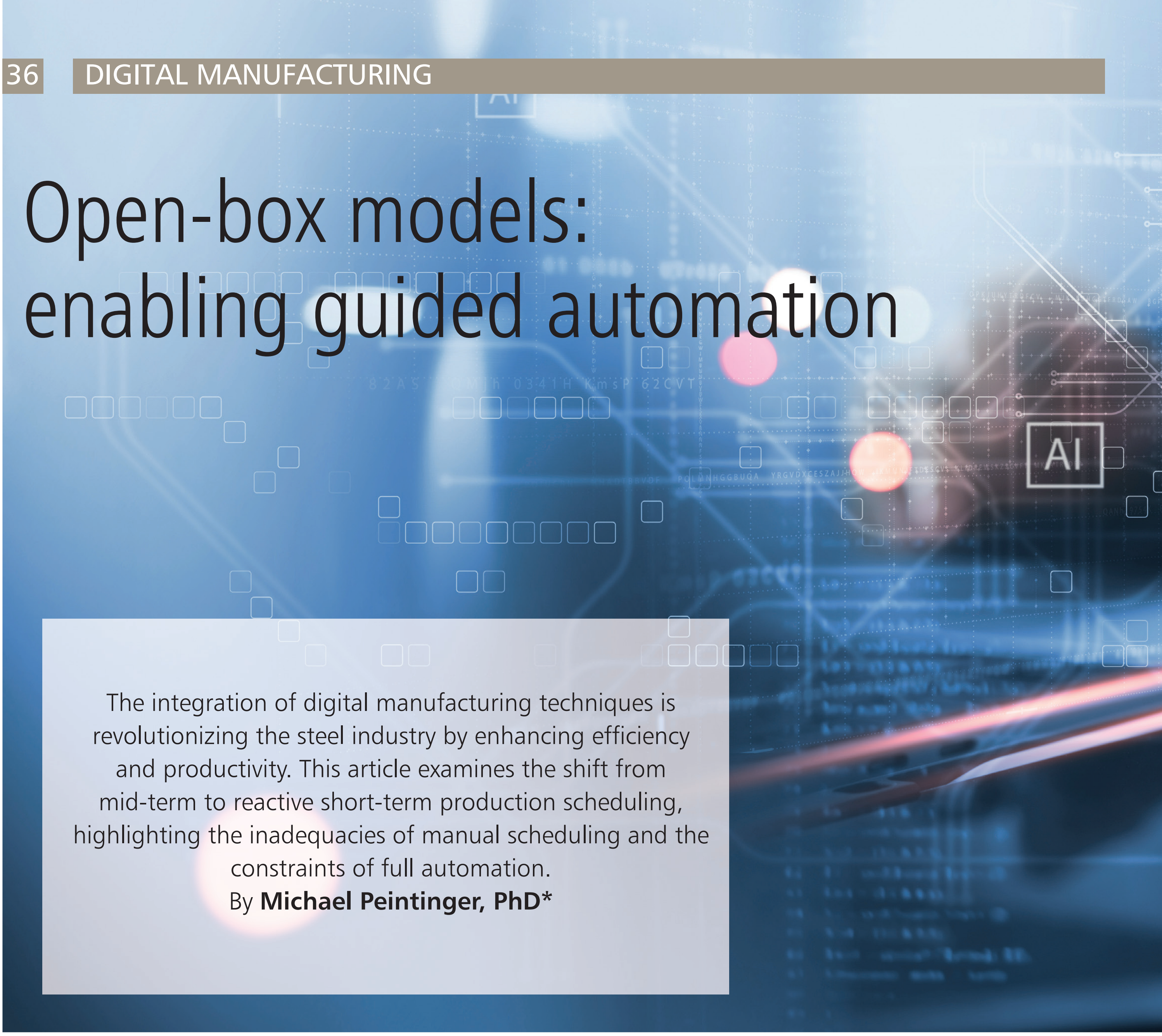

Open-box models: enabling guided automation

The integration of digital manufacturing techniques is revolutionizing the steel industry by enhancing efficiency and productivity. This article examines the shift from mid-term to reactive short-term production scheduling, highlighting the inadequacies of manual scheduling and the constraints of full automation.

By **Michael Peintinger, PhD***

AS the steel industry continues to evolve, the integration of digital manufacturing techniques becomes essential to address challenges like managing its highly interconnected production processes, responding to dynamic market demands, reducing equipment downtime, maintaining high-quality standards, and achieving energy efficiency. While the key value drivers, as discussed later, are different for integrated steel production (**Fig 1**) and thin slab casting setups (**Fig 2**), better planning and production scheduling can drastically increase efficiency by optimizing resource utilization, minimizing disruptions, and enhancing overall productivity for both scenarios.

Key value drivers

Fully integrated steel production is critical in addressing global demand for high quality steel products. In such mills, slabs or bars can be stored in hot or cold storage between casting and hot rolling. This flexibility allows for a wide range of steel grades to be produced, catering to diverse industrial needs. However, it also adds complexity to the scheduling process due to the need to co-ordinate multiple stages and manage inventory effectively. One of the key value drivers is to increase the average furnace charging temperature.

Modern steel production technology enables minimills to quickly switch from one grade to another. This leads to grade transitions, when production switches from one steel grade to another with different chemistry. The losses can be significant, especially when producing expensive steel grades and if transitions affect multiple coils. Better scheduling can help reduce the average number of transitions dramatically.

The overall goal in both scenarios is to increase the number of prime coils per order, e.g. by reducing jumps in the rolling schedule and avoiding large width adjustments while casting and, therefore, improving casting and rolling processes.

Mid-term planning defines the coarse parameters for short-term scheduling

Mid-term planning in steel production is essential for managing long-lead activities and aligning them with production capabilities and order commitments. Unlike short-term scheduling, which deals with the specifics of daily operations, mid-term planning provides a broader overview necessary for making strategic decisions. This includes purchasing scrap or external slabs, accepting and committing to large or complex orders, and scheduling significant maintenance activities.

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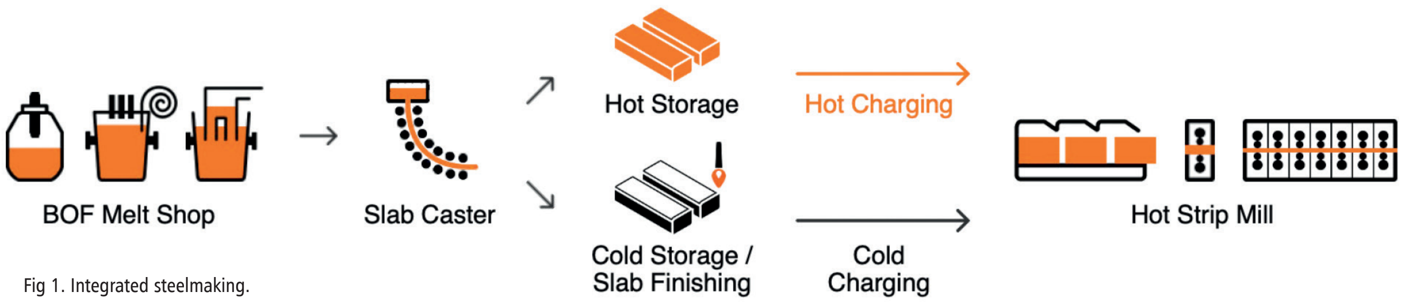
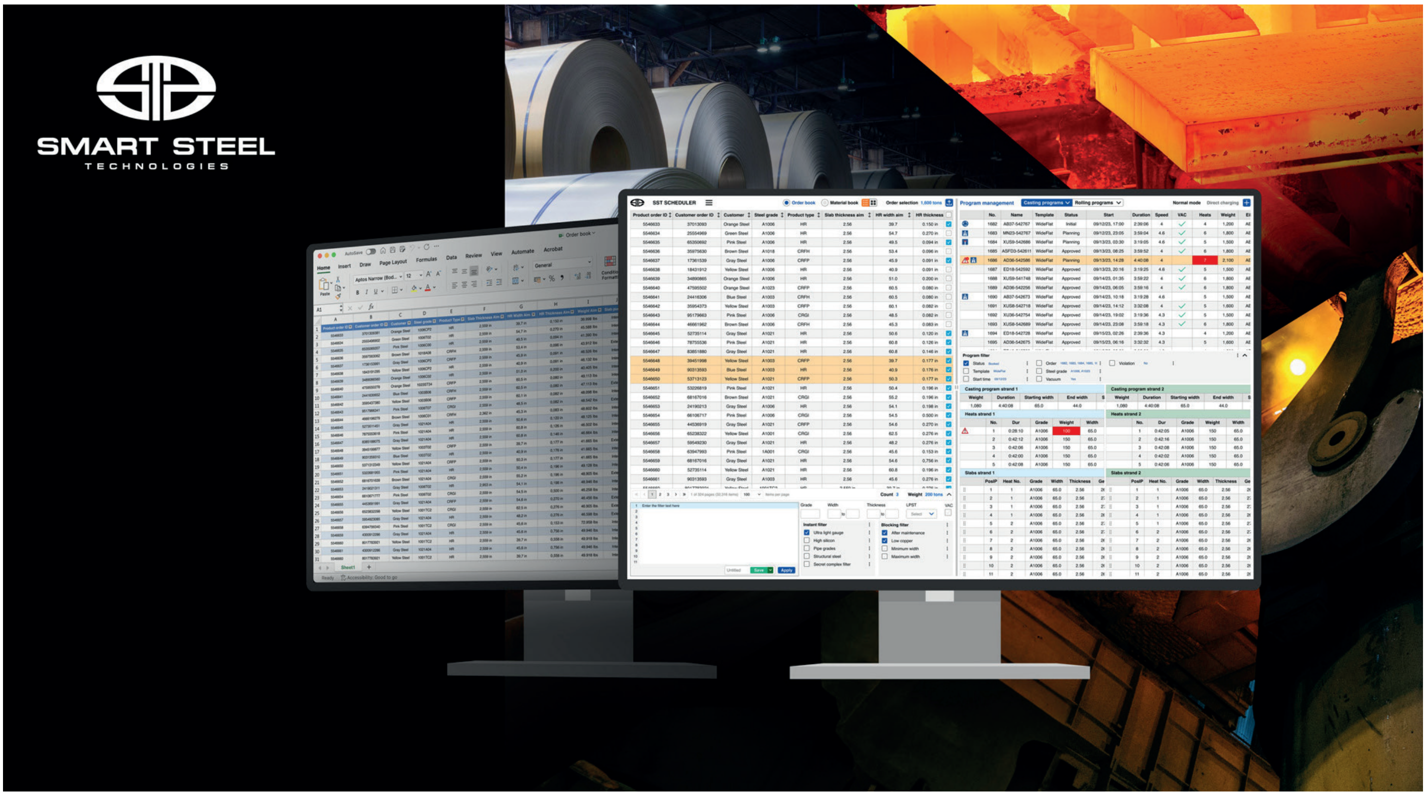


Fig 1. Integrated steelmaking.

Fig 2. Modern thin slab production.



Given the expected order book, one can anticipate future bottlenecks and future scarcities and suggest a mid-term plan to minimize or avoid them altogether. These activities require a rough but realistic plan that considers the plant's capacity and order book, ensuring that critical constraints are accounted for. Such plans typically sum up capacities and compare them with the order book, aiming for a balance that will later be refined in short-term scheduling. Although these plans are often rudimentary, they form the backbone for more detailed and precise short-term scheduling, ensuring that strategic decisions are feasible and align with production capabilities.

Towards guided automatic production scheduling

Limitations of manual scheduling

Traditional production scheduling in steel mills often relies on manual methods, such as simple pen-and-paper techniques or Excel spreadsheets. These approaches, while familiar and straightforward, are labour-intensive and prone to human error. Manual scheduling requires schedulers to consider numerous variables and constraints, including equipment availability, material flow, and production priorities. This complexity makes it diffcult to optimize schedules efficiently.

Manual scheduling also struggles with process disruptions. Equipment breakdowns or safety-related events necessitate the creation of an instant schedule, often resulting in suboptimal production sequences and increased costs. This highlights the limitations of manual methods and points towards the need for automation and, therefore, more sophisticated scheduling solutions.

Challenges of full automation

The idea of fully automating production scheduling, possibly through advanced algorithms or artificial intelligence, seems like a promising solution. However, full automation faces significant challenges. Automation of schedules usually requires strictly defined objective functions with exact dollar value trade-offs between objectives. In reality, production environments are dynamic, with economic conditions and stakeholder demands frequently changing.

Experienced schedulers often state, 'I know it when I see it,' indicating that what constitutes a 'good' schedule can vary and is diffcult to parameterize. Stakeholders' daily scheduling requests, often not transmitted via computer systems but verbally communicated in phone calls, are diverse and challenging to generalize, requiring flexibility that fully automated systems struggle to provide.

Necessity of user-guided automation

Given the limitations of both manual scheduling and fully automated systems, a hybrid approach that combines automation with user guidance is necessary. Open-box models offer a solution by allowing users to understand and adjust the scheduling process. Unlike black-box AI models, which are opaque and often require retraining with new data sets to tweak, open-box models provide transparency and flexibility.

Mixed Integer Linear Programming (MILP) models

A more suitable approach for guided automation is Mixed Integer Linear Programming (MILP). MILP models the scheduling problem as a linear programme with integer variables representing discrete decision-making elements. MILP solvers can incorporate a wide range of constraints and objectives, enabling the generation of schedules that minimize costs and maximize efficiency.

In MILP models, constraints are implemented as a set of rules based on mill capability and the vast experience of operators and schedulers. These rules are formulated into linear equations or inequalities that define the boundaries

within which the scheduling algorithm must operate. This allows the system to leverage practical knowledge and operational realities to create feasible and optimized schedules.

MILP models are open-box, meaning they can be understood and tweaked by the user. This transparency allows users to impose specific priorities and constraints, guiding the algorithm to meet their needs. For example, a user might instruct the system to produce a particular order, even at the cost of suboptimal schedules and late orders, as long as hard constraints are not violated. Alternatively, during periods of resource scarcity, users can direct the system to allocate materials, focusing on the most critical orders.

User-guided automation in practice

Our approach to automatic scheduling involves combining MILP with user guidance. This approach ensures that broad control, which is impossible with black-box algorithms, is maintained. Users must understand how the algorithm behaves to steer it in the desired direction, necessitating a user-friendly interface that allows for concise input and adjustments.

Smart Steel Technologies' SST Scheduling can be guided by users by order selection filters, adjustment of constraints, and cost functions. The systems can rapidly process large volumes of data, continuously update schedules in response to real-time changes, and provide optimized solutions that account for complex interdependencies between different stages of production. By adding AI models as additional optimized or predictive cost functions, the systems can forecast potential quality deviations and initiate proactive rescheduling.

Benefits of guided automatic scheduling

Guided automatic scheduling offers numerous benefits. It minimizes grade transitions, reducing losses when switching between steel grades. Slab yard logistics are optimized, ensuring efficient material storage and retrieval, while higher furnace charging temperatures lead to significant energy savings and reduced CO_2 emissions. The life of the planning group becomes easier as they are relieved from labour-intensive tasks, allowing them to focus on strategic decisions. Automated systems respond better during mill events, quickly generating new schedules that account for disruptions. They also optimize the calculation of order to products, increasing yield and enhancing material utilization. AI-supported cost functions improve cost forecasting and management, maintaining production quality while controlling expenses. Additionally, guided scheduling maximizes the number of fly tundish changes by planning programmes in sequence, maximizes and minimizes tundish wear depending on the type, reduces slab stock production, increases roll change wear, and lessens diameter changes in rebar mills. However, these benefits often compete, making savings difficult to evaluate. For instance, similar plants may have different hardware, leading to varied bottlenecks and KPIs, and even a single plant's KPIs can change over time. Therefore, a flexible scheduling system incorporating user input is essential to navigate these complexities effectively.

Conclusion

Manual scheduling is the current *status-quo* due to its familiarity and simplicity, but it cannot optimize complex production processes effectively. Full automation is also not feasible due to the need for dynamic adjustments and stakeholder inputs. The ideal solution lies in user-guided automation using open-box models like MILP, which combine the best of both worlds: the efficiency and optimization of automated systems with the flexibility and insight of human guidance. This approach not only enhances productivity but also ensures that the scheduling process can adapt to the ever-changing demands of the steel production environment. ■