The process "copper"

Copper plant scheduling and optimization

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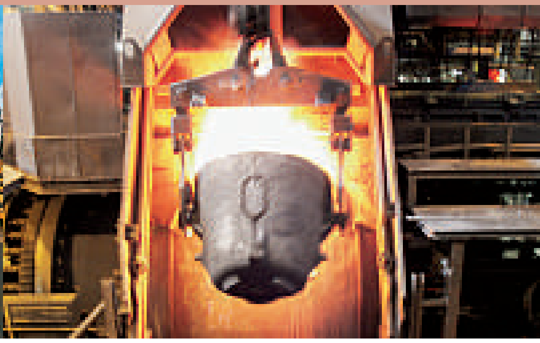
In a process such as copper production, numerous sub-processes are influenced by one another, and by external factors such as supply and demand. Running every sub-process at its local optimum often leads to a highly sub-optimal operation of the plant as a whole. Bottlenecks or shortfalls occur as sub-processes do not consume or produce at the same rate. Maintenance downtime further accentuates this. Add the effect of unpredictable disturbances and the task of optimization seems truly Herculean.

ABB's copper plant optimization tool is a software tool that knows how to stay calm and finds the best response no matter what is thrown in its path.



Copper is man's oldest metal, being used for more than 10,000 years. It has, throughout history, played an important role in everyday life. Today, copper, "the red gold", is used in a wide range of applications, including construction, electrical and electronic products, transportation, consumer products and industrial equipment. Copper can commonly be found in products from the automotive, marine, piping and telecommunication industries and is almost omnipresent. Curiously, a wide variety of vegetables, fruits, grains, dried beans, nuts, meats, seafood and chocolate, as well as drinking water contain small amounts of copper, which is essential to human health.

Copper is also the material of the future, not only because of its wide applicability in rapidly growing industries but also owing to its unique material properties and practically 100 percent ability to be recycled: Copper does not degrade, either in quality or value, during re-processing.

Global copper consumption has increased by more than 25 percent in the last 10 years, mostly in the fast-growing Asian economies. It can be expected that the major copper-consuming industries will continue to grow, keeping demand high. Global copper mining production has also been increased steadily over the last 100 years. In recent times the most active regions were South America and Indonesia. At present, copper is comparable to oil in the sense that it is sold at a globally defined market price. This spells out the need for higher overall production volumes and consequently a drive towards more efficient processes in existing plants.

Copper production is a complex process with many interdependencies, which makes it very difficult to foresee the overall consequences of a single local decision. The variability in raw-material has a significant impact on the process. Disturbances and equipment breakdowns are common. Daily maintenance operations are needed and material bottlenecks occur.

A tool developed by ABB in collaboration with NA (Norddeutsche Affinerie, Hamburg, Germany) analyzes and optimizes the most important aspects of copper production. It helps keep the copper plant profitable by improving overall efficiency and reducing the impact of disturbances. The scheduling solution enables a more efficient production, better overall coordination and visibility of the process, faster recovery from disturbances and an optimized maintenance planning procedure. This translates into increased throughput and revenues. This tool has been installed and is running at NA, the fourth largest copper producer in the World.

Production process

In theory the principle of copper production is quite straightforward: The objective is to remove all other elements from the copper ore (mostly sulfur and iron). As in all metals, this is done at extreme temperatures and requires special equipment. The process has several steps:

- The copper concentrate (25–35 percent Cu, produced from copper ore) is processed in a primary furnace where the copper level is enriched to around 65 percent.
- The molten copper (matte) is then processed in a converter, where the remaining sulfur and iron are removed through injection of oxygen-enriched air from below. The so called blister copper has a copper content of 98 percent.
- Various materials are added to achieve an optimal temperature, performance and internal and external recycling ratio of copper.
- The process continues in an anode furnace, the main purpose of which is to remove the accumulated copper oxides by blowing natural gas into the melt.
- Once the target purity (99.6 percent) has been achieved the copper is cast into copper anodes, which are cooled and processed further.

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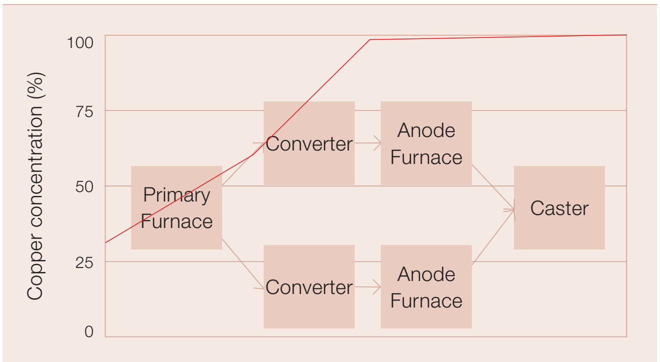
The processing equipment may hold over 300 tons of material at once. A large copper plant often has parallel processing lines for the bottleneck stages 1. In most copper plants, the material is transported in ladles using cranes. Depending on the plant layout, synchronization is required to prevent parallel activities overloading or blocking the cranes 2. This adds to the logistic complexity. The many interdependencies between equipment status, material amounts, process timings, and parallel process events may easily lead to schedules that are far from optimal.

Automation systems play a key role in this type of process: The reliability of equipment is paramount, slow process dynamics rule out rapid changes. Status and estimation dependent decisions must be made quickly.

The challenge: production planning

A copper production process is difficult to plan in advance due to the lack of measured data, complex logistics, and variability in raw-material specification, frequently occurring disturbances and additional tasks such as maintenance operations. Currently, production planning and scheduling is typically a manual task and the lack of a "global" overview for local detailed planning means that each component often ends up running at "full speed", ie, trying to produce as much as possible (local optimum). This results in overall productivity losses as the total process efficiency suffers with batches waiting unnecessarily for the next stage. It is also practically impossible to react promptly to disturbances or changes in the process conditions.

1 Alleviating process bottlenecks by running sections in parallel.



2 Optimization of crane movements helps alleviate production bottlenecks.

The variability of margins due to fluctuating copper and raw-material prices (copper price variation was 19 percent in 2002 and 48 perecnt in 2003) underline the need to adaptively optimize the production process.

Solution

The resulting decision support tool is novel and covers the main process steps. It makes it possible to optimally relate input material properties (amount, quality) to corresponding processing times and so enable a total planning and scheduling approach that considers key process parameters and reaction dynamics. The main input data comprises:

- Batch numbers and data (fixed material quantities are possible).
- Copper contents of various components (laboratory results and prediction).
- Current status of the equipment (with estimated end times).
- Maintenance jobs to be planned (exact time or a given time window).
- Start-time of the schedule horizon (automatic or manually entered).

It is also possible to either fix many of the decision variables or to let the optimization determine their values.

The optimization tool builds on a valid and robust process model that captures the main chemical reactions and takes into account the variable material quantities in predicting processing times. A mathematical approach was selected to ensure that an optimal solution is obtained. This posed two main challenges:

a) The resulting process model is in its pure form intractable, mainly due to the underlying chemical reaction kinetics.

b) Logical decisions that need to be made in a scheduling problem (commonly related to precedence and equipment assignment) must be represented by discrete or binary (zero/one) variables.

In order to make the problem solvable, a linearized process model was generated. This enables the use of standard Mixed Integer Linear Programming (MILP) optimization techniques, for which several robust solvers are commercially available. To ensure the validity of the linearization, the process model was verified with a significant quantity of real data from databases and manual logbooks. The resulting linear process model represents the highly non-linear real process well.

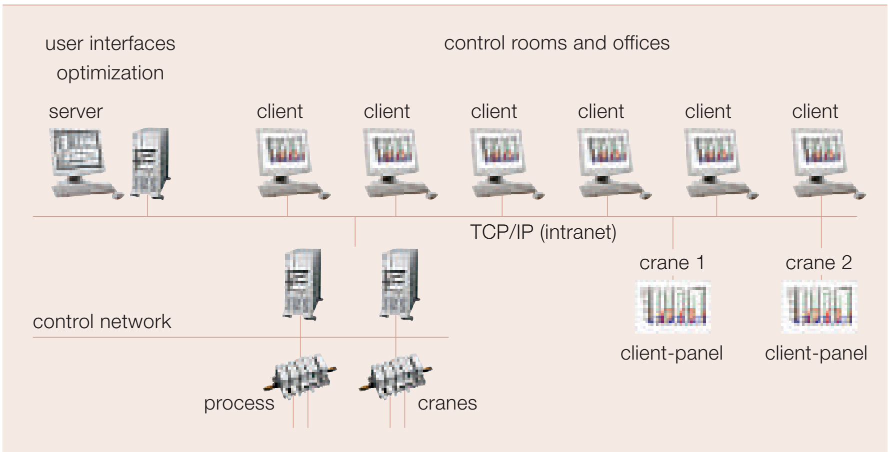
The optimization problem is solved using commercially available software (in this case ILOG CPLEX). This generates a schedule for all major process steps as well as the main material requirements for the production (optimal recipe definition for each batch). The schedule obtained is transferred to a crane simulation module (eM-Plant). This generates the detailed crane movements needed to check that the schedule is also realizable on the plant-floor. All solution components can be called through the graphical user interface (GUI). To make planning results available throughout the plant, HTML-pages are generated by the optimization server and can be browsed from virtually any PC connected to the intranet. All appropriate staff can view the most recent main planning results and automatically receive an update after changes. An overview of the system architecture is shown in 3 and the solution is summarized in 4.

The solution output contains data for and the graphical visualization of the optimal production plan. The most important output components are:

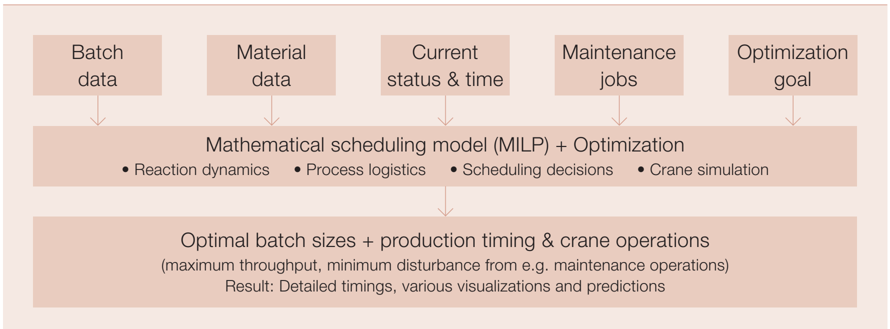
- Material quantity and detailed timings for each batch.
- Process phase diagram and Gantt chart.
- Process picture with key production parameters.
- Predicted SO_2-production.
- Corresponding crane jobs as a list and diagram.
- Updated web-client pages.

This solution is unique in performing a full scheduling optimization that takes into account equipment availability, process sequencing, material quantity (recipes) based on the chem-

3 System architecture.



4 Optimization solver overview.



ical reactions, crane actions and maintenance needs simultaneously.

The scheduling and optimization approach is modular, which in practice means that one module can be adjusted, expanded or tuned without requiring change in unrelated parts.

A typical scheduling horizon is 36 hours and since a continuous-time approach is adopted, the resulting schedule is exact. The MILP problem involves around 900 constraints and 750 variables, of which 50 are binary. It is solved within a few seconds.

User interface

The GUI provides a user-friendly environment for fast scheduling/re-scheduling. An example of the interface is shown in 5. The user can easily do a reschedule by adjusting only a few parameters. All results can be archived and later reloaded. Once an optimal solution has been obtained it can be "published": ie, shared with all web-clients and archived.

Through improved planning, the idle times of filled melt copper ladles are reduced, resulting in lower SO_2-emissions.

Due to the batch handling characteristics of the process and the modularity and flexibility of the solution, many of its components can be modified for other batch-related processes with relative ease. It is especially suitable for those applications where the selection of input-material quantities affects processing times, and the number of different products is restricted. The core continuous-time scheduling model is generic and easily portable through parameterization. Highly process-specific issues need to be treated on a case-by-case basis in order to maintain the tool's high solution quality. However, such work is mainly limited to the model part.

Benefits

An important question is what value the solution provides to the end customer. When operations are static (no disturbances or other deviations from "normal" operation) classic planning practices can be applied and these provide a close-to-optimal strategy. Unfortunately, this is rarely the case in copper production. Raw-material variability alone has a significant impact on the process. Disturbances and equipment breakdowns are common. Daily maintenance operations are needed and material bottlenecks occur. Furthermore, the understanding of "best operating practice" may vary from planner to planner, potentially leading to production conflict situations. The scheduling solution developed provides a common framework for all participants.

To summarize, the main benefits for the end customer are:

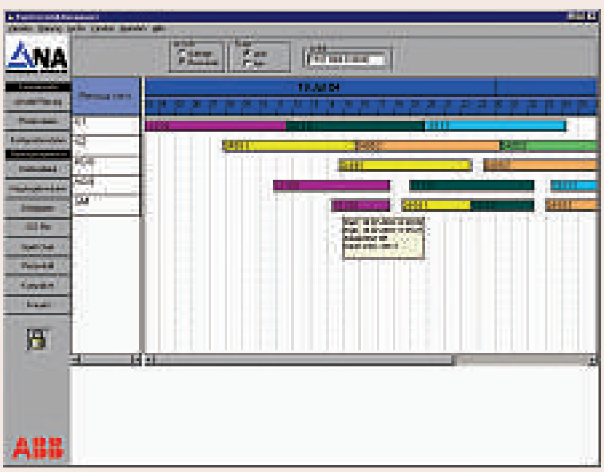
- Optimal production plan available on demand within seconds.
- Better overall coordination and visibility of the process.
- Optimized batch sizes for maximum total efficiency.
- Faster recovery from disturbances through efficient scheduling.
- Optimal maintenance scheduling.
- Optimized schedule for crane operations.
- Synchronization of all process steps.
- Increased throughput and revenues.
- Common planning culture and online information sharing across all departments.

In practice, this corresponds to a throughput increase of 10,000–20,000 tons of concentrate per year. This is equivalent to an annual production increase of one to two percent. Since many of the reactions are exothermic, direct energy savings can only come from reduced waiting times or transportation needs, but these gains are minor. The major environmental benefit can be found in the SO_2-emissions, which are now predictable. Through improved planning, the idle times of filled melt copper ladles are reduced, resulting in lower SO_2-emissions and consequently also in a lower consumption of active calcium hydrate. The reduction is estimated at around 150 tons/year.

Conclusions

This production planning and scheduling solution shows that systematic decision support tools do not only provide an increase in production and profitability. They also enable a more efficient internal communication between different units and provide a standardized framework for planning. This can have a substantial impact on productivity. The novel solution concept allows the plant to work more efficiently and makes planning activities more controllable.

5 Gantt chart window.



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