IMPROVED PRODUCTION FORECASTING THROUGH GEOMETALLURGICAL MODELING AT IRON ORE COMPANY OF CANADA

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ABSTRACT

A commitment to a core testing, plant modeling and reconciling technique has shown substantial economic benefits to IOC in terms of accurate production forecasting, smoother operation of the mill, improved expectations of throughput and co-operation across production departments from geology, planning, mining, and processing, to shipping of concentrate to market.

This paper describes a successful seven year program of forecasting throughput of the autogenous milling circuit at the Carol Lake concentrator of IOC. Work started with audits of the grinding circuit in 2001 and benchmarking of the data collected from samples of mill feed and plant operation to the CEET mill design and throughput forecasting model.

Initially 390 drill core samples were tested for SAG Power Index (SPI) to measure the energy required in milling, and the data distributed using a geostatistical technique across the two operating pits, so that hardness was estimated in each of the 40,000 blocks (or 1500 million tons) of potential ore. In 2004 a forecast of energy requirement, i.e. forecast of throughput for a given power availability at the mill, was produced for each ore block using the CEET model and used for mine planning to smooth plant throughput. The forecast for blocks mined on a monthly basis was reconciled with plant results over the next 2 years and minor changes made to the CEET model. The forecasting exercise was repeated in 2006 and in 2008 with the latest model based on the testing of almost 1300 samples of drill core at closer spacing.

INTRODUCTION

The contracting of sales to clients and the timely supply of products to meet those contracts is a cornerstone of good business practice. Ensuring the correct scheduling of production is a major concern of mining companies where the supply and qualities of the raw material is uncertain and production facilities are not flexible. This is particularly challenging when the product is of high volume and produced far from the customer, such as iron ore.

Apart from the metal content of the ore being mined, the greatest impact on production scheduling is the throughput of the comminution section of the extraction plant; most notably when size reduction is achieved by autogenous grinding. The response of the mills to variability in the hardness of the ore can change throughput by as much as 50% from day to day at some plants.

Iron Ore Company of Canada, IOC, approached the challenge of throughput control by obtaining an understanding of hardness variability in the ore body and using that in combination with mill modeling to establish a milling energy requirement for every block in the mine plan. This paper describes the establishment of that model using SAG Power Index (SPI) testing of drill core samples and the application of the CEET (Comminution Economic Evaluation Tool) mill modeling program (Kosick et al. 2001). Forecasts of mill throughput were regularly updated after the extension of SPI testing to drill core from new areas to adjust the hardness estimates of the mine blocks and reconciliation of mine and plant data to tune the mill model.

The exercise achieved benefits at the ore definition, mine planning, plant throughput, seasonal organization and concentrate shipping levels of the operation.

OUTLINE OF THE STRATEGY

Forecasting the grinding plant throughput for any mine block or assembly of blocks that constitute a production period rests on two legs: a model indicating the hardness of the ore body as it varies from block to block, and a model of energy use in the plant to grind ore to the required product size for subsequent treatment.

Many samples of drill core from an area soon to be mined were tested for grindability. Data from the samples were distributed to each block in the mine plan to produce a hardness model using an accepted geostatistical technique while recognizing the effect of ore type on hardness.

The plant was audited several times and samples of mill feed tested for SPI value, for comparison against energy used and grind achieved. It was demonstrated that SPI value was a reliable measure of the energy needed to mill a ton of ore to a specified size. The data was compared to a standard CEET model and fitted as required to produce a model for the specific energy required for that feed in those mills.

The models were used to calculate the expected plant throughput (on a monthly basis) for blocks recently treated and compared with plant results over the past few months. The plant model was tuned and a complete forecast was produced for throughput, energy requirement and grind of each block in mine plan.

After several months of operation, the forecast and actual results were reconciled on a monthly average basis and a search made for the reasons for any discrepancies. Corrections or improvements were made to the plant model where appropriate.

More drill cores were tested to cover future areas to be mined, a new block model of hardness was produced and a reforecast of plant throughput and energy requirement made. A cycle of further testing, reconciliation, model adjustment, and re-forecasting was established on a periodic basis.

AUDITING THE GRINDING CIRCUIT AND BENCHMARKING AGAINST THE CEET MODEL

The grinding section of the Carol Lake concentrator comprises three parallel fully autogenous mills of 10.4m diameter by 3.5m long (34 x 11.5 ft.), equipped with 6000 kW motors. The mills operate in closed circuit with single deck screens fitted with nominally 1.7mm apertures (1.4 x 25mm slots when new). The typical power draw for each mill is in the region of 5200kW with a feed rate of about 1700 tph (consuming about 3 kWh/t of energy), milling from a feed size of nominally 80% minus 150mm to a grind P_{80} in the region of 340 microns.

The ore at IOC is ideal for AG milling comprising a small amount of hard component that acts as grinding media for a soft component of mostly hematite (with some magnetite) iron ore. Ore is drawn from two open pits: the harder ore from Humphrey Main (HM) and the majority of the ore currently from the Luce deposit.

The plant was first audited by sampling one milling line in 2001 and then another line in 2003. Audits showed that one of the three mills had an energy consumption of about 10% less than the others for the same ore, a result that confirmed IOC operational findings and demonstrated the validity of SPI testing. The difference is suspected to be an error in power transformer readings or weightometers rather than a true difference in mill performance.

A total of ten surveys of one-hour each of smooth operation were conducted with mill product samples taken every 15 min to make composites. Feed samples were taken from two of the three feed belts for that mill at the end of the hour, after stoppage of the circuit. Feed samples were used to measure grindability for autogenous grinding using SPI and found to be very soft (4 to 13 min.). This is much softer than any other ore in the SGS database. A "crusher index" developed within SGS-MinnovEX was measured during sample preparation as an indication of friability. This measurement is used together SPI in the mill design and forecasting program known as CEET for estimation of AG mill feed size distribution. The CEET feed size estimation (using a Rosin-Rammler formula) for one survey is plotted in Figure 1 and compared with the actual size distribution of the AG feed sample.

The large discrepancy below the 50% passing size is due to the presence of the large proportion of friable hematite in the ore and presents a difficulty in modeling this grinding process. The large amount of fines of less than 1mm in the AG feed represents "free" mill production, needing no energy consumption, and is the reason why the initial CEET model included a factor of

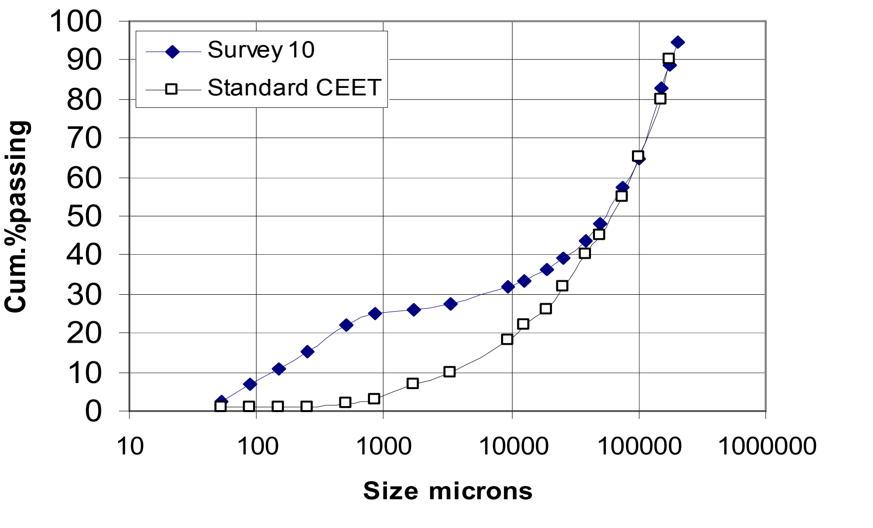

Figure 1: Typical AG feed size distribution as measured compared with Rosin-Rammler distribution generated within CEET

about 70% to correct from the standard CEET estimation of energy consumption to the measured values. Correct forecast of mill feed size distribution and the lack of routine plant data for correlation continues to be a potential source of error in the forecasts.

INITIAL FORECASTING OF THROUGHPUT

From 2001 onwards samples of drill core representing current and soon to be mined ore were tested for grindability. By mid-2004 almost 440 samples had been tested to show the variability of the ore bodies. Profiles (cumulative frequency distribution) of the SPI of the two deposits are shown in Figure 2 and compared with other operations. The IOC ore is regarded as very soft with SPI values normally less than 25 min. Generally speaking, an ore can be considered to be soft when the SPI values vary from 25 to 50min, and of medium hardness in the range 50 to 100min; with hard ore above 100min and very hard ore above 200min.

Drill core samples were usually taken from 15m lengths of core (approximately a bench height) with a drilling grid of 120 x 60m. A geostatistical study was conducted on the data to allow estimates of hardness to be distributed across the ore bodies. 127 samples were used to estimate the hardness of about 9000 blocks in the HM deposit (300 million tons) and 263 samples used for about 31000 blocks in Luce (over 1 billion tons). Mine blocks at IOC are 40m x 20m x 13.7m containing about 35000 tons of ore each. Approximately three blocks are mined and treated each day to feed 3 million tons through the plant in a month.

Statistical analysis of the data indicated two grindability domains based on ore types. (Dagbert and Bennett 2006) These are the softer but more variable "low magnetite" ore (lomag) with an average SPI of 11 min and the harder "high magnetite" ore (himag) with an SPI average of 23min. Other less frequent rock types were fitted into one or other of these due to lack of data preventing separate analysis. A general impression of the ore type situation showing folded layers of ore is given by the section through the geological model presented in Figure 3. Geostatistical analysis was conducted on the two ore types separately and only the same type was used for estimating the hardness of a block. The position of all samples tested that fall within this section are marked as black spots in Figure 3 showing that data was only available from the top of the ore body, close to current mining.

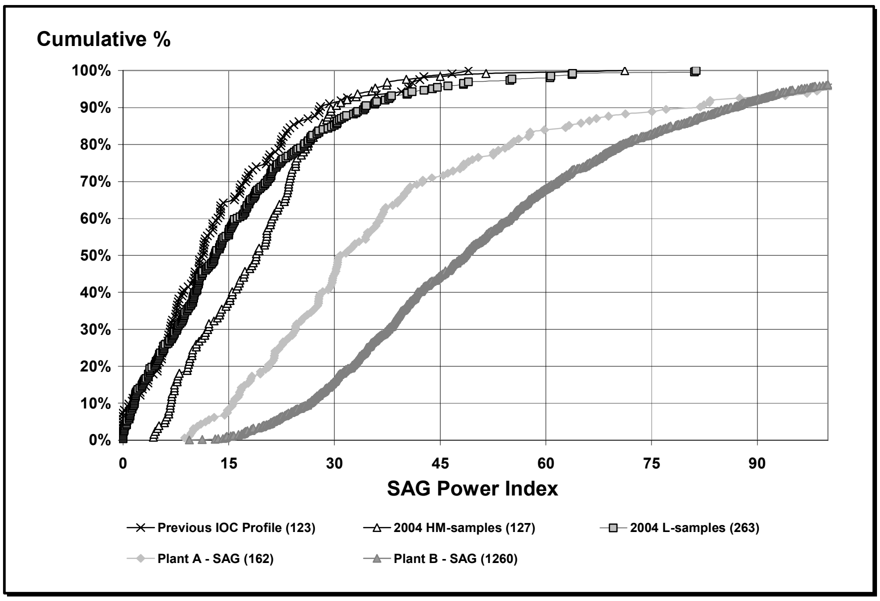

Figure 2: Comparison of the distribution of SPI values for IOC ore bodies with other soft to medium ore

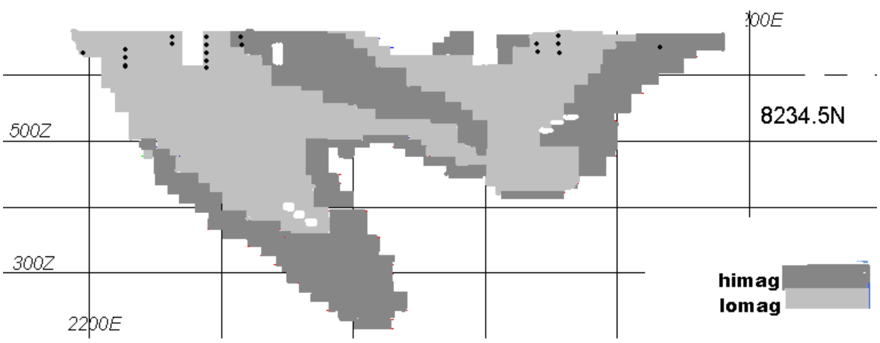

Figure 3: Section through Luce showing ore types

A geostatistical technique known as "kriging" was used to distribute hardness estimates to each block based on the values of surrounding samples within that rock type (hardness domain). Since one rock type is considerably harder than the other it was important that the geological model had correctly attributed the magnetite level to the block.

Kriging involves the construction of geostatistical variograms for each measure of grindability (SPI, Ci) by plotting the variance of differences in the value of pairs of samples of equal distance apart against that distance (Preece 2006). The variogram for SPI in lomag ore at Luce is plotted in Figure 4. The establishment of a model for the variogram allows the estimation of hardness and the precision of each estimate to be made for each block by combination of the values of samples that are within the range of influence. That range is determined by the shortest distance apart for pairs having attained the maximum variance. In this study the range for SPI values was 250 to 300m. The value where the curve cuts the y-axis is referred to as the nugget effect and is a measure of the inherent errors in sampling and measurement of individual data points. This was determined from duplicate or near-duplicate samples to be very low in this case and within the 10% maximum allowed for repeat test results. Variograms were determined in regular space and "unfolded space" (along the folding of the deposit) producing similar models.

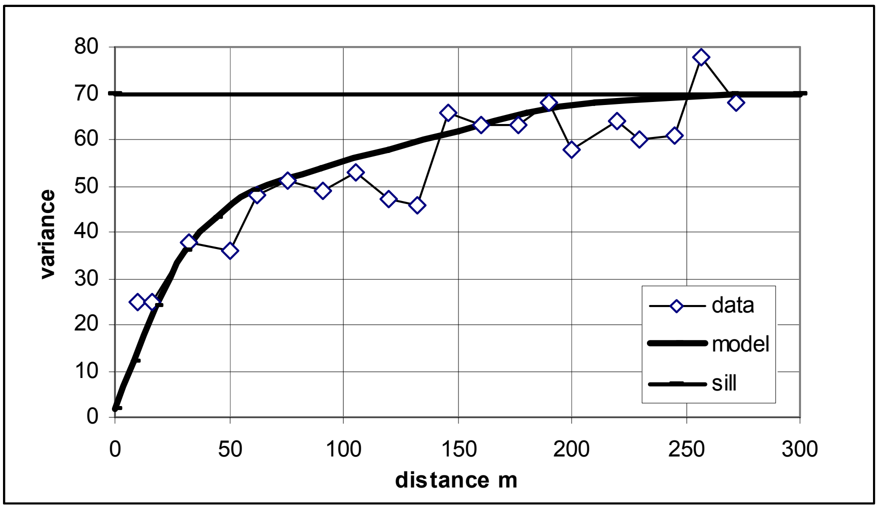

Figure 4: Variogram for SPI values in Luce ore body

Distribution of the hardness estimates can be seen from the section through the geological model presented in Figure 5; the same section as shown in Figure 3 for ore type. Note that the harder areas typically coincide with himag ore. The SPI ranges in this figure are fairly wide to make the figure readable in greyscale. Blocks shown in white are designated as waste. The position of all samples tested that fall within this section are again marked as black spots The uncertainty in the estimate for each block is determined from the variogram model with lowest uncertainty (statistical error) being near the samples, near surface. The deeper blocks are assigned the values close to the average of its expected rock type but with a high uncertainty.

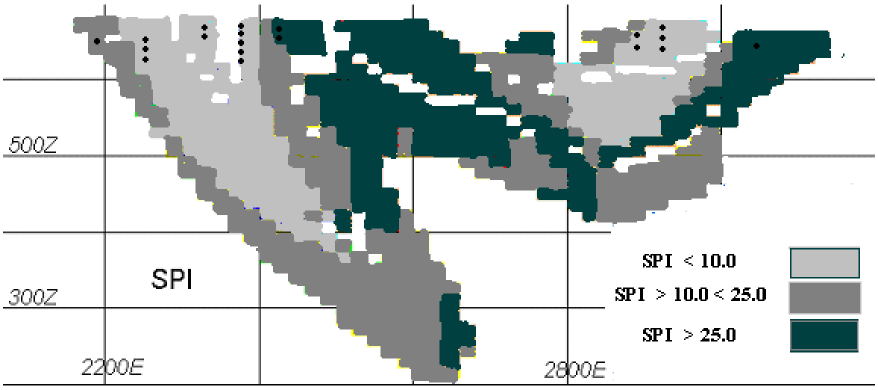

Figure 5: Section through Luce showing estimated SPI values for blocks

The average standard error for blocks in HM was 35% while Luce had an average of 68% since it contained a higher proportion of the more variable lomag ore and had less samples per unit volume. Errors were lowest nearer the current mining area in each case.

The CEET model for the plant as determined in the benchmarking was used to produce an initial forecast of plant results for each of the 40,000 blocks (Dobby et al. 2004). The plant results in terms of feed size distribution (80% and 50% passing), product size (80% passing) circulating load (%), throughput (TPH) and energy consumption (kWh/t) from the most recent 6 months (Oct 2003 to Mar 2004) were compared with the forecast monthly results for the blocks that had been mined each month. Most comparisons were considered to be adequate and minor changes made to adjust the CEET model. However, a serious discrepancy was found in the tph and kWh/t values such that a 70% correction had to be applied to the CEET model to adjust to lower kWh/t actually consumed at a given value of drill core SPI. This is an unusual case where the rock is much softer when measured at the AG mill feed (as used to generate the CEET model) than it is as drill core and may be because it is so soft ore that is easily fractured in blasting. It may explain why the SPI value of the AG feed during the audits (4 to 13 min.) was much less that the values of the drill core samples as shown in Figure 2.

A forecast was published in July 2004 in which each block was assigned the expected energy consumption (kWh/t). This allowed the mining schedule to be adjusted to accommodate hardness variation and achieve smooth plant throughput to meet the sales contract. Cumulative frequency distributions of block kWh/t values for each ore body are shown in Figure 6, and reflect the higher SPI values in HM and higher variability in Luce.

Monte Carlo simulations were run using the CEET model in order to understand the effect of the uncertainty of the estimated hardness of each block value on the expected energy use. The average standard error of block kWh/t was found to be 20% in HM and 37% in Luce. Obviously these errors were lower for an accumulation of blocks (say 90) from different areas that would describe a mining month since many more samples are involved in the estimations of block kWh/t mined from different parts of the ore body.

In January 2006 a geostatistical study was conducted for the mine schedule months of Oct 2004 to Dec 2005 to indicate expected accuracy on a monthly basis. The average standard error of the SPI of individual blocks to be mined was 40%, but the standard error of the average of the monthly accumulation of blocks was typically only 10% rising to 12.5% some months and peaking at 17.5% when mining areas of high variability were scheduled. This translated to a standard error on the average monthly kWh/t from the CEET model forecast that was typically 6.5%, rising to 12% at worst, i.e. the error for most months (95%) is expected to be within two standard errors or about 13% of the measured value. Note this is statistical error in estimating energy needs from the SPI data but excludes any possible error in the geological model, since the ore may be hard due to mining himag when the model expected soft lomag ore.

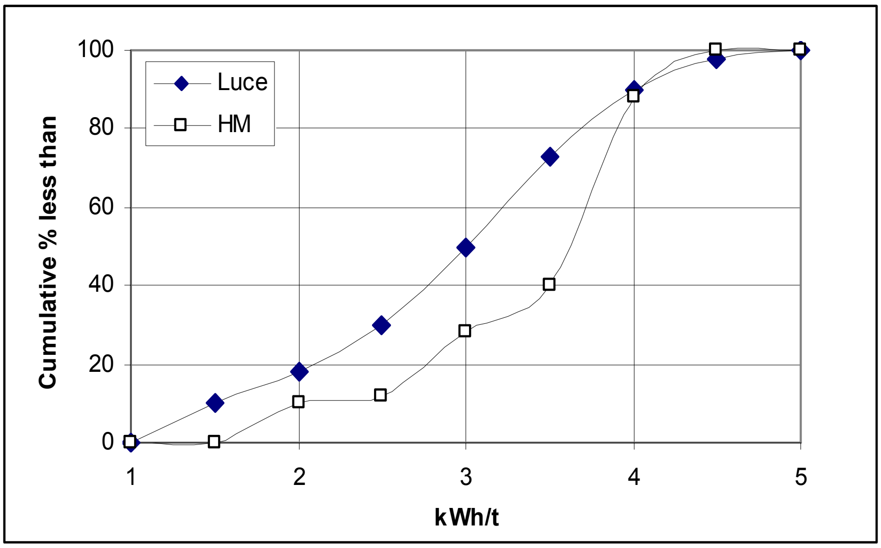

Figure 6: Distribution of energy requirements for blocks in each ore body

RECONCILIATION AFTER THE EVENT

On completion of the first production forecast a period of operation was lost to major strike action at IOC. After operations restarted the monthly average plant energy consumption was compared with forecast from actual blocks mined, not the budgeted mining schedule, since mining did not always follow the plan. The comparison after 3 months indicated the plant kWh/t was consistently above the forecast by about 10%. By April 2005 the error had reduced to an average 5% and by January 2006 to only 3%. A comparison by month is shown in Figure 6 which indicates a maximum error of 14% for a month, in line with expectations from the statistics.

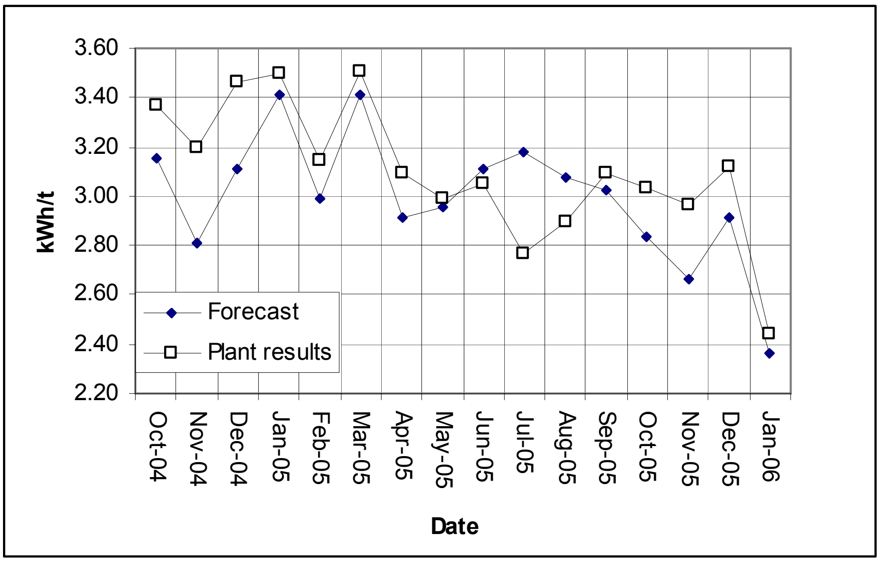

Figure 7: Comparison of plant energy usage with that expected from actual ore blocks mined Oct 04 to Jan 06

While kWh/t forecasts were subject to variability in the success rate, the P_{80} error was always within 5% at 340 microns.

FURTHER KNOWLEDGE OF THE ORE BODY AND MOVING FORWARD

Further deeper drilling, some infilling to a grid of 60 x 60m, and additional core testing was conducted in 2005/06 in advance of future mining so that by June 2006 an updated geostatistical study was made using 737 samples to estimate for 33000 blocks (1.1 billion tons) in the Luce ore body and 260 samples for 54000 blocks (nearly 2 billion tons) at HM. The average standard error of the SPI per block at Luce dropped to 55%, equivalent to 27% in the forecast kWh/t due to the extra samples; but was still 39% in SPI, or 20% in the kWh/t, at HM due to the enlargement of the mine model with extra blocks.

The most significant result of the additional testing of drill core was the proof of softer ore to be mined at depth, as expected by the IOC geologists. Whereas previously 20% of the ore had SPI greater than 25min, now only 5% of HM samples and 3% of Luce samples were more than 25 min. This change was previewed in the trend of kWh/t in Figure 7.

The new geostatistical study distributed all the accumulated hardness data to the blocks resulting in a forecast of reduced energy requirements for the whole ore body in particular that currently being mined. The plant results for Jan to May 2006 were then compared with the hardness of the blocks mined using the updated block model and adjustments were made to the CEET model. A new forecast of kWh/t for all the blocks in the ore bodies was produced in July 2006.

CORRECTIONS TO THE FORECASTING SYSTEM

A comparison of plant data and block forecasts conducted after April 2008 is shown in Figure 8. The gap in data in April 2007 is for a further strike at the mine. Overall the plant average energy consumption was 3% less than expected from the forecast (made in July 2006) with a monthly scatter of between 15% lower and 23% higher than forecast: the largest deviations occurring in the last 2 months. One standard deviation for the error is 9%, which is greater that expected from the earlier geostatistics study (6.5%).

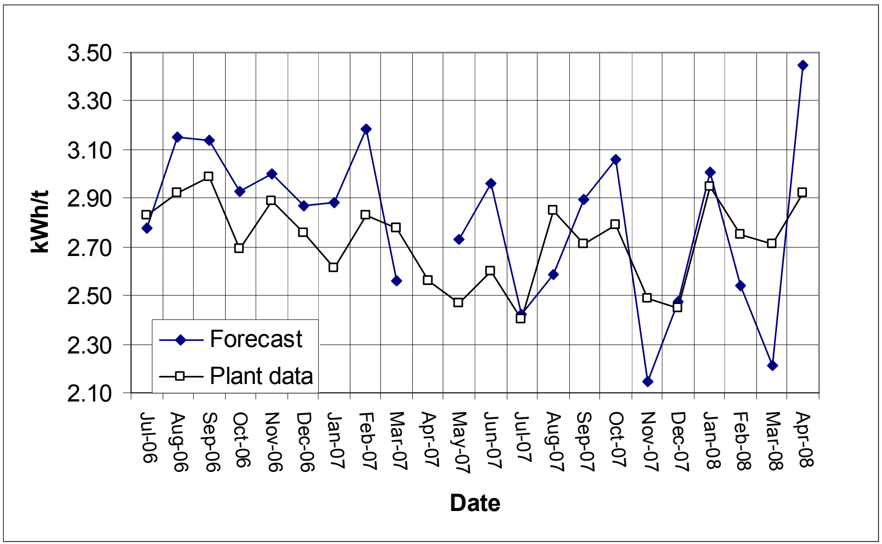

Figure 8: Comparison of plant energy usage with that expected from actual ore blocks mined July 06 to April 08

One possible reason for the reduced reliability of the forecast over time is that mining has moved further away from the location of the bulk of the sample data that was used in the geostatistical analysis prior to July 2006. In other words there was insufficient test data from previous drill core samples to accurately estimate the grindability as the mining is moving forward. One of the laws of good forecasting is "adjust the forecast frequently using recent real data". The reasons for the scatter were investigated at length in order to make the following corrections to the technique before the next update of the forecast.

SPI MEASUREMENT

It was noticed that any months when very soft ore was mined normally coincided with an underestimate in kWh/t demand in the plant. This suggested that measured SPI values of very soft ore may be under-valued to an increasing extent as the sample becomes extremely soft: a fact that may be true of all grinding tests, for the same reason. SPI is a measure of the time taken to grind a 2kg sample from an F_{80} of 80% - ½ inch (12.7mm), to a P_{80} of 80% - 10 mesh (1.7mm) and the energy used in grinding is a function of time taken. An assumption is that the constant 80% passing values F_{80} and P_{80} are a reflection of a consistent size distribution for the sample. However, this is patently untrue for very soft ore where the amount of -10 mesh (the finished product) in the feed is much higher when the ore is found to have a very low SPI value, as is shown for the 2007 round of testing IOC samples in Figure 9.

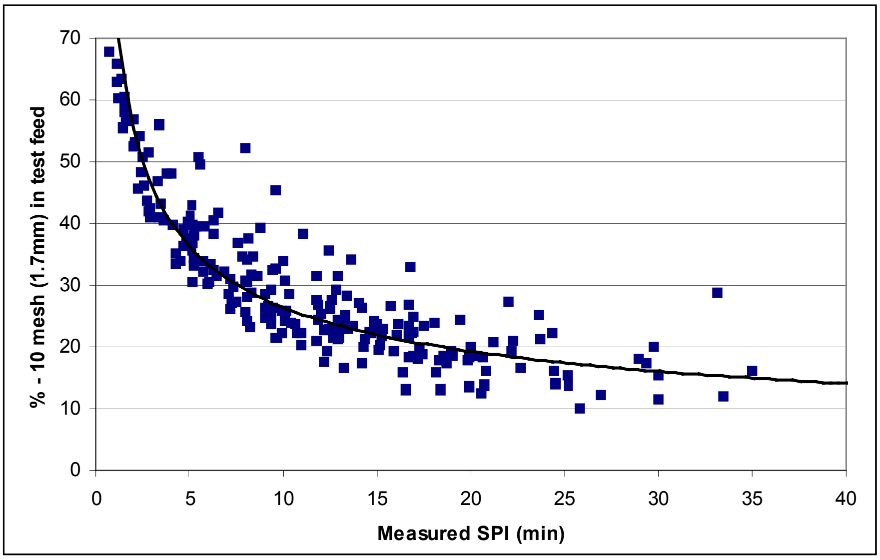

Figure 9: % minus 10% in SPI test feed vs. SPI value

At SPI values above 20 min. the amount of -10 mesh material is fairly steady at about 18% in the feed, which is close to normal for all other ores, satisfying the assumption of a consistent size distribution. However, there is no way of avoiding the presence of these additional fines in very soft ore since it breaks easily in crushing and even in screening ahead of the test. The softer the ore (or should we say the lower the SPI since SPI is the only measure that we have of hardness) the more fines are contained in the feed to the test, suggesting that less energy is actually required in the test to reach 80% - 10 mesh. A very low value for SPI is a reflection of low hardness, but may be biased lower due to the quantity of -10 mesh in the feed. Applying such biased low SPI values to the CEET model will result in biased low forecasts for plant energy requirements, becoming progressively worse as we move to softer ore. A correction was therefore developed for SPI times below 20 min and included in the plant modeling for the next forecast.

CALCULATED AG MILL FEED SIZE

The poor agreement between actual AG mill feed size distribution and that generated by the standard CEET model (as previously shown in Figure 1) was addressed by a change to a modified Rosin-Rammler equation that allows for inclusion of more fines, as shown in Figure 10. Although still not adequate for the IOC situation it is an improvement on the standard equation. It must be noted that there is still a potential for unknown error in practice due to the lack of plant measurements for reconciliation with the AG feed size distribution generated in CEET.

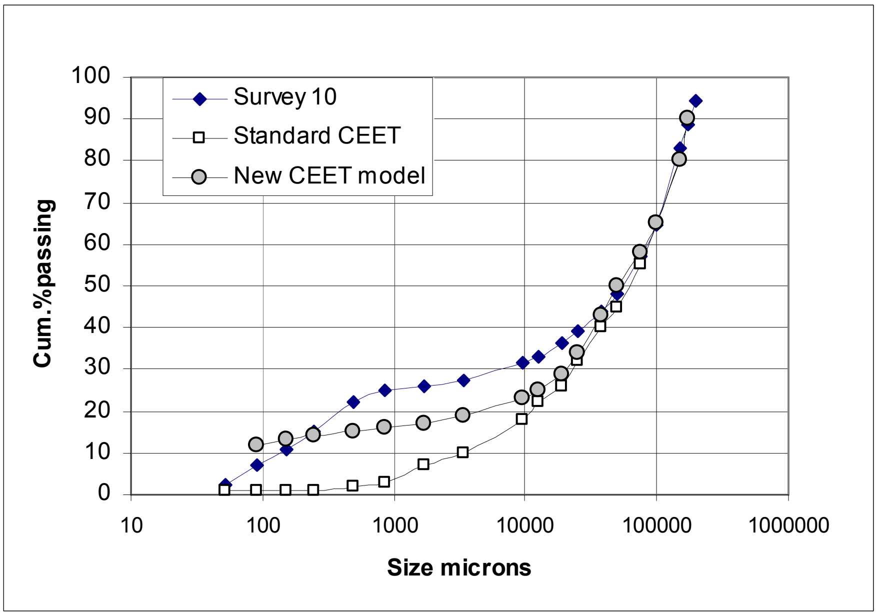

Figure 10: Improved AG feed size distribution generated by latest CEET version

REFORECASTING

The geostatistical study of Luce was updated in May 2008 based on further drilling and testing in 2007 from deeper in the ore body. The data were in line with the softer results of 2006, and showed the ore was not becoming progressively even softer. This time there were 1295 samples in 32000 blocks in the Luce an ore body, representing about 1.1 billion tons covering an area of 1.2km x 1.9km and a vertical height of 400m. Even with the additional samples there was still only about one sample per million tons: however they are concentrated close to the past and current mining areas. The new variogram models were very similar to the earlier ones with estimation still based on grouping the data into two grinding domains (rock types). The standard errors improved a little to an average of 50% (ranging from 15 to 85%) due to more samples. The lomag ore is still the most common type contributing to the biggest variability. Estimations of the hardness values for the blocks were updated from the new study. No further sample testing and modeling was conducted for HM since it no longer contributes a significant amount of ore.

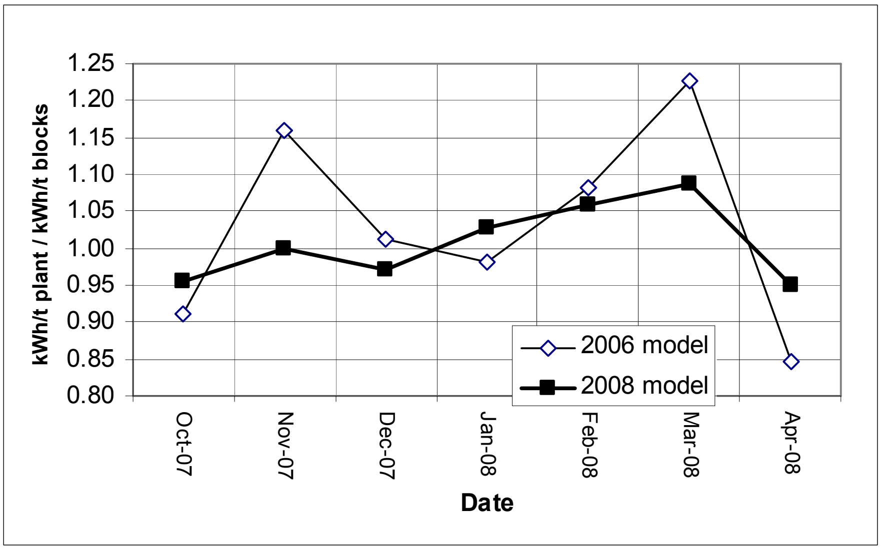

Figure 11: Improvement in agreement when using the latest sample data and CEET model

The corrections to the system as discussed above were combined with the updated hardness estimates for the latest block model to calculate expected energy requirements for each month from Oct 2007 to Apr 2008. These were compared with the plant results as the ratio of plant measurement to block expectation, shown in Figure 11, indicating a much better agreement that in Figure 8. The changes were used to generate an updated mine block forecast in May 2008 as a basis for mine planning over the next two years.

OTHER SOURCES OF ERROR

Despite the large amount of effort put into testing and modeling over the past 7 years, there is still the potential for poor agreement between forecast and plant results due to limitations of the forecasting procedure or operating practice such as:

- Statistical limitations due to insufficient drill core data. The samples are too far apart (at 60 by 60m drill grid) or not far enough ahead of mining to produce low uncertainty in individual block estimates.
- Possible errors in the geological model resulting in blocks that are incorrectly assigned hardness due to being labeled with the wrong ore type.
- Inclusion of unplanned waste of unknown hardness together with the ore.
- Changes in blasting practice such as changes in spacing affecting plant feed size distribution or the amount of micro-fracturing in the ore.
- Inadequate pit reconciliation, since poor surveying of working faces can lead to errors in the estimation of mined material.
- Stockpile movements where blocks mined are not the same as those milled. This is not accounted for at IOC as there are poor records of what or when ore was sent to or removed from stockpile causing a difficulty in trace-ability. There were more than 1 million tons on stockpile at the end of 2004 and it is possible to have as much as 3 million tons (or 1 month of mill feed) on stockpile at the end of a summer to allow for winter mining conditions.

- A lengthy delivery period between mining of the ore and delivery to the plant making it uncertain which blocks are actually being milled at a given time, increasing the difficulty in forecasting for shorter periods.
- Periods where there is a lack of ore; or a rapid change in ore hardness or AG feed size, all of which can reduce plant efficiency.
- Changes in the plant practice that are not recognized as significant, and not accommodated in changes to the CEET model.
- Inadequacy of the plant model due to missing measurements, e.g. AG feed size distribution is not measured regularly for correction of the CEET model.

BENEFITS

The benefits flowing from reliable forecasting of grinding energy requirements on a mine block basis are obvious to the mine and plant operators but always difficult to measure in terms of increased production or reduced costs since there are so many other variables affecting the results. Unfortunately improvements to the "bottom line" cannot be quantified to justify the dedicated time and expense of the ongoing forecasting exercise. However, the following benefits have been achieved and represent a contribution to increased profits.

ORE BODY DEFINITION

Forecast of the block hardness (or grinding energy requirement) of a block as an addition to grade allowed a reconsideration of ore definition. Marginal grade ore with low energy requirement can move from "resource" to "reserve" for current AG mill plant capabilities. Alternatively a block requiring high kWh/t can be revised as waste due to its low throughput and resultant high cost for plant treatment.

OPTIMIZED MINE PLANNING

Incorporation of forecast block kWh/t requirements into the mine plan constrained the mine model that was previously based solely on NPV from metal grade. This allowed optimization of the mine design and schedule to include improved plant throughput and concentrate production resulting in maximized profits.

ORE HARDNESS STABILIZATION

Variations in the ore hardness delivered to the mill cause fluctuations in throughput. It has been shown in the past that consistency in ore hardness (in terms of specific energy requirements) was beneficial to both throughput and plant weight yield (metal recovery) compared to variations, even when the variations were long term. Since the grinding plant has a maximum power draw limitation, the treatment of hard ore results in limited throughput. Attempting to balance this by a period of soft ore is frustrated by the limitation of throughput of the downstream operations losing the full utilization of AG mill capacity. An accurate forecast of the energy requirement by mine block allows hardness of ore to the plant to be stabilized by planning the simultaneous mining of hard and soft blocks from different faces. Such blending during mining is cheaper than an equivalent stacker-reclaimer operation.

BETTER STOCKPILE UTILIZATION

When mine production is sufficient, stockpiles are typically produced according to the magnetite content of the ore, to meet current and future demand for magnetite concentrate. Magnetite content generally correlates with hardness (himag ore is harder than lomag on average). When problems occur (such as model inaccuracy or equipment breakdown), these soft and hard ore stockpiles are used for blending to control the hardness to the plant. When there is sufficient material, multiple stockpiles are separated into high and low hardness to allow the mine to more effectively blend the ores.

REDUCED DOWNTIME LOSS

Grinding plant throughput and the stable production of concentrate is maintained during periods of planned mill downtime, such as relining, by targeting softer mine blocks with forecast low energy requirement.

IMPROVED SEASONAL OPERATION

During the long winter season at IOC the mining operation experiences reduced production due to issues such as blinding snow storms, extreme cold weather, and high carry-back (from plant to mine) of frozen material in the rail cars. In order to ensure that the maximum utilization of available mill power is exploited despite the shortage of ore supply to the plant, the harder mine blocks with high energy requirements are targeted for the winter months and ore is recovered from hard ore stockpiles during bad weather. Once summer begins, a greater quantity of ore can be mined and delivered to the plant and a higher throughput achieved by targeting the softer ore blocks.

REDUCED SHIPPING COSTS

The forecasting of energy requirement for each mine block has improved the short term control over mill throughput and consequently the concentrate production rate. Product is correctly scheduled to meet the demand for customer shipments preventing the occurrence of demurrage charges for railcars and ships.

INTER-DEPARTMENTAL RELATIONSHIPS

The reconciliation between mine models and plant values and confidence in the forecasting results has improved the communications and working relationships between the mining and milling staff. Incorporating the requirements for sustained mill output into the mine production schedule has reduced the traditional inter-departmental friction between personnel, generating a more co-operative working environment.

CONCLUSIONS

The milling plant energy consumption and throughput have been successfully forecast at the Carol Lake operation of IOC for the past four years by:

- Ongoing drill core sampling and testing for hardness by SPI measurement.
- Applying geostatistics to the sample results and distributing a hardness estimation to each mine block recognizing the geological models of the ore bodies.
- Using a CEET model that links hardness to plant operating results to forecast mill energy requirements for each mine block as a guide to the mining schedule.
- Updating the hardness estimates every two years based on new drill core test data.
- Reconciling the latest mined ore block hardness estimates with plant records of energy use (after the fact) and adjusting the CEET model where needed.
- Recognizing the limitation of the forecasting accuracy by geostatistical determination of standard error, which is typically 6.5% for a forecast month, i.e. forecast of the monthly average for kWh/t is expected to be within about 13% (19 times out of 20) at the current sample density and hardness variability.

The benefits are difficult to quantify or place in financial terms but the operators have identified improved ore body definition, better mine planning, consistency of ore hardness delivered to the plant, reduced downtime losses, improved seasonal operation, and reduced risk of additional shipping costs. The intangible benefit of an improved inter-departmental working environment must not be overlooked.

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