Integral Planning of the Process-Chain Performance

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ABSTRACT

One of the weak points in the production plan estimation using the block model is the limited representativeness of the plant responses, namely, throughput and recovery.

It is also critical the current projection of results obtained from simple but imprecise small-scale tests which often drive to biased industrial production program because they do not consider important aspects like mass transport, non-linear behavior of ores and process variability affecting the results in real comminution and flotation plants.

A realistic estimate of the production plan should involve a well-settled phenomenological process-chain simulator, including at least the processes of blasting, crushing, grinding and flotation.

In addition to the physical sense of the chain-simulator, actual operational strategies need to be incorporated into the simulation as well as maintenance predictive strategies based on characteristics of the ores, operational practices and fail pattern of machines.

Finally, always said but rarely practiced, a cost/benefit model needs to be part of the production plan simulator in order to estimates economics of any faced production scenario.

An integral model of the above-described kind is here reported and a study case is developed to show the impact in final results along the production chain from blasting to flotation.

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INTRODUCTION

Huge capacity in modern concentrator plant demands more accurate planning methodologies of the copper production. Current tools to predict throughput and recovery are not enough fine to assure precise results along the whole chain of processes and also along the time.

Estimates of the block model are quite gross and often generated under idealized conditions. Dynamic phenomenological models properly complemented with predictive maintenance models, sensitive to characteristics of the ore, the applied operational conditions and variability are necessary to include in order to approach the reality. Also a cost/benefit algorithm is convenient to include in order to provide an economical viewpoint to take business decisions.

In the following sections these ideas are developed and a specific study case is presented in detail.

METHODOLOGY

Simulator description

Figure 1 is a simplified block diagram of the integrated mine-to-plant simulator here presented.

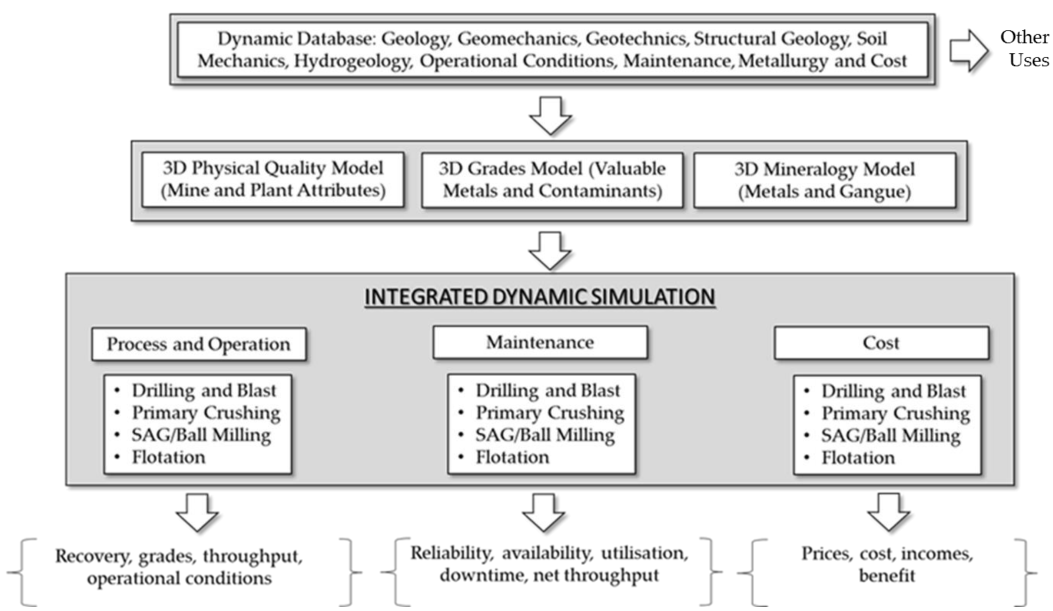


Figure 1 Block diagram of the suggested simulator

Use of this simulator involves a continuous analysis of geology, geomechanics, geotechnics, structural geology, soil mechanics, hydrogeology, operational conditions, as well as maintenance and metallurgy practices, variability and cost along the process-chain and time. Information on the ore is first used to build the "physical quality" model, in addition to the "grades" and the "mineralogy" models, all continuously updated along the time. Note that same above-mentioned data give origin to sub models required by the standard block model.

The simulator itself is composed by 3 main lines of parallel calculations. The first one is the "process simulator" where set points, process stability and modes of operation are input data. The second line includes "maintenance aspects" depending on the historical pattern and characteristics of the ores beneficiated and also on the actual operational conditions. The third line is linked to "production cost" along the process chain and it primarily depends on what is actually performed at the plant.

Even not necessary it is recommended that model construction and calibration employ phenomenological modelling, big data, artificial intelligence and IoT framework.

Models description

Only a brief (but properly referenced) explanation on the considered models is here given. Detailed description is beyond the scope of this paper.

Blasting

It is a phenomenological population balance model made by DRM and successfully applied in CODELCO DGM, BHP Minera Spence, AMSA Antucoya, CODELCO DRT, among other companies. It is fully described in a paper presented at Procemin 2018 (Menacho, Verdugo and Vega, 2018).

Crushing

It is also a phenomenological population balance model for the crushers and Tromp curves for the screen classifiers. It was also developed by DRM and successfully applied in CODELCO DGM, BHP Minera Spence, AMSA Antucoya, CODELCO DRT, BHP Cerro Colorado, Anglo American plc Collahuasi and others. Details can be found in (Menacho, Verdugo and Vega, 2017).

SAG milling

It is another phenomenological model developed by DRM and it is composed by four submodels: (i) Population balance submodel dealing with the comminution process (L.G. Austin, J. Menacho and F. Pearcy, 1987), (ii) Power consumption submodel based on the torque approach (R. Hogg and D. Fuerstenau, 1984, Sepúlveda, 2017), (iii) Mass transport submodel using the porous media transport theory (Menacho et al., 2008), and (iv) Slurry evacuation system described as arrangement of classifiers (L. Magne et al., 1995).

Ball milling

It is also a phenomenological model developed by DRM and it is composed by three submodels: (i) Population balance submodel to describe the comminution process (L.G. Austin, 1984), (ii) Power consumption submodel based on the torque approach (R. Hogg and D. Fuerstenau, 1984, Sepúlveda, 2017) and (iii) Grate classifier when dealing with grate mills (L.G. Austin and F.J. Concha, 1994).

Flotation plant model

A two-phase kinetic flotation model is employed. Bubble aerodynamics in the slurry and the froth phases is included (Menacho et al., 2014). Parameters are sensitive to particle size distribution, mineralogy, liberation degree, bubble size distribution and operational conditions. It has been applied at BHP Los Colorados and Laguna Seca, Anglo American plc Collahuasi, Glencore plc Altos de Punitaqui and others. An updated version is available in (Menacho, Vega and Manríquez, 2018).

Maintenance model

The maintenance model is a datasheet developed by DRM. It contains an historical maintenance matrix which is sensitive to the changing characteristics of the ores under beneficiation, such as lithology, type and intensity of alteration, rock hardness and abrasiveness and it also depends on the actual operational conditions. Final results are: availability, utilization, downtime, reliability and net throughput (Menacho et al., Service report to CODELCO DGM, 2017-2018).

Cost/benefit model

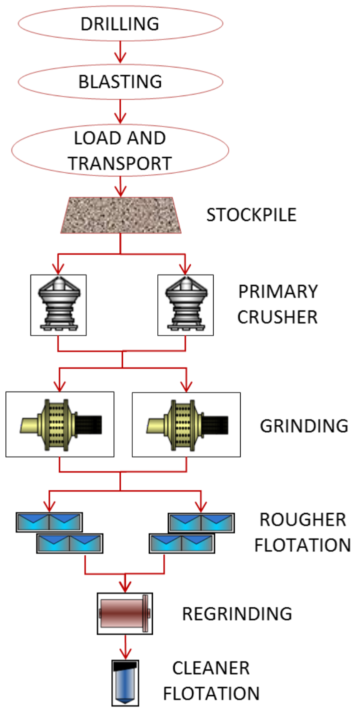
Each step of the process chain in characterized by the main operational cost properly identified. Any optimizing change can be immediately evaluated, as well as the corresponding net benefit given by the process simulation. The cost distribution in the study case was set according to (COCHILCO Publication, 2014).

RESULTS AND DISCUSSION

Study Case: Single feed versus feed segregated by grade

Plant description

Figure 2 shows a simplified flowsheet of the Operation under study as well as some of its relevant characteristics. It is a conventional open pit mining operation which feed two lines of primary gyratory crushers followed by corresponding SAG/Ball mill and rougher flotation lines. Concentrates regrind and finally feed column cleaner flotation cells working with conventional scavenger cells.



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	4,257
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, %	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

Figure 2 Simplified process flowsheet and main operational conditions

OPEX distribution

Table 1 Shows main operational cost distribution considered at the mine and the plant.

Table 1 Operational cost distribution

Open-pit Mine Cost Distribution		**Concentrator Plant Cost Distribution**	
Mine Processes	Cost Distribution, %	Concentrator Processes	Cost Distribution, %
Drilling	0.5	Crushing	4.0
Water	0.6	Grinding	49.0
Truck Hopper Expense	0.9	Collective Flotation	11.0
Others	1.1	Selective Flotation	4.0
Electric Energy	1.1	Tailings	3.0
Blasting	6.1	Desalinated Water	21.0
Tires	7.2	Auxiliaries	5.0
Wages	11.2	Others	3.0
Fuel (Oil and Lubricants)	28.6		
Maintenance and Repair	42.7		

Option to be evaluated

It is desired to know convenience of introducing a sorting step at the loading site based on Cu grade monitoring and automatic remote truck dispatch to specific crushers as shown in Figure 3. Separated lines at the plant operate until the rougher circuit and then concentrates are mixed together to follow same current single route.

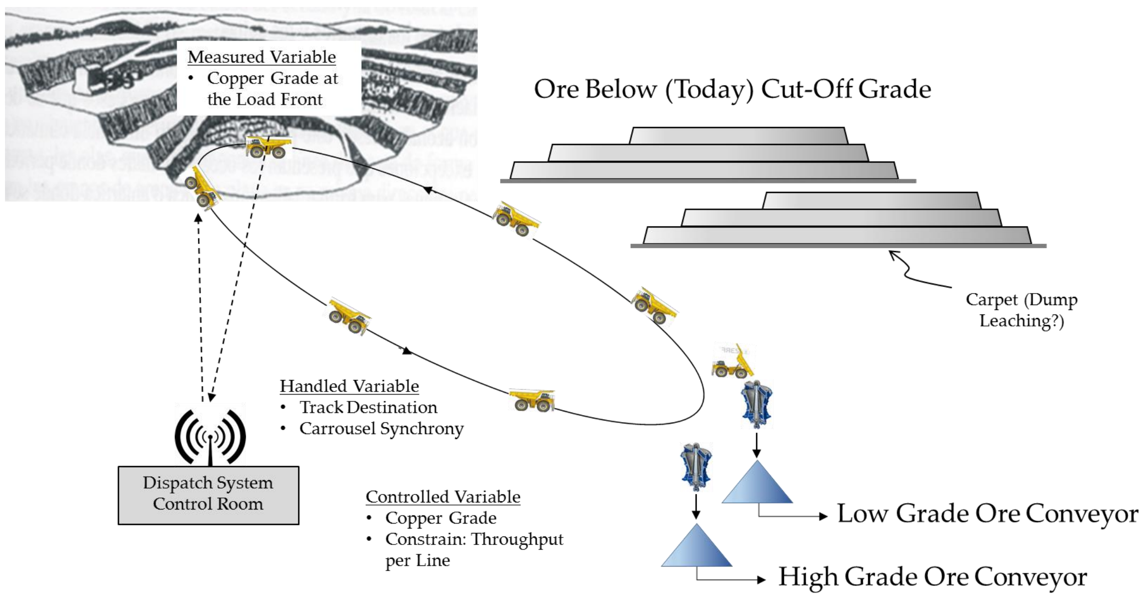


Figure 3 Ore separation at the mine

Technology to implement this option is nowadays available in the industrial market (M. Talikka and A. Remes, 2017). Decision should be taken on convenience or not to adopt this route affecting the mine and the plant performance and results of the business.

Process model calibration

Individual process models were calibrated with industrial data such as shown in Figure 4.

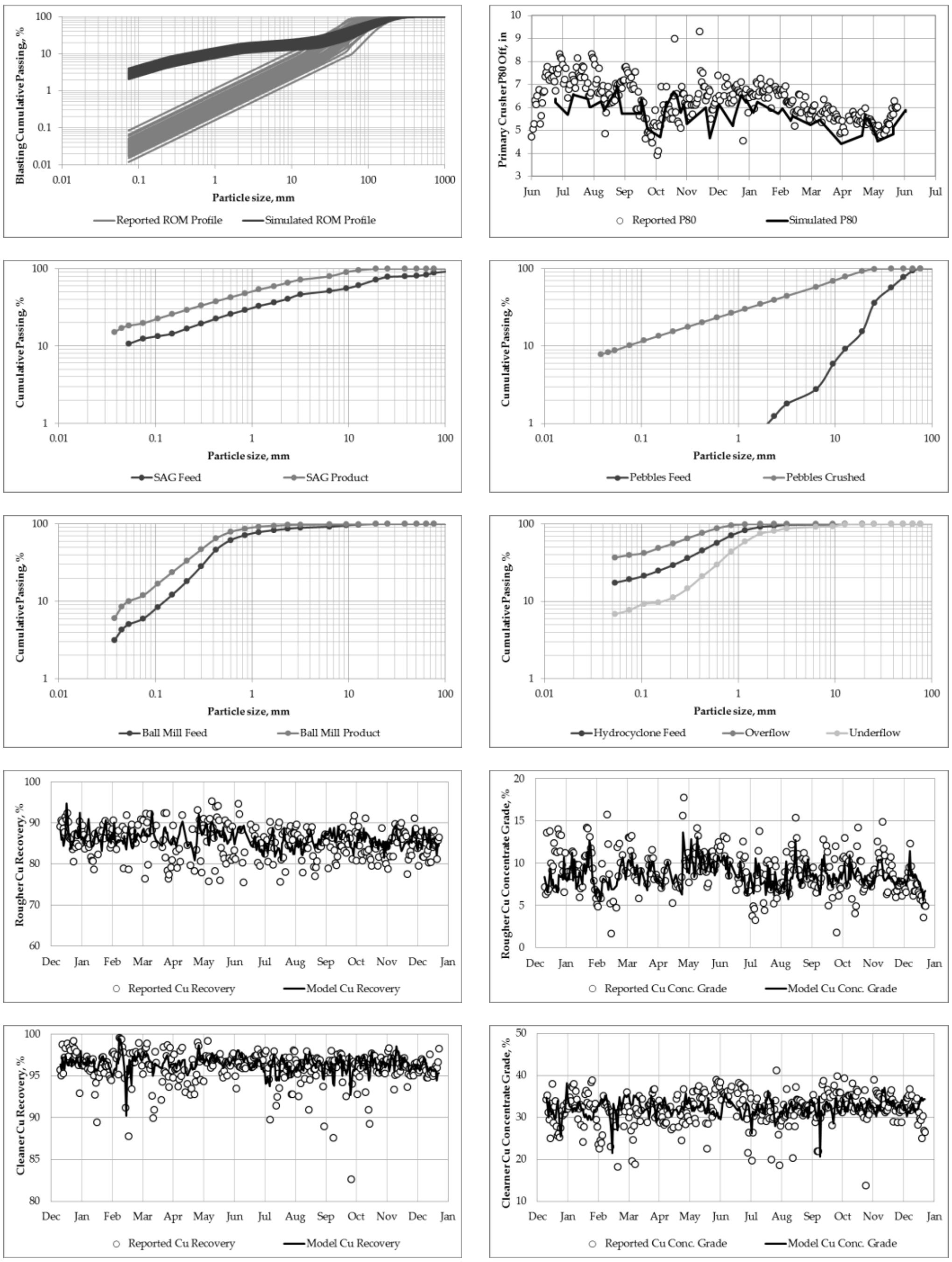


Figure 4 Calibration of the process models

Sensitivity analysis

Figure 5 illustrates relationship among different variables either metallurgical or economical.

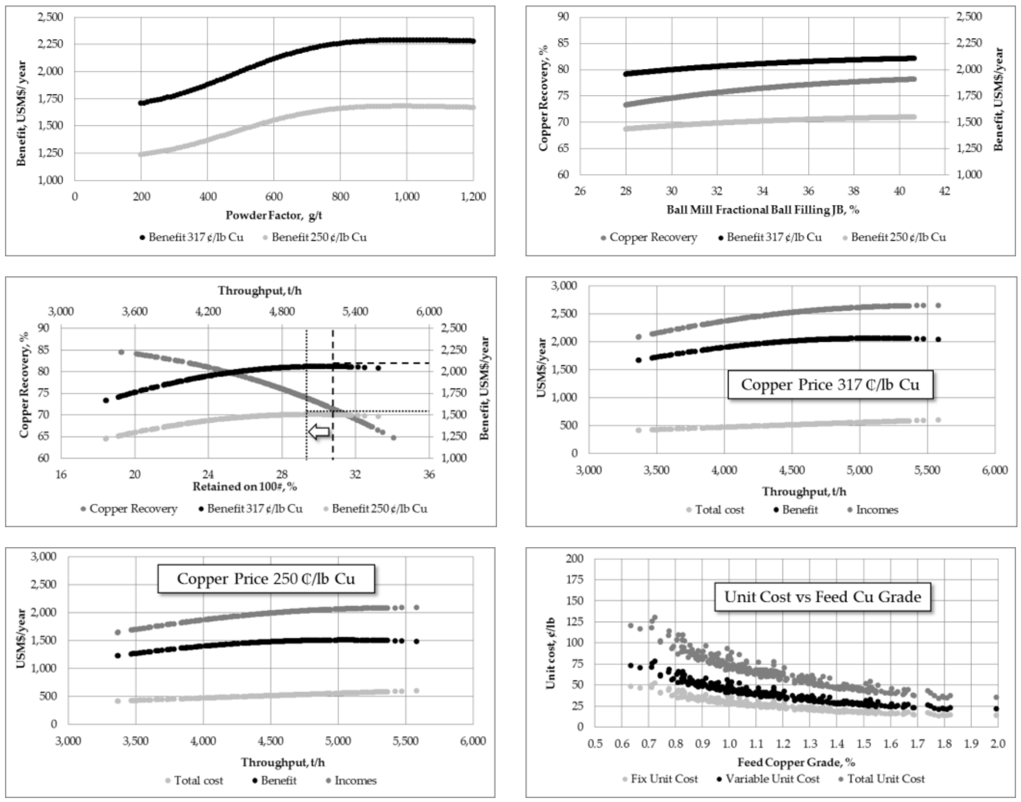


Figure 5 Particle size/ throughput/rougher recovery/net benefit/ cost relationships

Main Results of the Study Case

Main results of the simulation are summarized in Table 2 and Figure 5. Significant benefit comes from the ore separation into lines of high and low copper grade, either for 317 ¢/lb Cu or 250 ¢/lb Cu. Strategy was the application of differentiated conditions at each line such to privilege the higher grade ore. To make fair the comparison, same optimization changes were also introduced in the reference option but here applied to the whole stream instead of a selective application to only the high grade stream. For the present application a net benefit ranging 87 to 119 US$ millions/year is computed.

Table 2 Main results of the evaluated option

Parameter Single feed	Base Case	Segregated feed		Delta Benefit
		High Grade	Low Grade	
Throughput, t/h	4,257	2,129	2,129	
Head Copper Grade, %	1.20	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**

CONCLUSIONS

Decreasing grades and cyclic metal prices demand different ideas to get different 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 "robust" 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 integral business viewpoint.

Modern operations have to take advantage of the new automation options, considering big data, artificial intelligence and IoT tools.

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