OPTIMIZATION OF THE XSTRATA NICKEL-SUDBURY SMELTER CONVERTER AISLE USING DISCRETE EVENT SIMULATION

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ABSTRACT

During the last decade or so, Xstrata Nickel’s Sudbury smelter has significantly extended plant capacity and improved the overall performance. As part of the quest for further enhancements at the plant, a new dynamic simulation model was developed incorporating a complete metallurgical model together with converter aisle logistics based on the ARENA™ software platform. The model, which included a number of special animation features along with the use of plant operating data, is described in the present paper. Tested against a “base case” representing actual operations, the model was found to reflect operating conditions very well. The model was used to evaluate a number of potential converter changes, including the effect of the following on plant capacity: the use of larger ladles, the effect of higher converter blowing rates and the impact of lengthening the converter vessels. It was found that in many instances, so-called plant bottle-necks were often “coupled” and hence it was found necessary that multiple decisions were needed to be taken together to significantly improve converter aisle capacity. The model was successfully used to verify that the proposed smelter changes previously identified to allow the plant to handle future higher throughputs were feasible from a scheduling perspective.
INTRODUCTION

Operations at the Sudbury smelter of Xstrata Nickel have been described in a number of previous papers [1-6] and only a general process description from the perspective of the present study is given here. The key process steps at the plant are the following:

- Feed receiving and preparation
  - Concentrate received as bone dry, filter cake and as slurry
  - Custom feed materials
- Fluid bed roasting, off-gas cleaning and acid plant
- Electric furnace smelting
- Converter aisle - matte converting, slag cleaning and matte granulation

Figure 1 illustrates a schematic flowsheet of the plant subsequent to the feed preparation step.

Feed receiving and preparation

The concentrate is received at the smelter either as bone dry, filter cake (by rail) or as concentrate slurry (by truck). These feeds are blended to produce a roaster feed slurry having a density of approximately 70% solids. The slurry is then pumped to surge tanks before being introduced to the roasters by a slurry gun located on the roaster roof; sand flux is also introduced at the top of the roasters. Depending on the type of custom feed, this material is typically treated in the different units of the smelter.
**Fluid bed roasting, off-gas cleaning and acid plant**

The two fluid bed roasters typically each handle about 40 tph per roaster and operate to give over 70% sulfur elimination. This degree of roast is approximately equivalent to about 90% oxidation of contained FeS to magnetite in calcine, with the remaining sulfur mainly associated with nickel and copper. The roasters were originally designed to operate with a fairly high free space velocity, about 1.3 m/s, whereby most of the calcine reports to the bank of off-gas cyclones [1]. The cyclone off-gas is first treated in the ESP and is then sent to the acid plant where the sulphur dioxide is recovered as sulphuric acid.

**Electric Furnace Smelting**

The roaster products are delivered to the electric furnace by drag conveyors together with a small amount of added coke to promote reductive smelting conditions. At a total calcine rate of about 90 tph, the 30 m by 10 m furnace operates at up to 45 MW. While most of the sulphur in calcine reports to the metalized matte, a small proportion of the sulphur also reports to the furnace off-gas. The converting of the highly metalized matte evolves sulphur dioxide only towards the end of the final converting stage, thus improving environmental conditions compared to converting of a non-metalized matte.

**The converter aisle - matte converting, slag cleaning and matte granulation**

The converter aisle handles matte and slag essentially in a counter-countercurrent manner [5]. Matte is handled in three stages as indicated in Figure 1. The 1st stage is the No.8 slag cleaner (SCV), the 2nd stage is the No.7 slag-make converter (SMC) and the 3rd stage being the No.5 & No.6 finishing converters (FV - two identical FV units). The matte to be converted thus moves from left to right in Figure 1 with a corresponding lowering in iron content, while the slag moves from right to left undergoing slag cleaning in the process. Typically the %Fe in the SCV matte is 25-30%Fe, the %Fe in the SMC matte of the SMC is approximately 15% and the %Fe in the FV matte is 2%. The slag from the finishing vessels has elevated levels of Co and Ni which are partially recovered in the SMC due to its lower oxidation potential relative to the FV. The SMC slag is then transferred to the SCV where final converter aisle slag cleaning is carried out [5]. The slag produced from the SCV is sufficiently low in Co, Ni and Cu to be discarded. Finish matte is skimmed to ladles for subsequent transfer to matte granulation [5]. After de-watering and drying, the matte is packaged and shipped to the Company’s refinery in Norway for metal refining [7].

As discussed by Salt and Cerilli [5], a number of potential changes at the converter aisle had been identified for the plant to manage a capacity increase from 67,000 tpy of contained nickel up to 85,000 tpy of contained nickel and potentially higher. These approaches were then thoroughly validated using the present scheduling model together with the generation of the numerical supporting data as described in the present paper. The main changes considered by Salt and Cerilli [5] were as follows:

- Increase in ladle size from 200 ft$^3$ nominal capacity to 400 ft$^3$ nominal capacity (from 5.6 m$^3$ to 11.2 m$^3$)
- Lengthening the SCV by about 40%, from 12.2 m to 16.8 m, making it the same length as the SMC (40 ft to 55 ft)
- Increase in the blowing rates of the SMC vessel by 50%
- Increase in the capacity of the matte granulation unit and the granulated matte handling system.

It is noted that in general a process involving a number of individual steps in series may not be capable of operating at the rate of the fastest step and may indeed operate below the production rate of the slowest step due to process interactions. Maintenance down-times, shift schedules and interaction between the steps all need to be considered, and this can often lead to lower production rates. In this context, it is valuable to have the capability for analyzing the production steps with special software allowing one to examine the interaction between steps.

The Arena™ software [8] was used for modeling the logistical aspects of the Sudbury smelter converter aisle. The present scheduling study on the nickel smelter was carried out prior to a later study carried out by Xstrata Process Support and Xstrata Copper for the Horne copper smelter and recently described by Coursal et al.
It is to be noted that even though the two plants have quite different metallurgy but the logistics related to plant scheduling and the like revealed that the two plants had a number of features in common. In particular, this included items such as: crane management and crane maintenance algorithms and the fact that each plant uses a number of batch-operated converter-type vessels, etc. As such, modeling techniques previously established for the first project (as described in the present paper) was of value in the later project (copper smelter) and vice-versa. In the case of the present work for the Sudbury nickel smelter, the logistics model utilized data developed in a separate Metsim model [6]. It is noted that Metsim is a familiar software used extensively in the metallurgical and allied industries [10].

The present work was therefore carried out in support of a capacity study [5] for the Sudbury smelter and included validation of the required changes for increasing the converter aisle capacity from the present level of 67,000 tonnes of contained nickel per year, up to 85,000 tonnes of contained nickel per year. Plant simulations performed by the Arena software provided confirmation and documentation of the impact of parameters such as vessel length, vessel blowing rate, ladle size and maintenance times amongst others in meeting production targets.

**STRUCTURE OF THE ARENA MODEL**

From the outset of the present work, it was determined that for a number of reasons the fluid bed roasters and the electric furnace would be excluded from the scheduling study. These units were known to have some capacity upside and flexibility and the on-line time was reliably high. Further, separate studies had identified approaches for increasing the throughput at the fluid bed roasters and electric furnace and projects for achieving this had already been identified. The present paper therefore focuses on the converter aisle operation and describes how the strategy to potentially increase future converter aisle capacity from 67,000 to 85,000 tonnes of contained nickel per year was developed.

Figure 2 illustrates the main screen of the Arena model; this figure also shows a schematic layout of the Sudbury smelter converter aisle. As indicated earlier, the Ni-Cu matte is produced in the electric furnace and after batch tapping this matte is transferred by ladle to the converter aisle. The matte transfer proceeds firstly to the “cleaner” vessel (Figure 2), then to the “slag-make” vessel and thence to the finish vessel (either to No. 5 or No. 6 - these vessels are identical). Also, it is noted that converter aisle slag essentially moves countercurrently to the matte, that is, slag moves from right to left in Figure 2, with the final slag contacting the high-iron metalized electric furnace matte in the “cleaner” to provide for conditions that maximize slag cleaning [5].

The input variables (in excess of 75) for the model were conveniently handled via an Excel input sheet where, for example, the user can input or change variables, such as the production rate or other key performance indicators and compute the impact of a given change. In practice, the Arena software was initialized with the Excel input file, and minimal knowledge of specific Arena programming was required to actually run the scheduling model.

The model outputs were also provided in an Excel output file; this included information such as the average daily production rate and other key performance indicators, as will be described in a later section. The main features of the model logic, the input and output parameters will firstly be described in the following section.

**General features of the logic used for the model**

The model logic was separated into different “logic blocks” for each main process unit which were essentially independent from one another, while maintaining the ability to interact with each other. Each “logic block” had an internal algorithm which raised “flags” to another logic block so as to offer/request, for example, matte or slag for transfer to a given vessel. It is noted that the logic blocks could be turned on/off to simulate, for example, vessel rebricking.
The main logic blocks adopted for the present model were the following with additional details provided below:

- Crane management
- Electric furnace
- Slag cleaning vessel (SCV)
- Slag-make converter (SMC)
- Finishing vessel No. 5 (FV)
- Finishing vessel No. 6 (FV)

A number of rules were established as regards the raising of a “flag” to another logic block as described below, with examples of such “flags” being the following:

- SMC has produced sufficient slag to be transferred to the SCV:
  → Status = to go to standby if slag level too high
  → Status = return to blowing if slag level not too high

- FV No. 5 needs an additional ladle of matte:
  → Status = standby

The management of the converter aisle may initially appear reasonably straightforward by inspection of Figure 2. However, deeper study shows that in reality this can become quite challenging when all of the variables for each vessel are taken into consideration, quite apart from managing the necessary crane priorities and potential crane movement conflicts. As occurs in actual plant practice, Figure 2 indicates (at far left) the option of electric furnace matte being sent “outside” (in actual practice, a ladle of matte is occasionally transported outside the aisle where the matte is allowed to cool; the matte is later broken and crushed for re-smelting/converting). It can be appreciated that if the electric furnace smelting rate were to be increased without any corresponding adjustment at the converter aisle, an increasing and obviously undesirable amount of matte would need to be “sent outside”. For the present work, a maximum amount of 3% of matte production sent outside was adopted. Further, in studies carried out to determine maximum throughput rates under a given scenario, the 3% figure for matte sent outside was used as a trigger to identify to the model operator that the maximum throughput had in fact been reached.

As mentioned, the present Arena™ model dealt mainly with converter aisle logistics; the metallurgical model [6] established the mass and heat balance data and thus input variables for the Arena™ model for a given
operating scenario. The Arena™ model then ran the case simulating plant operating conditions. It was recognized that metallurgical parameters could affect plant capacity. The requirement to produce 85,000 tpy of contained nickel at a Cu/Ni ratio of say 0.3, is from a metallurgical perspective, quite different to producing the same amount of contained nickel but at a higher Cu/Ni ratio of say 0.5 (i.e., higher copper over nickel grades). In this case, more matte would have to be handled to produce the same amount of nickel. Hence, it can be seen that each Arena™ simulation could represent a number of parameters impacting converting aisle productivity, which was generally defined as the amount of contained nickel produced as opposed to the amount of matte to be processed.

Initially a “base case” was established corresponding to plant conditions at the time; correspondence between this model simulation and the actual operations was very good. Almost all of the various operational procedures were identified at this early stage of the model work including: the different matte and slag transfer stages, vessel down-times for re-bricking and the like. Some individual steps such as movement of an empty ladle and ladle cleaning operations (e.g., skull removal) were not identified individually, but were accounted for using a time allowance added to certain other individual moves. A simplified strategy was then used to evaluate the maximum capacity of the converter aisle in that the electric furnace matte output was gradually increased until the converter aisle could not handle all the matte (as judged by the fact that 3% of the matte was sent outside). Once the maximum amount of matte capacity was noted by this approach, the “bottleneck” was then identified and the Arena™ model was run to evaluate the effects of potential changes at the converter aisle, in essence to “de-bottleneck” the simulated plant, thus increasing the converter aisle capacity. Then for a given operating scenario, the impact of plant changes such as a larger ladle size (generally reducing crane movements for ladle transfer), the impact of different nominal blowing rates, vessel lengthening (a change in vessel diameter was not considered due to the requirement to maintain hooding geometry), together with changes in certain procedures and priorities that were traditionally followed in the converter aisle, were evaluated. The most important application of the Arena™ model work was to be able to simulate a given scenario, understand and document the incremental capacity that could be realized by a specific change to converter aisle operation.

Algorithm for Management of the Cranes

One of the most difficult aspects to consider regarding the converter aisle modeling was a suitably robust logic for the management of the cranes. The important aspects in developing the algorithm for this are listed below:

- Handling crane conflicts
- The priority list for crane movements
- Allowance for maintenance (daily and weekly)
- The use of multiple or cascading crane strategies

Crane conflict was defined as that situation that occurs, for example, when the first crane is required to move from A through position B to position C, but the second crane is active in position B thus blocking the timely execution of the first crane movement. While appearing simple at first glance, there were a large number of potential moves that could result in conflicts - these were developed and listed in a master table during model development, leading to the generation of a complex algorithm. In this particular example, when required, an action could be taken by the second crane to move out of the way or, alternatively, the first crane would have to wait until completion of the current move by the second crane before being able to perform its own move. This latter procedure involved a longer time for the first crane to complete its move. Such a wait may or may not slow down the aisle, depending on the specific situation.

Typically for a converter aisle such as this, each crane has a “favorite sector” in which to mainly operate. It is reasonable that each crane typically operates in its particular sector; hence there is normally a priority list for such moves performed by each of the cranes. Also, each crane would need to identify what were the most important moves within its own list of preferential moves. Clearly the transfer of matte and slag to/from the converters, moves most likely to impact production, would normally have higher priority. As the model was running, the cranes would receive “requests” and these requests were sorted by the model software in a priority list and in this manner a “queue” was developed. Arena™ included typical crane availability factors based on
operating data. The Arena software was designed with these concepts (request, transport, queues, etc.) integrated into the software. The Arena software provided the possibility to include any aspect of the operation the user deems of value, but the adopted logic had always to be consistent to avoid premature ending of a simulation run and the need to carry out the resulting corrections. As noted, the weekly maintenance and the daily maintenance activities for the cranes were included in the model; at the plant, these activities are normally coordinated with other maintenance activities to minimize the impact on productivity. There can be more that one algorithm for managing the cranes. Depending on the status of the cranes or the status of the converter or slag vessels, the most appropriate logic was adopted and applied.

**Electric Furnace**

As noted, modeling the electric furnace was excluded from the present study, and a simplified procedure for the furnace was used. For example, matte “production” only at the furnace was considered with slag production/slag tapping excluded. A logical loop was used to “produce” a ladle of matte at the furnace at a given time according to a frequency schedule based on smelter matte tapping records. The matte tapping frequency included a step change which could typically occur at shift change. The simulated level of matte in the furnace was also followed in the model. The input file contained a tabulation of tapping frequency (as the number of ladles per time interval) for each 0.5 hour interval of the day as based on plant data. Such a list was equivalent to a certain plant throughput (as an example, the base case of 67,000 tpy of contained nickel). The matte “production” schedule was maintained in the Excel input file and could be “scaled-up” as required for a higher throughput, while still maintaining the same type and shape of the base case tapping frequency distribution.

If for some reason the simulated matte level in the furnace was to become too high and for some reason matte could not be transferred to the converter aisle, such matte would be sent “outside”. As previously discussed, the strategy to identify the maximum capacity was to fix all the converter aisle model parameters and then to extend the matte output/tapping frequency until 3% or more of the matte would be sent outside. At this point, the tonnage of nickel contained in finish matte was then taken as the maximum plant capacity for the scenario under study.

**Slag Cleaning Vessel (SCV)**

The slag cleaning vessel (SCV) [5, 11] is the final cleaning step for converter aisle slag prior to slag disposal. The role of this vessel is to lower the levels of Ni, Co and Cu in converter slag by metal oxide reduction followed by settling. Proper slag settling in practice is achieved by operating with a cycle such that sufficient settling time in the vessel is allowed before slag tapping. Slag reduction in the SCV is achieved both by contact of the slag with low-grade metalized matte (high in Fe) and also by reaction with added Fe-Si alloy [5]. The %Fe in SCV matte is typically 25-30% and is a few percentage points lower than the iron level of the added electric furnace matte.

As discussed by Salt and Cerilli [5], approximately 40% of the electric furnace matte is transferred to the SCV; the balance of the electric furnace matte is largely processed in the slag-make converter, with a small amount treated in the FVs. In operation, typically 4 to 5 ladles of slag-make converter slag are transferred to the SCV, along with 2 ladles of electric furnace matte (a nominal ratio of about 2 to 2.5 ladles of slag per ladle of electric furnace matte is followed). While specific “recipes” can vary, the following cycle was incorporated into the scheduling model. Each cycle step was represented by a variable in the Excel input file (refer to example below with variables “A” to “E” ), with the programmed logic controlling the sequencing and cycle repetition:

- Loading “A” ladles of slag
- Loading “B” ladle of matte
- Nitrogen blowing for stirring for “C” minutes
- Allow slag settling for “D” minutes
- Tapping of the slag “E” minutes per ladle
- Repeat the cycle.
If the SCV required slag, this was “flagged” in the model and the crane would be triggered to transfer slag from the SMC or from an FV if SMC slag was not available. If the SCV needed matte (for example, to satisfy the above noted slag/matte ladle ratio), this would have priority for furnace matte over matte transfer to the SMC or an FV. There were numerous such priority rules; however they could be modified or changed if required to test different operating strategies. The SCV logic module included a number of variables, the main ones explored here being: (i) The impact of the vessel length on the ultimate capacity of the converter aisle, and (ii) The slag/matte ratio that could be maintained during operation of the SCV for the given scenario.

As described by Salt and Cerilli [5], the 16.8 m (55 ft.) SMC contains enough matte to recharge a finishing vessel, however the existing 12.2 m (40 ft.) long SCV unit, installed prior to the SMC (SMC installed mid-1999), does not hold sufficient matte to fully charge the larger SMC. As noted, this is adjusted for by transferring electric furnace matte directly to the SMC to make up the balance. In the scheduling model, the effect of a lengthened SCV vessel - about 40% longer to match the length of the SMC - was examined. The lengthened SCV was found to allow for improved co-ordination in the converter aisle, while at the same time maintaining and even improving, in theory, the slag cleaning capability of the unit by retaining more of a true countercurrent slag/matte movement in the converter aisle. This result would translate to higher metal recoveries.

![Figure 3: The 12.2 m (40 ft.) long Slag Cleaning Vessel (SCV) during slag tapping from the end wall at the end of a cycle [5]](image)

**Slag-make Converter**

The objective of the slag-make converter [5] is to carry out the first stage of converting of high-iron SCV and electric furnace matte down to 10-20% Fe, while at the same time providing an initial cleaning action of returned finish vessel slag. The SMC is charged via the mouth (for both matte and slag); transfers out of the vessel are also via the mouth. During operation, the bath levels are monitored with a dip bar [5]. It is noted that the SMC vessel carries out about 50% of the converting duty in the converter aisle, and it produces approximately 50% of converter aisle slag.

It is evident that a 3-step counter current process requires more crane movements that a 2-step process. Intuitively the addition of an extra stage to a 2-stage process (thus effectively doubling the number of transfers) might be considered to similarly double the number of crane related moves. In the actual operation, studies
showed that the total number of moves was more than doubled due in part to additional factors such as vessel and crane maintenance.

The on-line time of a semi-continuous or batch vessel, defined as the time in which a given vessel is blowing, is generally targeted in a well-run plant to levels in the neighborhood of 80% to 85%. This is considered acceptable in a situation where there are a number of holding vessels such that the individual process steps can be largely decoupled. In the present case, if the on-line time of the SMC was as high as 80%-85%, thus in effect limiting the time for slag or matte removal, the other vessels in the aisle (FV and SCV) would in this case typically have to wait for matte or slag transfer. In other words, a high on-line time for the SMC would in the end translate to a lower on-line time or lower productivity for the FV and SCV. If the SMC had been performing the bulk of the converting and slag cleaning duty on the aisle, such a situation might be acceptable, but as mentioned above, the SMC only completes approximately 50% of the matte converting load and handles about 50% of the slag cleaning duty.

Consequently, for maximum aisle productivity, the SMC thus needs to have a “status” between that of a holding vessel and a continuous converter. It was considered that if the SMC was available to accept or provide either slag or matte for about 20-40% of the time, the aisle operation would as a whole be smoother. If the productivity of the aisle were to be increased, without a concomitant change as regards the SMC blowing rate, it was considered that more slag by-pass would occur and the SCV would in this case require a more intensive operation in order to maintain the required recovery target. The “by-pass” term is used here denoted the occurrences when the slag from the finishing vessel had to be transferred directly to the SCV without handling in the SMC unit first (=slag by-pass), or the occurrences when electric furnace matte needed to be charged directly to a finishing vessel (=matte by-pass).

The logic block for the SMC was structurally different to that for the SCV or the FV, in part because the level of slag and matte in the vessel is the trigger for either slag or matte removal or, slag or matte loading. Thus the actual “cycle” of the SMC could vary, in fact other than the above, there was no defined SMC cycle as such. There was a further difference in the SMC module compared to the SCV module. During operation of the SMC, silica sand as flux is added to the bath as the iron is converted forming the slag. There is a lowering in the matte level as converting proceeded, while at the same time there was a rise in the slag level. The Metsim model effectively modeled both these bath changes, termed in the model as matte “consumption” and slag “production”. In practice, the steady state scenarios were computed by Metsim with the output then included in the Arena® model. In this way, the correct metallurgical balance for a given scenario was maintained and the vessel scheduling scenario also remained valid.

Examples of SMC variables included in the scheduling model are listed below:

- The matte “consumption” term per blow (from the METSIM model)
- Slag “production” term per blow (from the METSIM model)
- Slag level (high and low level limits)
  - If slag is over the limit, then,
    → Vessel goes to standby and waits to transfer slag to the SCV
    → Cannot take slag from FVs.
  - If slag is at or below the lower limit, then
    → Stop skimming.
- Matte level (high and low limits)
  - Before matte is over high limit, then,
    → Refuse to accept matte from the electric furnace.
  - Before matte is below lower limit, then,
    → Refuse to transfer matte to FV.
- Time for each blow:
  - Based on blowing rate and the quantity of air required to drop the iron level to the desired level.
- Vessel status
- Blowing
- Standby, followed by Maintenance.
The impact on capacity of increasing the SMC blowing rate was of major interest in terms of planning for future increases in plant capacity. Another important parameter monitored was the fraction of FV slag that bypassed the SMC (i.e., transferred directly to the SCV, thus potentially negatively affecting metal recovery, and, in addition, how such slag bypass proportion was affected by a change in SMC blowing rate.

**Modeling of the Finishing Vessel**

The objective of the batch-operated finishing vessel is to complete the converting process and produce “finish” 2% Fe Bessemer matte. Ideally, as little slag as possible should remain in the vessel near the end of the cycle to minimize the amount of slag present at the high oxidation levels required to reach the target iron content. In addition, ideally all of the FV slag should be transferred to the SMC for “pre-cleaning” before transfer to the SCV. Depending on the availability of the SMC to take FV slag, more or less slag may be sent directly to the SCV and as such, is referred to as by-pass slag.

The finishing vessel cycle is more complex than that for the SCV. Thus the finish vessel operates with successive matte blows and associated slag skimming as the % Fe in matte is gradually lowered. In addition, a certain amount of custom feed material may be added. At the end of the final blow, the finish matte is skimmed for transfer to matte granulation. A typical “generic” FV cycle is illustrated below, where the parameters A-G were provided by the METSIM model or from operational data:

1. Charge custom feed
2. Charge A ladles of matte (preferably from slag-make converter, or from the SCV)
3. First blow (B minutes)
4. Skim slag (For C minutes/ladle of slag)
5. Add 1 additional ladle of matte (preferably from SMC)
6. Charge custom feed (optional)
7. Blow (D minutes)
8. Skim slag (For C1 minutes/ladle of slag)
9. Repeat the above steps 5 to 8 (D1 times)
10. Final blow (E minutes)
11. Skim final slag (For F minutes/ladle of slag)
12. Matte granulation (for G minutes/ladle of matte)

As with the SMC the matte level in the finish vessel is steadily lowered as the blow proceeds (there may be temporary level increase as new matte is added), while the total amount of slag is increased according to the METSIM computations. As slag is skimmed, the level will also drop.

There was no specific model developed for the matte granulation step. The time interval for matte granulation time was accounted for in the finishing vessel module.

**STATISTICAL OUTPUTS**

The Arena™ model was able to generate a number of statistical parameters for review regarding each option examined, in addition to the main requirement to meet the target of the required amount of nickel contained in finish matte. For any given operating scenario, statistics on a daily basis were typically compiled regarding factors such as: the amount of furnace matte produced, the amount of contained nickel in finish matte, and the fraction of electric furnace matte which would have been sent outside in the situation when the converter aisle could not take all the electric furnace matte. For some specific studies, one particular statistic may be of more interest than another and this could readily be added into the Arena™ code and then tracked as needed.

To ensure metal recoveries were maintained at the converter aisle, ideally all or nearly all of the electric furnace matte should be processed in the SCV first. Also, as noted, there was a limit on the amount of matte that can be handled in the SCV due to the present size of the vessel. Nevertheless, there was interest in the various plant changes that would maximize the amount electric furnace matte that could be handled in the SCV. Thus one important statistical output of the model was the split of electric furnace matte treated in each of the converter aisle vessels: SCV, SMC and the FV. Inevitably, some electric furnace matte was always handled in the SMC (first choice after the SCV). Further, a small amount of matte could be tolerated in the FV with little consequence.

The crane utilization factor (corresponding to the % of the time a given crane was in use) was another key parameter that was monitored. It was found that generally with the model, this factor for each crane could not practically exceed about 85% (including maintenance and other on-line time factors). In addition, statistics were generated for each vessel as regards the following: the blowing time, the time for skimming, charging, waiting etc. The occurrence of certain events occurring at the same time was also of interest and information on this was provided by the model - both as a time interval (in minutes or hours) and also as a % of the time. As an example, information of such an occurrence for the two finishing vessels blowing simultaneously was a case in point. In practice the two FV units could simultaneously blow for short periods. This condition was rare and generally avoided but when it occurred, the blows would normally be staggered so that the two FVs would not be on a final blow together. This would avoid scheduling issues and potentially higher sulphur dioxide emissions at the converters.

Typically, the plant simulations were performed to cover a reasonably long period of plant operational time, typically in the range of 2-3 months of equivalent plant time so as to reach and maintain steady state conditions. Depending on whether the “animation” feature was running or not, simulating say a 3 month plant period on the model could be completed in several minutes; it would take considerably longer with the animation feature running. Usually, at the start of a given simulation, the initializing period in order to fill the vessels and reach steady state was not included in the statistical results.

**CASE STUDIES**

As discussed earlier, a number of concepts had already evolved at the plant for improving productivity and increasing plant capacity prior to commencing the present study. Several case studies involving specific plant modifications were however examined in detail using the model in order to improve the precision of the proposed
changes in particular, for the higher capacity scenario to produce a contained nickel output of 85,000 tpy was examined. Thus, the following case studies were carried out.

Increase in ladle size by a factor of two, from 200 ft$^3$ to 400 ft$^3$ (5.6 m$^3$ to 11.2 m$^3$)

It was found that operating the converter aisle with larger ladles improved converter operations and overall capacity. The improvement was especially notable during those periods when only one crane was in operation (the other crane being out of service for scheduled or un-scheduled maintenance). However, the use of larger ladles on its own was found to be not the biggest enabling factor affecting converter aisle capacity.

Increasing the length of the SCV by 40% from 12.2 m to 16.8 m (40 ft. to 55 ft.) - same length as SMC

The model studies showed that a moderate increase in capacity could be achieved by lengthening the SCV (thus giving more holding/sludge cleaning capacity). The proposed lengthening would be to bring the SCV to the same length as the SMC. While interesting, this change in itself was found to be not the main enabling factor for increasing plant capacity. Nevertheless, it allowed more electric furnace matte to be processed in the SCV (less matte by-passing the SCV), which would correspond to the need for less Fe-Si reductant and overall, pointing to better metal recoveries. These factors alone were considered to potentially justify a lengthened vessel.

Increasing the SMC blowing rate by 50%

It was surprising at first to find that this parameter appeared quite important in raising plant capacity. It is noted that the proposed future increase in nickel output from 67,000 tpy of contained nickel to 85,000 tpy of contained nickel, or an increase of 18,000 tpy, corresponded to roughly a 25% increase. It was found that taking the logistics and scheduling factors into account a 50% increase in SMC blowing rate (rather than 25%), combined with the above two changes (larger ladles and lengthening the SCV) would together provide for conditions allowing for the required future capacity increase to 85,000 tpy of contained nickel. Obviously the SMC blowing rate and the % blowing time (presently quite low) were related and this aspect was also examined.

CONCLUSIONS

By combining the Metsim metallurgical model with the Arena$^{\text{\textregistered}}$ scheduling model, a logistical model for the converter aisle of the Xstrata Nickel Sudbury smelter was built and operated. The model was successfully used to confirm from a metallurgical and scheduling perspective the proposed future plant changes initially considered required to provide for a 25% increase in contained nickel output, from the present level of 67,000 tpy of contained nickel, up to 85,000 tpy of contained nickel.

In addition to exploring options for increasing future plant capacity, the Arena$^{\text{\textregistered}}$ model was found to be quite robust and valuable in developing new operating strategies for specific plant situations, such as vessel re-bricking.

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