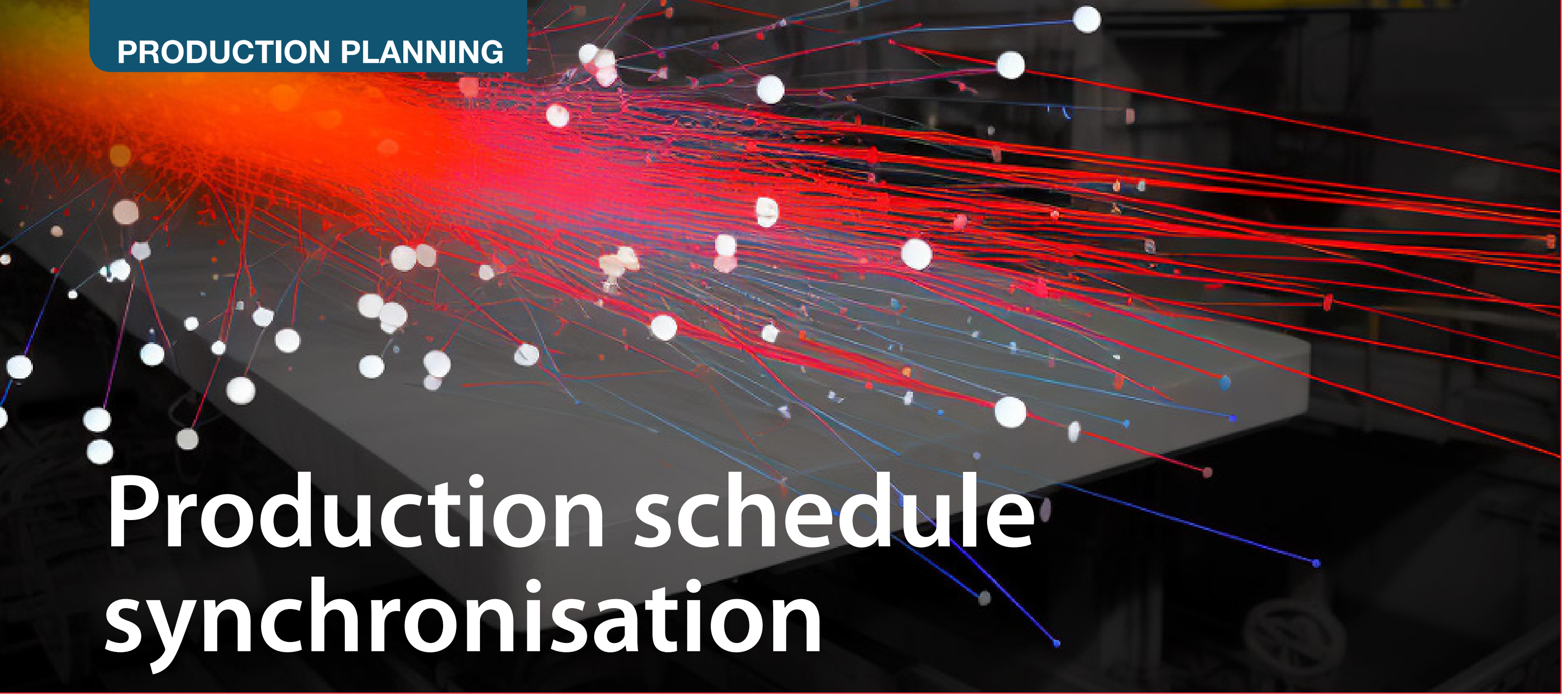


Production schedule synchronisation

From melting to hot rolling, increasing the reheat furnace charging temperature by schedule optimisation

Fully integrated steel mills play a vital role in meeting the ever-growing global demand for steel products. These complex facilities encompass various interconnected processes from: blast furnaces; basic oxygen furnaces; ladle treatment stations or ladle metallurgy furnaces; vacuum degassers – such as vacuum tank degassers or Ruhrstahl-Heraeus degassers in steelmaking; multi-strand continuous casters for slab production; hot strip mills for strip production; plus pickling lines, cold rolling mills, annealing lines and continuous galvanising lines in finishing. In contrast to in-line thin slab to strip producing mini mills, slabs in complex facilities are stored between casting and hot rolling in a slab yard, either in hot or cold storage (Figure 1).

The ability to produce a huge steel grade portfolio along multiple process routes is a significant advantage for fully integrated steel mills, as it allows them to cater to the diverse needs of industries, such as automotive, construction, energy and appliances. It also poses a unique challenge for the scheduling group responsible for planning and optimising production.

However, the largest scheduling complications involve multiple constraints of different nature: upstream/downstream capacities and equipment availabilities, mechanical and metallurgical constraints regarding the order of produced material, fulfilling due dates, 'starting up' the caster and rolling mill or considering roll-wear for high-quality steel.

Unforeseen equipment breakdowns require quick on-the-fly reaction and instant schedule creating abilities. Changes in external factors, such as market demand fluctuations and raw material availability, require the cost function to be dynamically adjusted.

Direct charging, hot storage and hot boxes

After casting, slabs may either be processed for quality improvement (scarfing or grinding), sent to a slab storage area or taken directly to the hot mill for processing. Some steel grades require direct charging for quality reasons.

Traditionally, however, the majority of hot rolled slab comes from the yard's cold storage, and is reheated from ambient to rolling temperatures in the reheating furnaces. This method presents several challenges, including higher energy consumption and slightly longer processing times. In the pursuit of increased productivity and energy efficiency, steelmakers need to start focusing on increasing the percentage of hot storage and hot charging.

In hot storage areas, often located close to the hot strip mill, hot slabs are stacked and scheduled to remain for the minimal amount of time so they lose less heat, thus requiring less reheating and therefore shorter oven soaking times. While this saves energy and increases throughput, it adds complexity to the scheduling process.

Directly charging hot slabs from the caster into the hot mill with minimal reheating in the furnace can greatly increase the energy efficiency. By leveraging the heat already present in the slabs, the need for additional energy input in reheating furnaces is minimised, resulting in significant energy savings. Since the soaking times are greatly decreased, the bottleneck of the furnace capacity is removed and productivity increased.

In the pursuit of increased productivity and energy efficiency, steelmakers need to focus on increasing the percentage of hot storage and hot charging

As steelmakers strive for enhanced efficiency and sustainability, hot charging and direct charging of slabs have emerged as good practice in integrated steel mills. The widespread adoption of hot charging has the potential for significant savings in energy consumption and therefore lowering CO_2 emissions.

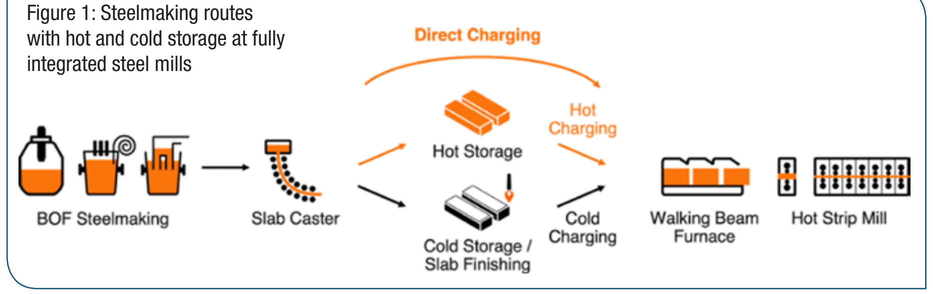
Digital twins & virtual yards

Digital twins enable operators to optimise material tracking by continuously gathering real-time data from various sources, including sensors, production equipment and other systems. By integrating this data into a virtual replica of the physical piece of material, steel manufacturers can monitor the performance of different processes, detect anomalies and identify potential bottlenecks.

This real-time monitoring enables proactive decision-making and minimises the risk of unplanned downtime or production delays. Operators can simulate different production scenarios and evaluate their impact before implementing changes in the physical environment. Therefore, digital twins provide a platform for continuous improvement and process optimisation.

Extending the idea of digital twins of material to synchronised production planning, with the goal of increasing reheat furnace charging temperatures, a virtual slab yard can be created. Virtual slabs enable planners to model and plan for slabs that do not yet exist physically. This capability allows for accurate capacity planning, plus the selection of the best routes for downstream processes. Capacities and possible routes need to be modelled in advance for all process steps.

Figure 1: Steelmaking routes with hot and cold storage at fully integrated steel mills



Manual versus automatic production scheduling

After implementing a capacity planning model that roughly balances inventory and product mix at regular intervals, as well as capacities and equipment availability of the plant, a detailed production schedule must be generated. The tools currently utilised for this purpose can vary significantly, ranging from traditional pen-and-paper methods, to Excel spreadsheets, or planning modules integrated within either internally developed or commercially available manufacturing execution systems (MES).

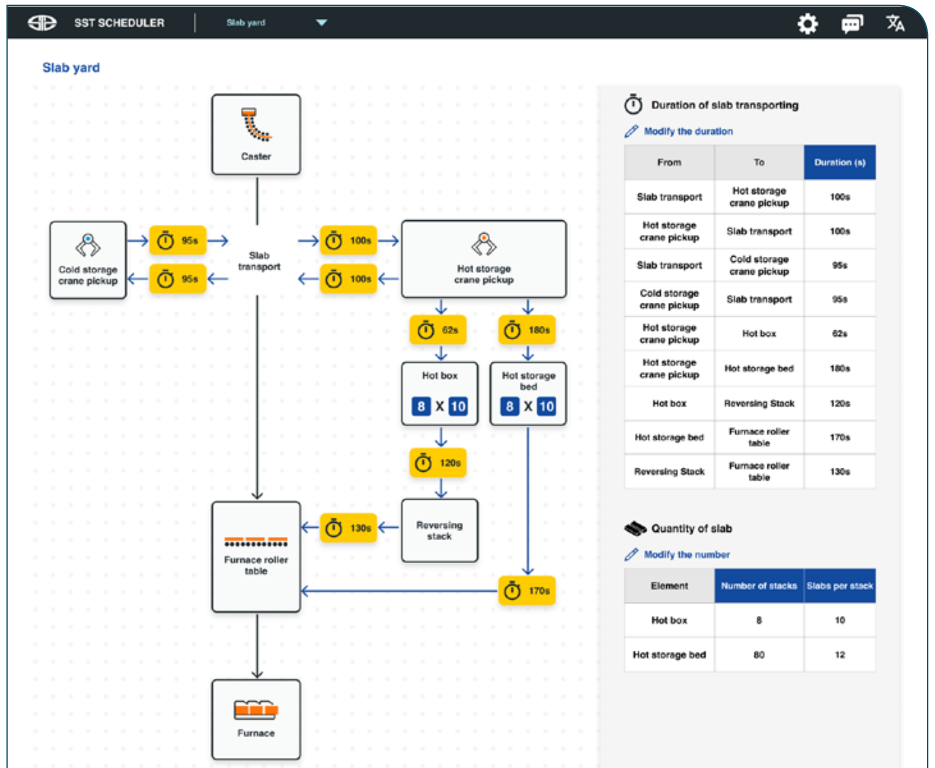
Scheduling groups face challenges due to mill capability limitations, as well as temporary constraints, such as line downtimes and extensive product grades. Frequently, traditional tools do not support scheduling based on product grades. This predominantly manual process is labour-intensive and fails to deliver optimal results due to the complexity of the process, mill constraints and order priorities. Additionally, any process disruption necessitates the creation of an 'instant schedule' using available slabs, incurring higher costs as a penalty. Logistics of hot and cold storage further complicates the procedure.

Given the multidimensional nature of the problem, mathematical algorithms are well-suited for its resolution. Mixed Integer Programming (MILP) emerges as an ideal tool for generating a production schedule, by modelling the problem as a linear program incorporating integer variables representing discrete decision-making elements. The critical step involves formulating the cost function to minimise or the profit function to maximise.

Mill constraints are expressed as linear equations or inequalities and incorporated into the linear programming model. Once the model is defined, including the objective function and constraints, the MILP solvers can be employed to find the optimal solution or a close approximation, depending on the available computational resources.

Smart Steel Technologies' 'SST Scheduling AI' includes MILP solvers which are employed for different types of mathematical problems to guarantee optimised results and short computation times. The obtained solution represents the optimal production schedule that satisfies constraints and minimises the cost function.

Given the need for frequent updates due to unexpected events as described above, the MILP solver must be highly efficient, enabling the re-optimisation of the production schedule in response to such changes to ensure it remains current and optimised.



From	To	Duration (s)
Slab transport	Hot storage crane pickup	100s
Hot storage crane pickup	Slab transport	100s
Slab transport	Cold storage crane pickup	95s
Cold storage crane pickup	Slab transport	95s
Hot storage crane pickup	Hot box	62s
Hot storage crane pickup	Hot storage bed	180s
Hot box	Reversing Stack	120s
Hot storage bed	Furnace roller table	170s
Reversing Stack	Furnace roller table	130s

Element	Number of stacks	Slabs per stack
Hot box	8	10
Hot storage bed	80	12

Figure 2: Visualisation of process routes, including cold storage, hot storage and hot boxes

The optimised schedule should be presented in a visually intuitive manner, offering an overview of one or multiple casters as well as subsequent process steps. Incorporating colour coding facilitates swift review by the scheduling team, enabling them to quickly assess the optimised schedule.

Changes in demand or the order book can lead to varying process steps becoming bottlenecks. To address this, the cost function can be customised to prioritise the utilisation of specific steps. Effective planning of multiple process steps with optimal route selection is crucial.

However, challenges arise when dealing with insulated hot storage boxes which have limited capacity, or hot storage areas located in close proximity to the HSM. Storing multiple slabs closely or transporting materials to cold storage at first sight complicates the generation of the cost function, but the algorithm also aims to simplify for slab yard logistics and provides a recommendation – of which slabs to store in which stacks – for easier retrieval in the yard. In cases of unexpected downgrades, the scheduler must rework the material. Certain slabs are vital for rolling programs, and their absence could result in program cancellation.

By incorporating AI models to forecast quality deviations, proactive rescheduling can be initiated in advance. Additionally, applying AI techniques can significantly aid in deriving optimal cost functions for optimiser algorithms.

Increasing efficiency

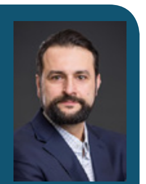
Understanding the complexity of the production process in fully integrated steel mills is key to a successful implementation of any software project in this industry. Therefore, every software project that tries to improve the production planning process starts with a consulting phase, where interviews with all stakeholders are conducted to map out the process, identify bottlenecks and potential savings, and prioritise key value drivers.

Connecting production lines and building bridges between these traditionally isolated islands, is key to synchronising production which leverages cost savings. However, the key value drivers, and therefore highest priority goals in the implementation of scheduling AI, is the optimised capacity utilisation to avoid bottlenecks, as well as the risk minimisation due to unplanned events. And in the case disturbances occur, the ability to quickly and efficiently react to such unplanned events.

Energy and CO_2 savings are generated by increasing the average furnace entry temperature through direct charging, and by making optimal use of hot boxes.

Authors

Michael Peintinger, PhD
Managing director americas
Smart Steel Technologies



Vladimir Finkelshtein
Team lead Optimisation
Smart Steel Technologies

www.smart-steel-technologies.com