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USE OF PROCESS SIMULATION TO DESIGN A BILLET CASTHOUSE

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Abstract

Designing a casthouse for billets is a complex activity. It must be correctly sized to optimize metal flow and continuously feed the homogenization shop. It must also be borne in mind that over-sizing adds no value and is costly. To solve this problem, casthouse operations must be analyzed accurately in real time using a discrete simulation model. Such a model was developed, with a library containing all the necessary equipment: conveyors, continuous and batch furnaces, and finishing stations.

The model was used to design a fully integrated casthouse, requiring flexible, robust facilities and management of complex product mixes. By combining this model with the metal-flow sizing model, design execution and its impact on casthouse operation was optimized. The result is a shop designed for customer needs, at optimal cost.

Introduction

High value-added products are well rated in the aluminium market for their specialty and their manufacturing complexity. For marketing strategy reasons, a project to build a billet casthouse to cope with the increase in capacity of the Isal smelter in Iceland was launched in 2009. The aim of this project is to build a fully integrated billet casthouse: a billet casting shop complemented by a billet homogenization shop.

As-cast billets need to be homogenized to improve extrudability and ensure specific mechanical properties in the extruded profiles. Billets are homogenized in either batch or continuous homogenizing furnaces. They are heated and held at a temperature slightly below their melting point for several hours. They are then rapidly quenched in air to below 300°C in dedicated coolers, or in a cooling chamber in the case of a continuous furnace, and further cooled down to below 80°C.

The product mix to be considered for the casthouse was broad:

- Commodity (6060 and 6063 alloys), Specialty 1 (6xxx alloys) and Specialty 2 (3xxx alloys) alloy billets.
- Diameters from 7" to 10".
- Lengths varying between 6 m and 8 m.

Sizing casthouses is a regular activity for the Rio Tinto Alcan engineering site in France. Tools are used for modeling the metal flow between the potline and the casthouse furnaces, the metal preparation area and billet casting. All dimensional designs are analyzed and validated using flow simulation models. The challenge of this project was that there were no tools available for modeling a billet homogenization shop. It was therefore difficult to design the casthouse in its entirety.

It was clear that process simulation modeling would be required to allow effective casthouse design. Process simulation is a model-based representation of physical, chemical or other processes and operations in software. The goal of process simulation, which is a well established technique [1], is to find optimal conditions for an examined process. Within a few months a new process simulation tool had been developed. A shop model was built, calibrated and optimized so as to have a well sized billet homogenization shop. Figure 1 shows the billet homogenization shop designed with the new tool.

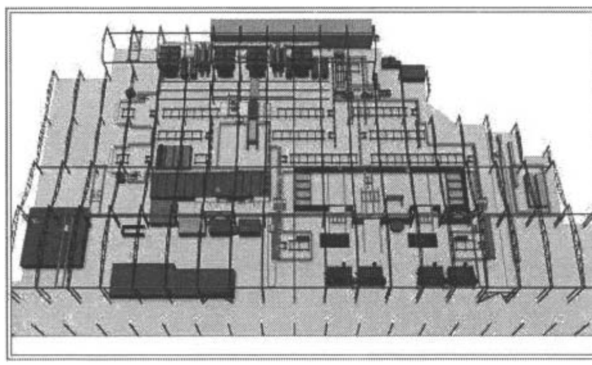

Figure 1 – Billet homogenization shop design.

Metal flow modeling

The casthouse study was separated into two parts:

- Metal flow between the potline and billet casting.
- Billet homogenization.

In order to complete the studies as quickly as possible, the teams were divided into two. The first team was in charge of building a metal flow model on the basis of an existing library. This library contains modules representing potline tapping groups, metal ladle transport vehicles, ladle cleaning, furnaces and casting pits. It covers the required product mix, furnace charging times, metal preparation times, equipment reliability, etc. The resulting model is shown in Figure 2. It was first calibrated using current plant data, then tested in both nominal operation and downgraded mode (four-week furnace shutdown for relining, one-week maintenance work on a casting unit).

The model was used to optimize casthouse dimensional design and metal ladle flow logistics. It integrated process and potline operating constraints.

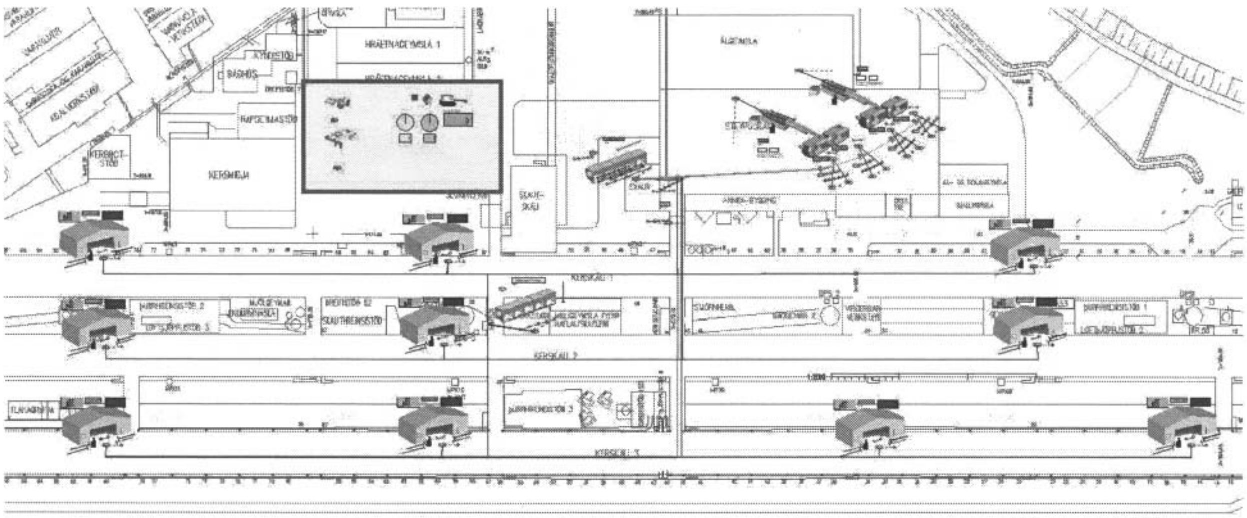

Figure 2 – Schematic diagram of modeling metal flow between the potline and casthouse

Development of a new tool

The second part of the casthouse study included construction of a tool for modeling a billet homogenization shop and then modeling the shop required for the study. We did not have this modeling tool at our disposal. Some equipment suppliers used simulation models, but they did not take the whole workshop into account. It was more prudent to incorporate all shop management rules, conduct the tests and then be in a position to check if results tallied with those of suppliers.

We also wanted to connect the two models together, taking billet casting times given in the metal flow model results and importing them into the homogenization shop model. The tool had to cater for the following needs:

- Model a complete shop, from billet stripping to the finishing and bundle-marking stations,
- Launch standard production plans corresponding to the required product mix and other non-standard plans,
- Visualize bottlenecks,
- Validate shop dimensional design.

The tool was developed using ExtendSim software, selected for its robustness, its integrated database and easy interfacing with the model, its three-dimensional development capabilities and the fact that the team was already familiar with it. All equipment items were modeled, resulting in a library dedicated to this type of shop, including:

- Conveyors
- Visual inspection
- Saws
- Helical ultrasonic inspection
- Continuous homogenization furnaces
- Batch homogenization furnaces
- Coolers
- Bundle storage areas
- Stacker
- De-stacker
- Automatic handling trolley
- Billet finishing and marking station

Conveyors

Each conveyor operates independently. It moves the billets one by one according to a predefined cycle and its own breakdown rules.

Inspection, sawing and finishing stations

Each device processes the billets one by one and is fully configurable (cycle times, breakdowns, etc.). Figure 3 shows the modeled billet sawing station.

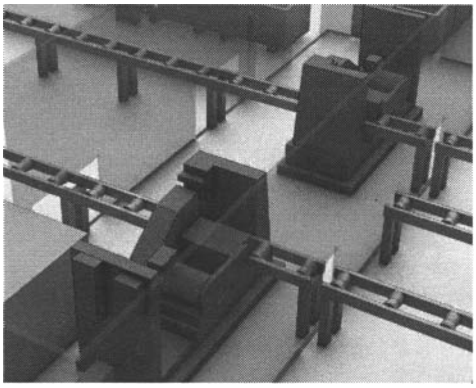

Figure 3 – Model of billet sawing station

Continuous furnace

The continuous furnace is intended for homogenizing Commodity and Specialty 1 type billets. Billets enter the furnace one by one on a conveyor set at a rate that varies according to the required homogenization time. Figure 4 describes the continuous homogenization cycles. The furnace is divided into three zones for heating, temperature-holding and cooling. The model of the continuous furnace is shown in Figure 5.

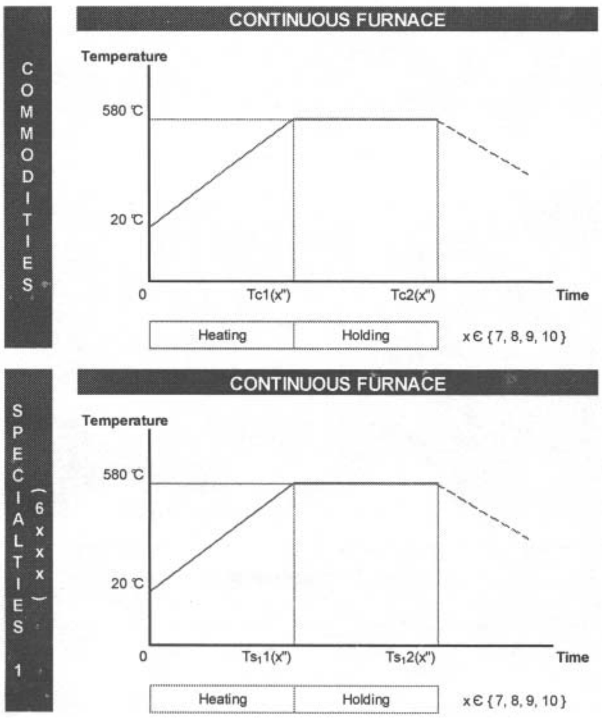

Figure 4 – Continuous homogenization cycles

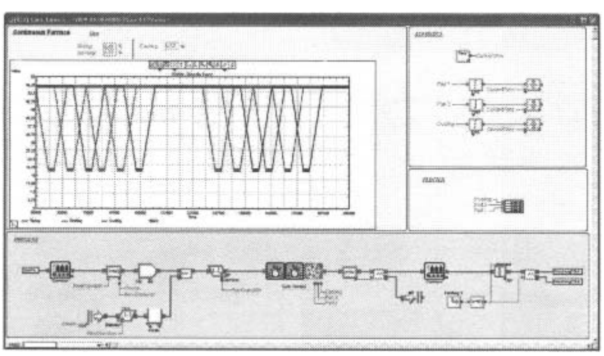

Figure 5 – Model of continuous homogenization furnace

Batch furnace

The batch furnace is intended for homogenizing all types of billet. Process times, as shown in Figure 6, are calculated according to billet type and diameter.

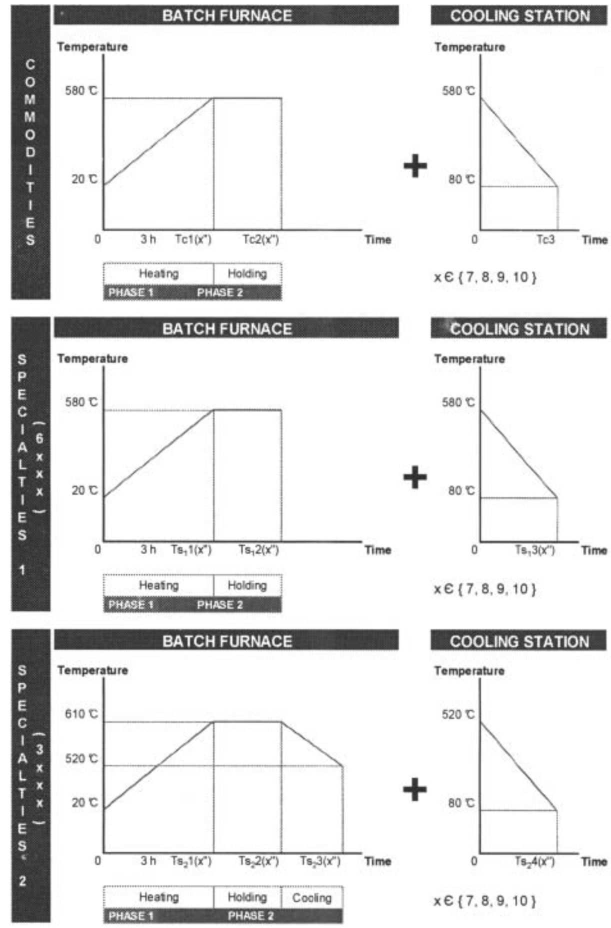

Figure 6 – Batch homogenization cycles

Upstream of the batch furnaces, as shown in Figure 7, a machine automatically stacks billets from a given cast to form bundles. These bundles are then taken by charging car to one of the batch furnaces. The homogenization cycle starts up in the batch furnace. Once completed, and if a cooler is available, the charge is removed automatically by the charging car. If no cooler is available, the charge is held in the furnace.

After the cooling cycle, the charge is finally moved to the de-stacker. The bundles are de-stacked automatically and placed on a conveyor. Temporary storage areas are provided between the furnaces in order to absorb variations in charges.

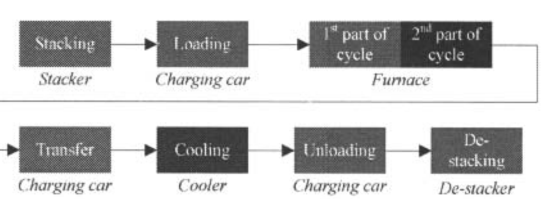

Figure 7 – The stages of batch homogenization process

Shop modeling

Once the new tool was developed, the next stage was to assemble the modules representing the equipment, just like assembling Lego® bricks. This provided the main features of the shop:

- two billet feed conveyors,
- two visual inspection stations,
- one helical ultrasonic inspection station,
- two saws,
- four batch homogenization furnaces + two batch coolers,
- one continuous homogenization furnace, and
- two finishing stations.

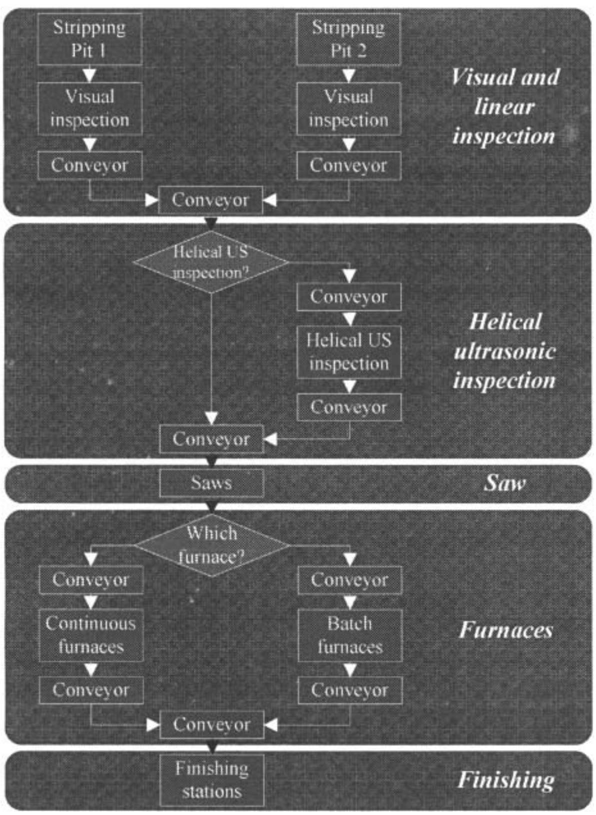

Figure 8 – Flow diagram of billet flow through the workshop

The billet flow through the workshop is shown in Figure 8. Once the billets are stripped, they are laid on one of the two conveyors at the shop entrance. Specialty 1 billets must be moved to a helical ultrasonic inspection station, while Commodity and Specialty 2 billets go directly to the sawing station. After sawing, Commodity billets are preferably sent to the continuous furnace, while Specialty billets go to the batch furnaces. On leaving the furnaces, all billets are sent to the finishing and marking stations.

The difficulty at this stage was to correctly define the system rules, in particular at conveyor intersections. A major constraint was to avoid splitting casts, even in the event of equipment failure or conveyor overloading.

Each intersection was therefore programmed at a high level of complexity. On leaving the billet sawing station, Commodity billets are preferably sent to the continuous furnace, and Specialty 1 and 2 billets preferably to the batch furnaces. Equipment overloading always needs to be considered. For example, it is sometimes preferable to occupy a batch furnace with a Commodity billet cast. Otherwise, the helical ultrasonic inspection station may become blocked by a Commodity billet cast waiting for the continuous furnace to become available.

A shop power limit also had to be incorporated. For reasons of available smelter-power levels, no more than one batch furnace can function in operating phase 1 at any given time. Before operating a batch furnace it therefore has to be checked that no other furnace is already in this initial phase of its heating cycle. Figure 9 shows a bundle waiting in front of a batch furnace.

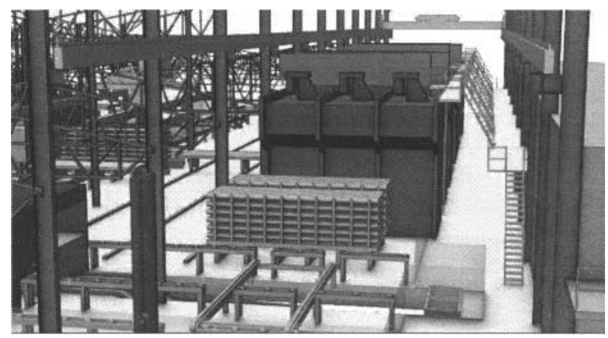

Figure 9 – Model of the bath furnace showing, in the foreground, a bundle waiting to be loaded.

Production plans were validated with experts in the subject. The plans had to guarantee that sales requirements be met and installation overloading avoided as much as possible. Product changes, which are always detrimental to production yields, had to be limited. Each equipment item was configured (cycle time, availabilities, etc.) by comparing supplier data with internal plant records. Parameters were adapted whenever considered necessary. The modeling of the shop is shown in Figure 10.

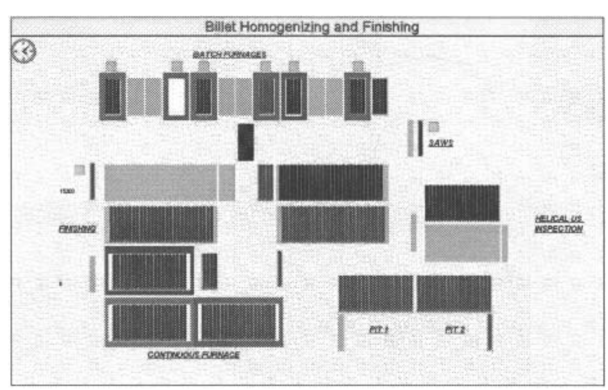

Figure 10 – Plan showing simulation of shop operation in progress

Results obtained

One year of production was simulated. Using the software it is possible to track variations on graphs in real time, view animations and see the shop load factor (utilization rate, number of waiting casts, etc.). Simulations quickly showed that some rules had to be adjusted. For example, it was preferable to send all Specialty 1 billets to the batch furnaces because the continuous furnace was a critical item of equipment and was not to be slowed down.

In billet casthouses, it is generally recognized that the major criterion is waiting time at the casting pits, otherwise the casthouse becomes the smelter bottleneck. A threshold was therefore set at:

- A delay of one potline shift at any time (i.e. 2 casts waiting in our case) over a year in normal configuration.
- A delay of two potline shifts in downgraded configuration.

The downgraded configuration adopted corresponds to exclusive production of 6 m long billets for two consecutive weeks. This is equivalent to increasing the number of billets by 14% during this period. Figures 11 and 12 show respectively, acceptable and unacceptable levels of casts on hold at pits, from simulation results over a one year period.

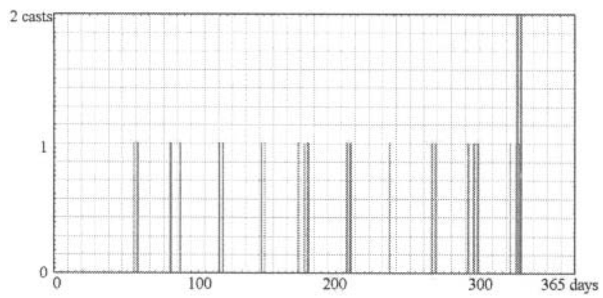

Figure 11 – Graph of simulation results for casts on hold at a pit over a 1 year period (acceptable level)

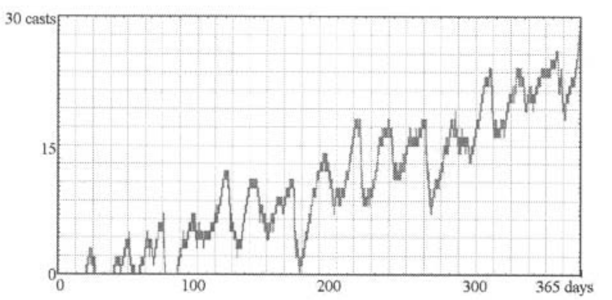

Figure 12 – Graph of simulation results for casts on hold at a pit over a 1 year period (unacceptable level)

The simulations identified the bottlenecks at the facilities. They were classified according to three types: layout, rules and data as shown in Figure 13.

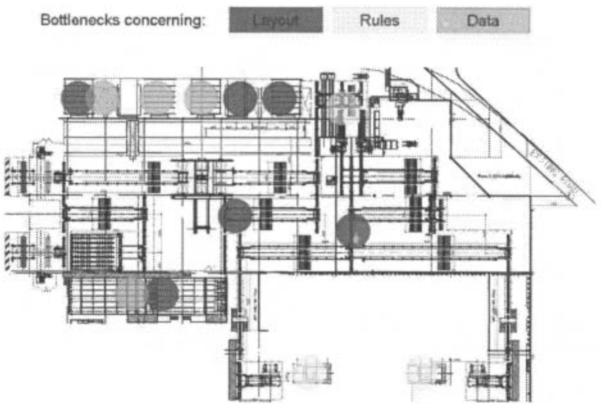

Figure 13 – Plan of the facility showing locations of bottlenecks

Examples of bottlenecks:

- ***Layout:*** The buffer stock upstream of the continuous furnace is very important for smoothing the charge, and hence maximizing the continuous furnace filling rate.
- ***Layout:*** The number of waiting spaces at the batch furnaces helps absorb production variations and allows a degree of flexibility in the production plan.
- ***Layout:*** It is vital to set aside room to store casts upstream and downstream of the helical ultrasonic inspection station. This disconnects the station from the rest of the facilities and avoids blockages (namely in cases of breakdown).
- ***Rules:*** In production plan, billet diameters have to be smoothed.
- ***Data:*** The shop power limit has to be respected.

Different strategies were tested for managing the facilities. Impacts of the various products (type, diameter and length) were analyzed and quantified, and recommendations formulated for scheduling production:

- Impact of 7" billets – essentially Commodities: given the large number of billets to be processed one by one in the continuous furnace (112 billets per cast), 7" Commodities casts are critical in the installation. Conversely, 10" Commodities (56 billets per cast) enable the shop to empty the buffers.
- The recommended sequence used for the first pit production plan is shown in Figure 14.

7" Commodities	7 successive casts	Buffers saturated Continuous furnace full
10" Commodities	14 successive casts	Buffers and continuous furnace "empty"
8" Commodities	21 successive casts	Buffers and continuous furnace moderately saturated
9" Commodities	7 successive casts	Buffers and continuous furnace relatively "empty"

Figure 14 – Recommended production plan to minimise bottlenecks

Impact of Specialty 2 billets: due to long homogenization time (10" billets are almost twice as long as Specialty 1 billets of the same diameter); it is preferable to smooth Specialty 2 production as much as possible.

The recommended production plan adopted in the simulations is a Specialty 2 – Specialty 1 – Commodities sequence lasting 18 days on the second pit, followed by production of Specialty 1 for 22 days. This production plan matched our dimensional design criteria. One of the results thus obtained was the utilization rate of the various equipment items, as shown in Figure 15.

Delay on the stripping on one cast:	Max 2 casts
Utilization rate of saw 1	55%
Utilization rate of saw 2	0%
Utilization rate of batch furnace 1	91%
Utilization rate of batch furnace 2	89%
Utilization rate of batch furnace 3	90%
Utilization rate of batch furnace 4	87%
Utilization rate of batch cooler 1	48%
Utilization rate of batch cooler 2	15%
Utilization rate of finishing station 1	73%
Utilization rate of finishing station 2	0%

Figure 15 – Predicted equipment utilization rates

The second saw is only used as a backup when the first saw is down for long periods. Both coolers are required to operate batch furnaces at maximum capacity. The second finishing station is only used in downgraded configurations (temporary shop over-production). During these critical periods, putting the second station into operation avoids slowing down the furnaces and keeping products waiting at the casting pits.

Product mix changes

The model was used to track changes in the product mix required by customers, assess different layouts and define buffer needs. In total, about one hundred configurations were tested. These were used to fine-tune the layout, define the project phases and optimize the shop according to the space available in the buildings and the required product mix.

With the aim of maximizing value, the starting hypotheses were changed and the product mix modified to include more Commodities and only Specialty 1 billets. The batch furnaces, which are much more costly than continuous furnaces, could therefore be eliminated.

The model was adapted to meet the needs of this new homogenization shop comprising, at most, three continuous furnaces. Furnace capacity was tested, billet distribution challenged, billet circulation in the shop reviewed and buffer sizes studied in detail. This resulted in a solution compliant with our dimensional design criteria: a casthouse that is neither oversized nor a bottleneck for the entire smelter.

Conclusion

The Isal smelter project was launched in September 2009. Its billet casthouse will be completed in April 2012 and it will reach full capacity in July 2014. Casthouse operators, equipment suppliers and the engineering department collaborated throughout this project, combining optimum technological design with best operating practices.

Future operators are now aware of the impact of key parameters and suppliers have had the chance to test and calibrate their simulation models. The Rio Tinto Alcan engineering department has at its disposal a new tool capable of simulating the operation of a billet homogenization shop. The models developed are available for future shop optimization studies and can be used for other billet casthouse projects.

References

[1] Professor Stewart Robinson, "Simulation: The Practice of Model Development and Use", Warwick Business School, University of Warwick.

[2] Jean-François Claver, Jacqueline Gélinier, Dominique Pitt, "Gestion de flux en entreprise, Modélisation et simulation".