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Advanced Modeling Methods and Tools Applied to Aluminium Smelter Projects

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ABSTRACT

Over the years there have been significant enhancements to smelter configurations by applying LEAN methods to identify and eliminate waste and to reduce the potential for an accident. Most enhancements to the plant layout have been driven by opportunities identified through the Aluminium Center of Excellence 5-step LEAN methodology, with many of the opportunities underpinned by discrete event modelling and 3D models.

This methodology has been widely applied to smelter configurations that helped differentiate Bechtel, win projects and deliver lasting value for our customers. In this paper, selected examples on recent smelter studies and FEED reports and publications are presented.

Examples from potroom erection, cathode re-lining facility throughput scaling and alumina handling at port and transportation to smelter are discussed.

NOMENCLATURE

3D modeling	Three-Dimensional Modeling
4D modeling	Three-Dimensional Model, Evolving in Time as 4th Dimension
ACE	Aluminium Center of Excellence
Alba L6	Aluminium Bahrain Line 6 Project
BDD	Basic Design Data
BTJ	Bechtel Technical Journal
CPC	Calcined Petroleum Coke
DEM	Discrete Event Modeling
FEED	Front-End Engineering Design
GPC	Green Petroleum Coke
GTC	Gas Treatment Center
LEAN	Business Strategy on Eliminating (Generalized) Waste While Satisfying Customer Needs
LoB	Line of Balance (Schedule)
Ma'aden	Ma'aden Aluminium
TMS	The Minerals, Metals & Materials Society
VSU	Vacuum Suction Unloader

INTRODUCTION

Over recent years there have been significant enhancements to smelter configurations by applying LEAN methods to identify and eliminate waste and to reduce the potential for an accident. Most enhancements to the plant layout have been driven by enhancement opportunities identified through the ACE 5-step LEAN methodology, with many of the opportunities underpinned by discrete event modelling (DEM) and 3D visualization models.

These achievements, derived from the above approach, have been documented in internal reports and captured in papers published in the former Bechtel Technology Journal, at TMS, and other international conferences.

A technical grant, awarded in 2010 also facilitated development of a methodology and tools for digitizing a layout so that it could readily interface with a DEM, thereby reducing cycle time and enhancing the applicability to other projects.

This methodology has been widely applied to smelter configurations that helped differentiate Bechtel, win projects and deliver lasting value for our customers. There have since been progressive enhancements to the methodology and tools culminating in the recent Alba L6 Project 3D / 4D effort.

In this paper, selected examples on recent study and FEED reports and publications are presented.

POTROOM CONSTRUCTION USING TOWER CRANES

A 3D animated model of a facility can significantly affect the success of its construction and operation in terms of safety, cost and schedule. Our use of 3D modelling goes beyond the typical static model developed in planning and scrutinizes the motions and operations of equipment in more detail than a typical 4D model. We do this by applying known parameters and limits to equipment and run animations to prove constructability and function.

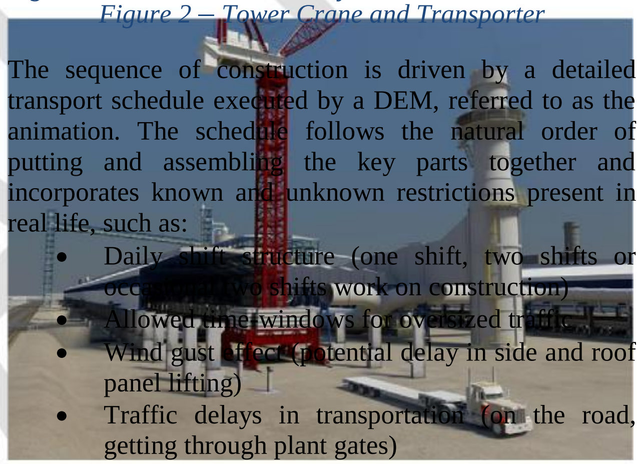
Figure 1 shows one half of the projected Alba Line 6 potline expansion, as fully built. We compared new constructability solutions for competing layouts and designs to weigh risks against rewards. The result is expected to be a safe, lean design and constructible configuration. To virtually execute the construction process step-by-step, each key part of the potrooms and courtyard facilities had to be represented as a realistic, 3D object. Figure 2, shows a half-built phase of the construction, where some of these visual objects could clearly be identified:

- Precast posts and slabs
- Wall and roof panels
- Gas collector ducts
- GTC duct and chimney

Further to these objects, a generic transporter and a tower crane are also shown.

Figure 1 – Alba L6 Potroom Layout

Figure 2 – Tower Crane and Transporter



The sequence of construction is driven by a detailed transport schedule executed by a DEM, referred to as the animation. The schedule follows the natural order of putting and assembling the key parts together and incorporates known and unknown restrictions present in real life, such as:

- Daily shift structure (one shift, two shifts or occasional two shifts work on construction)
- Allowed time windows for oversized traffic
- Wind gust effect (potential delay in side and roof panel lifting)
- Traffic delays in transportation (on the road, getting through plant gates)
- Crane breakdown and maintenance cycles

The potroom construction is built around the innovative utilization of travelling tower cranes. A potroom is built sequentially like a “horizontal high-rise”. The tower crane

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executes the majority of the lifting tasks. Mobile cranes are still used at the work site, but their role is secondary, limited to lifting smaller parts (duct elements) and accelerating GTC construction.

Figure 3 shows a pre-assembled side and half-roof module delivered to the construction site, close to the tower crane. The lifting mechanism is already attached to the module, ready for lifting.

Figure 4 is taken from the lifting process, the module is approaching its destination. During the simulated 4D potroom construction, data is collected and processed to report on achieved results. Several scenarios were executed to demonstrate likely problems and effectiveness of proposed remedies.

Figure 3 – Side Panel Assembly Transport

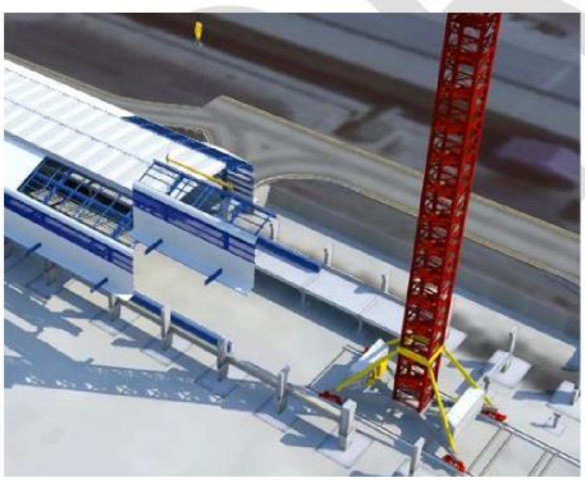


Figure 4 – Side & Roof Module Lifting

In order to measure achieved results to the LoB, data was collected on the progress of:

- Precast mounting
- Steel module mounting
- Structural turnover

Figure 5 shows the predicted progress, along with the scheduled completion and the applied shift schedule.

After analysis with the model, it was concluded that the construction could be done successfully with the tower cranes and this new method was proposed to management for consideration and execution. It was agreed to present this innovative solution to the customer during the bid presentations, which ultimately contributed to successfully winning the next phase of the project design and execution.

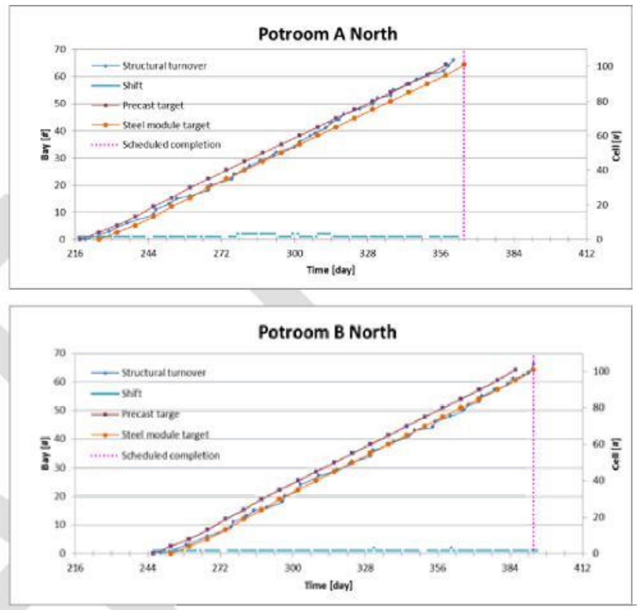


Figure 5 – Potroom Construction Projected Progress

CATHODE RE-LINING FACILITY SCALING

Another example of the use of a DEM is to establish the best configuration of a key support facility (cathode re-lining) to maintain an optimum, cost effective, weekly throughput. The DEM combined with a financial spreadsheet allowed the team to efficiently and effectively demonstrate and cost multiple scenarios. These tools generate data that will be used to determine the cathode relining configuration for an optimum lifecycle cost.

During the FEED phase of the Ma'aden aluminium smelter project, a study was done for a new cathode re-lining facility within a limited available space. Figure 6 shows the general arrangement for the facility as well as its implementation in the 4D simulation.

It is known from experience that the first-generation pots fail following a Weibull distribution curve. Waiting for the pots' natural end of life would induce a peak, a very high re-lining demand, and therefore a high capital cost re-lining facility. Most new smelters prefer to remove pots out of service before the true end of their service life in order to reduce the peak re-lining demand and therefore reduce the necessary capital cost of the facility.

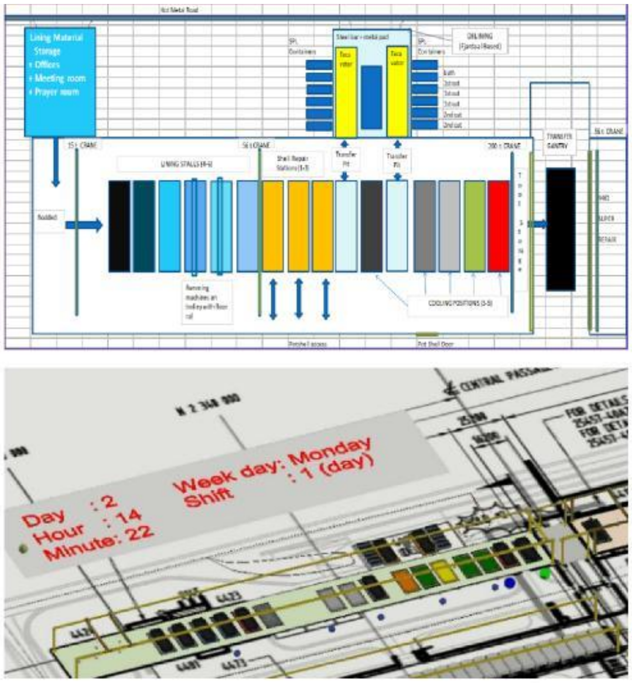


Figure 6 – 4D Simulation of Worksite

Using a dynamic model combined with a lifecycle cost analysis, it was possible to generate a curve to determine the optimum lifecycle cost considering operating and capital cost for a series of different peak pot re-lining rates. Figure 7 shows an example of multiple relining rates with their relative cost impacts.

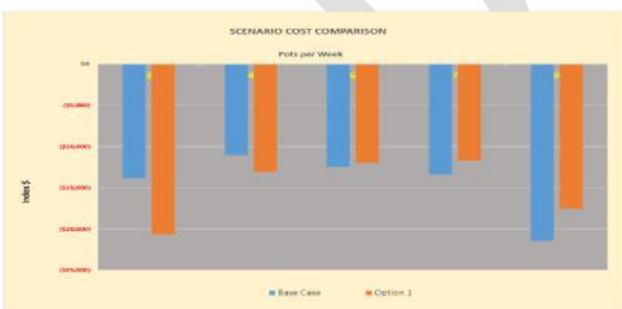


Figure 7 – Cost Comparison or Multiple Re-Lining Rates

It is also possible to include risk cost impacts into the financial model. Figure 8 shows the relative revenue losses (lost metal production) for different future pot failure rates and multiple future profit margin scenarios.

The now available combined “economic process” model is well parameterized, adaptable to other plants and provides the benefit of a more controlled program for various pot failure and subsequent re-lining demand scenarios.

It is a difficult task to select the best scenario for the re-lining facility. Indeed, using past data on pot life is not an exhaustive basis, as often, pot life has been influenced by amperage increase, pot design changes and operational upsets. Therefore, a basic toolset, containing all the major equipment of a generalized re-lining facility has been developed to help in analyzing the multiple scenarios.

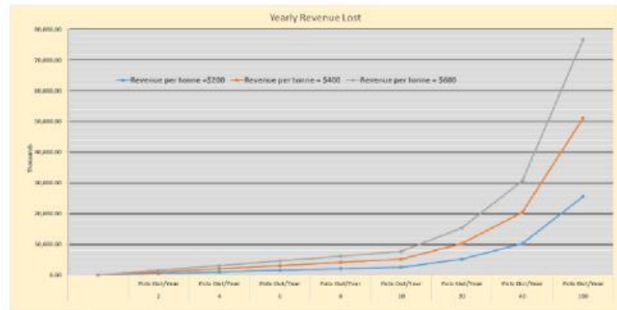


Figure 8 – Cost Analysis of Impacts of Future Cell Failure Rates

By using the combination of a DEM and economic analysis, it was demonstrated that these tools facilitate the decision making for the design and configuration of future re-lining facilities.

ALUMINA HANDLING AT PORT AND TRANSPORT FROM PORT TO PLANT

Ship Handling

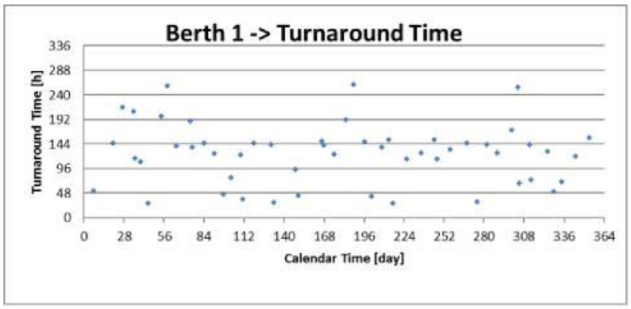
Alba operates a port facility in the Sitra Basin of Bahrain, consisting of two Berths. Berth 1 is dedicated to unloading green coke, calcined coke and liquid pitch while Berth 2 is dedicated to unloading alumina and loading excess calcined coke from the calciner located at the port. The berth arrangement is shown in Figure 9.

Panamax ships of up to 62,000 t alumina cargo are received at Berth 2 and are unloaded by a 1,000 t/h vacuum ship unloader. Material is transported from the ship unloader by conveyors and airlifts to two onshore 50,000 t silos. An arriving ship could either go directly to an available berth, or moor and wait for a berth, then the ship undergoes numerous procedures before unloading starts.

Figure 9 – Ship Handling at Alba Port

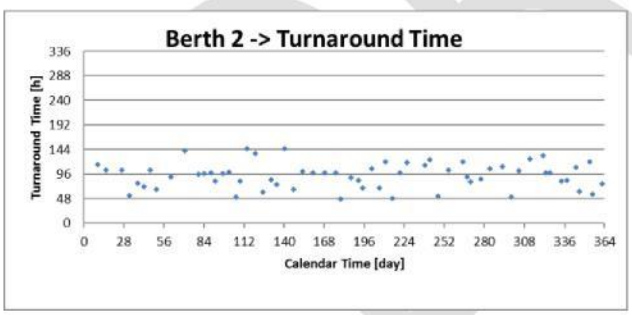
The unloading process follows strict protocol, including the unloading phase with the main vacuum unloader, cleaning-up phase with a mobile vacuum unloader and ship repositioning (if needed) to access a particular hold.

An emptied ship, after clearance, leaves the berth. Figure 10 and Figure 11 show the resulting turnaround times for ships handled at Berth 1 and Berth 2, respectively, based on a DEM of the operation.



Berth 1		Turnaround Time
Ships handled	[#]	52
Time (NOR to Departed)		
	average [day]	5.23
	min [day]	1.19
	max [day]	10.89

Figure 10 – Berth 1 Turnaround Summary



Berth 2		Turnaround Time
Ships handled	[#]	62
Time (NOR to Departed)		
	average [day]	3.90
	min [day]	1.97
	max [day]	6.06

Figure 11 – Berth 2 Turnaround Summary

Alumina Transfer to Port Silos

The port has two 50,000 t alumina silos where the alumina is transported from the ships. With the Alba Line 6 expansion, a second truck loader station will be built. The proposed integration of the new truck loader to the existing alumina handling system allows ship unloading directly to the truck loader bin.

Figure 12 shows the Line 6 alumina transfer routes (upper chart), as well as a projection for an eventual Line 7 extension (lower chart).

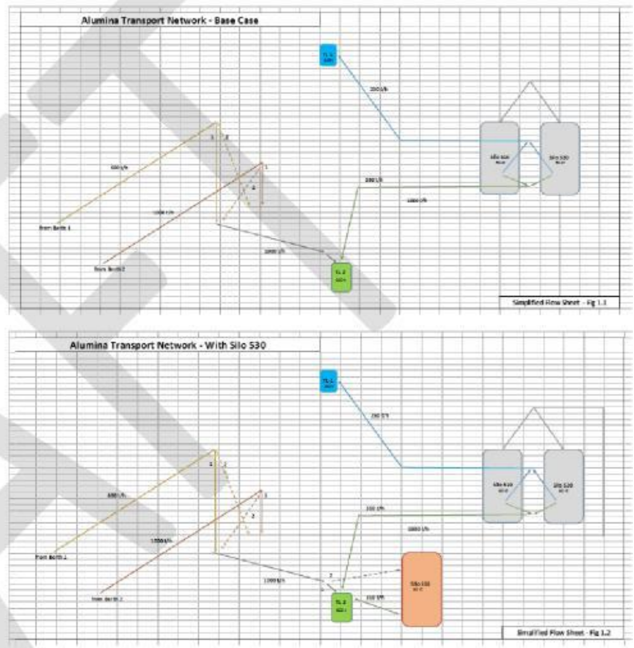


Figure 12 – Port Alumina Silos Filling

Alternatives **Port Alumina Silos Inventory**

The predicted dynamically forming port alumina silo inventory is shown in Figure 13.

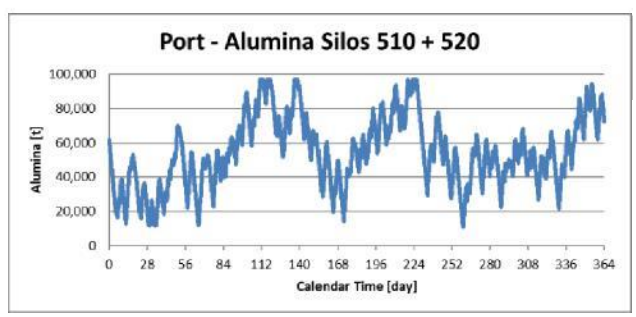


Figure 13 – Port Alumina Silo Inventory

For completeness, Figure 14 - Figure 16 illustrate predicted smelter silo inventory for the other key commodities.

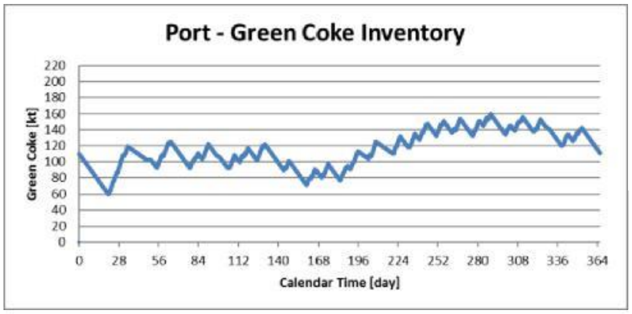


Figure 14 – Port Green Coke Silo Inventory

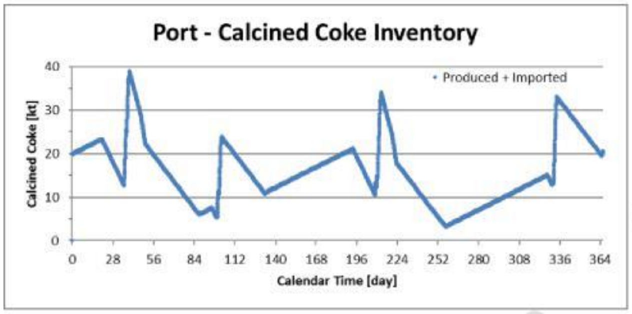


Figure 15 – Port Calcined Coke Silo Inventory

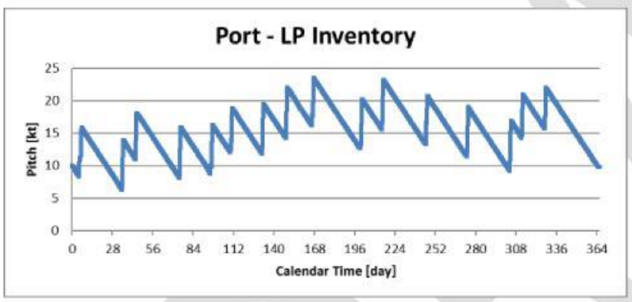


Figure 16 – Port Liquid Pitch Inventory

Alumina trucking to plant

Alumina is trucked from port silos to smelter silos by a fleet of 34 t bulk tanker trucks. Two truck loaders at the port are modelled, similar in design with four loading spouts that connect to a gravity top loaded transport tanker. The existing loading bin, which is 140 t capacity, was built originally before the present Berth 2 and port silos were instituted. The new truck loading bin has been increased to 200 t, more consistent with the loading demands.

Truck queuing predicted at the two truck loaders are given in Figure 17.

The applied logistic orders trucks on a shift-by-shift trucking plan to receiving (smelter) silos, matching smelter demand. The dispatching is based on three 8-hour shifts per day. Each truck starts a shift with a 15-minute shift start briefing and driver inspection and then departs for the smelter. The route to each silo is tracked at speeds and delays established by the route with traffic rules and truck acceleration and deceleration properties obtained from operations. Predicted cycle times, waiting, queueing, and idle times are tracked in the model.

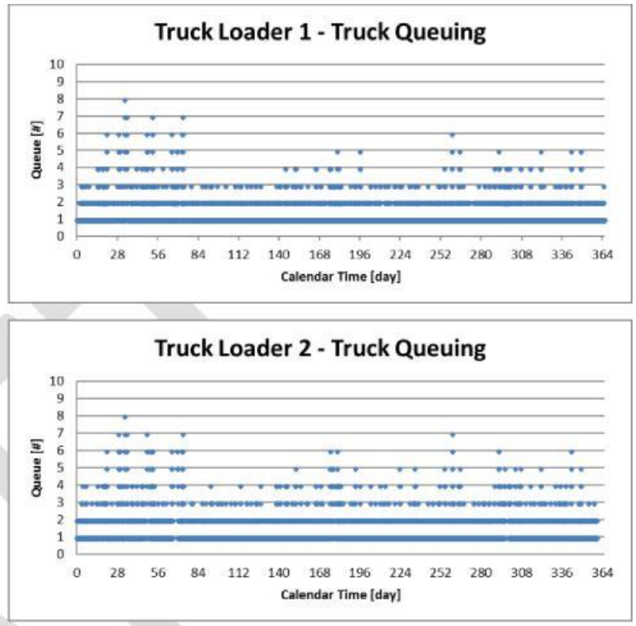


Figure 17 – Truck Queuing at Truck Loader 1 & 2

Smelter Alumina Silos Inventories

The smelter is serviced by nine silos feeding GTC operations. These vary in size and therefore also contain varying capacities and inventory in days of operation should the supply system be interrupted or shipping be significantly delayed. Consequently, the model tracks the inventory in these silos and it is prudent to maintain them as full as possible but without running the trucking overly, and therefore port silos more regularly, at empty or smelter silos all full, thus minimizing disruption of trucking operations.

The predicted status over a year was monitored in the model to see if the system is properly paced with the number of trucks in service. As examples, the Line 6 alumina silos predicted inventory (Silo North and Silo South) are given in Figure 18.

It was desired that the alumina transport should keep up with consumption and if possible, use the available trucking capacity to build-up smelter silo inventories to a target. This is advantageous, as liberating the port silo facilitates continuous ship unloading. As combined results of ship arrivals, ship unloading and alumina trucking, it was possible in the second half of the year to approach, then meet this target.

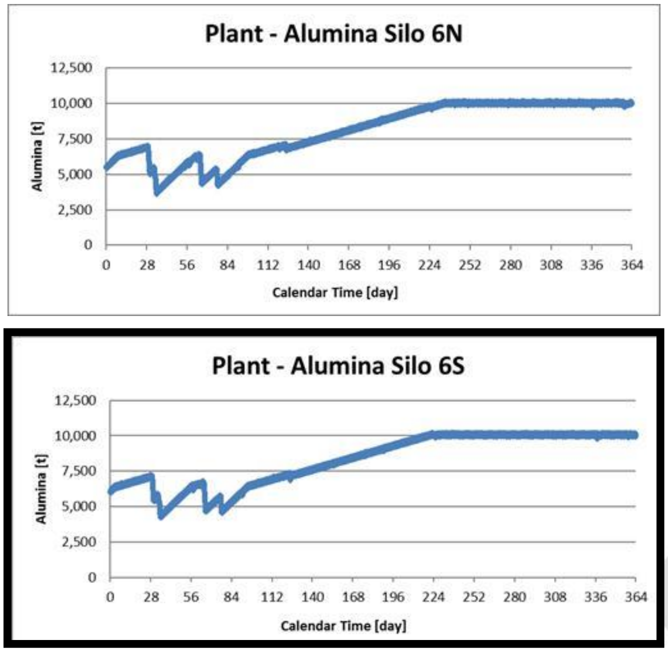


Figure 18 – Plant Alumina Silos Line 6 North and South

Recommended Berth 1 and Berth 2 Upgrades

The simulation results for this very complex interrelated system were analysed. Several modifications and alterations were proposed each with a positive predicted operating value that was not initially understood. The model was essential to understand the need for various upgrades suggested. In discussions with the Alba team, the scope of upgrades to be considered were as follows:

- To cater to the Line 6 demand, a further quantity of 100,000 t of CPC per annum is required over present production. To be imported with the present two berths necessitates the provision of one new CPC unloader and associated conveying system.
- Existing VSU will be 20 years old by the time Line 6 operation takes place. A second VSU on Berth 1 would provide a short-term emergency route for alumina. In view of the above, it was suggested to install one single VSU unit at the old jetty which could handle both alumina and CPC unloading, therefore providing needed redundant routes for alumina import.
- For CPC, the existing truck loading station meets demand. A study by Bechtel also confirmed an additional CPC silo was not justified.
- Additionally, the true operational advantages and risk reduction of a new alumina silo was quantified.

CONCLUSION

With the help of the available DEM models, it was possible to address a wide variety of economical and operational questions in each of the key phases of smelter design and construction. During recent years, the in-house modeling toolset has been systematically developed in each smelter area. Now, a variety of boundary condition modules and control logic modules are available for easy model development to suit most smelter customer needs.

Benefits from the model-based approach, pre-developed with parameters used in most plants today and combined with the ability to quickly adjust to a user who is willing to explore innovations, offers potential facility and operating cost savings and an increased level of confidence in the optimized plant configuration.

TRADEMARKS

FlexSim is registered trademark of FlexSim Software products Inc.

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