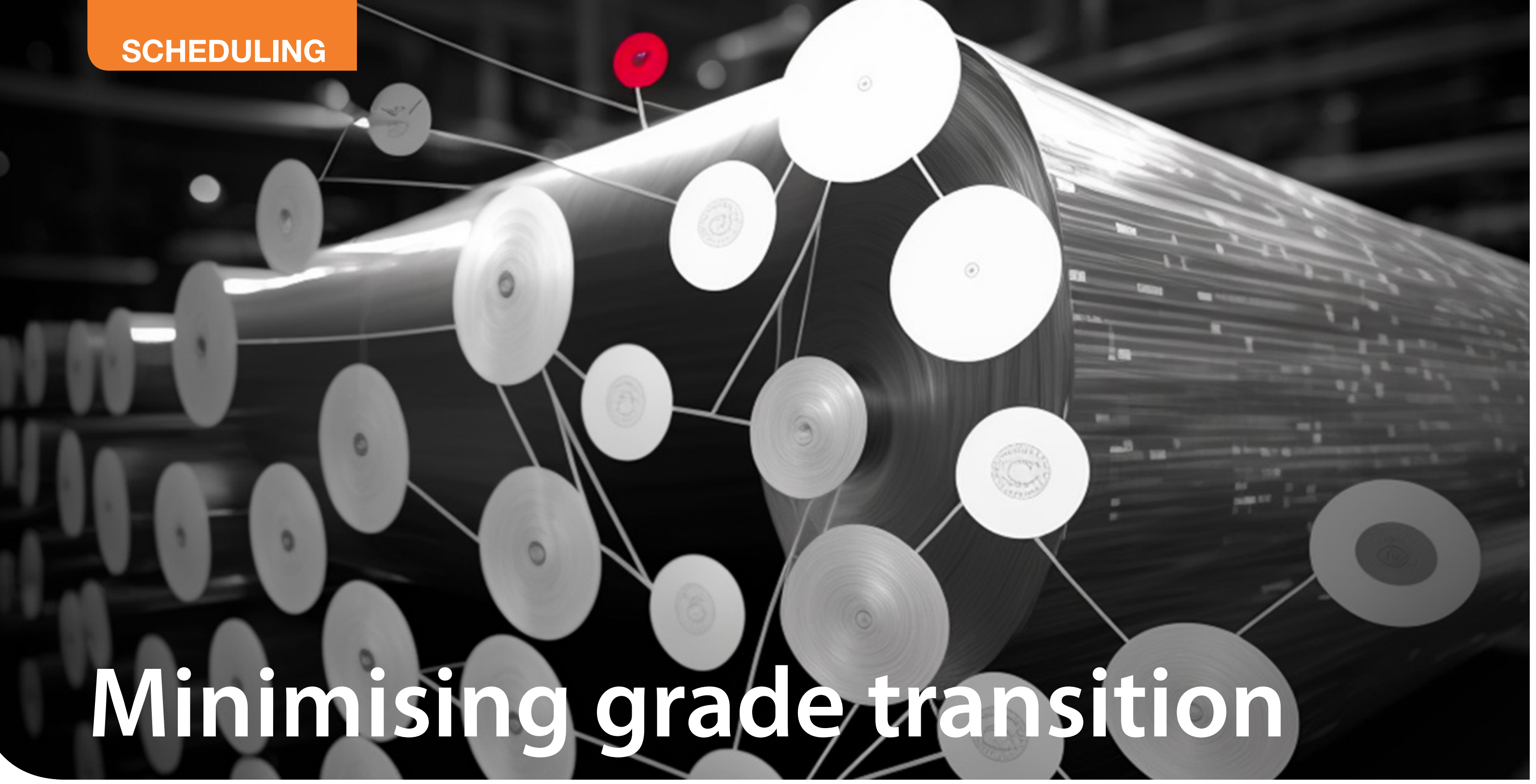

Minimising grade transition

Increasing yield by optimising production schedules for a minimum of grade transitions

Modern mini mills that use electric arc furnaces to melt scrap and convert it into new steel products can nowadays produce a wide range of finished steel products, from rebar and structural steel to specialty steels for the automotive and aerospace industries.

In steel strip production, three prominent methods are used: endless strip production (ESP), compact strip production (CSP) and quality strip production (QSP). These technologies are typically more flexible and efficient than larger, integrated steel mills, and can often produce steel at a lower cost.

However, this flexibility that enables mini mills to produce a huge variety of steel grades also leads to grade transitions and therefore transition losses. Scheduling experts must carefully plan their production schedules to minimise the number of grade transitions.

The cost of grade transitions

Modern steel production technology enables mini mills to quickly switch from one grade to another. This leads to frequent grade transitions and transition losses. Grade transitions occur when production switches from one steel grade to another with different chemistry. For example, if the mill is producing low copper steel and then switches to higher copper steel or steel grades with varying carbon content.

> ***Grade transitions occur when production switches from one steel grade to another with different chemistry***

The losses can be significant, especially when producing expensive steel grades. In addition, each time there is a grade transition, this can impact the quality of the steel being produced. Transition pieces will be either directly cut out and scrapped at the caster or result in downgraded coils. Three-coil-transitions can be extremely costly.

Manual versus automatic

Following a rough-cut-capacity-planning model, that coarsely balances inventory and product mix periodically, a detailed production schedule needs to be created. The tools used in practice vary dramatically from pen-and-paper to Excel sheet based tools, or planning modules in home grown or market-sought manufacturing execution systems (MES).

Mill capability restrictions, as well as temporary constraints, e.g. line downtimes, and the huge variety of grades provides a challenge to the scheduling groups. Often, the tools used do not support scheduling by grades. Flexible chemistries add an additional challenge and are often not reflected in the schedule. Violations for flex chemistries occur frequently. An estimated 50% of the proposed schedules can be rejected. The users receive an error from the MES, then either pull the schedule back and change it, or a metallurgist has to verify that the errors blocking the schedule can be manually overridden.

This mostly manual procedure can be labour intensive and does not deliver optimal results, due to the enormous complexity of constraints and order priorities. In the case of any process disturbance, an 'instant schedule' using fill-in slabs needs to be created on short notice which carries the penalty of an even higher cost.

The multi-dimensional character of the problem makes it suitable to be solved by mathematical algorithms. Mixed Integer Programming (MILP) is the ideal tool to create a production schedule by modeling the problem as a linear program with integer variables that represent discrete decision variables. The production schedule can be optimised to minimise transitions, while satisfying all of the constraints. The most important step is the generation of the cost function that is being minimised or the profit function that is being maximised.

Mill constraints are formulated as linear equations or inequalities and added to the linear programming model. Once the linear programming model has been defined, including the objective function and the constraints, the MILP solver can be used to find the optimal solution or a good approximation of it, depending on the available computational resources.

The solution obtained provides the optimal production schedule that meets constraints and minimises the cost function. The production schedule may need frequent updates to reflect changes due to unexpected events, such as equipment breakdowns. Therefore, the MILP solver needs to be extremely efficient so it can be used to re-optimise the production schedule based on these changes to ensure that the schedule is always current and optimised.

The optimised schedule needs to be displayed giving an overview over one or multiple casters, and feature a colour coding, so that the scheduling team can quickly review the optimised schedule.

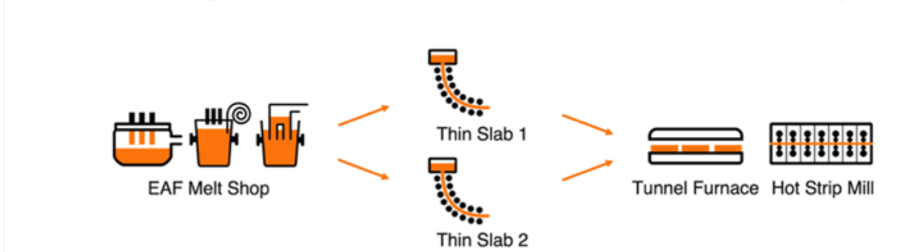

Figure 1: Modern thin slab production

Constraints & cost functions

The cost of production plays the crucial role in determining the optimal scheduling of production activities. Therefore, scheduling brown field projects begins with a consulting phase. In interviews with the melt shop, caster and hot mill, mill capability, process, grade and potential event-based restrictions are discussed, logged and then implemented into the scheduling model. Exemplary restrictions are steel grade chemistries, tundish weight during grade changes for soft and radical changes, weight, width and thickness. Also, time for roll changes and narrow-wide-narrow profiles during roll changes as well as delivery times and upstream/downstream throughputs need to be taken into account.

Priority of scheduling material per line is sorted according to profitability. One example for such a prioritisation:

- Continuous galvanising line (CGL)
- Pickling line and tandem cold mill (PLTCM)
- Batch annealing (BA)
- Hot strip mill (HSM)

But also carry-over stock (safety stock) needs to be taken into account.

Increasing efficiency

The tedious process schedulers have to follow can be dramatically simplified by software-based automation. In general, four things need to be defined by the user: (1) the available orders the scheduler is able to use during the optimisation, (2) the planning horizon, (3) Maintenance times or availability of the relent process aggregates and (4) prioritisation.

One click starts the optimiser and within minutes an optimised schedule is displayed to the user, that can be downloaded as a spreadsheet or directly injected into the MES. At any time, the schedule can be updated by re-running the optimiser if events force an alteration. There is no need to place fill-in slabs. This dramatically increases productivity.

Prediction models as cost function

AI-based quality prediction models in steel production rely on machine learning algorithms to analyse data from various sensors, e.g. automated surface inspection systems (ASIS), flatness or thickness gauges and other sources to predict the quality of finished steel products. These models use historical data and real-time data from the production process, to make predictions about the quality attributes of steel products.

The models can be used to predict various quality characteristics of steel, such as surface quality or material properties. By analysing the data in real-time, the models can also detect anomalies and predict when quality issues are likely to occur. The predicted quality can serve as input for the SST Scheduling Optimiser. It can determine if critical products need to be remade. This enables the planning system to act proactively instead of just reacting to the situation and puts the steel mill at a competitive advantage.

Towards an operating system for production

The smart steel mill, a facility that allows highly flexible production to meet customer-specific product requirements at almost no additional cost and in a short time to market, is becoming a reality. From setting optimised melting temperatures at the EAF using Temperature AI models to save energy, and CO_2 to providing casting parameters with a combination of casting and surface AI, AI-based production assistance will be the future efficient way to operate a mill. Combining these models with automatic scheduling using mixed integer programming makes the smart steel mill the default that enables companies to unleash significant benefits in terms of cost savings, product quality and customer satisfaction.

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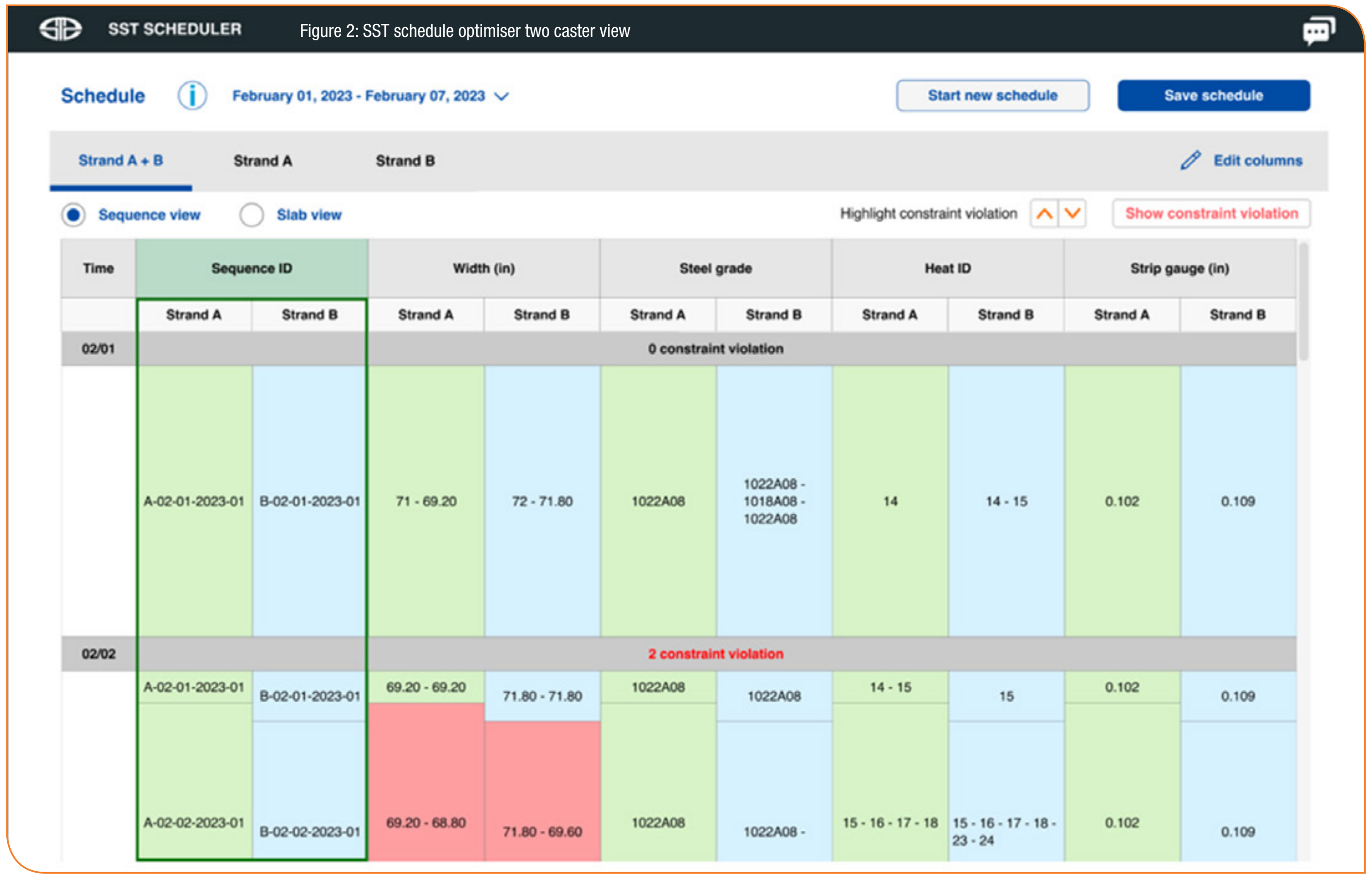

Figure 2: SST schedule optimiser two caster view

February 01, 2023 - February 07, 2023

● Sequence view ○ Slab view

Time	Sequence ID		Width (in)		Steel grade		Heat ID		Strip gauge (in)	
	Strand A	Strand B	Strand A	Strand B	Strand A	Strand B	Strand A	Strand B	Strand A	Strand B
02/01	0 constraint violation									
	A-02-01-2023-01	B-02-01-2023-01	71 - 69.20	72 - 71.80	1022A08	1022A08 - 1018A08 - 1022A08	14	14 - 15	0.102	0.109
02/02	2 constraint violation									
	A-02-01-2023-01	B-02-01-2023-01	69.20 - 69.20	71.80 - 71.80	1022A08	1022A08	14 - 15	15	0.102	0.109
	A-02-02-2023-01	B-02-02-2023-01	69.20 - 68.80	71.80 - 69.60	1022A08	1022A08 -	15 - 16 - 17 - 18	15 - 16 - 17 - 18 - 23 - 24	0.102	0.109