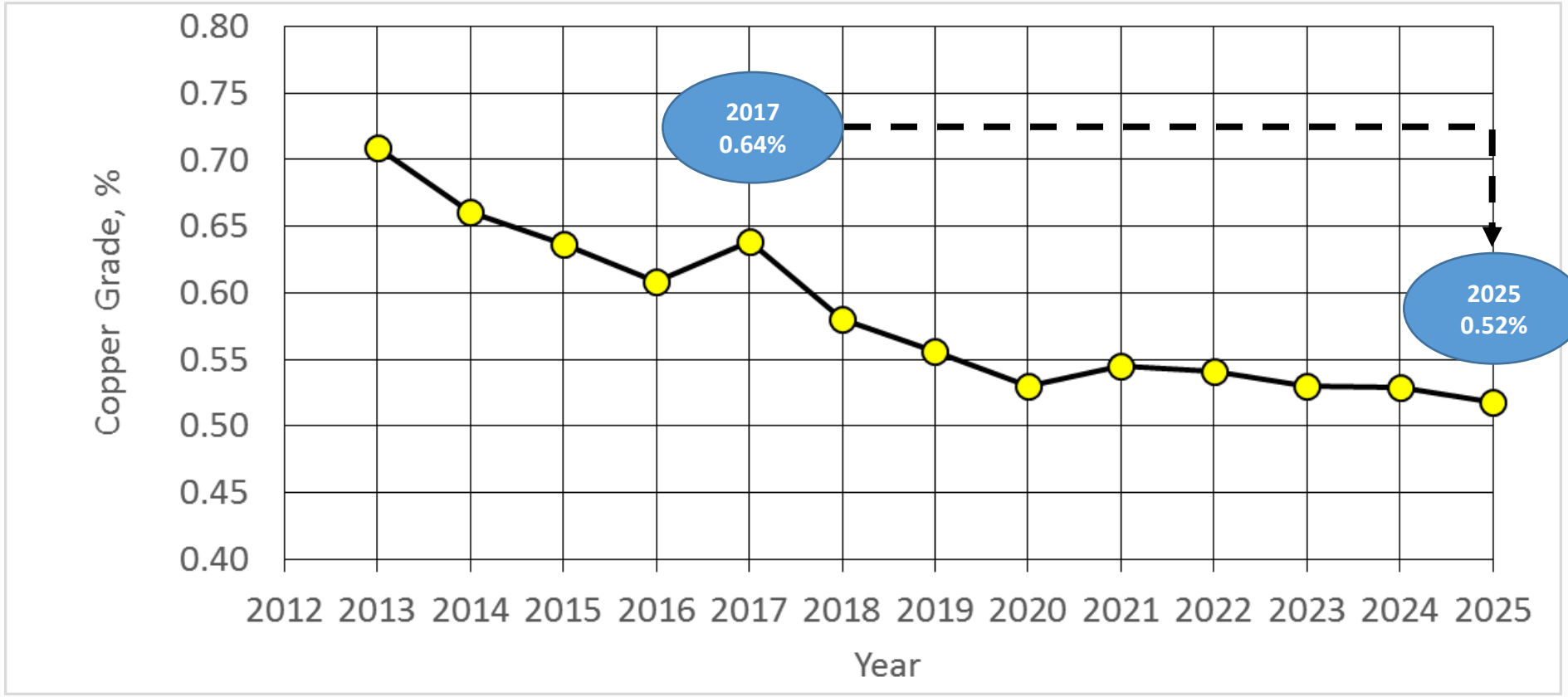
Usual

- The largest throughput
- Intensive blasting
- Coarse grinding
- The simplest flotation circuit
- High water recovery
- Contained cost policy
- ***And pray for the price keep high!!!***

Required

- Precon tech to avoid excessive tonnages
- Business view from geology to market
- Tailings as potential asset
- Automation within Big Data and IoT frame
- Flexible process chain and modular plants
- Maximum water recovery
- Improved management of mine stocks
- Metallurgical blasting
- Process-oriented maintainability

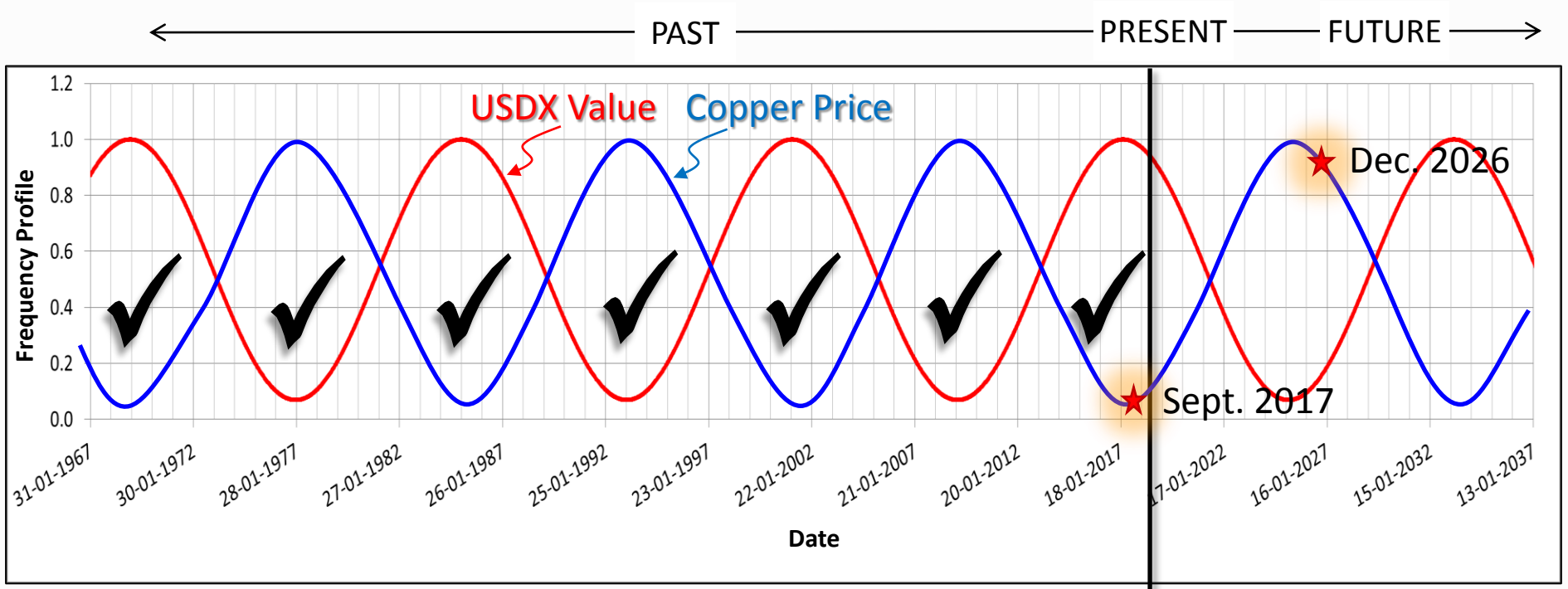
Projected Cu Grade in Chile



https://www.cochilco.cl/Listado%20Temtico/Inversi%C3%B3n%20en%20la%20miner%C3%ADa%20chilena%20-%20Cartera%20de%20proyectos%202014%20-2023.pdf

http://www.miningpress.com/nota/294168/la-hora-de-invertir-en-cobre-la-recuperacion-gradual-de-las-materias-primas

Cyclic Behavior of the Copper Price

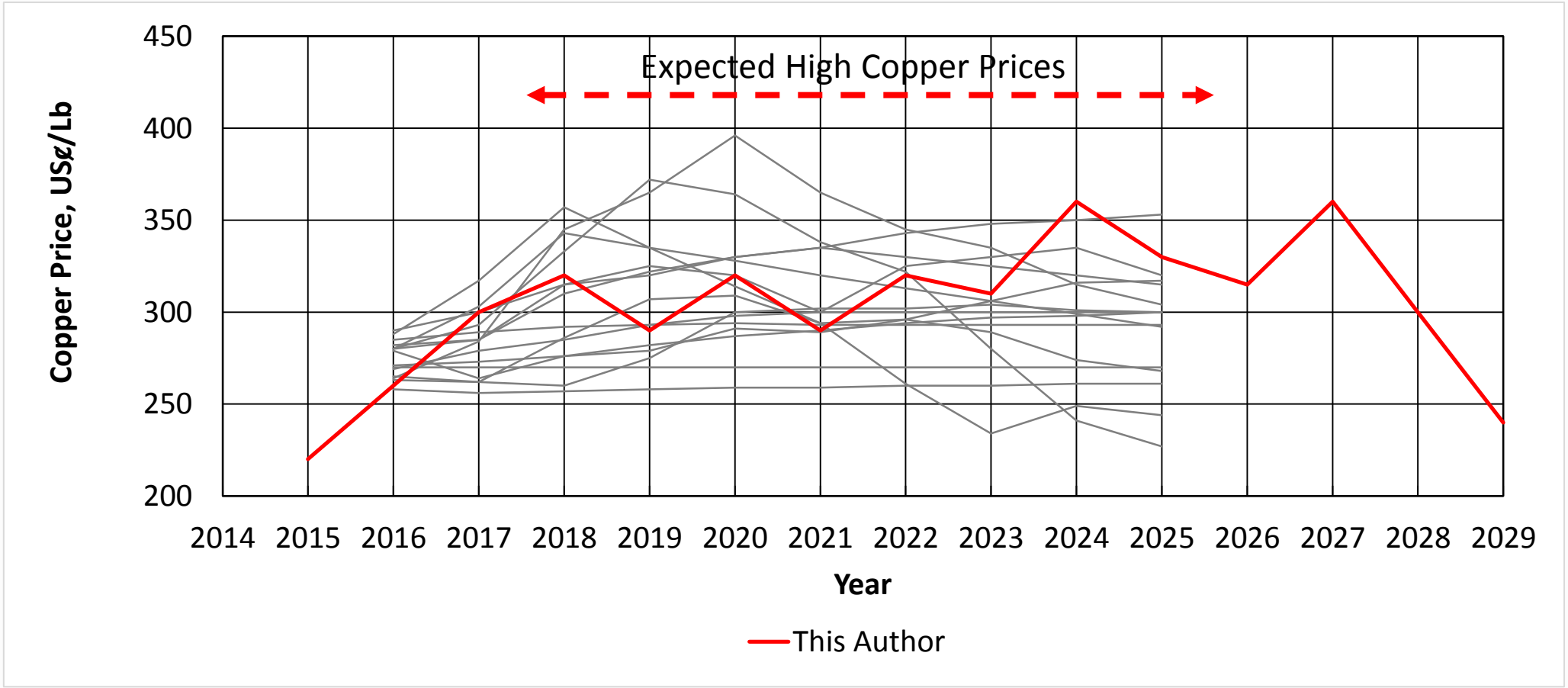


- There is a strong inverse correlation between Copper price and the USDX index.
- A high price wave is expected to occur since middle of 2017 to end of 2026.
- This plot indicates frequency of occurrence, but not magnitude.

June 2018

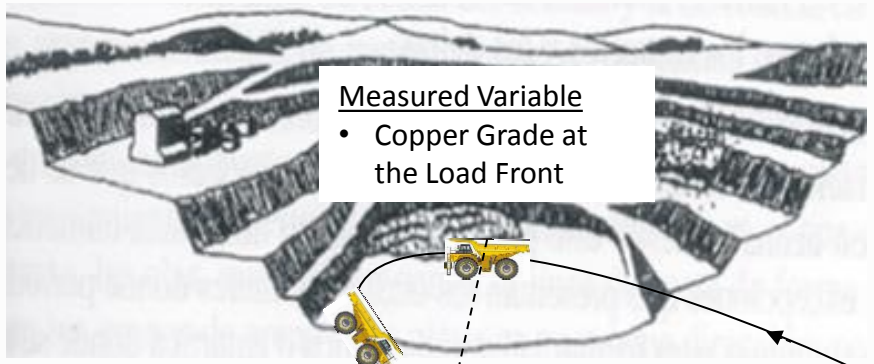
J. Menacho, "Macroeconomics and the Copper Business: Past, Present and Future" 8th Int. Seminar on Process Hydrometallurgy, Santiago, June 15– 17, 2016.

Future Price According to Experts



http://www.portalminero.com/display/NOT/2015/08/12/Expertos+estiman+precio+del+Cobre+sobre+USD+3%2C00+por+libra+en+2018-2022

The Mine is not a Supermarket, but It Should Be…



Measured Variable
- Copper Grade at the Load Front

Handled Variable
- Track Destination
- Carrousel Synchrony

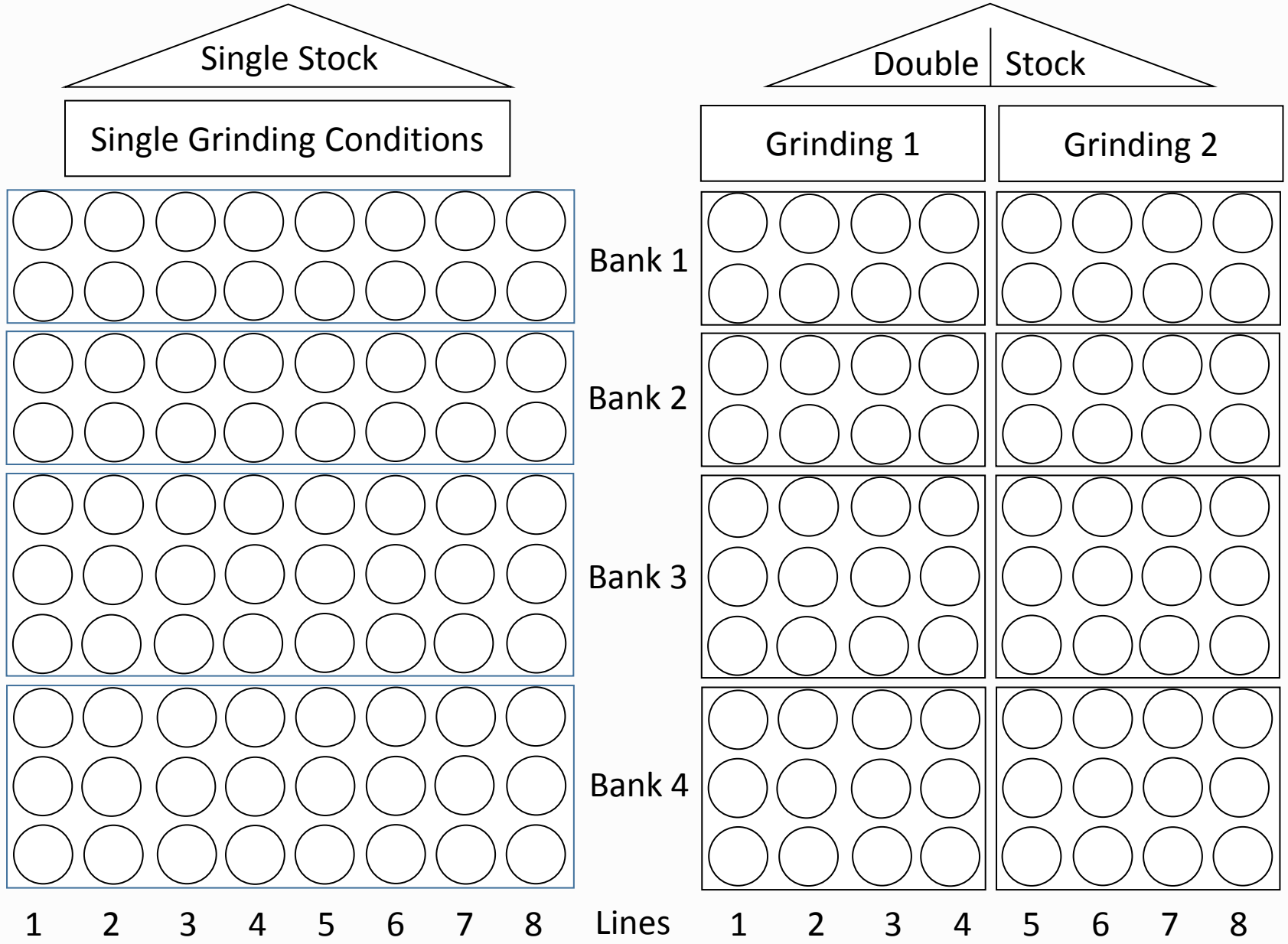
Dispatch System Control Room

Controlled Variable
- Copper Grade
- Constrain: Throughput per Line

High Grade Ore Conveyor

Low Grade Ore Conveyor

Accomodating the Flotation Circuit



Tailings: From Waste to Asset

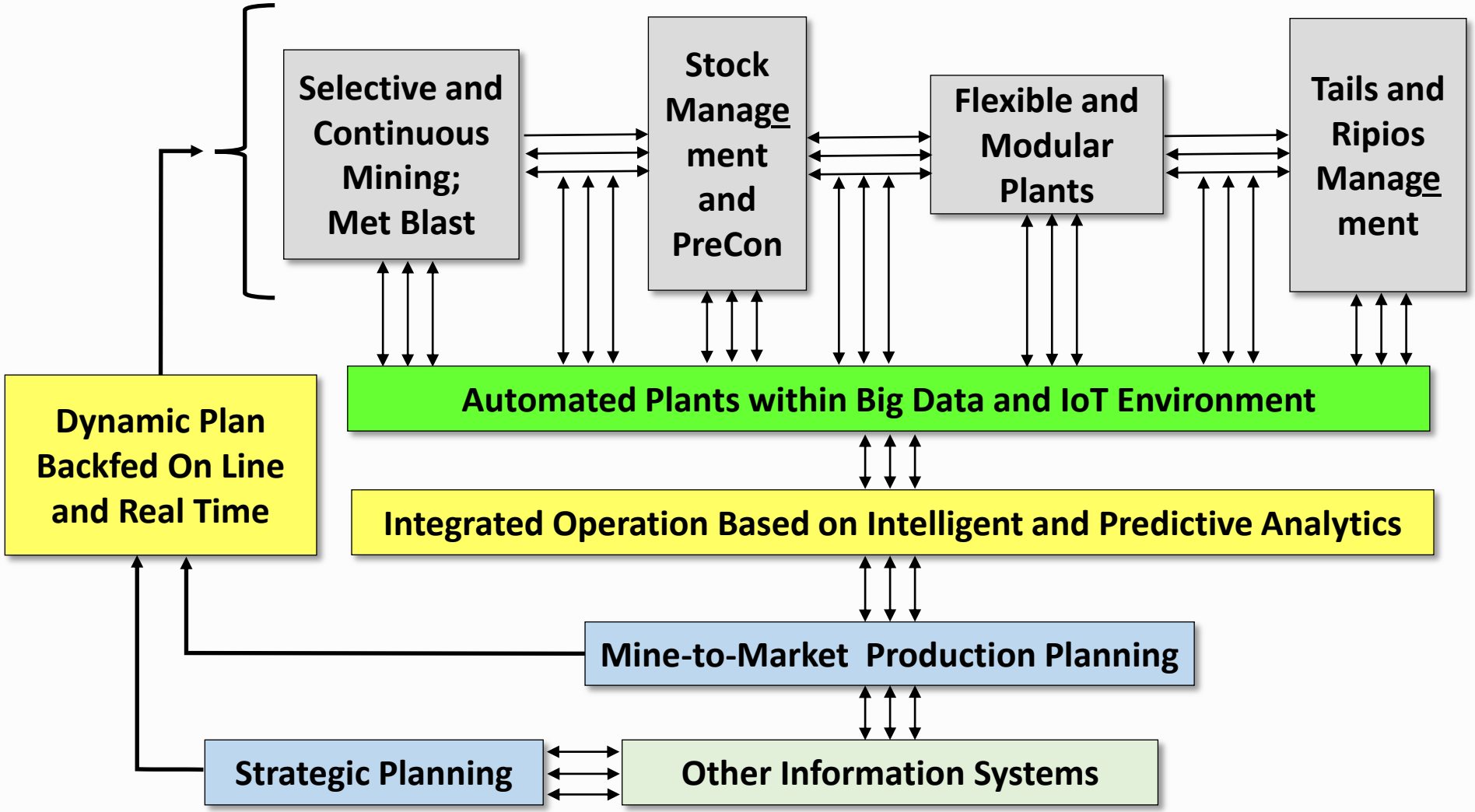
Historically, plants have shown little concern on systematic waste disposal… key aspect to economically recover valuable components.

Classical Waste Disposal

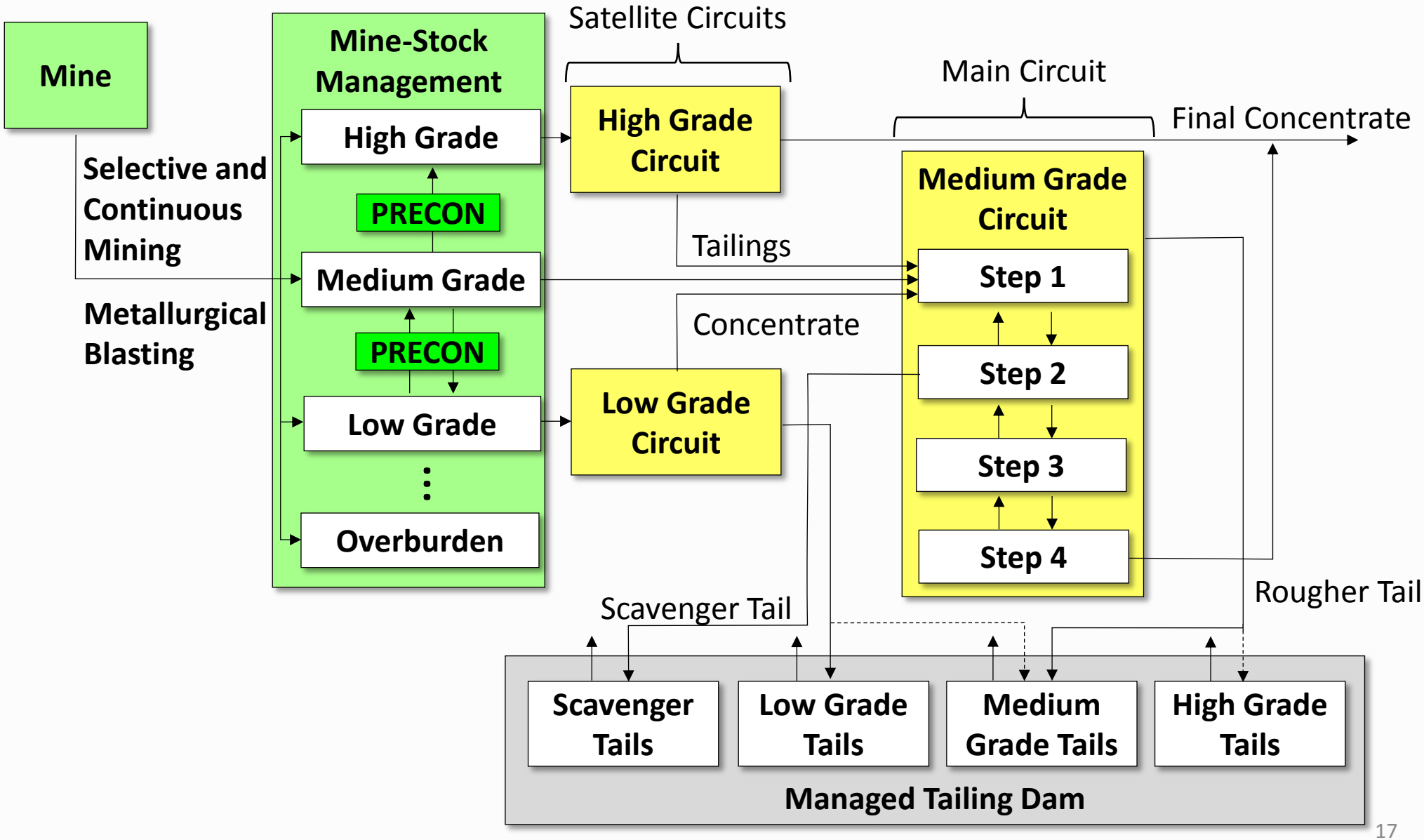
Modern Design of Waste Dams

J. Menacho, "Mine-to-Plant Strategies within the Cyclic Copper Business" 12th International Mineral Processing Conference, Santiago, 26 – 28 de Octubre 2016.

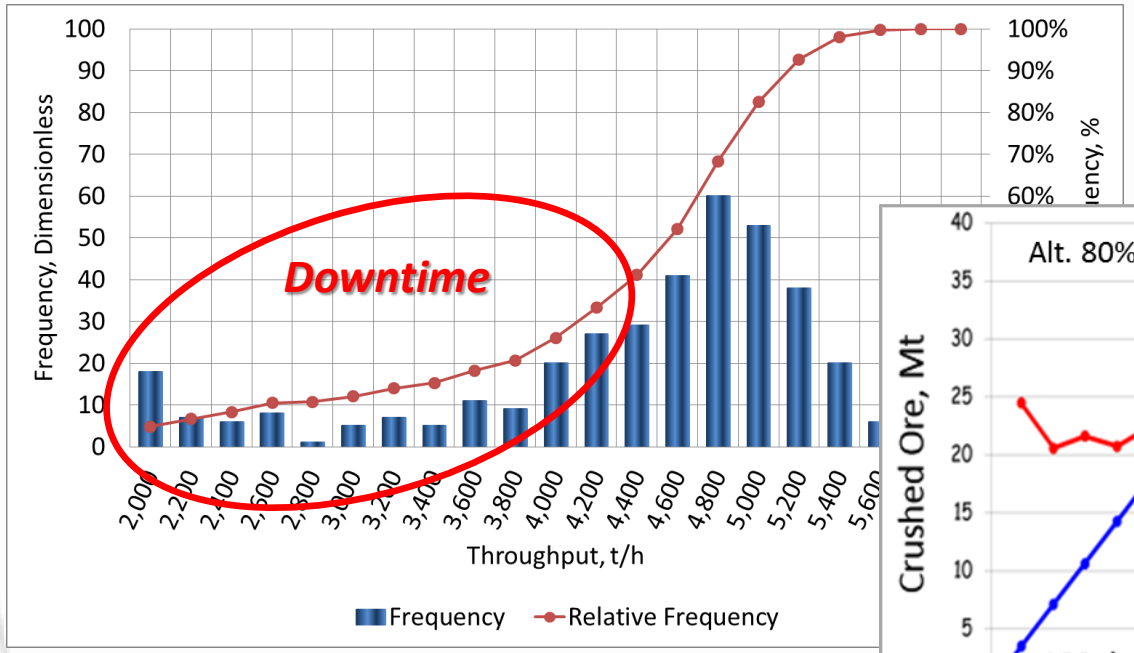
Smart Planning and Operation



Re-Thinking the Overall Circuit…

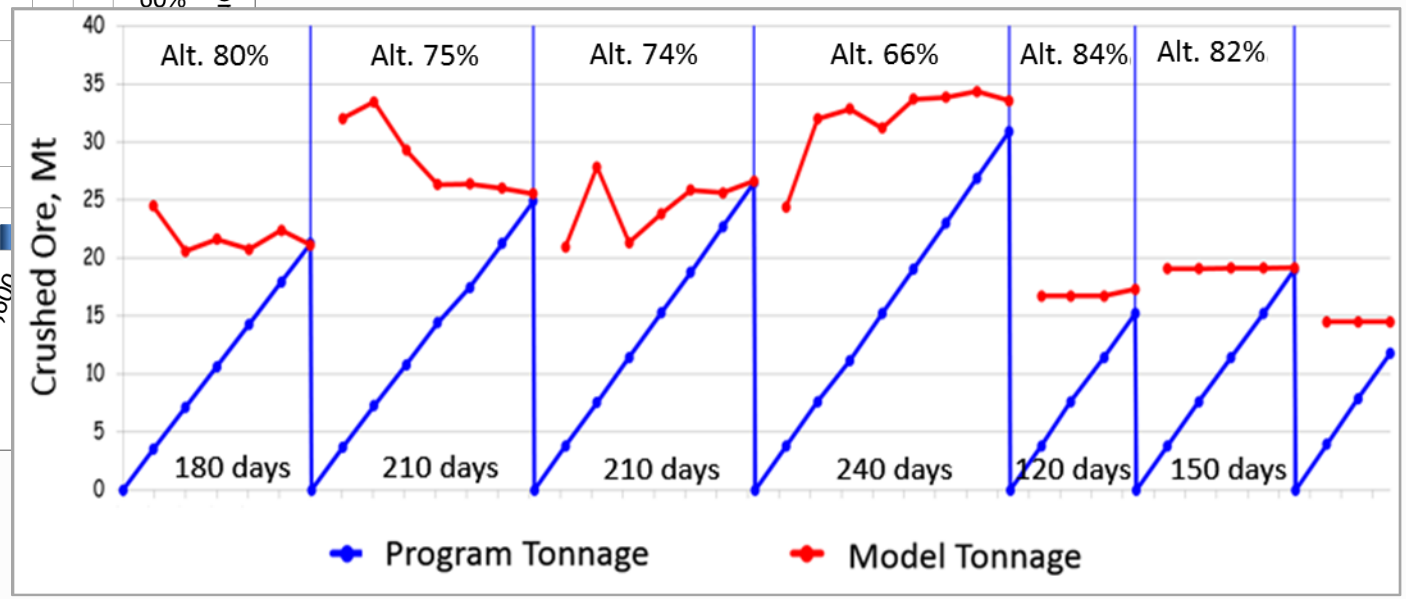


Keep High Reliability, Availability and Utilisation KPI´s…



Optimal Maintainability needs to synchronize the Fail occurrence to Ore-Process-Machines and the Maintenance intensity.

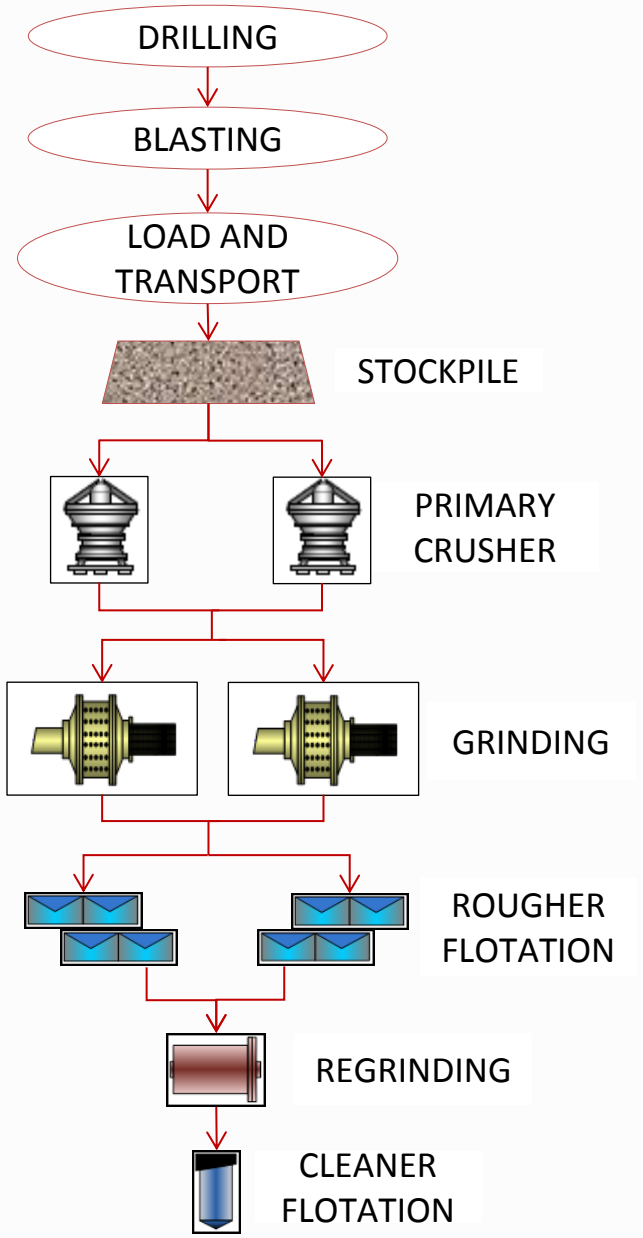
Example: Prediction of concave change in the primary crusher from geological and process model:



… In addition to pure Maintainance models, integrated predictors are useful for optimum planning.

Study Case

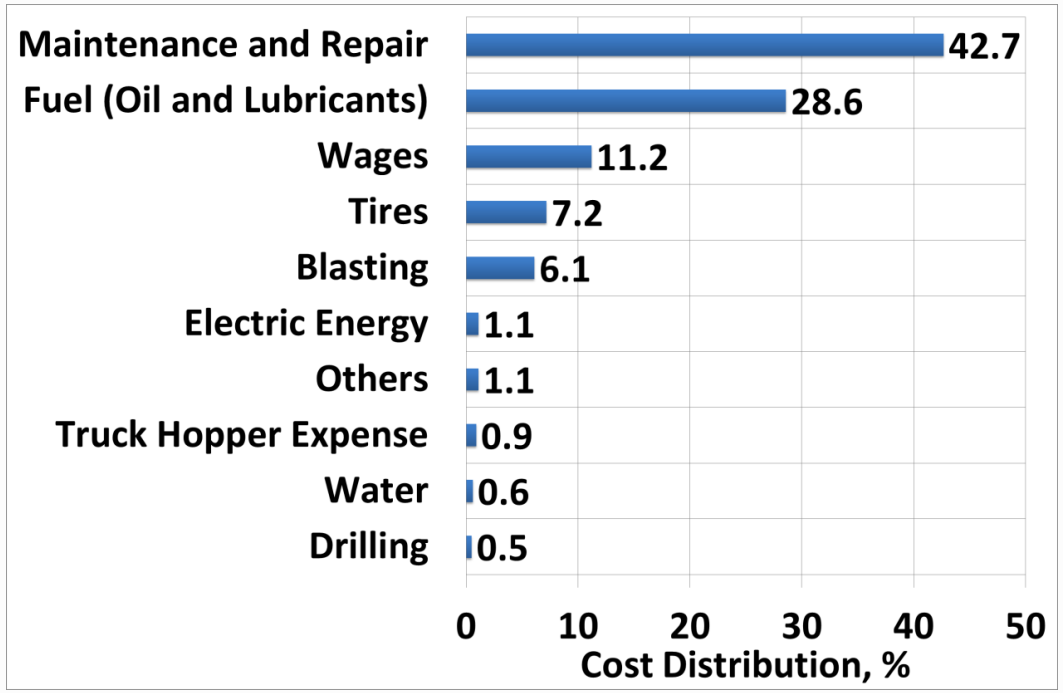
Plant Description



Main Operational Conditions

DRILLING AND BLASTING	
Burden, m	8.0
Spacing, m	9.0
Powder Factor FC, g/t	500
Drilling Diameter, in	12.25
ORE IN STOCKPILE	
CuT,%	1.19
FeT,%	1.71
Cpy,%	1.21
Cc,%	0.78
Cv,%	0.25
CRUSHING	
Throughput, t/h	4,257
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, %	32
Grinding Total Power, kW	50,973
FLOTATION	
Rougher Flotation Time, min	28.13
Collector Dose, g/t	12
Rougher Mean Froth Height, cm	80
Cleaner Mean Froth Height, cm	80

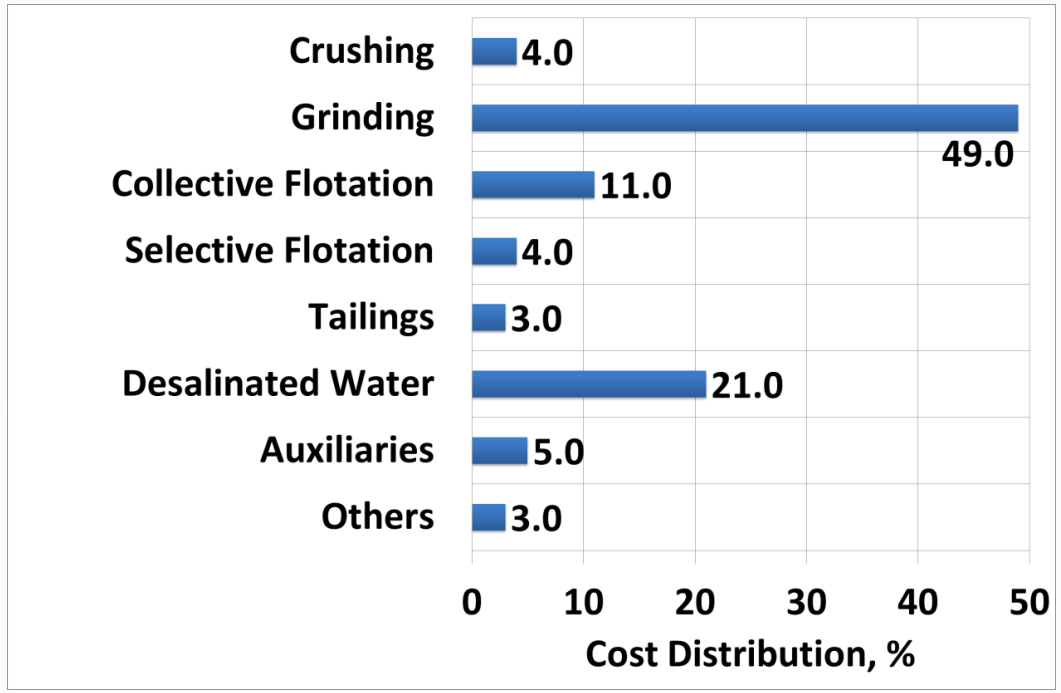
OPEX Distribution



Open-pit Mine
Cost Distribution

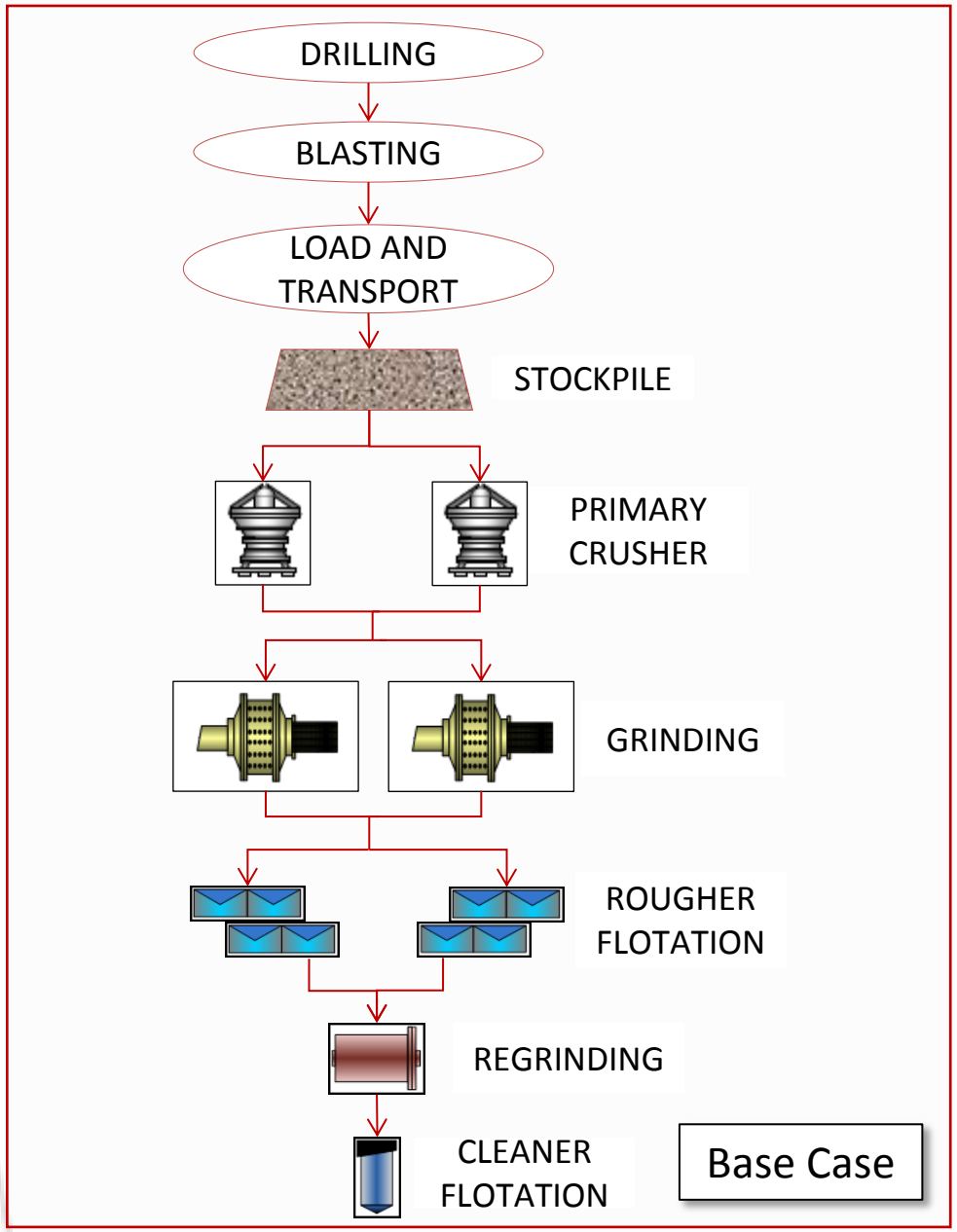
Note: Wages are Included Into each Item.

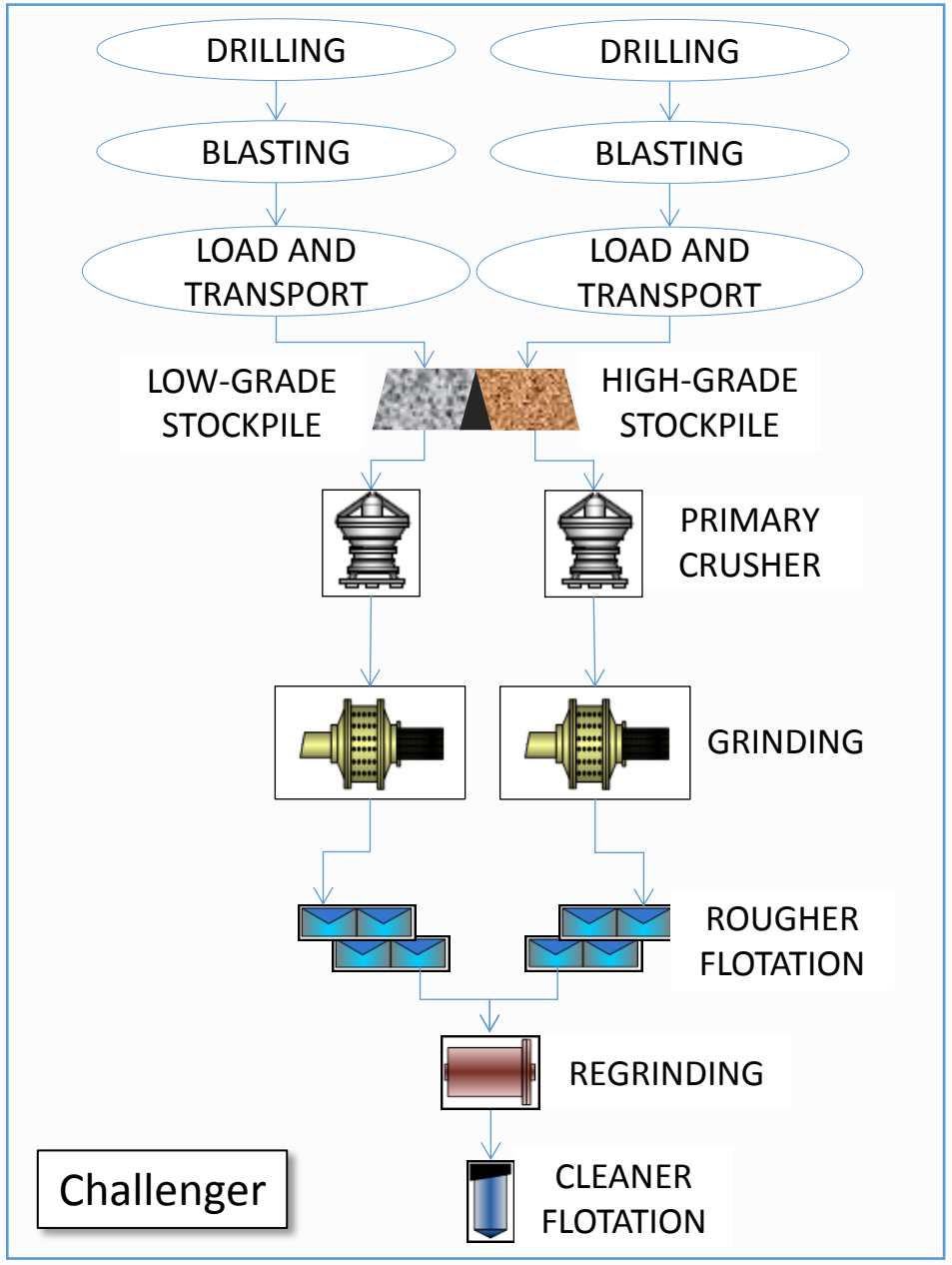
Concentrator Plant
Cost Distribution



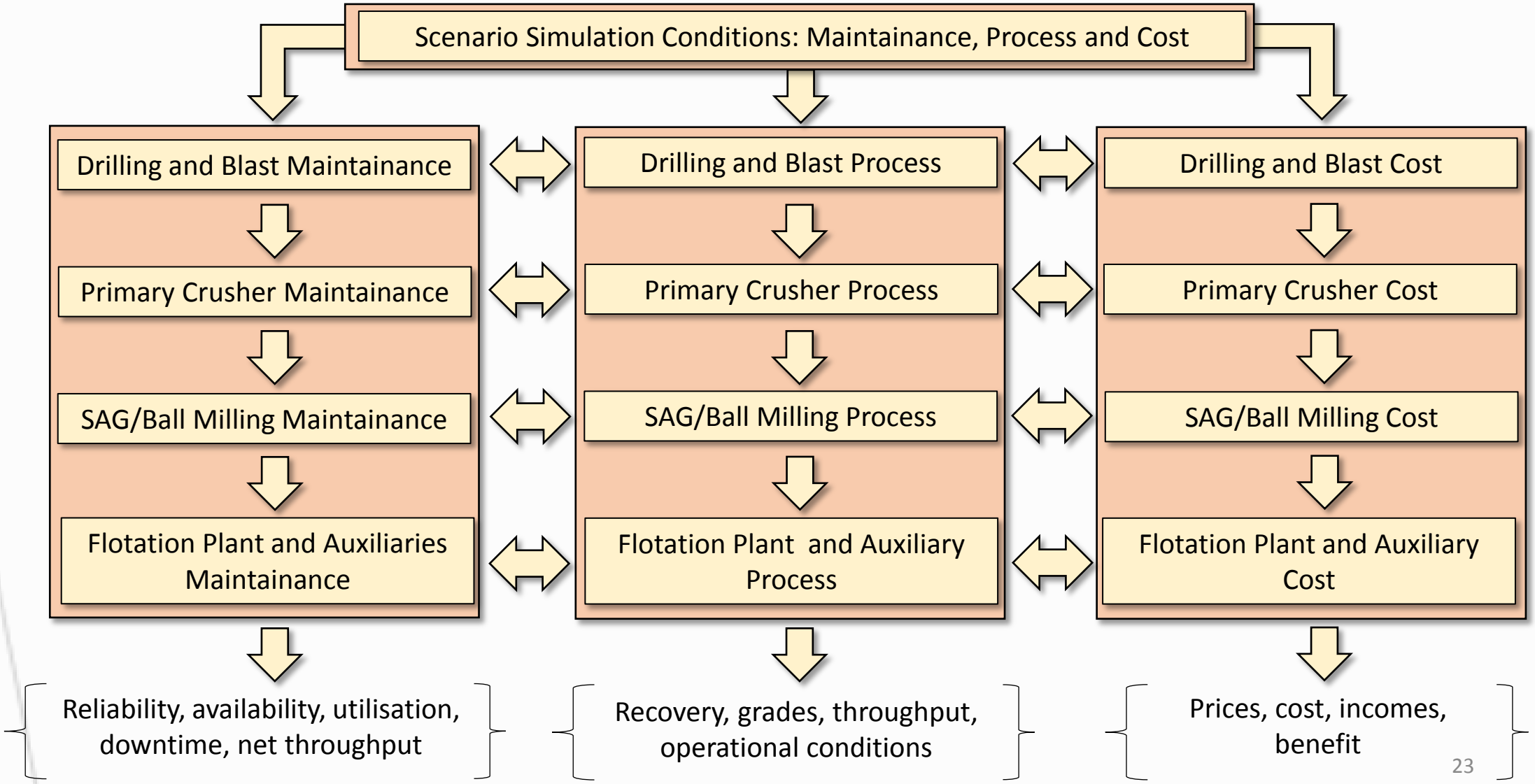
Cochilco, "Identificación de insumos críticos para el desarrollo de la minería en Chile", Pub. 2014.

Options to Be Evaluated





Technical-Economical Dynamic Simulator as Planning Tool



Process-Model Calibration

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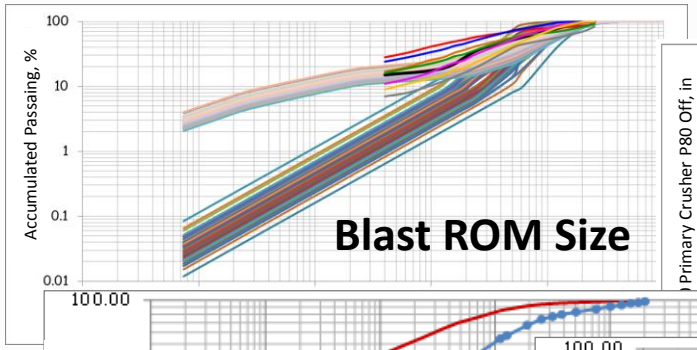
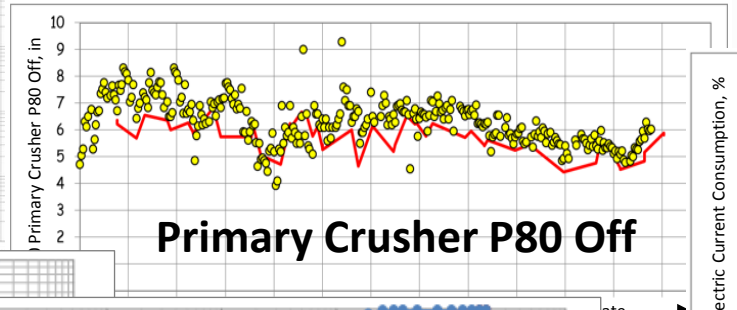
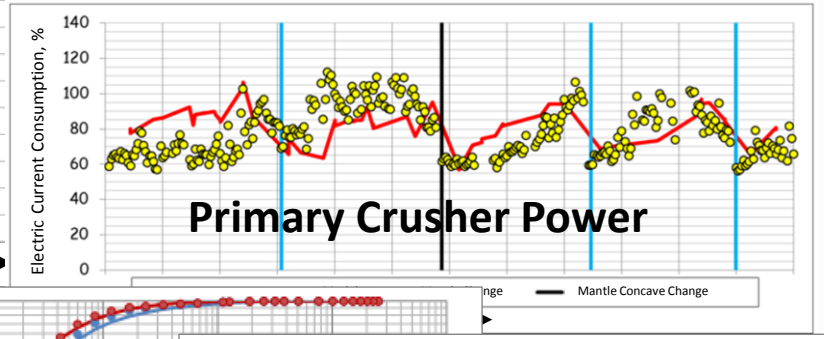
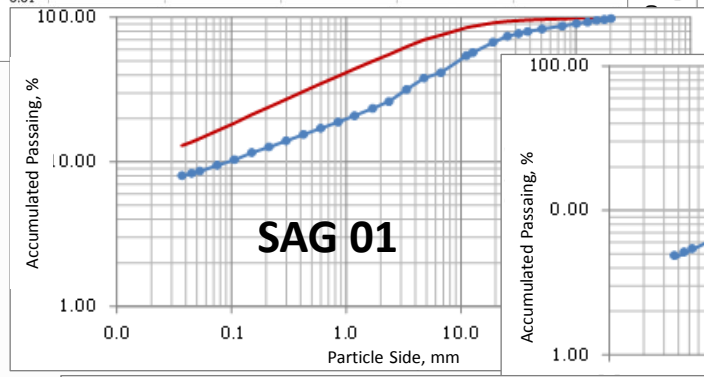
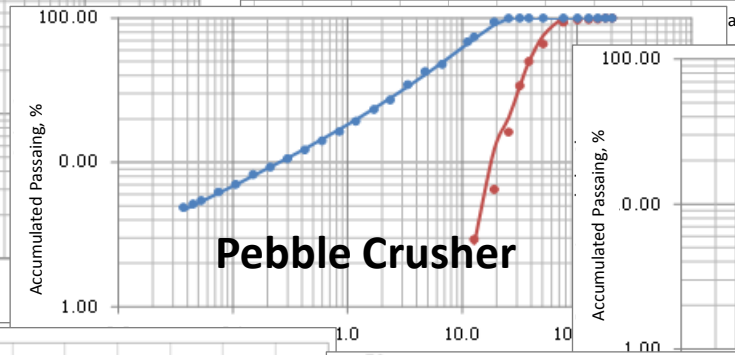
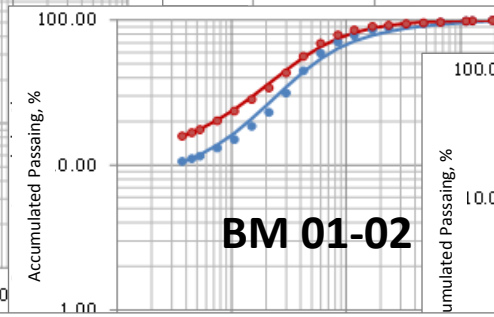


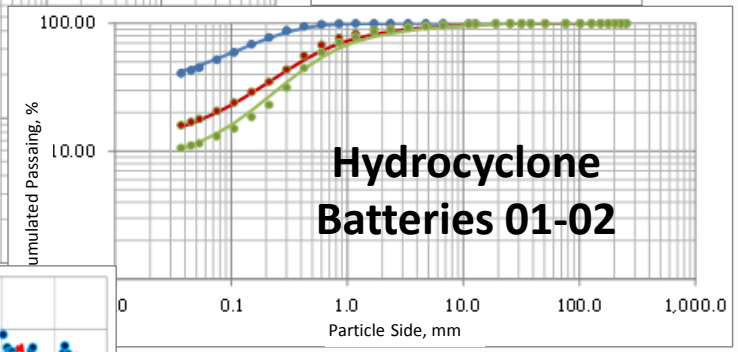


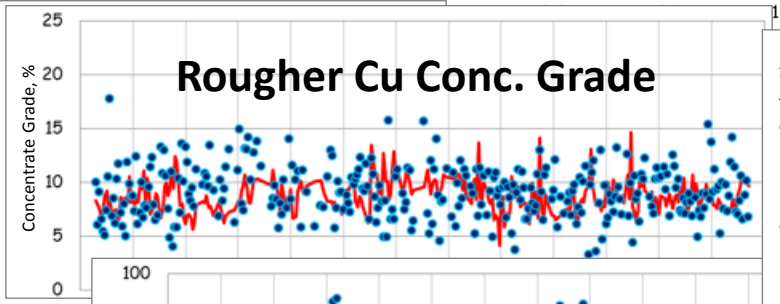


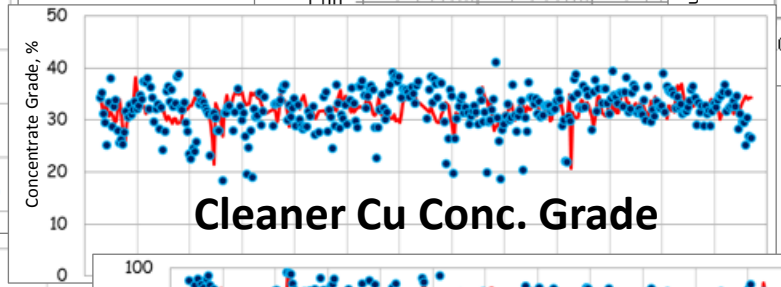


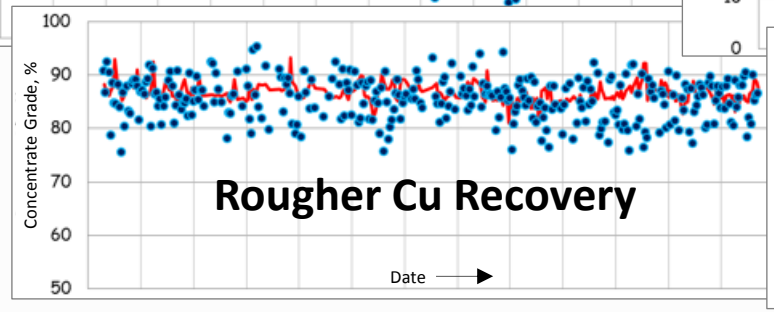


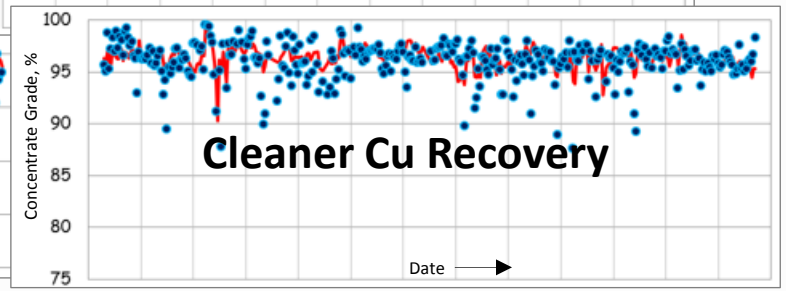








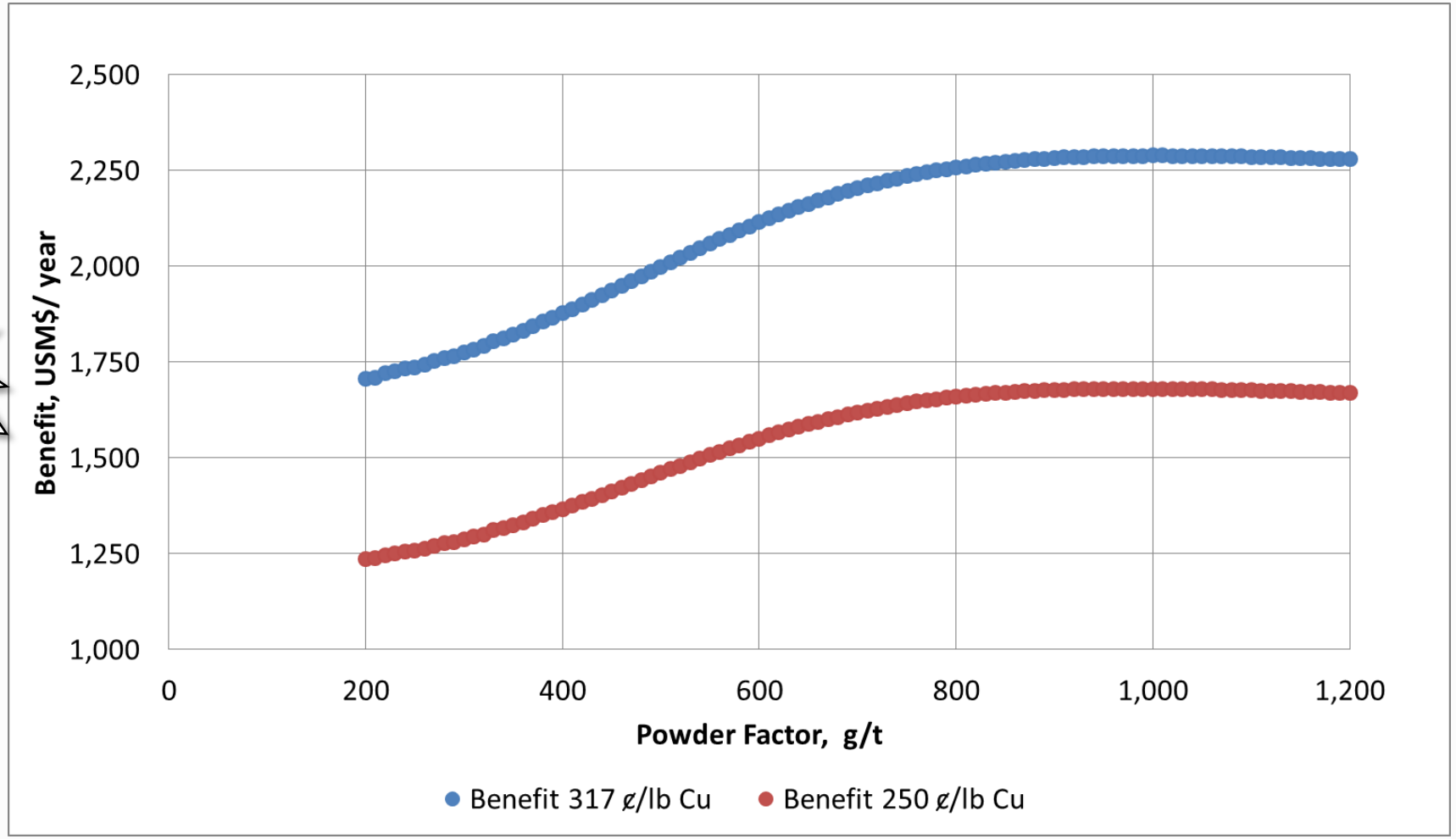




Model description is beyond the scope of this presentation

Net Benefit vs Powder Factor

Sensitivity Analysis



Powder Factor, g/t	CuT, %	FeT, %	Cpy, %	Cc, %	Cv, %	Tonnage, t/h	Cp, %	BM Ball Filling,%	+100#, %	Collector Dose, g/t	Rghr. Froth Height, cm	Clnr. Froth Height, cm
Variable	1.2	1.7	1.2	0.8	0.3	4,591	29.7	32	Variable	12	80	80

Overall Recovery/Grade vs Powder Factor

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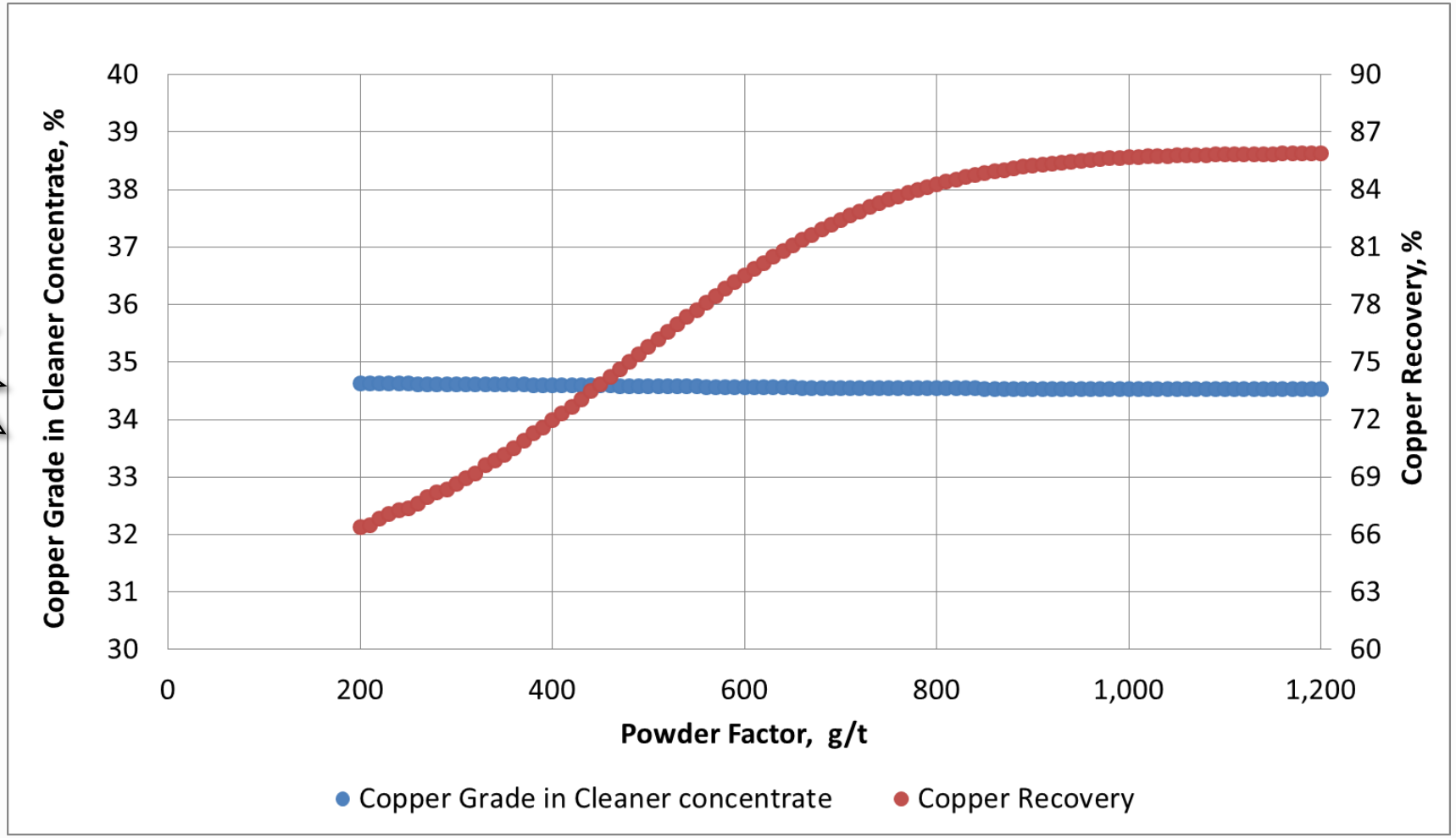
Sensitivity Analysis



Powder Factor, g/t	CuT, %	FeT, %	Cpy, %	Cc, %	Cv, %	Tonnage, t/h	Cp, %	BM Ball Filling,%	+100#, %	Collector Dose, g/t	Rghr. Froth Height, cm	Clnr. Froth Height, cm
Variable	1.2	1.7	1.2	0.8	0.3	4,591	29.7	32	Variable	12	80	80

Rghr. Recovery vs BM Filling in Ball Mills

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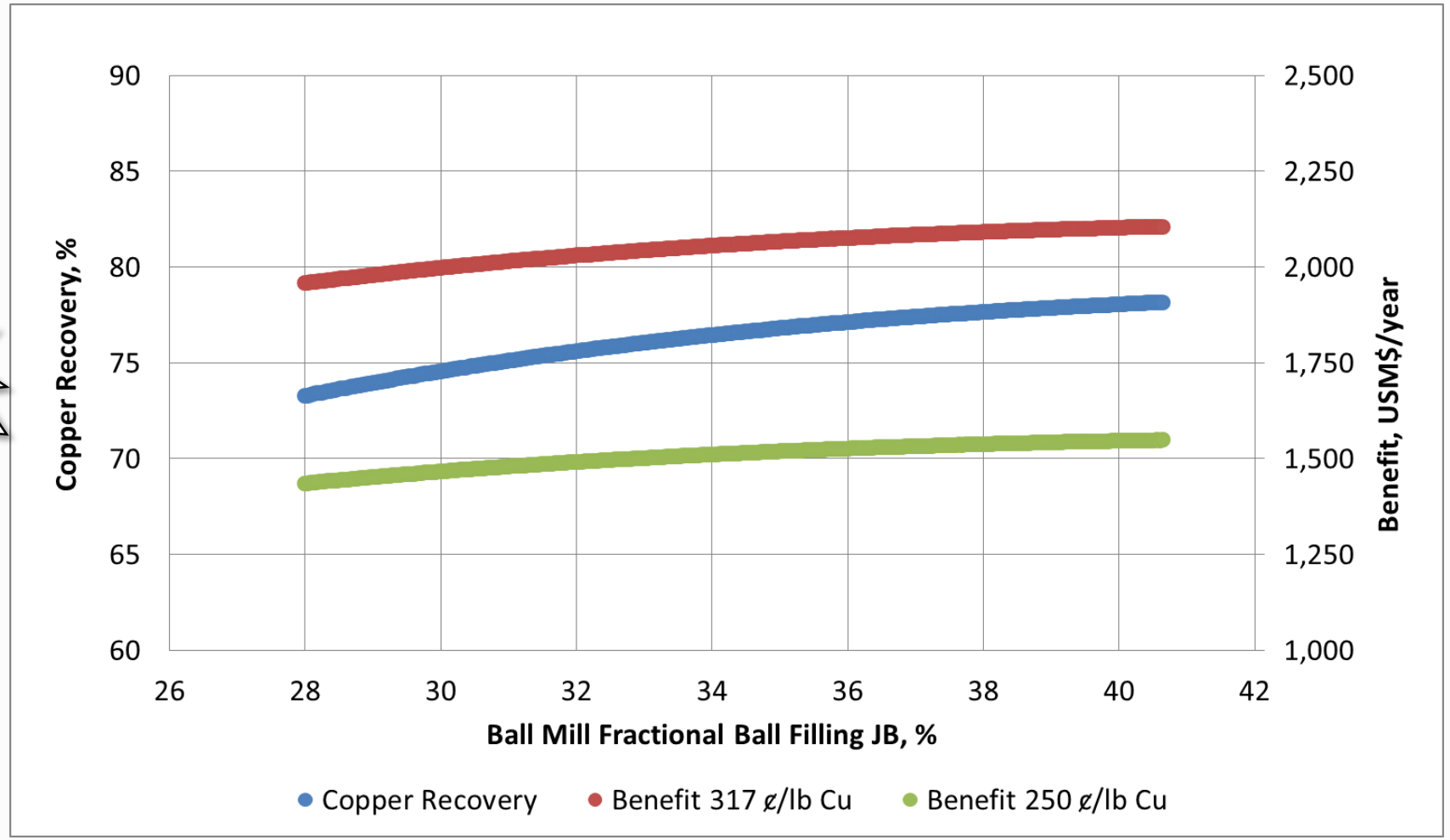
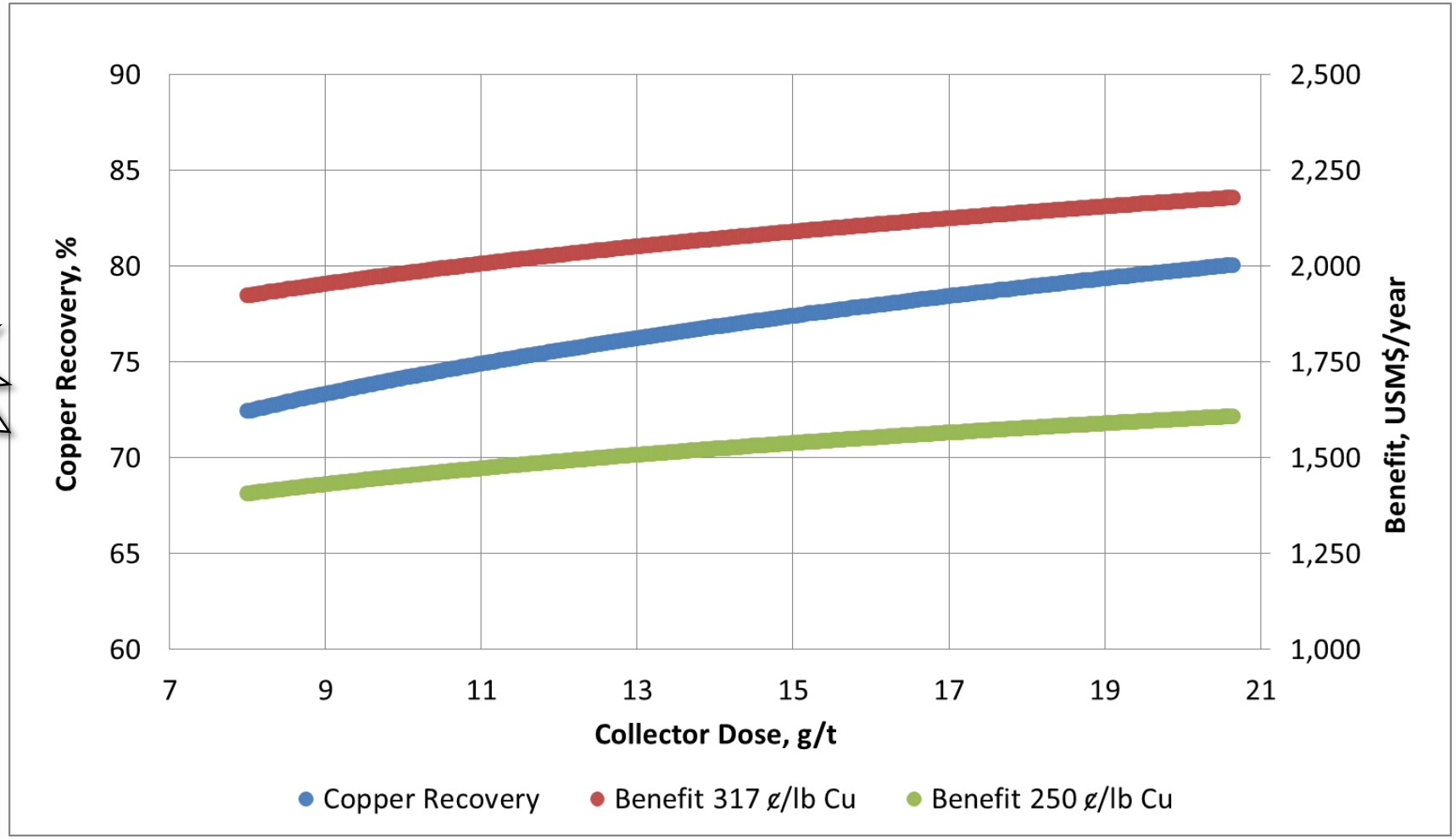
Sensitivity Analysis



Powder Factor, g/t	CuT, %	FeT, %	Cpy, %	Cc, %	Cv, %	Tonnage, t/h	Cp, %	BM Ball Filling,%	+100#, %	Collector Dose, g/t	Rghr. Froth Height, cm	Clnr. Froth Height, cm
500	1.2	1.7	1.2	0.8	0.3	4,591	29.7	Variable	Variable	12	80	80

Rougher Recovery vs Collector Dose

Sensitivity Analysis



Powder Factor, g/t	CuT, %	FeT, %	Cpy, %	Cc, %	Cv, %	Tonnage, t/h	Cp, %	BM Ball Filling,%	+100#, %	Collector Dose, g/t	Rghr. Froth Height, cm	Clnr. Froth Height, cm
500	1.2	1.7	1.2	0.8	0.3	4,591	29.7	32	28.3	Variable	80	80

Rougher Recovery/Grade vs Froth Height

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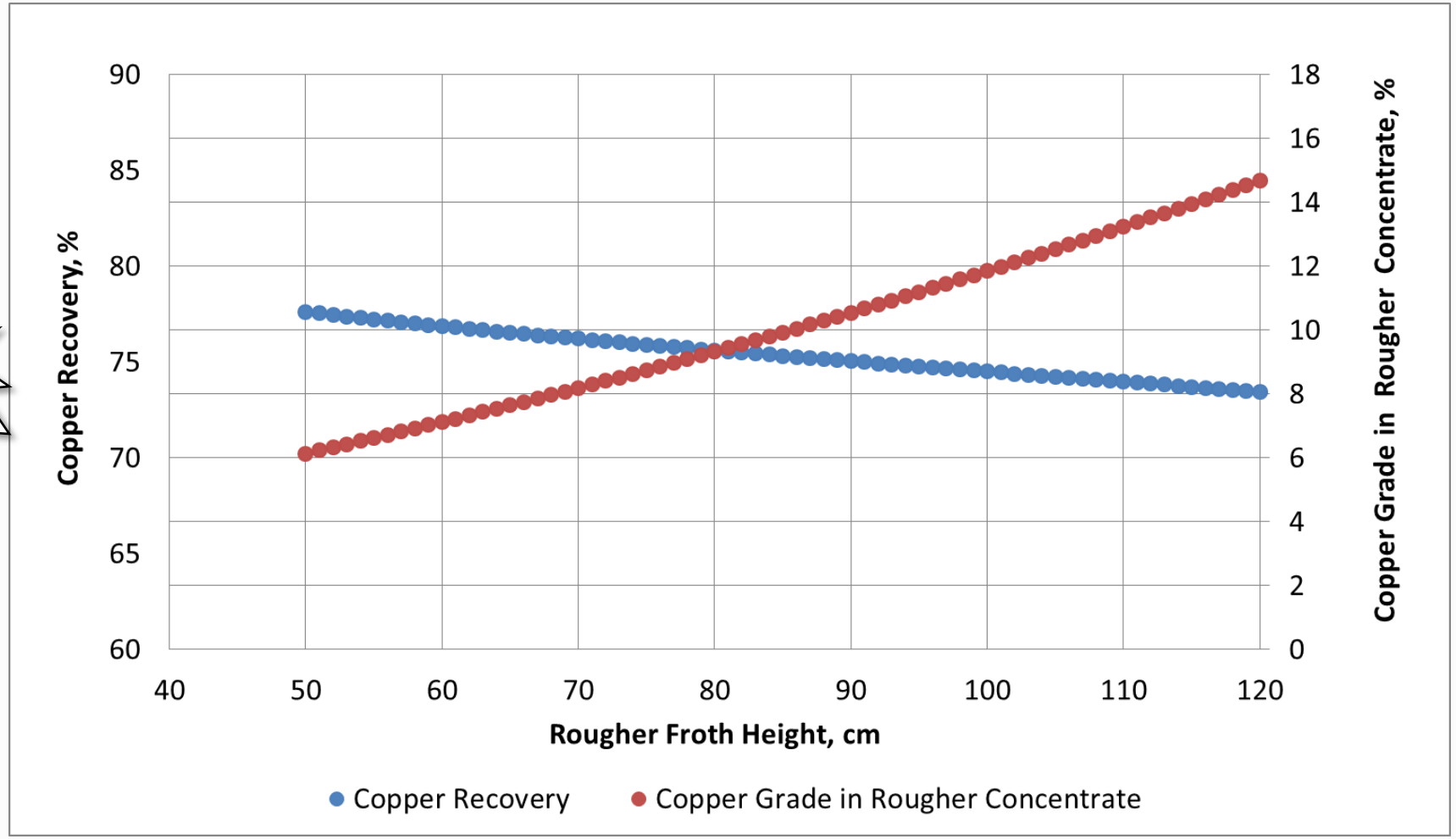
Sensitivity Analysis



Powder Factor, g/t	CuT, %	FeT, %	Cpy, %	Cc, %	Cv, %	Tonnage, t/h	Cp, %	BM Ball Filling,%	+100#, %	Collector Dose, g/t	Rghr. Froth Height, cm	Clnr. Froth Height, cm
500	1.2	1.7	1.2	0.8	0.3	4,591	29.7	32	28.3	12	Variable	80

Rghr. Recovery/Net Benefit/Particle Size

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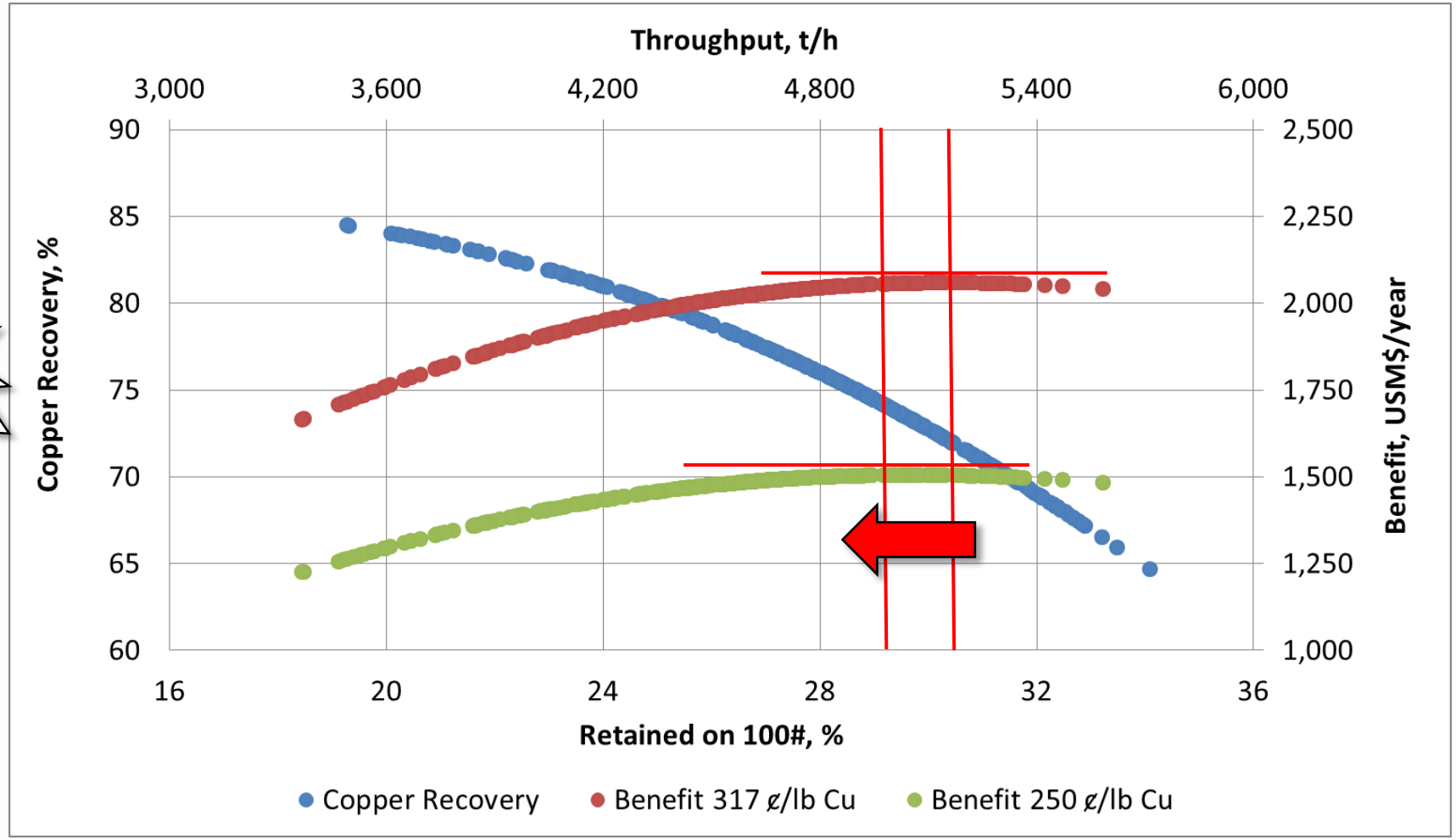
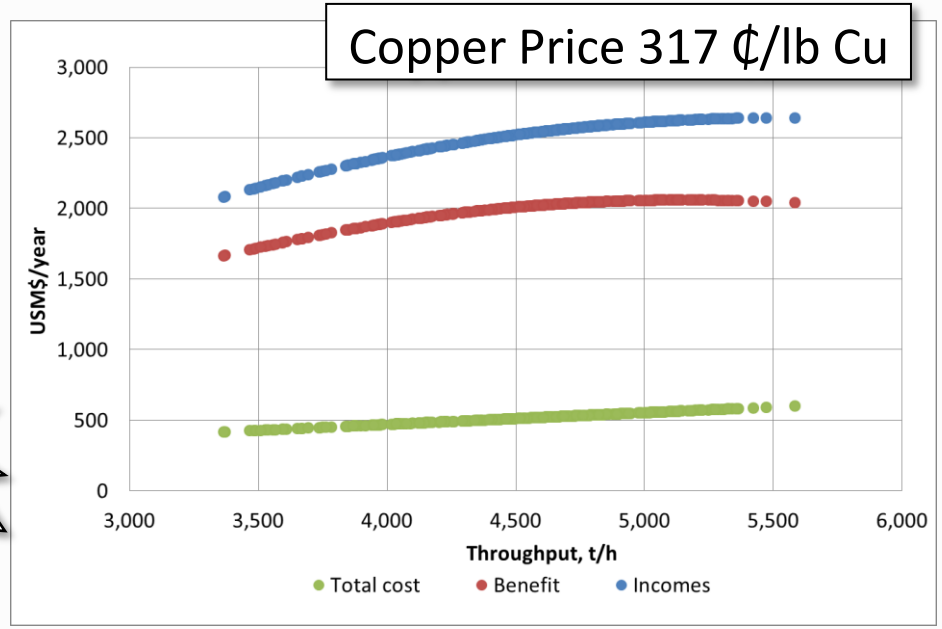
Sensitivity Analysis

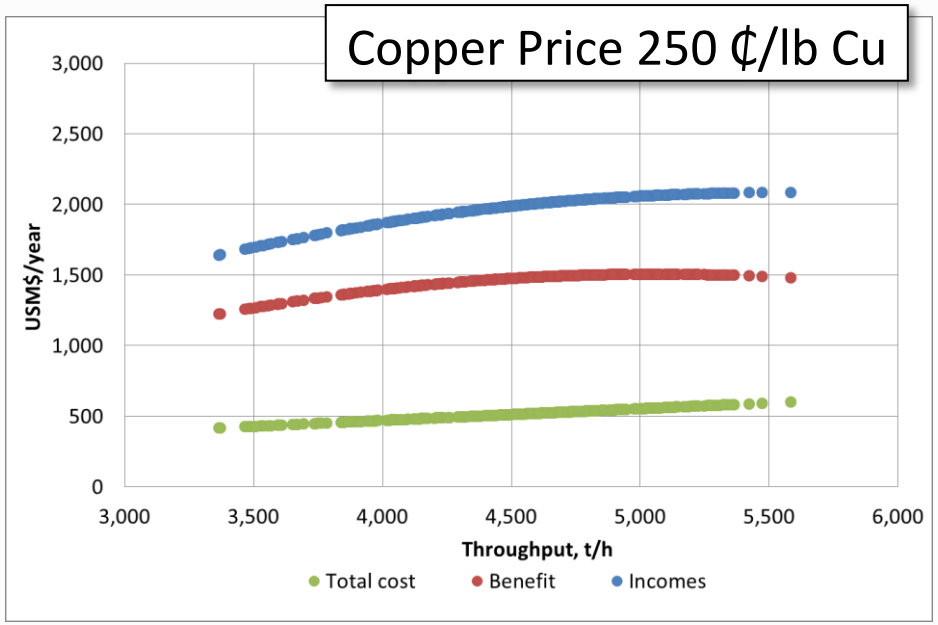


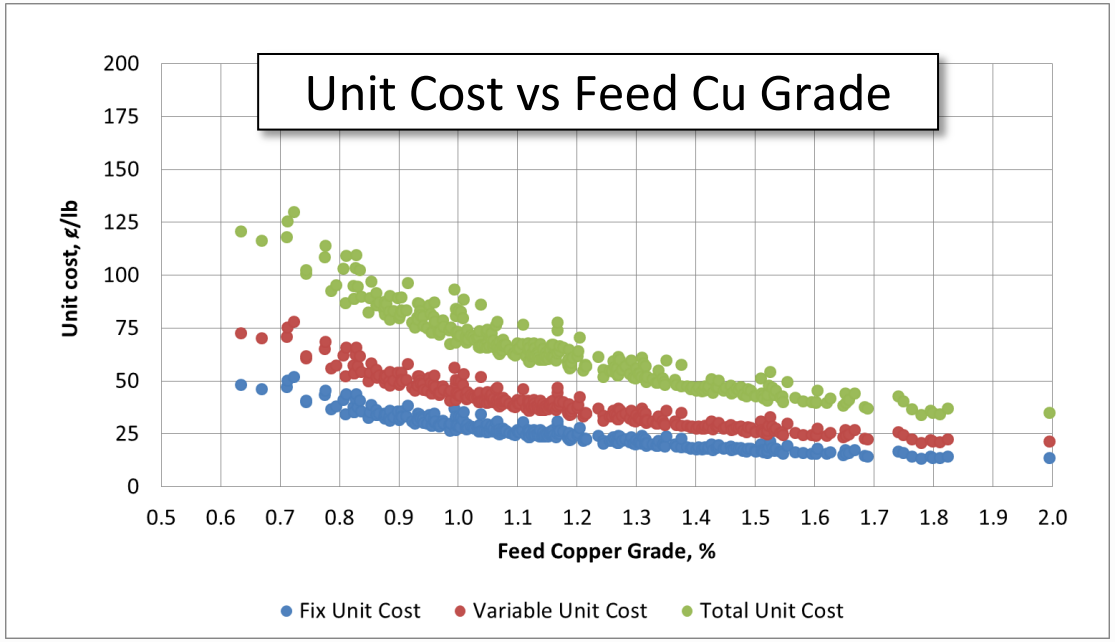
Powder Factor, g/t	CuT, %	FeT, %	Cpy, %	Cc, %	Cv, %	Tonnage, t/h	Cp, %	BM Ball Filling,%	+100#, %	Collector Dose, g/t	Rghr. Froth Height, cm	Clnr. Froth Height, cm
500	1.2	1.7	1.2	0.8	0.3	Variable	29.7	32	Variable	12	80	80

Net Benefit vs Throughput

Sensitivity Analysis







Summarized Results of the Study Case

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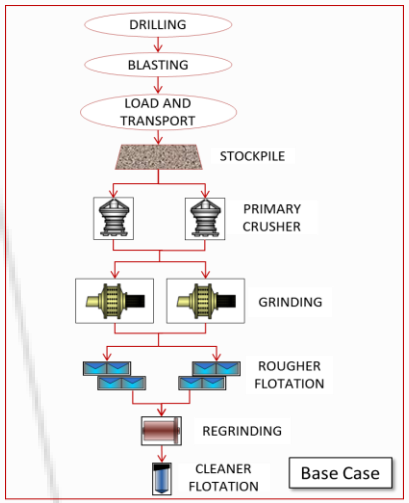
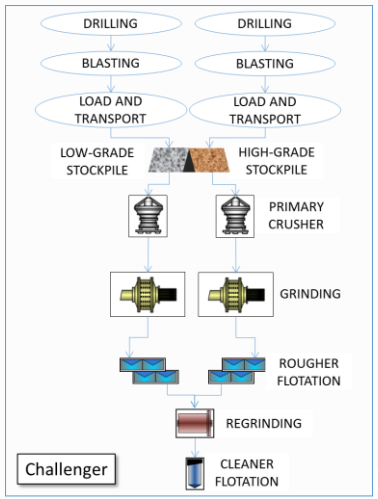
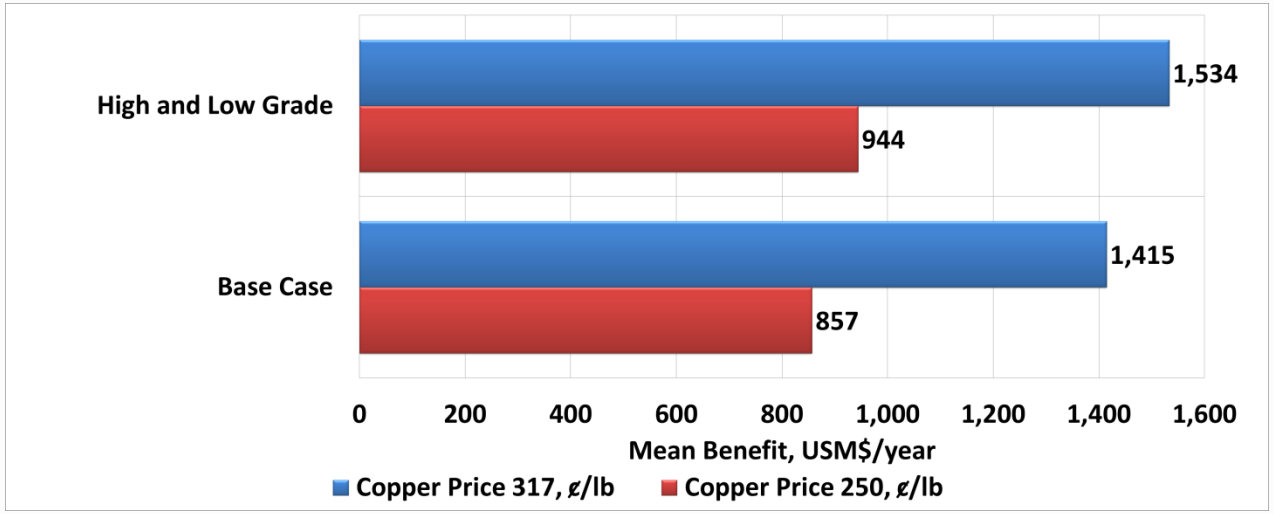
Parameter	Base Case	High Grade	Low Grade	Base Case	High Grade	Low Grade
Throughput, t/h	4,257	2,129	2,129	4,257	2,129	2,129
Head Copper Grade, %	1.20	1.41	0.98	1.20	1.41	0.98
Powder Factor FC, g/t	650	800	500	650	800	500
Ball Filling JB, %	35	38	32	35	38	32
Collector Dose, g/t	14.68	17.36	12.00	14.68	17.36	12.00
Rougher Mean Froth Height, cm	68	60	75	68	60	75
Cleaner Mean Froth Height, cm	90	80	100	90	80	100
Overall Cu Recovery, %	78.59	93.07	70.69	78.59	93.07	70.69
Cu Grade in Final Concentrate, %	34.18	34.08	34.37	34.18	34.08	34.37
Cost, USM$/year	1,225	637	618	1,225	637	618
Incomes, USM$/year	2,640	1,829	959	2,082	1,442	756
Benefit, USM$/year	1,415	1,193	341	857	806	138
		1,534 (317 ¢/lb)			944 (250 ¢/lb)	







Final Remarks

- ✓ Current process strategy includes the largest effective throughput, an intensive blasting, a coarse grinding, the simplest flotation circuit and a maximum water recycle. This is complemented with a contained cost policy.
- ✓ Decreasing grades and cyclic metal prices demand additional measures: Preconcentration technology, selective dispatch and better management of stockpiles are necessary to consider.
- ✓ Today more than never the integrated view of the production chain is a “must”. Planning tasks should be assisted by Process/Maintainance/Economical simulators. Do not confuse accountability simulation with predicting dynamic simulation.
- ✓ Blasting must be promoted to “metallurgical unit process” and it needs to be optimized from the business viewpoint.
- ✓ It is verified in the Study Case the business is more sensitive to throughput compared to recovery with a slow displacement to lower tonnage as the copper price reduces.

Final Remarks

- ✓ Maximum metal-mass throughput can be assisted by other asset feeds, like low grade ores and tailings. Modular and flexible plant flowsheets are needed. Tailings need to be disposed according to specific quality.
- ✓ Automate as much as possible, but go beyond the conventional concept, thinking now in Big Data, Artificial Intelligence and IoT framework.
- ✓ The economical viewpoint has to be always present. Main cash cost item in Chile are:

Open Pit Mine, %	
Maintenance and Repair	43
Fuels	29
Wages	11
Tires	7
Blasting	6
Others	4
Total	100

Concentrator Plant, %	
Grinding	49
Desalination Plant	21
Flotation	15
Tailings and Auxiliaries	8
Others	7
Total	100

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III Minerals Flotation International Congress

Lima, June 07 - 08

"A New Approach to Flotation Plants"

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De Re Metallica Ingeniería SpA, DRM-Tech

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