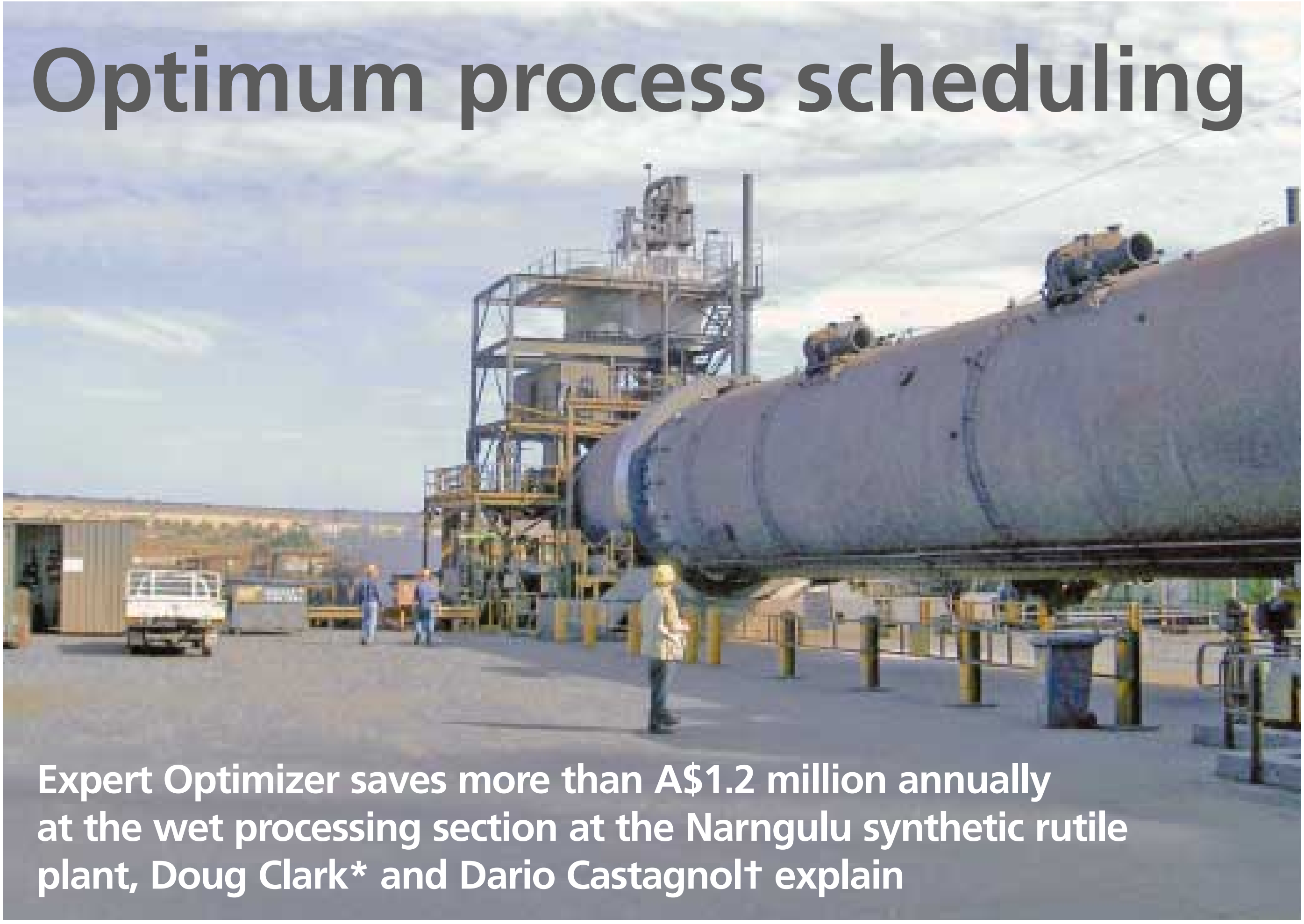
Optimum process scheduling



Expert Optimizer saves more than A$1.2 million annually at the wet processing section at the Narngulu synthetic rutile plant, Doug Clark* and Dario Castagnol† explain

Optimum scheduling for the wet section of the Becher process at Iluka, Narngulu was achieved using ABB's Expert Optimiser. A mixed logical dynamical model of the process is solved in real time in order to find the optimum operating strategy for a 43 hour time horizon and the strategy applied. The resulting smoother operating gives savings in both material and energy leading to a dramatic reduction in annual operating costs. Savings of A$1.2 million/y were achieved, giving a project payback of less than six months.

Iluka Resources use the Becher process to produce synthetic rutile from ilmenite at its Narngulu site in Western Australia. The process has two distinct elements, the dry and wet sections. In the dry section ilmenite is mixed with coal and is processed in rotary kilns to reduce the iron oxide in the mineral to iron metal. The reaction that takes place is:

$$CO + FeO.TiO2 \Diamond CO_2 + Fe + TiO_2$$

Two different products are produced 'standard' and SREP (Synthetic Rutile Enhancement Process). In SREP hydroborasite flux is added to the kiln so that heavy metals can be removed from the reduced ilmenite (RI) in the wet processing. After the kilns any unburnt coal (char), is separated from the RI in a magnetic separation plant to be returned to the kilns.

In wet separation, iron is separated from the titanium oxide as the RI passes through a separation system, and in the case of SREP heavy metals are also removed.

Aeration is the first phase of wet separation. Here the RI is reacted in batches with ammonium chloride in 22 sparged agitated tanks, to remove metallic iron from the mineral grains. The time required for the batch reaction varies but is generally in the range of 16 to 20 hours. The reaction is exothermic and completion is detected by temperature. After aeration the resulting slurry is fed to a cycloning system where the iron is removed with the overflow and the mineral is recovered in the underflow. This is a semi-continuous process. What happens to the underflow after the cycloning depends upon whether the product is 'standard' or SREP. SREP heavy metals are leached out using sulphuric acid. In the 'standard' case, there is a bypass system which simply pumps the slurry from one tank to another providing some additional buffer capacity. Finally the slurry is fed to a filtering and drying system. The kilns' off gasses provide heat for drying which can be supplemented by a gas burner if required.

Optimising the wet part of this process is highly problematic because of the need to predict the state of the process in two days time and produce the most cost effective strategy to give smooth operation. To compound the difficulty, some of the equipment can be assigned to either product line and the optimisation must be able to cope with this without requiring re-engineering. ABB was selected to work with Iluka to optimise this process due to the pre-existing good relationship between the two companies and due to the good pedigree of the Expert Optimizer system.

Optimisation tasks

There were two optimisation tasks. The first was to control the kilns to improve output and quality, the second was to schedule the operation of the wet section in real time to meet various objectives. This discussion covers the latter part of the project.

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In order to schedule the wet system the optimiser system decides:

- When to charge and discharge the aerators
- When to start and stop the cyclone systems
- When the leach system should run and, if running, what the setpoint should be
- When the dryer systems should run and, if running, what the setpoints should be.

Expert Optimizer provides recommendations to the operators to charge or discharge aerators; automatically starts and stops the cyclone systems; changes the setpoints for the leaching and drier systems and can recommend stops/starts of these systems as required. It is anticipated that in the future the charging and discharging of the aerators will be automated.

The model

The chosen solution method was to model the process as a Mixed Logical Dynamical (MLD) system using the ABB Expert Optimiser toolkit and then to apply Model Predictive Control (MPC). Expert Optimiser provides a unique graphical tool for programming MPC models that brings the techniques into a factory safe environment.

The general method of working is:

- The process is decomposed into control volumes (in this case, RI bin, aerators, cycloning, leaching & drying)
- Each control volume is modelled independently using a combination of blocks from a palette and, if required, imported code written in the Hysdel language
- Control volume models are linked together graphically to produce a model that closely matches the process flowsheet. The model for 'standard' is shown in Figure 1.
- The MLD blocks are parameterised using drag and drop
- The objectives are each given a cost that reflects their priority

The model implemented in this case predicts the state of the process for the next 43 hours and calculates the best operating strategy over this period by minimising the cost of operation over the time horizon. In the same way that an expert chess player tries to foresee the development of the game and then makes the initial move that is most likely to lead to victory, the MPC calculates a time series of setpoints likely to lead to the lowest cost outcome and then the first step of the setpoint vectors are implemented. The process then evolves and the model is recalculated so that if the expectation does not match the reality a new winning strategy is applied in real time.

The form of the model in MLD is given by,

$$x(t+1) = Ax(t) + B_1u(t) + B_2\delta(t) + B_3z(t)$$
$$y(t) = Cx(t) + D_1u(t) + D_2\delta(t) + D_3z(t)$$
$$E_2\delta(t) + E_3z(t) \le E_1u(t) + E_4x(t) + E_5$$

Where:

¬ x represents the state of the process, for example a tank level

¬ u are the inputs to the model some of which can be controlled (changed) by the model and some of which are uncontrolled. An example of a u would be a dryer feedrate setpoint

¬ y are variables used for control decisions, for example costs

¬ E represent the constraints on the process. These constraints may be 'hard' or 'soft'. Hard constraints must be respected or the model will fail; soft constraints may be violated but this adds a very high cost to the model so that violation becomes unlikely.

The equations above are matrix ones, covering the whole process time horizon. The user does not see this because the graphical model is automatically converted to a matrix representation by the Expert Optimizer system. These matrices end up being extremely large, making the solving of the model in real time difficult. The level of difficulty is then massively increased by including Boolean variables (example, run/stop) and for this reason we believe this is probably the most complex real-time MLD system ever deployed on an industrial scale.

In no particular order, the constraints considered in the model include:

- Keeping the initial feed bin at a low level (improves quality, reduces aeration time & prevents kiln stops in case of wet section breakdowns)
- Not charging more than one aerator on each line at one time (physical constraint)
- Not discharging more than one aerator on each line at one time (physical constraint)
- Not having mature aerators that cannot be discharged due to lack of tank space (improves quality and reduces power usage)
- Keeping the level of the tanks within target ranges and ensuring no overflows
- Not stopping the SREP leach system unless absolutely necessary but if it must be stopped then not starting it until a minimum time period has passed (improves quality and reduces acid consumption)
- A minimum consecutive up time for the cyclone systems (operator preference)
- Running the dryers at steady output (maximises use of waste heat)
- Allowing equipment to scheduled as not available (for planned maintenance).

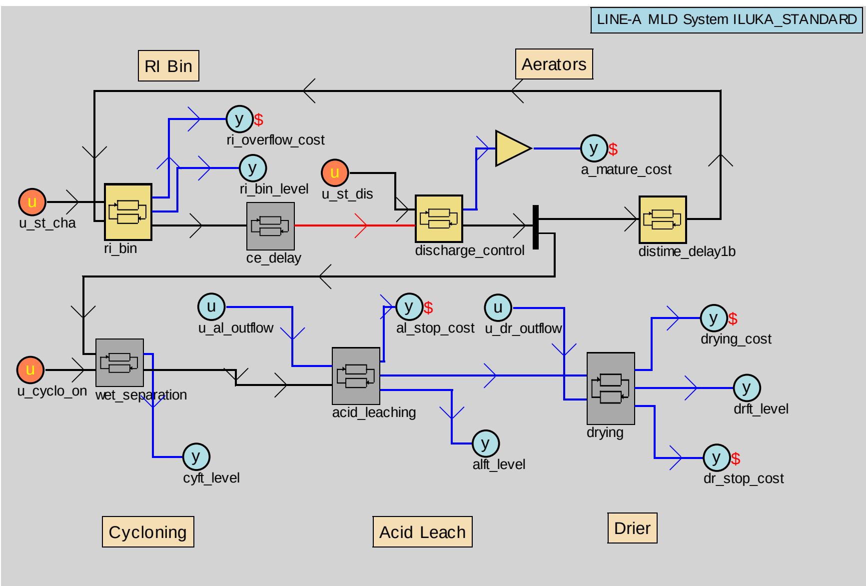
An example of an aerator schedule is shown in Figure 2.

Project procedure

The project proceeded in several steps. First, there were two site visits where ABB and Iluka engineers cooperated to understand the mass balance of the process and the rules on how it should be operated.

ABB developed an initial model and tested using data collected during the visits. A high level of communication between the engineers was essential to ensure that the model closely matched the reality. At the end of this step the initial model was used to train Iluka engineers on the use

Figure 1: MLD model for "Standard" production



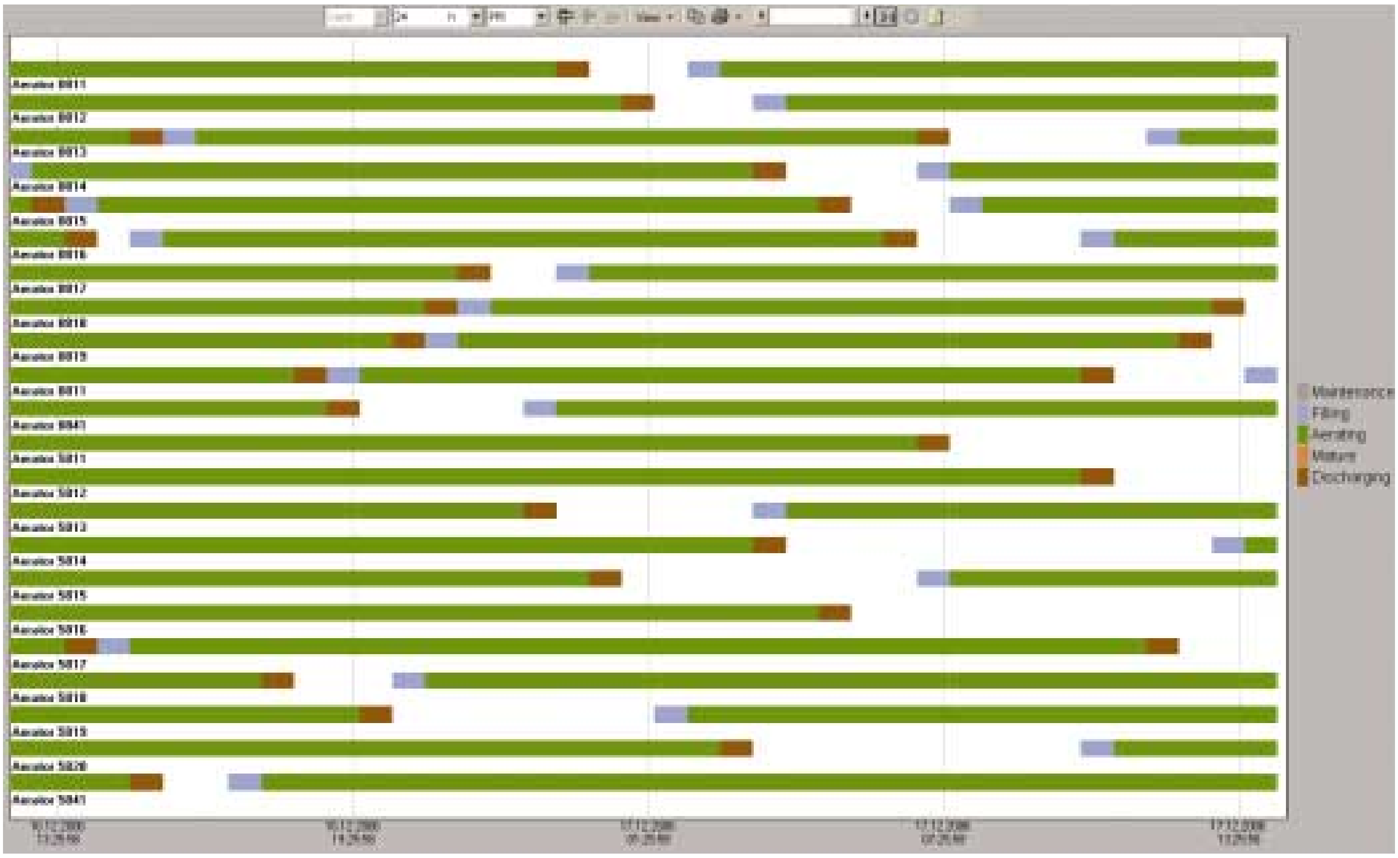


Figure 2: Predicted Aerator schedule for 24 hours

of the Expert Optimizer system facilitating their participation in the commissioning.

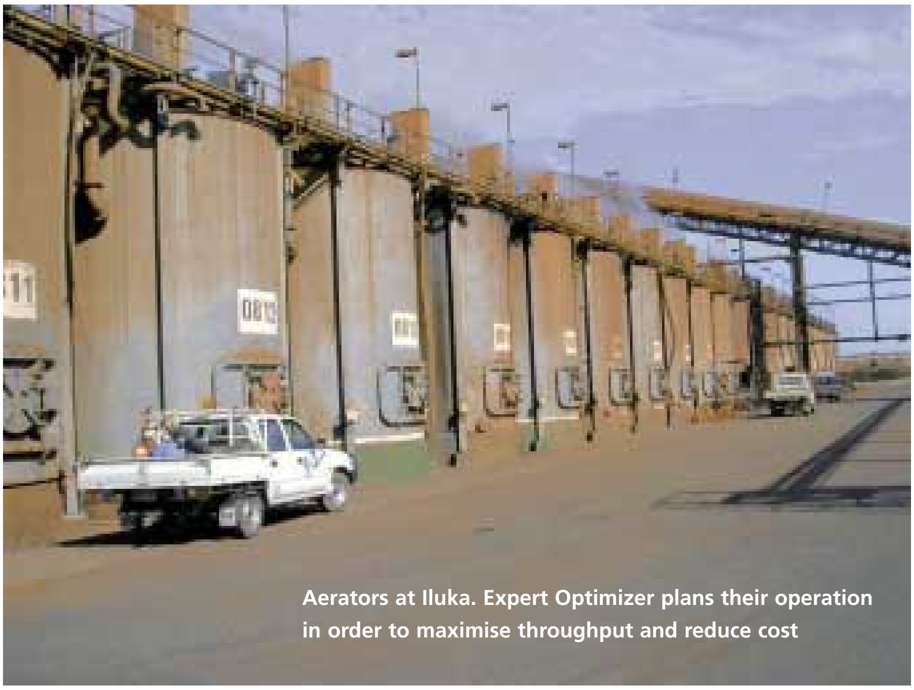
Working in co-operation with the process control department at Narngulu, two ABB engineers commissioned the strategy over a five week period. The system was then left running for about three months. During this time the site engineers observed the system, made modifications when required and determined where the strategy should be refined. The ABB engineers returned to site for a two week visit to refine the strategy, ironing out any bugs detected since the first visit.

Operating the system following the rules above provides several benefits:

- Keeping the RI bins at low levels ensures that the aerators are fed with fresh, hot material. This speeds up reaction time and gives a better quality product
- Discharging aerators as soon as they are mature reduces power consumption and improves quality by not over processing the RI
- More continuous running of the SREP leach system decreases the acid and lime consumption, and improves quality
- Running the dryers at a steady rate to maximise the use of waste heat for drying and minimises the use of gas
- Preparing the system for maintenance so that a queue of undischarged aerators does not develop whilst downstream equipment is unavailable.

After six months of operating the results are as show in the table:

The annual total savings are A$550,000 in materials and A$696,000 pa in power, giving a project payback of less than six months. As well as these obvious tangible benefits the system has the intangible benefit of freeing the operators to take an overview of the process instead of always concentrating on the nitty-gritty. Operator Murray said “I never turn it off, it does a great job. It makes life here [in the control room] so much easier”. Operator Ian said “I was always trying to see what would happen tomorrow, it does it so much better than I could”. ***IM***



Aerators at Iluka. Expert Optimizer plans their operation in order to maximise throughput and reduce cost