MANAGING COMPANY RISK BY INCORPORATING THE MINE RESOURCE MODEL INTO DESIGN AND OPTIMIZATION OF MINERAL PROCESSING PLANTS

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ABSTRACT

The variability within an orebody with respect to both plant throughput and metallurgical response typically is a significant problem to address during the design phase of a mine. In addition, for existing operating plants, the variability in throughput and metallurgical response needs to be clearly understood and accounted for if plant performance is to be optimized. MinnovEX Technologies, in a collaborative program with major mining companies, is continuing to develop methodologies and tools to address the issue of variability in ore characteristics (such as ore hardness and flotation response). The comminution component of the program is referred to as CEET, for "Comminution Economic Evaluation Tool". The flotation component of the program is referred to as FLEET, for "Flotation Economic Evaluation Tool". These tools were designed for the purpose of managing company and bank risk with respect to the design and production forecasting for comminution and flotation circuits. The tools are used for design and scale-up of these process unit operations and for prediction of throughput, quality of grind, recovery and final concentrate grades throughout the mine resource model. They are used to better quantify the value of each block of ore in the resource model. This paper describes the concepts and approach of the technology, including the importance of linking the mine resource model as an input to the design tools. It also outlines how this technology can be used to refine reserve and resource estimates and how it will be applied to other unit operations in the future.

INTRODUCTION

The value of each block of ore in the resource model is a function of cost/ value components such as head grade, mining costs, commodity price, undesirable elements that invoke smelter penalties and environmental costs, transportation costs, processing costs, rate of production, and recovery and grade of the commodity. Each component contributing to the block value has to be estimated and then all components combined to determine what the true value is for each ore block. The combined value of the ore blocks along with the mine plan is offset against the capital investment to determine the return on investment for the project. The value of each block is also used to classify blocks into reserve, resource or waste designations.

The approach used to estimate the cost/ value components that determine the block values will generally establish the degree of success or failure for any greenfields project. If the cost/ value components are well understood then design and optimization strategies can be invoked to maximize return on investment over the time frames required to match the objectives of the investor.

The approach being embraced by many major mining companies for obtaining the cost/value components for the comminution and flotation stages of a mining operation are described within this paper. It is based on application of the resource model as a dataset for the CEET and FLEET process models used for design and optimization. A similar approach can and will be applied to other unit operations in mineral processing in the near future. The medium for facilitating the access between the process models and the resource model data set is a tool called Process Access.

Once the impact of the mine resource model on the unit process operations is well understood, appropriate circuit configuration and design can be selected using CEET and FLEET to manage production expectations. This production forecasting information can then be used to improve upon advanced control strategies currently being invoked through the use of expert system technology.

COMMINUTION

If a block of ore is very hard then the tonnage through the comminution circuit will be reduced when that particular block of ore is being processed by the plant. This means that the amount of desired metal or commodity produced from that block of ore over a given time period will be less than the amount produced from a softer block of ore, given that other cost components such as grade are equal. This in turn means that the revenue to the owner/investor is reduced over that time period. The reverse can be true for softer blocks of ore assuming no constraints upstream or downstream from the comminution circuit. Therefore, the hardness of a block of ore is a cost component that should be taken into consideration when establishing the value of a block of ore and determining what the revenue generating potential of that block of ore will be. In some cases a block might be hard enough to be determined waste if it is marginal in grade already. This is an important factor in production planning and the forecasting of revenue over set time periods. In addition, the hardness of each block of ore will have an impact on the design and capital cost of a comminution circuit; the harder the ore the larger the capital cost of the comminution circuit, if throughput targets are to be met. But how can the hardness of each block of ore in the orebody be determined; and, if it can be determined, how then can an optimal circuit be designed when consideration has to be given to as many as 750,000 blocks of ore and a variety of flowsheets and equipment types and sizes? It cannot be done with conventional engineering approaches.

Historically, a common method for designing comminution circuits was to divide the resource model into ore types determined by the geologists and then, based on comminution testing of relatively few samples (due to sampling requirements), give each ore type a comminution power requirement. The power requirements were then scrutinized for determining the size, number and type of grinding mills. Other methods used a higher frequency of testing but employed tests (such as the Bond test) developed for ball milling, as opposed to SAG/AG milling which has different breakage characteristics than a ball mill (for convenience, the remainder of this paper will use SAG as an acronym for both SAG and AG milling). Subsequently, variability of SAG/ball mill circuit throughputs within and across ore types was frequently mis-understood, leading to shortfalls in expected plant production. Production planning on a block-by-block basis throughout the resource model was never attempted. The development of the MinnovEX SAG Power Index Test (SPI) in 1994 made production planning on a block-by-block basis possible. The development of the CEET program made it a reality.

The SPI test was based on using smaller but more frequent samples in order to better understand the power requirements within and across ore types for SAG milling (1). With SPI testing, a profile of ore hardness could be created throughout the orebody. The development of the CEET program began in the summer of 1998 (in partnership with major mining companies) (2). The objective of the CEET program was to develop a software tool that could exploit the information derived from SPI tests to:

- design the optimum comminution circuit for any given orebody, and
- carry out production forecasting for existing comminution circuits.

Rigorous benchmarking of comminution circuits around the world was carried out to validate CEET (3). The key differences between CEET and process models of the past were:

- CEET uses process models with the SPI test for SAG milling and process models with the Bond test for ball milling, and
- more importantly, CEET was capable of (but not limited to) using one or all of the blocks of ore within the actual resource model as the data set for the circuit design carried out using the process models.

This meant that the comminution circuit being designed would incorporate a very accurate model of the power requirements throughout the life of the orebody and the circuit would be optimized on capital cost to yield the desired production targets over the complete mine life. The accuracy of the design and throughput forecasts could also be well quantified using geostatistics (4) for various time periods. CEET could output tph and grind size expected for every block of ore in the resource model. This meant that for the first time, investment risk (from the point of view of comminution circuit design, and throughput forecasting and planning) could be measured and managed.

The CEET program was expanded in early 2000 to incorporate a block-by-block understanding of feed size distribution, in-circuit crusher performance and transfer size distribution between the SAG mill and ball mill (5). In addition to being a tool for throughput forecasting and the design of the mill configuration and power requirements for the orebody, this second phase made CEET into a powerful optimization tool for existing operations and greenfields plants. Now such things as the optimum grate/screen combinations for the orebody (or portions of the orebody) and crusher contribution per block of ore could be understood and taken advantage of. Figure 1 summarizes the way CEET works in design mode.

Split NQ drill core samples are used for SPI and modified Bond testwork, 2 kg and 1.2 kg respectively per test. The data is then distributed throughput the blocks in the resource model using geostatistical techniques. The block data is fed into CEET along with the mine plan and user input, applying such parameters as average, minimum and maximum desired throughput rates and desired grind size for feeding downstream unit operations. CEET then generates information that yields the optimal circuit and power balance on the mills to do the job at the lowest capital cost.

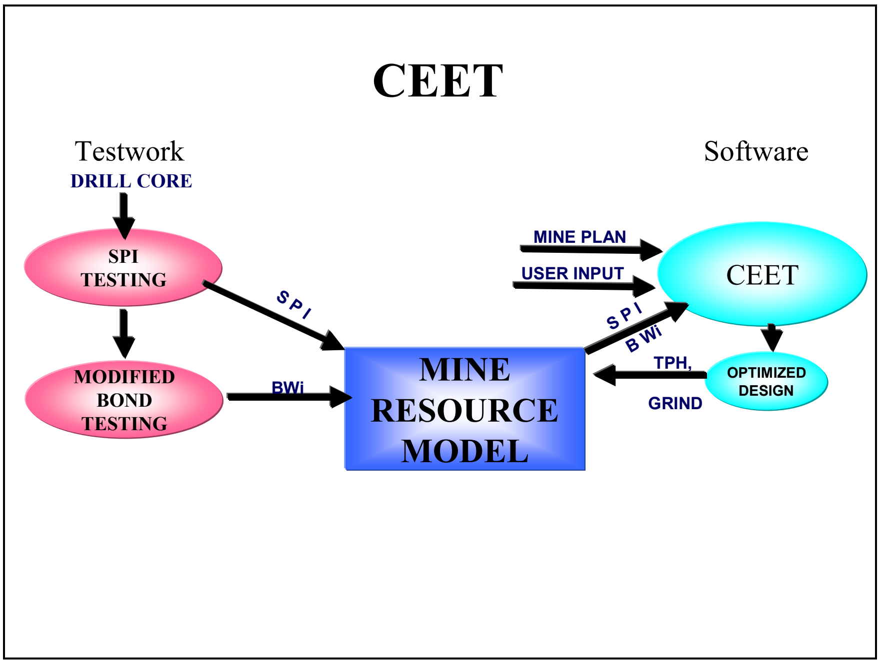

Figure 1: Schematic of how CEET works in design mode

FLOTATION

The expected grade and recovery from of each block of ore make up the flotation cost/revenue components. If a block of ore is refractory and produces low recovery or grades, then the revenue generating potential of that block of ore is reduced. In addition, the cost to recover that block of ore may well increase; an example would be where a series of ore blocks in a sulphide deposit have a high talc content which require large additions of the costly reagent CMC to depress the talc (in order to make a saleable concentrate). Therefore, the recovery and grade of concentrate can also be a significant cost/revenue component that should be taken into consideration when establishing the value of a block of ore and determining what the revenue generating potential of that block of ore will be. In some cases a block might be refractory enough to be determined waste if it is marginal in head grade already. These are important factors in production planning and for the forecasting of revenue over set time periods.

A conventional approach used to design flotation circuits has been to carry out laboratory flotation tests on samples (or composites of samples) that represent ore types. The grade and recovery results from the tests were used to assign the ore types an expected grade and recovery number that was supposed to be represented by the main plant. Large and expensive pilot plant campaigns were frequently carried out on large segments of ore taken from one or more places in the orebody to confirm the results of the lab data. In a few instances, grade and recovery numbers taken from laboratory tests were used for distribution throughout the block model with the anticipation that these numbers would reflect reality. After this work was carried out the flotation plant was designed and scaled-up mainly based on past practice and rule of thumb scale-up factors (with some exceptions; column flotation scale-up models were well understood in recent years, although these models were not applied to the mine resource model). Although much good work is carried out in laboratories and pilot plants, the approach is inherently inaccurate and has significant risk with respect to both circuit design and revenue management for the following reasons:

- The grind size distribution carried out in the laboratory ball mill for an ore type cannot be assumed to match the grind derived from individual blocks of ore of different hardness and feed size through a full scale SAG/ball mill circuit. Therefore, the liberation characteristics of the ore in the test sample cannot be assumed to match the liberation characteristics in the main plant, and recovery and grade are usually strongly governed by liberation.
- The throughput of each block of ore is governed by the hardness and feed size and can change dramatically. This will directly affect retention time in the main plant. Therefore, it cannot be assumed that the consistent retention time from a laboratory test will match the retention time for the various blocks of ore, and recovery is usually strongly influenced by retention time.
- Scaling up from laboratory and pilot plant work has not been well understood and practically applied to the resource model. Efficiency factors for the collection zones of the various cell types and sizes, and froth recovery, froth mobility and entrainment factors were not rigorously applied. Also the effect of regrind, activators and depressants, recycled water, etc. on rate constant distributions for different mineral species and particle sizes on a block-by-block basis were not taken into account.

For these reasons, the grade and recovery values yielded from laboratory or pilot plant campaigns cannot be directly entered into the block model. A more fundamental and robust approach needs to be taken if the resource model cost/revenue components of flotation are to be understood and managed successfully.

In addition to the three factors above, compositing samples can sometimes yield misleading results if the individual samples are not tested first. This is because one does not necessarily know the blending capabilities of a mine before the mine plan is developed. Hence, care must be taken when using blended results.

Figure 2 illustrates that throughput (retention time) and grind size distribution (liberation) per block must be considered prior to extrapolating results from laboratory tests. In addition, it indicates that the flotation circuit configuration, equipment size and operating practice (e.g. froth pull rates) must be included in the scale-up. If the flotation cost/revenue components

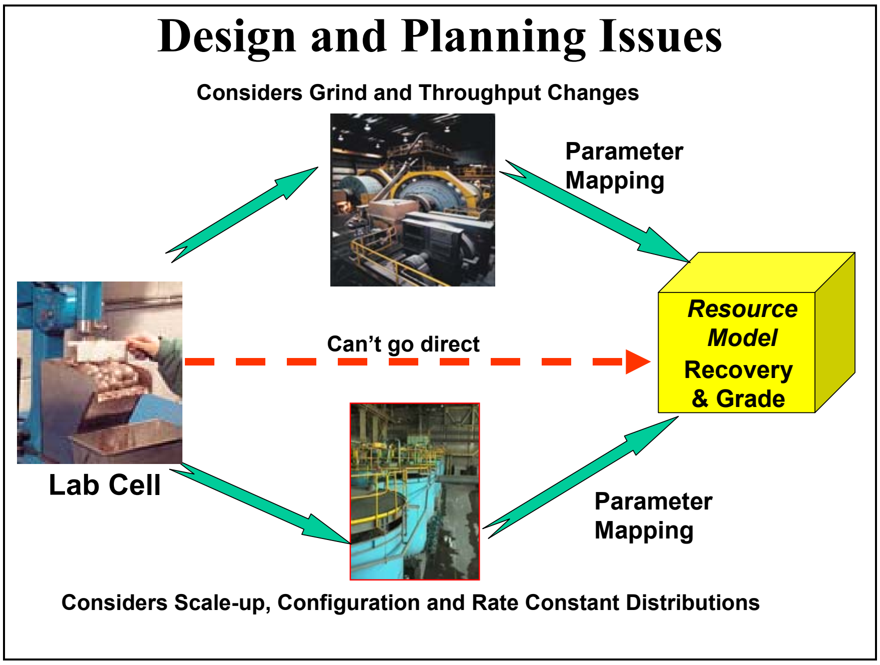

Figure 2: Schematic illustrating that laboratory grade and recovery cannot be directly mapped to the resource model

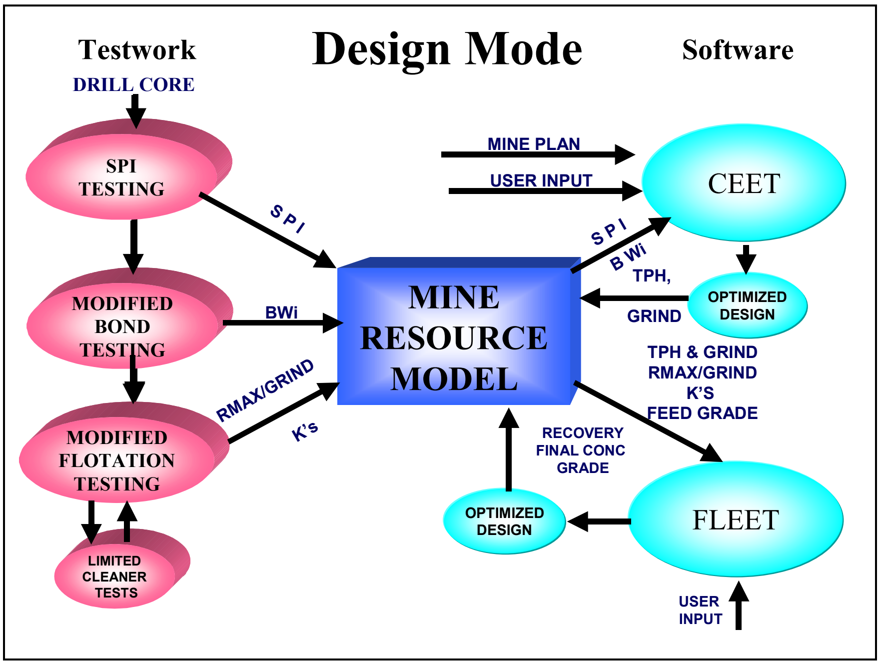

Figure 3 : Schematic of how CEET works with FLEET in design mode

per block are to be understood then flotation circuit design and production planning has to be accurate. In part this means that more fundamental attributes than grade and recovery have to represent the flotation process within the resource model. Such attributes are flotation rate constant distributions per mineral, and maximum recoveries. With this approach, when a circuit design is changed, the resultant change in grade and recovery per block can be forecast. Based on the success of the first and second CEET projects, a third project called FLEET was initiated in 2000 to address the issue of variability of flotation response throughout an orebody and the effect this has on design, and production grade and recovery forecasting for flotation circuits (6). FLEET, as with CEET, was based upon using the mine resource model as the data set that feeds very advanced process models to resolve the three challenges stated above. FLEET achieves its optimal value when the output of CEET can be used as the input to FLEET. In this way the grind and throughput issues stated in challenges 1 and 2 above can be properly accounted for. Although not slated for full completion until the end of 2002, commercial applications of FLEET have been carried out beginning March 2002. Figures 3 and 4 demonstrate how CEET and FLEET work together to manage risk associated with determining and controlling the cost/revenue components of comminution and flotation unit operations. Figure 3 is for circuit design while Figure 4 shows application to production planning.

Fundamental flotation parameters from laboratory tests (rate constants distributions per mineral, maximum recoveries and grind recovery relationships) are distributed using geostatistics throughout the resource model. This information is combined with the CEET output of tph and grind size per block on the model. The combined block values then form the data set upon which FLEET will carry out the tasks of design or production planning. The user will create a flowsheet on the internet either representing an existing circuit or a new circuit and select the equipment from the FLEET database. The program can then be run and the flowsheet and equipment varied to optimize the existing circuit or the greenfields plant. FLEET can then be used to simulate mining the orebody and to output the forecasted grade and recoveries expected per block of ore in the resource model. The flotation revenue component per block of ore can now be more accurately forecast and the precision of the estimate can be determined. The grade/recovery information can be correlated to the cost of flotation per block yielding the cost component per block for flotation.

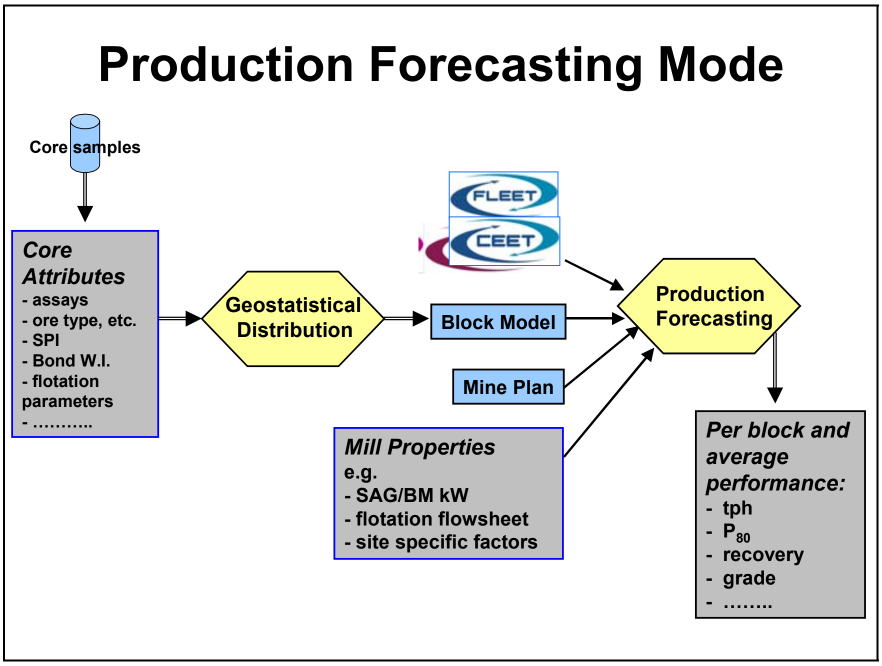

Figure 4: Schematic of how CEET and FLEET work in production forecasting mode

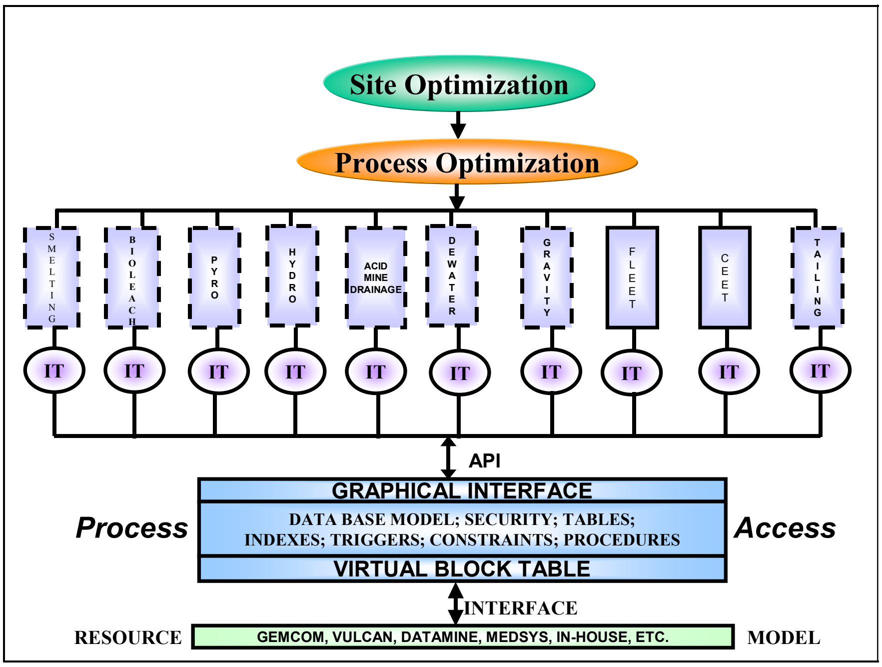

Figure 5: Process Access schematic showing existing and potential process models (existing models – solid line box)

Given the cost and complexity of the software being developed to serve the mining industry, the internet is proving to be a valuable tool for enabling the development of this software technology on a sustainable basis. In addition, the internet allows the advanced software tools discussed above to be accessible by a wide variety of authorized mining personnel around the world without the need for configuring individual computers to run the software or for installing powerful and expensive servers at each site (with all the required redundancy and on-site support). This eliminates a large maintenance overhead for both the user and supplier of the technology and allows for more timely and controlled upgrades to the technology.

Linking attributes from the mine resource model to process models requires significant two-way data transfer. As more and more process models are adapted to work with the resource model it will be necessary to have a single platform whereby selected attributes from a company's resource model can reside in one virtual resource model. This virtual model can then be used to work with all the various process models that are applicable for design, forecasting and revenue/cost component determination. The data output and input for the resource model will then always be between the same two points.

The software tool designed for facilitating access to the CEET and FLEET tools is called Process Access. Process Access is a web interface and navigation tool for mineral processing engineers. It is designed to be the link between a mine-site's resource model and the best process models available, all through a single access point. This makes Process Access an unprecedented resource for the refinement of plant design, production planning, circuit optimization and, in the future, site economics. It enables engineers to use the mine resource model and mine plan as a data set that feeds the various process models. In this way each processing unit operation represented by a process model within Process Access can be designed or optimized for any mine plan represented by the dataset. In addition, production/performance forecasting for each unit operation over any portion of the mine plan can be carried out.

HOW DOES IT WORK?

Mining personnel can link attributes from their mine resource models to the Process Access platform, which is a secure and protected site, accessible only by authorized users. Essentially, the user creates a virtual resource model which stores whatever block attributes from the site resource model that the user wishes to work with. From the Process Access platform the user will be able to navigate through and apply any of the available process models (for which they have authorization) to the data from the mine resource model. For instance a user may have unlimited access to CEET but may not elect to use FLEET since flotation is not a unit operation which that company employs. Another user may wish to access CEET, FLEET and an acid rock drainage model (potential future model to accurately forecast costs per block due to acid producing potential).

The current two-way interfaces available between the resource models and Process Access are via ASCII and Excel. Direct two way interfaces to user proprietary pit design software as well as commercial packages (such as Gemcom, Vulcan, Medsystems and Datamine) can also be generated in co-operation with mine software vendor.

MAKING INFORMED DECISIONS

As more models are added within Process Access the user will have more opportunities to carry out economic optimization across the various unit process operations. For example, from the mine plan and CEET, a user could currently identify years six to ten as years where the ore is soft and full of clay. This means that there is potential to get much higher than normal throughputs but the flotation metallurgy is poor, giving slow flotation rates. Using FLEET, the user could identify the costs required to expand the flotation circuit to take advantage of this increased throughput without suffering from a loss due to poor metallurgical performance. The user could then make an informed financial decision as to whether or not to expand the floor space to permit a planned expansion in year five to take advantage of the higher throughput.

Data output from the process models to the blocks in the resource model, (such as tph, grade and recovery, acid generating costs, etc.), can be used to further optimize the mine planning process. Eventually, economic modules can be added on top of the process models to more rigorously optimize site wide economics with respect balancing mining operations and process operations to increase and manage the value of the orebody.

Production forecasting and optimization tools such as CEET and FLEET can also be set up to run in real time to work in conjunction with advanced expert and neural network control systems for continual feed forward and point-in-time optimization of control strategies.

Never before has there been such easy access to process design and performance predicting models with the resource model and mine plan as the data set. This is an elegantly simple concept that has profound implications on how tasks will be done in the future.

CONCLUSIONS

- It is the authors' viewpoint that the budgets spent on large pilot plants would be better used funding: a) more laboratory flotation testwork to represent the flotation characteristics over the entire orebody from a geostatistical point of view and, b) more mineralogical work, especially focused on the more refractory areas of the orebody outlined by the laboratory testwork.
- Pilot plants, when carried out, should be smaller in size and focused on the more refractory areas of the orebody identified by flotation mapping and mineralogy.
- If the orebody is well understood then the current process models available can be put to use to optimize the design of new and existing comminution and flotation circuits and to more accurately quantify and manage the cost/revenue components of comminution and flotation unit operations throughout the mine resource model.
- All major unit operations in mineral processing should be designed using the mine resource model as the data set for process models that define the operation. This is the only way that the impact of the resource model on the full scale unit operations will be understood. It allows the circuits and equipment to be designed so that revenue and cost components can be forecasted and managed on a monthly, semester and yearly basis.

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