



Research Article

## COM\_TRD\_Sim: A Size Reduction Trade-off Software Part 1: Software Capabilities and Infrastructure

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### A B S T R A C T

In the past five decades, significant advancements in process simulators and calculators have transformed the mineral processing and chemical industries. These software solutions leverage mathematical models to monitor crucial control variables such as recovery rates, concentrate grades for flotation, ore-to-water feed ratios, and power consumption during crushing and grinding operations. The primary objectives of these applications revolve around optimizing design processes, which can be classified into dynamic (real-time) and steady-state simulations (offline analyses), with the latter predominating in contemporary applications. This paper categorizes the existing software solutions into several key types, including individual unit operation models, integrated flowsheet solvers, iterative simulators, and material balance models, while also highlighting their applicability and evolution through the introduction of complex unit equipment and mass/material balance equations. Despite notable progress, few software tools specifically target the simulation of capital expenditure (CAPEX) and operating expenditure (OPEX) for designed flowsheets, thereby highlighting a critical gap in the market, particularly concerning the economic implications of processing materials with varying characteristics (e.g., abrasiveness and grindability). To address these needs, we introduce the COM\_TRD\_Sim (Comminution Trade-off Simulator), which estimates consumable requirements based on user-defined parameters and ore characteristics, facilitating informed decision-making in size reduction processes.

**Keywords:** Process Simulation, Mineral Processing, CAPEX, OPEX, COM\_TRD\_Sim.

### Nomenclature

$BW_i$ / $BW_i$ : Bond ball mill work index, kWh/t  
 $C_{D_1}, C_{D_2}, C_{D_3}, C_{D_1}, C_{D_2}, C_{D_3}$ : mill diameter cost constant  
 $C_{L_1}, C_{L_2}, C_{L_3}, C_{L_1}, C_{L_2}, C_{L_3}$ : mill length cost constant  
 $C_1, C_2, C_3, C_4, C_1, C_2, C_3, C_4$ : constants used for crusher wear model equation  
 $C_{11}, C_{12}, C_{11}, C_{12}$ : constant used for SAG lifter consumption  
 $C_5, C_6, C_7, C_5, C_6, C_7$ : constants used for crusher liner cost equation  
 $C_8, C_9, C_{10}, C_8, C_9, C_{10}$ : constant used for crusher equipment cost  
 $C_p, C_p$ : mill power cost constant  
 $CW_i$ / $CW_i$ : Bond crusher work index, kWh/t  
 $F_{80}, F_{80}$ : 80% passing size of the product,  $\mu\text{m}$   
 $F_{ai}$ / $F_{ai}$ : French abrasion index, gram/ton  
 $J_B$ / $J_B$ : ball charge filling, %  
 $K_1, K_1$ : 1.0 for all circuits that do not contain a recycle pebble crusher and 0.95 where circuits do have a pebble crusher

$K_2, K_2$ : 1.0 for all crushers operating in closed circuit with a classifying screen. If the crusher is in open circuit, eg. pebble crusher in a AG/SAG circuit, K2 takes the value of 1.19.

$K_3, K_3$ : 1.0 for all HPGRs operating in closed circuit with a classifying screen. If the HPGR is in open circuit, K3 takes the value of 1.19.

$L_{MIN}, L_{MIN}$ : set minimum (closed set), meter

$L_T, L_T$ : Throw, meter

$M_{ih}, M_{ih}$ : HPGR ore work index and is provided directly by SMC Test®, kWh/ton

$M_{ia}, M_{ia}$ : coarse ore work index and is provided directly by SMC Test®, kWh/ton

$M_{ib}, M_{ib}$ : fine ore work index, kWh/ton

$M_{ic}, M_{ic}$ : crushing ore work index and is provided directly by SMC Test®, kWh/ton

$M_{lifter\ consumption}, M_{lifter\ consumption}$ : HPGR lifter consumption amount, tons

$P_{80}, P_{80}$ : 80% passing size of the feed,  $\mu\text{m}$

$P_K, P_K$ : packing characteristics

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$Q_m Q_m$ : maximum capacity, ton/hour  
 $RW_i RW_i$ : Bond rod mill work index, kWh/t  
 $S_c S_c$ : parameter related to surface characteristic  
 $W_h W_h$ : specific energy for HPGRs, kWh/t  
 $W_{SDT} W_{SDT}$ : AG/SAG pinion energy from F80 152.4 mm to T80 1.7 mm, kWh/ton  
 $W_a W_a$ : specific energy to grind coarser particles in tumbling mills, kWh/ton  
 $W_b W_b$ : specific energy to grind finer particles in tumbling mills, kWh/ton  
 $W_c W_c$ : specific energy for conventional crushing, kWh/ton  
 $W_i W_i$ : work index, kWh/t  
 $d_{MAX} d_{MAX}$ : maximum particle size,  $\mu m$   
 $d_{MEAN} d_{MEAN}$ : mean particle size,  $\mu m$   
 $d_{MIN} d_{MIN}$ : minimum particle size,  $\mu m$   
 $\dot{m}$ : specific throughput, ts/hm<sup>3</sup>  
 $m_s m_s$ : SAG mill feed sample mass, gram  
 $w_c w_c$ : charge % solids, fraction by weight  
 $x_1 x_1$ : P80 of the circuit feed,  $\mu m$   
 $x_2 x_2$ : 750,  $\mu m$   
 $x_2 x_2$ : P80 of the circuit product,  $\mu m$   
 $x_3 x_3$ : fractional volumetric void space between rocks and balls  
 $\varepsilon_B \varepsilon_B$ : the fractional volumetric void space between rocks and balls use (0.3)  
 $\rho_c \rho_c$ : density of the charge, t/m<sup>3</sup>  
 $\rho_b \rho_b$ : density of the balls, t/m<sup>3</sup>  
 $\rho_s \rho_s$ : density of the solids, t/m<sup>3</sup>  
 $\phi_c \phi_c$ : mill speed as a fraction of critical  
D: Mill effective diameter, meter  
ATWIATWI: ATWAL Wear Index, gram/ton  
AiAi: Bond abrasion index  
EE: specific energy consumption, kWh/ton  
GG: gape, meter  
GbpGbp: last three net grams per revolution, gram/rev  
GprGpr: weight of the test sieve fresh undersize per mill revolution, gram/rev  
JJ: mill charge filling, %  
LL: mill effective grinding length, meter  
S.F.S.F.: SAG cost factor with respect to ball mill  
TT: throughput rate, ton/hour  
WW: width of jaw plates, meter  
aa: model constant  
dd: model constant  
revsrevs: cumulative number of SAG test mill revolutions to T80 1.7 mm, measure by SDT  
tt: time, hours  
uu: circumferential speed of the rolls

## Introduction

Over the past 50 years, substantial advancements have been made in the development of process simulators and calculators for the mineral processing and chemical industries. These software solutions employ mathematical models to track critical control variables, which include recovery rates and grades for flotation, as well as the ore-to-water feed rate and power draw for crushing and grinding processes. The primary goals of these software programs are design and optimization, which can be categorized based on the types of equations they employ: either dynamic (for online applications) or steady-state (for offline applications). Most existing software solutions are primarily configured for steady-state operations.

Figure 1 summarizes some of the key software/simulators utilized in the mineral processing industry. The classification presented in Figure 1 can be expanded to include several categories:

Individual unit operations vs. integrated flowsheet solvers (Sastry and Adel, 1984)

The iterative approach differs from simulators based on the simultaneous equations approach (Mular and Richardson, 1986). • This study focuses on direct versus reserve simulators (Guillaneu et al., 1992). • The discussion centers on the differences between offline (Mular and Herbst, 1980) and online optimizers (Bazin et al., 1984).

The literature compares material balance (Wiegel, 1972; Laguitton, 1980) with flowsheet solvers (Richardson et al., 1981; Gupta and Messa, 1980) and simulation software (Rajamani and Herbst, 1980; Adel, 1982; Adel and Sastry, 1983; King, 1983).

Through the evaluation of technology and the application of complex unit equipment models, ore characteristic parameters, and mass and material balance equations, software has become capable of performing mass balances, flowsheet design, and simulations simultaneously using USIMPAC (Brochot et al., 2002), MODSIM (King, 1983), METSIM (Bartlett, 1987), and JKSimMet (McKee and Napier-Munn, 1990).

However, there is a dearth of software specifically designed to produce or simulate the capital expenditure (CAPEX) and operating expenditure (OPEX) of a given flowsheet. It has been noted that the main goals have not focused on assessing the cost of equipment and the unit cost of processing a particular type of material (abrasiveness, grindability, specific gravity, etc.) in terms of energy and consumables. Instead, cost vs. capacity equations for equipment costs have been integrated into simulators (USIMPAC; Brochot et al., 2002). The developed software, COM\_TRD\_Sim (Comminution Trade-off Simulator), is capable of sizing and estimating consumables as a function of user-specified schedule data and ore test parameters for the size reduction process. This study focuses on the development and capabilities of the COM\_TRD\_Sim software, aimed at the mineral processing industry. The purpose of this study is to address the critical gap in existing process simulation software by introducing a tool that can estimate both capital and operating expenditures (CAPEX and OPEX) based on user-specified parameters and ore characteristics. COM\_TRD\_Sim is designed to optimize size reduction processes by assessing power demand, specific energy needs, and consumable consumption for various equipment types and configurations. This software enhances industry capabilities by enabling informed design and operational decisions through comprehensive comparative analyses and simulations of different size reduction strategies and their economic implications.

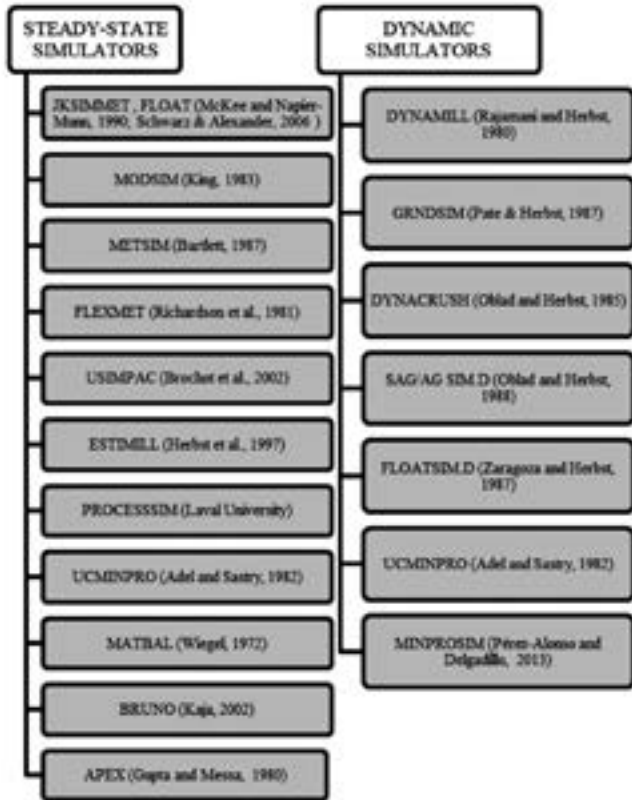


Figure 1. List of major process software/simulator

**1. Materials and Methods**

The software accepts the following input parameters (Figure 2a):

- Ore-specific crushing/grinding indices,
- Ore-specific gravity,
- User-defined availability and annual ore processing amounts,
- Consumable unit costs.

The software outputs (Figure 2b):

- Annual liner/lifter consumption and unit operating costs,
- Annual ball/rod consumption and unit operating costs,
- Annual energy consumption and unit operating costs

The following conventional flowsheets are integrated into the software:

Alternative 1: Primary Crushed SABC

- o Equipment 1: Jaw/Gyratory Crusher
- o Equipment 2: SAG Mill
- o Equipment 3: Pebble Crusher
- o Equipment 4: Ball Mill

Alternative 2: HPGR/Ball Milling Circuit

- o Equipment 1: Jaw/Gyratory Crusher
- o Equipment 2: Secondary Crusher
- o Equipment 3: HPGR
- o Equipment 4: Ball Mill

Alternative 3: Conventional Crushing/Ball Milling Circuit

- o Equipment 1: Jaw/Gyratory Crusher
- o Equipment 2: Secondary Crusher
- o Equipment 3: Tertiary Crusher
- o Equipment 4: Ball Mill

Alternative 4: Primary Crushed SS SAG

- o Equipment 1: Jaw/Gyratory Crusher
- o Equipment 2: SAG Mill

Alternative 5: Conventional 3 Crushing/Rod + Ball Milling

- o Equipment 1: Jaw/Gyratory Crusher
- o Equipment 2: Secondary Crusher
- o Equipment 3: Tertiary Crusher
- o Equipment 4: Rod Mill
- o Equipment 5: Ball Mill

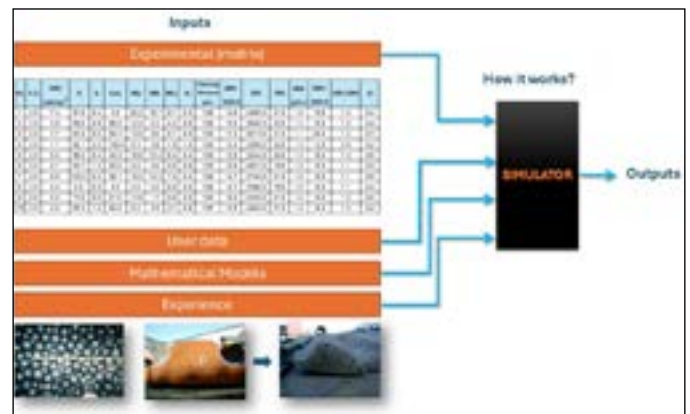


Figure 2a. Visual representation of software input

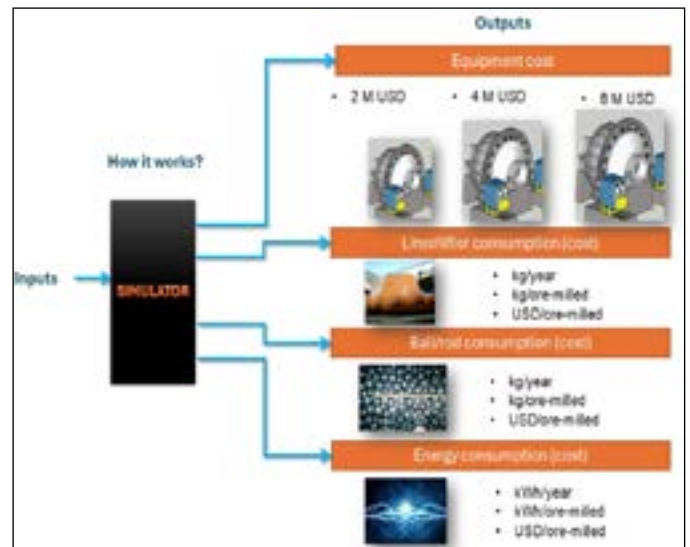


Figure 2b. Visual representation of software output

**1.1. Software by Mineral Processing Wise**

The software employs various power and capacity models, experimental indices, equipment cost models, and abrasion tolerances to estimate the sizing of the size reduction system and the consumption of consumables. Once input data is entered into the software, the required hourly capacity is determined, and the calculation sequence proceeds as depicted in Figure 3.

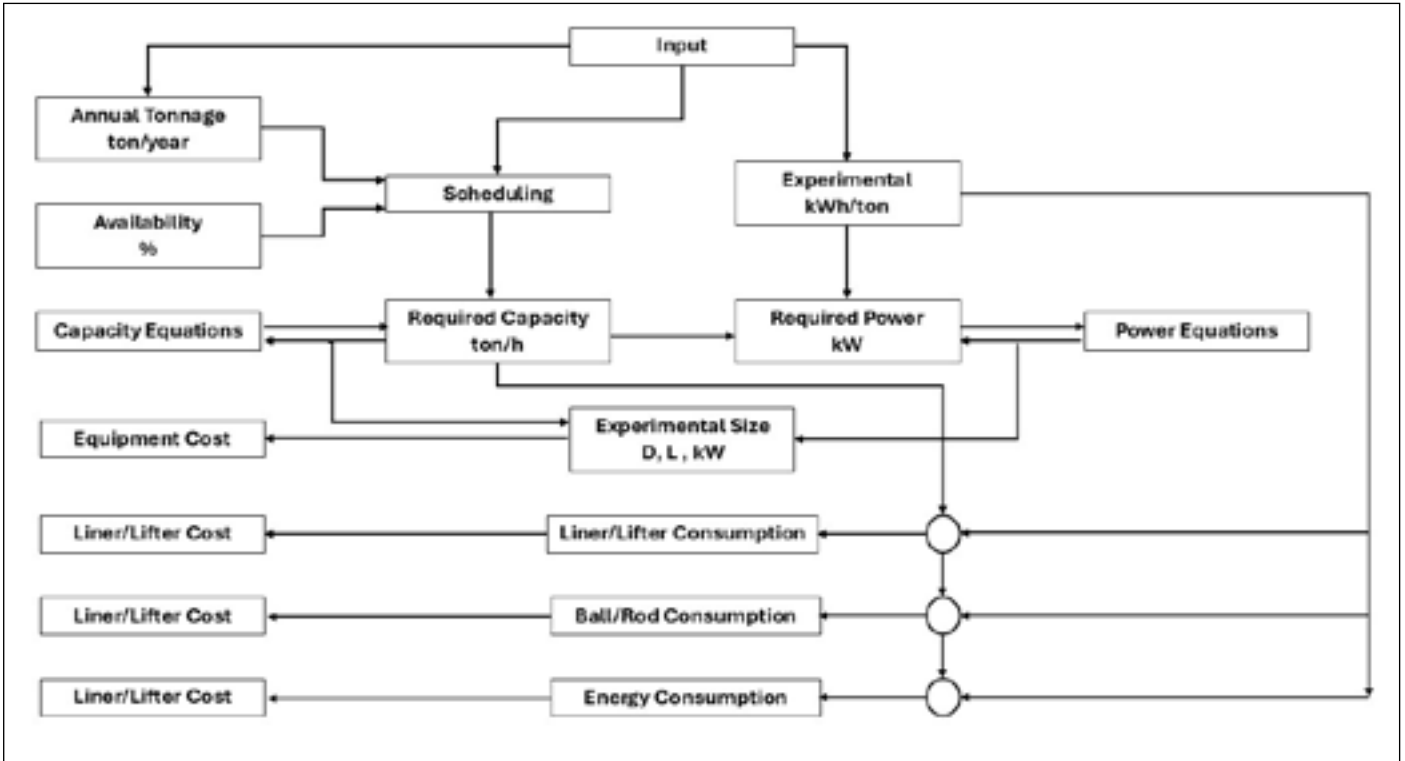


Figure 3. Software calculation order

The software is not designed for mass and material balance calculations; however, the amount of material entering specified equipment can be manipulated using a coefficient known as the “circulating load ratio.” Table 1 presents the model library utilized by the software. Empirical models based on practical experience are categorized as “In-house models,” which have been developed over the years through observation and expertise.

1.2. Software Architecture: Backend and Frontend Development

1.2.1. Back-end and Front-end Coding

MPES has developed a web-based software application that offers several advantages, including minimal computational effort

Table 1. Models utilized by COM\_TRD\_Sim.

Model name	Model Equation	Reference
Power and Capacity Models		
Mill	$E = 10W_i \left( \frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}} \right) \quad (1)$	(Bond, 1952)
Hogg_Fuerstenau	$P = 0.238(D \times 3.28)^{3.5} \left( \frac{L}{D} \right) \phi_c \rho_c (J - 1.065J^2) \quad (2)$	(Hogg and Fuerstenau, 1972)
Austin	$P = 10.6D^{2.5}L(1 - 1.03J) \left[ (1 - \epsilon_B) \left( \frac{\rho_s}{W_c} \right) J + 0.6J_B \left( \rho_b - \frac{\rho_s}{W_c} \right) \right] (\phi_c) \left( 1 - \frac{0.1}{29 - 10\phi_c} \right) \quad (3)$	(Austin, 1990)

required for calculations. Installation is unnecessary; any computer or mobile device equipped with a web browser can access the application. A monolithic architecture has been adopted (as represented in Figure 4), considering the small size of the development team and the expectation that the application will not experience exponential growth in the short term.

Unified Modeling Language (UML) class and use case diagrams have been employed for software design. The front end utilizes the AngularJS 4 framework, a widely used JavaScript API suitable for developing single-page applications. SCSS is implemented for styling. For the back end, Spring Boot—a Java framework for developing web services—is utilized. Deployment involves creating a Docker container from the build to virtualize the application, and Docker Compose is employed to serve the application on a DigitalOcean cloud server.

	Model name	Model Equation	Reference
Crusher	Rose and English	$P = W_i Q 10 \left[ \frac{1}{\sqrt{700,000(L_{MIN} + L_T)}} - \frac{1}{\sqrt{630,000G}} \right]$	(4)
		$Q_M = 2820 L_T^{0.5} W (2L_{MIN} + L_T) \left( \frac{R}{R-1} \right)^{0.5} \rho_s f(P_K) f(\beta) S_c$	(5)
		$P_K = \left( \frac{d_{MAX} - d_{MIN}}{d_{MEAN}} \right)$	(6)
		$\beta = \frac{set}{mean\ feed\ size}$	(7)
HPGR		$P_{HPGR} = T \times W_h = \frac{t}{h} \times \frac{kWh}{t} = kW$	(8)
		$T = \dot{m} \times D \times L \times u$	(9)
Experimental Indices Related to Power, Capacity and Abrasion			
Primary Crusher			
	Bond Low Impact	$CW_i = \frac{53.9 \times \left( \frac{J}{mm} \right)}{S.G.}$	(10) (Bond, 1947)
Secondary / Tertiary Crusher			
	Bond Low Impact	$CW_i = \frac{53.9 \times \left( \frac{J}{mm} \right)}{S.G.}$	(11) (Bond, 1947)
	SMC	$W_c = K_2 M_{ic} 4(x_2^{f(x_2)} - x_1^{f(x_1)})$	(12) (Morrell, 2009)
		$f(x_j) = -(0.295 + \frac{x_j}{1,000,000})$	(13) (Morrell, 2006)
Ball Mill			
	Bond Ball Mill	$BW_i = \frac{48.95}{P_c^{0.23} \times Gpr^{0.82} \times \left( \frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)}$	(14) (Bond, 1960)
		$W_a = K_1 M_{ia} 4(x_2^{f(x_2)} - x_1^{f(x_1)})$	(15)
	SMC	$W_b = M_{ib} 4(x_3^{f(x_3)} - x_2^{f(x_2)})$	(16) (Morrell, 2009)
		$M_{ib} = \frac{18.18}{P_1^{0.295} (Gbp)(p_{80}^{f(p_{80})} - f_{80}^{f(f_{80})})}$	(17)
Rod Mill			
	Bond Rod Mill	$RW_i = \frac{68.2}{P_1^{0.23} \times Gpr^{0.625} \times \left( \frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)}$	(18) (Bond, 1960)
	Bond Low Impact	$CW_i = \frac{53.9 \times \left( \frac{J}{mm} \right)}{S.G.}$	(19) (Bond, 1947)
SAG Mill			

Model name	Model Equation	Reference
SMC	$W_a = K_1 M_{ia} 4(x_2^{f(x_2)} - x_1^{f(x_1)})$	(20) (Morrell, 2009)
	$W_b = M_{ib} 4(x_3^{f(x_3)} - x_2^{f(x_2)})$	(21)
	$M_{ib} = \frac{18.18}{P_1^{0.295} (Gbp)(p_{80}^{f(p_{80})} - f_{80}^{f(f_{80})})}$	(22)
MacPherson- $W_{MAC}$ $W_{MAC}$	$W_{MAC} = kWh/ton$	(23) (MacPherson and Turner, 1978)
Starkey- $W_{SDT}$ $W_{SDT}$	$W_{SDT} = \frac{revs * (16,000 + m_s)}{(447.3 * m_s)}$	(24) (Starkey et al., 2006)
HPGR		
SMC	$W_h = K_3 M_{ih} 4(x_2^{f(x_2)} - x_1^{f(x_1)})$	(25) (Morrell, 2009)
Abrasion		
Crusher	$Wear Model = \frac{\#liner\ pair}{5000\ hours} = 5 x a x e^{b(C_2 x A_i^2 + C_3 x A_i + C_4)}$	(26)
	Experienced based $a = C_1 x P^{-d}$	(27) In-house model
	$F_{ai} = C_2 x A_i^2 + C_3 x A_i + C_4$	(28)
Ball Mill	Bond Ai $Ball\ Wear = 0.159 (Ai-0.015)^{0.34}$	(29) (Bond, 1963)
	$Liner\ Wear = 0.0118 (Ai-0.015)^{0.3}$	(30)
	French Ai in terms of Bond Ai $F_{ai} = C_2 x A_i^2 + C_3 x A_i + C_4$	(31) In-house model
HPGR	Atwal gram/ton	(32) ATWI
SAG Mill	Experienced Based $M_{lifter\ consumption} = C_{11} x P x t - C_{12}$	(33) In-house model
Equipment Cost Model		
Crusher	$Crusher\ Eq.\ Cost = C_8 x P^2 + C_9 x P + C_{10}$	(34) In-house model
	Data base fitted our model $Liner\ Cost = C_5 x P^2 + C_6 x P + C_7$	(35)
Ball Mill Rod Mill	$Ball-Rod\ Eq.\ Cost = (C_{D_1} x D^2 + C_{D_2} x D + C_{D_3}) x D + (C_{L_1} x L^2 + C_{L_2} x L + C_{L_3}) x L + C_{L_4}$	(36) In-house model
SAG Mill	$SAG\ Eq.\ Cost = S.F. x Ball\ Eq.\ Cost$	(37) In-house model
Abrasion Tolerances		In-house model
Mill	Experienced based %40 for mill liners, %40 for mill liners, %30 for HPGR liners	In-house model

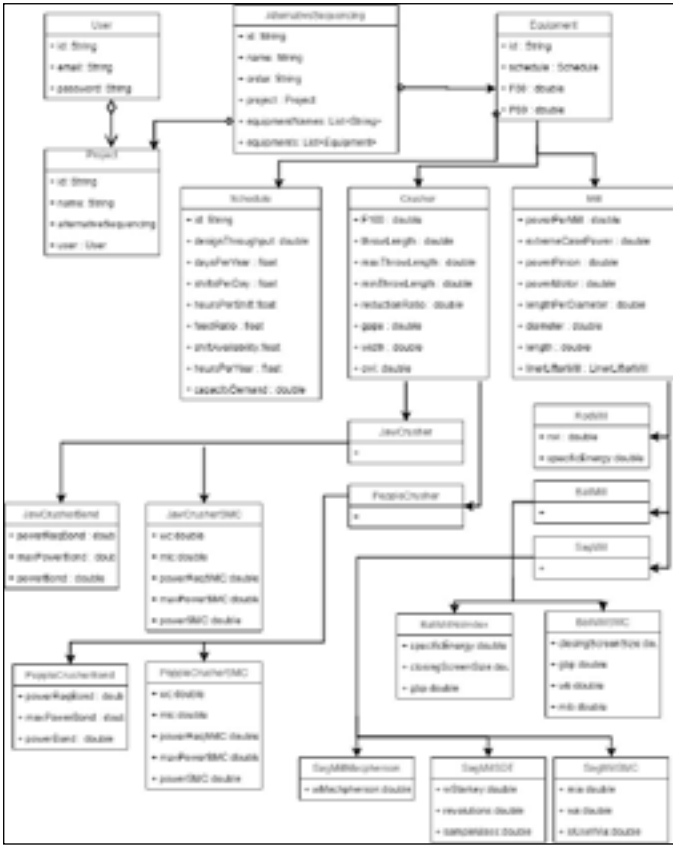


Figure 4. Software architecture

1.2.2 GUI/UX (Graphical User Interface / User Experience Design)

MPES has employed the Lean UX methodology in the development of its software product. Lean UX is centered around three primary concepts: Think, Make, and Check. The “Think” phase involves generating hypotheses regarding a particular problem and leveraging existing knowledge about the subject area. During this stage, we examined users’ mental models and initiated ideation sessions to explore potential solutions.

The “Make” phase is iterative in nature, emphasizing the creation of wireframes and prototypes to test minimum viable functionalities. In the final “Check” phase of our Lean UX loop, we conducted testing of our software product with users to validate our hypotheses. Several usability tests were undertaken to gain insights into how users interact with the product, thereby informing our design decisions and enhancing clarity. The main page of the graphical user interface (GUI) is depicted in Figure 5.



Figure 5. Software GUI showing selection of alternatives

2. Continuous Development

The COM\_TRD\_Sim team is committed to continuously enhancing the software by integrating new models and improving overall functionality for industry applications. To this end, new models (outlined in Table 2) will be incorporated to expand the available options. Additionally, the GUI (illustrated in Figure 6) will enable users to select their preferred combinations rather than being limited to predefined conventional models.

Table 2. New models those will be added

	Current Approach	Model/Coming Approach	Model/Coming Approach
<b>Power and Capacity Models</b>			
<b>Mill</b>	Bond Hogg and Fuerstenau Austin	Loveday and Barratt Morrell C	
<b>Crusher</b>	Rose and English		
<b>HPGR</b>		Austin and Trubelja	
<b>Experimental Indices</b>			
<b>Primary Crusher</b>	Bond Low Impact	Narayanan & Whiten rebound pendulum JKMRC-Drop weight	
<b>Secondary / Tertiary Crusher</b>	Bond Low Impact SMC	Narayanan & Whiten rebound pendulum JKMRC-Drop weight	
<b>Ball Mill</b>	Bond Ball Mill SMC	Selection and Breakage Functions ( $S_i$ and $B_{ij}$ )	
<b>Rod Mill</b>	Bond Rod Mill Bond Low Impact		
<b>SAG Mill</b>	SMC MacPherson- $W_{MAC}$ $W_{MAC}$ Starkey- $W_{SDT}W_{SDT}$	SAG power index-SPI JKMRC-Drop weight	
<b>HPGR</b>	SMC		
<b>Abrasion</b>			
<b>Mill, crusher</b>	Bond $A_iA_i$ , French $A_iA_i$	JKMRC $A_iA_i$	
<b>HPGR</b>	Atwal		
<b>Lifter material</b>	Steel	Rubber and hybrid materials	

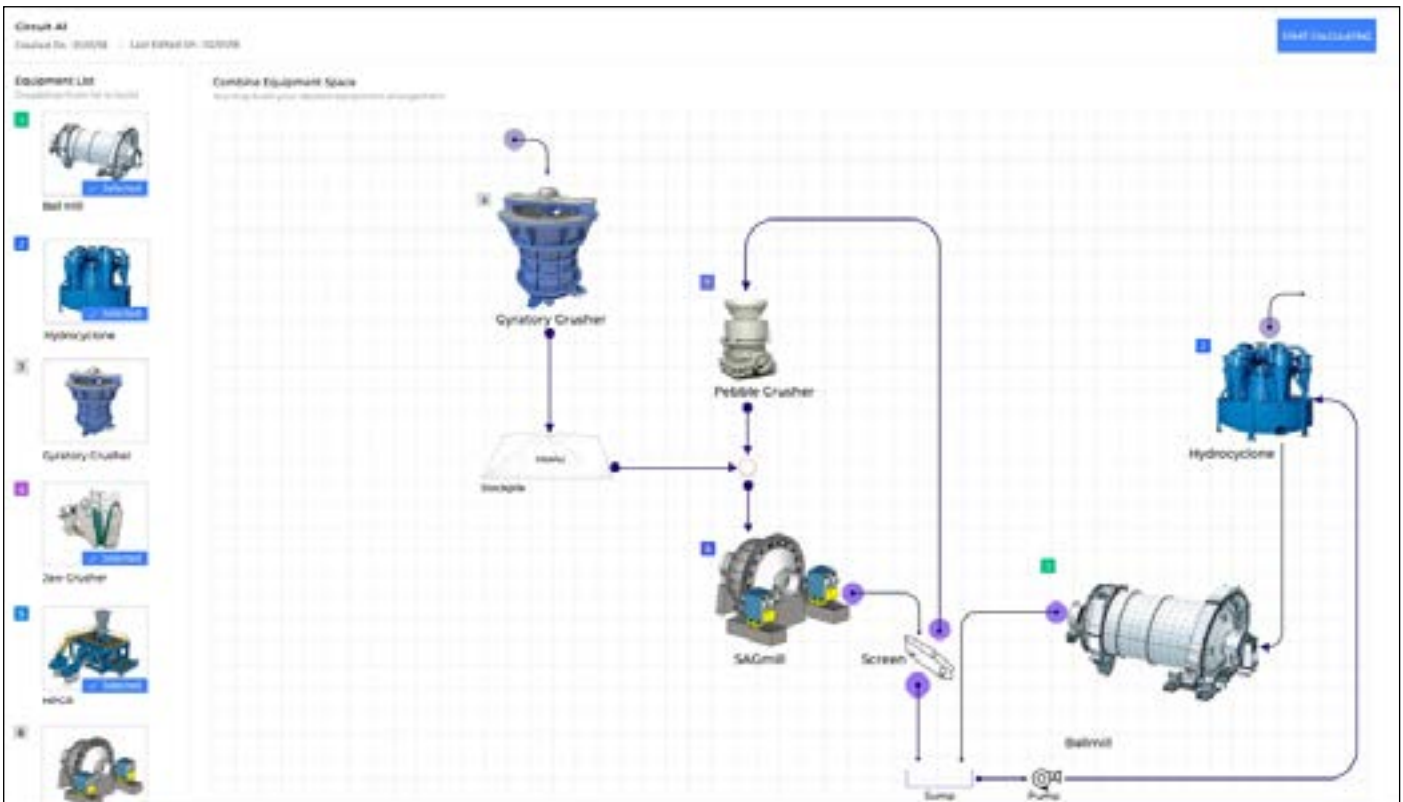


Figure. 6. CAPEX, OPEX vs experimental indices and availability

### 3. Discussion and Results

In evaluating the performance and utility of COM\_TRD\_Sim, the following key findings and advantages were highlighted:

**Operational Efficiency:** COM\_TRD\_Sim was tested across several mineral processing scenarios, based on real-world data from industry partners. The program demonstrated an ability to reduce the time needed for selecting size reduction alternatives, thanks to its streamlined, integrated approach that consolidates multiple tasks into a single platform.

**Accuracy and Consistency:** The software's prediction accuracy was assessed using a dataset of historical process simulations. Results showed that COM\_TRD\_Sim achieved over a 95% consistency rate in predicting energy consumption and mill sizing. The close alignment of the simulation outputs with empirical data underscores the robustness of the underlying models.

**Cost-Benefit Analysis:** Utilizing COM\_TRD\_Sim for CAPEX and OPEX estimation proved advantageous, with the software enabling a reduction in projected operational costs by optimizing equipment configurations and avoiding over-specification of machinery. This resulted in tangible savings for industry users, particularly in energy usage and consumable procurement.

**User Experience:** Feedback from pilot users indicated that the software improved design workflow efficiency, with user-friendly interfaces and intuitive model selection enhancing the decision-making process. The software was rated highly for user satisfaction.

Overall, COM\_TRD\_Sim demonstrates significant improvements in efficiency and cost savings, offering consistency in outputs and flexibility in its application. The software stands as a valuable tool for enhancing strategic planning and operational efficiency within the mineral processing industry.

### 4. Conclusions

The findings of this study highlight the capabilities of the COM\_TRD\_Sim software in quantifying critical factors related to size reduction. The software systematically decomposes and analyzes:

- Power demand
- Power needed at pinion
- Specific energy demand
- Operational specific energy demand

These data points are assessed against:

Various experimental indices associated with specific types of equipment (e.g., SMC, Bond, MacPherson)

Different equipment types (e.g., SAG mills, ball mills, rod mills, jaw crushers)

Multiple OPEX components (e.g., energy, ball, and rod consumption)

Diverse CAPEX and OPEX configurations stemming from distinct experimental indices

Various CAPEX and OPEX options resulting from different size reduction methodologies

The current version of the software encapsulates five alternative configurations for comparative analysis:

Alternative 1: Primary Crushed SABC

Alternative 2: HPGR/Ball Milling Circuit

Alternative 3: Conventional Crushing/Ball Milling Circuit

Alternative 4: Primary Crushed SS SAG

Alternative 5: Conventional 3 Crushing/Rod+Ball Milling

Furthermore, the software incorporates a minimum of 36 principal mathematical models, which include:

Nine power and capacity models applicable to mills, crushers, and HPGRs

Twenty-three experimental indices relevant to power, capacity, and abrasion for mills, crushers, and HPGRs

Four equipment cost models for mills, crushers, and HPGRs

The innovative software, COM\_TRD\_Sim, addresses a significant gap by merging theoretical frameworks with practical industrial requirements. Its operational logic integrates the following critical elements:

Investors as key determinants and contributors to capacity

Laboratories as providers of diverse experimental indices

Design engineers as integrators and compilers of comprehensive data

This collective approach facilitates the identification of the most viable size reduction options and enables comprehensive comparisons of these alternatives from both technical and economic perspectives.

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## Compliance with Ethical Standards

**Conflict of interest** The author declares no conflict of interest in terms of the publication of the present article.

## References

- Adel, G. T., 1982. An Interactive Simulation Package for Mineral Processing Systems. D. Eng Thesis, University of California, Berkeley, California.
- Adel, G. T., Sastry, K. V. S., 1983. A Computer Simulator for Dynamic Analysis of Mineral Processing Circuits. In: AIME Meeting, SME, Atlanta, Georgia
- Adel, G.T., Sastry, K.V.S., 1982. Design aspects of a mineral processing simulation package. Proceedings of the APCOM'82, AIME, New York.
- Austin, L.G., 1990. A mill power equation for SAG mills. Mining, Metallurgy & Exploration, 7(1), 57-63.
- Bartlett, J. T., 1987. Process Simulation and Optimization Using METSIM. In Mineral Resource Management by Personal Computer, T. M. Li, S.D. Hadelsman and L. Kovisaars (Eds.). SME, Littleton, 105-116.
- Bazin, C., Franklin, M., Perry, R., 1994. On-line Material Balance for flotation plants. In: International Conference on Innovations in Mineral Processing, Sudbury.
- Bond F.C., 1947. Crushing Tests by Pressure and Impact. Trans. AIME, Vol. 169, 58-66.
- Bond F.C., 1960. Crushing and Grinding Calculations. British Chemical Engineering. Vol.6 (Rev 1961 by A/C Pub. 07R9235B).
- Bond, F. C., 1963. Metal Wear in Crushing and Grinding. Allis Chalmers Publication No. 07P1701.
- Bond, F.C., 1952. The third theory of comminution. Trans. AIME, Vol. 193, 484-494.

- Brochot, S., Villeneuve, J., Guillaeneau, J.C., Durance, M.V., and Bourgeois, F., 2002. USIM PAC 3: Design of mineral processing plants from crushing to refining. In: Mineral Processing Plant Design, Practice, and Control, A.L. Mular, D.N. Halbe, and D.J. Barratt (Eds.). Society for Mining, Metallurgy, and Exploration (SME), Vancouver, Canada, 479-494
- Grinding Roll Technology, Vancouver, Canada, Paper No 12.
- Guillaeneau, J.-C., Villeneuve, J., Blot, P., 1992. Advances in the Design and Optimization of Mineral Processing Plants. Proceedings of the APCOM'92, 23rd International Symposium on the Application of Computers and Operations Research in the Mineral Industry, Tucson, Arizona, U.S.A., April 7-11, Chapter 54, 549-566.
- Gupta, V.S., Messa, C.J., 1980. AMAX process evaluation executive (APEX): a general purpose simulator for computing steady state material and energy balances of metallurgical process flowsheets. In: 109th AIME Annual Meeting, Las Vegas, Nevada.
- Herbst, J.A., Rajamani, K., and Kinneberg, D.J., 1977. ESTIMILL - A Program for Grinding Simulation and Parameter Estimation with Linear Models. User's Manual, Dept. of Metallurgy, University of Utah, Salt Lake City, Utah.
- Hogg, R., Fuerstenau, D.W., 1972. Power Relationship for Tumbling Mills. Transactions of the Society of Mining Engineers-AIME, Vol. 252, 418-432.
- KAJA, D.M., 2002. BRUNO: Metso Minerals' Plant Simulator. In: Mineral Processing Plant Design, Practice and Control, A.L. Mular, D.N. Halbe, and D.J. Barratt (Eds.). Society for Mining, Metallurgy, and Exploration (SME), vol. 1, 404-420
- King R. P., 1983. MODSIM, Modular Method for Design, Balancing and Simulation of Ore Dressing Plant Flowsheets. Report No. G9, Department of Metallurgy, University of Witwatersrand, Johannesburg, South Africa.
- Klymowsky, R., Patzelt, N., Knecht, J., Burchardt, E., 2006. An overview of HPGR technology. In: Proceeding International Conference on Autogenous and Semiautogenous Grinding Technology, Vancouver, Vol. IV, 11-26.
- Laguitton, D., 1980. Material Balance of Mineral Processing Flowsheets: FORTRAN Program MATBAL2 - Users Manuel. Report No. MRP/MSL 80-33 (IR), CAN-MET, Ottawa, Canada.
- MacPherson A. R., and Turner R. R., 1978. Autogenous Grinding from Test Work to Purchase of Commercial Unit. In: Mineral Processing Plant Design, A.L. Mular and R.B. Bhappu (Eds.), AIME, New York, 279-305.
- McKee, D.J. Napier-Munn, T.J., 1990 The status of comminution simulation in Australia. Minerals Engineering, 3(1-2), 7-21.
- Morrell, S., 2009. Predicting the overall specific energy requirement of crushing, high pressure grinding roll and tumbling mill circuits. Mineral Engineering, 22(6), 544-549.
- Morrell, S., 2006. Rock characterization for high pressure grinding rolls circuit design. In: Proceedings of the International Autogenous and Semi Autogenous Grinding Technology, Vol. IV, Vancouver, 267-278.
- Mular, A. L., Richardson, J. M., 1986. Metallurgical Balance. In: Design and Installation of Concentration and Dewatering Circuits, A. L. Mular and M. A. Anderson (Eds.). SME, New York, 607-632.
- Mular, A., Herbst, J., 1980. Digital Simulation: An aid for Mineral Processing Plant Design. In: Mineral Processing Plant Design 2nd ed, A. L. Mular and B. Bhappu (Eds.). SME, New York, 306-338.
- Oblad, A.E., Herbst, J. A., 1985. DYNACRUSH - A Program for the Simulation of the Dynamic Behavior of Crusher Circuits, User's Manual, Dept. of Metallurgy, University of Utah, Salt Lake City.
- Oblad, A.E., Herbst, J.A., 1988. SAG/AG S1M.D - A Program for the Dynamic Simulation of Autogenous and Semi-autogenous Grinding Circuits, Manuscript in preparation.
- Pate, W.T., Herbst, J.A., 1987. GRINSIM.D - A Fortran Simulator for Steady State Grinding Circuits. Manuscript in preparation.

- Pérez-Alonso, C. A., Delgadillo, J. A., 2013. DEM-PBM approach to predicting particle size distribution in tumbling mills. *Mining, Metallurgy & Exploration*, 30(3), 145–150.
- Rajamani, K., Herbst, J. A., 1980. A Dynamic Simulator for the Evaluation of Grinding Control Strategies. *Proceedings Particle Technology*, Frankfurt, West Germany, Vol. 1, pp. 64-81.
- Richardson, J. M., D. R. Coles, and J. W. White., 1981. FLEXMET. A Computer Aided and Flexible Metallurgical Technique for Steady-State Flowsheet Analysis. *Eng. And Min. J.* 182, 88-95.
- Rose, H.E., English J.E., 1967 *Transaction of. IMM*, 76, C32.
- Sastry, K. V. S. & Adel, G. T, 1984. A survey of computer simulation software for mineral processing systems. In: *Control '84*, J. A. Herbst (Ed.), AIME, New York, 121-130.
- Schwarz, S., Alexander, D., 2006. JKSimFloat V6.1PLUS: Improving flotation circuit performance by simulation. In: *Proceeding of the Mineral Process Modelling, Simulation and Control Conference*, Laurentian University, Mineral Industry (APCOM), Santiago, Chile, 461-466.
- Starkey, J., Hindstrom, S., and Nadasdy, G. 2006. SAGDesign Testing-What it is and Why it Works. In: *Proceedings of the Conference on International Autogenous and Semi-Autogenous Grinding Technology*, Vancouver, 240-254.
- Wiegel, R. L., 1972. *Advances in Mineral Processing Material Balances*. Canadian Metallurgical Quarterly, Vol. 11, No. 2, 417-424.
- Zaragoza, R., Herbst. J.A., 1988. Model-based Feedforward Control scheme for Flotation Plants. *Minerals and Metallurgical Processing* Vol.5, No. 4, 177-185.