QUALITY IMPROVEMENT OF CASTER SCHEDULING AT TRINECKE ZELEZARNY

Eng. Konvicka D.[1], Ass. Prof. PhD Eng. Solodovnikov V.[1,2]

[1] LOGIS Research and Development Laboratory, Frenstat pod Radgostem, Czech Republic
[2] National Research University Higher School of Economics, Moscow, Russia
E-mail: vsolodovnikov@hse.ru

Absract *The paper analyzes melt shop and caster scheduling at special steel maker – Trinecke Zelezarny. The main optimization objectives of melt shop and caster scheduling are defined as: minimization of earliness and lateness of orders, maximization of tundish utilization, minimization of steel grade changes and minimization of mold width changes, minimization of stock, minimization of over grading, management of iron inventory. The following key problems of scheduling are defined: underdeveloped optimization algorithms and insufficient computer performance. Based on this the key provisions of a new method of melt shop and caster scheduling are proposed. The method significantly improves quality of planning. It includes the following three stages: production capacity allocation; heat building; sequencing. An experience of successful practical development and implementation of specialized software solution based on the new method at Czech special steel maker is provided.*

KEYWORDS: MELT SHOP AND CASTER SCHEDULING

1. Introduction

The efficiency and effectiveness of melting, steelmaking and continuous casting management has a profound effect on competitive advantages of a steel company and in most aspects defines its financial performance. Permanently strengthening intensity of competitive struggle of steel companies and rise of volatility on the ferrous metals market define importance of development and implementation of new approaches to solving a task of qualitative melt shop and caster scheduling. This task is a NP kind problem. In fact, it is a combination of complex problems that has historically been somewhat impervious to practical, optimized solutions. Often steel companies with their partners tried to develop new methods in this area. Partners were scientific institutes and leading software vendors. Many initiatives in the area of development of specialized solution independently or in cooperation with partners have not brought desired results or fail despite significant financial and labor investments. Main reasons for that were underdeveloped optimization algorithms for the problem and insufficient computer processing speeds. Recent advances in this area allowed LOGIS specialists to develop a method and solution which let planners to create qualitative melt shop and caster schedules to directly drive efficient shop floor operations at large steel producers. The development of the new scheduling method and solution was based on data of Czech special steel maker – Trinecke Zelezarny.

2. Preconditions and means for resolving the problem

2.1. Czech steel maker description

Trinecke Zelezarny is one of the leading producers in Europe. Its production assortment includes: wire rods, rebars, rails, flat products, seamless pipes, and sections. The company produces hundreds of steel grades. Its annual production is about 2.4 million tons. The staff is about 5 500 employees. The production supply chain of the company includes integrated facilities of iron and steel making. (see Figure 1).

Steel is produced in basic oxygen furnaces (BOF) and in electric arc furnaces (EAF). Steel casting is done through continuous casters and by ingot teeming. Depending on method of casting, profiles, and sizes, semi-products (ingots, blooms, billets) are transported downstream through production supply chain. As could be seen from the scheme the melting and casting are the key stages of production. That is why melt shop and casting scheduling is so important for the company.

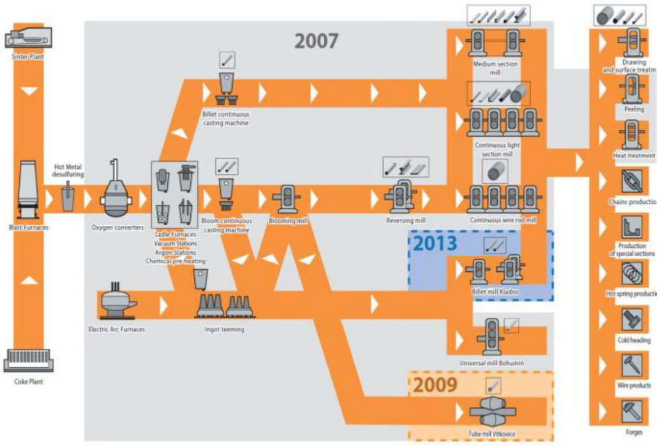

Fig 1 *Supply chain scheme*

The old scheduling process was arranged in the following way. Input data was prepared in manual mode by 5 specialists, who prepared requirements for casting based on planned orders of rolling mills. Based on the requirements, specialists created melt shop and caster schedules. These schedules had sufficient accuracy on the horizon of 4 – 7 days. Beyond this horizon the accuracy significantly deteriorated. Scheduling took much time and efforts. Rolling mills requirements changes or deviations from the schedule in many cases lead to rescheduling. Often because of high laboriousness rescheduling was done after the end of working days or on weekends. Absence of rolling mills requirements beyond 1-2 week horizon significantly reduces efficiency of decision making of planners. Also data quality needed to be improved. Manufacturing execution systems monitored only general volumes of production without accounting for heats, heats sequencing, and without information about allocated orders.

As a result the company had high level of work in process and low due date performance. It was logical that the issue of rearranging of scheduling process and improving its efficiency was open.

2.2. General task formulation of melt shop and caster scheduling

Melt shop and caster schedules are normally generated at least once a day—sometimes more often. Thousands of orders must be combined and sequenced for production through iron making, steelmaking, and continuous casting. Each time this occurs, the planner tries to balance multiple business objectives, which exist in a tradeoff relationship.

The first goal of melt shop and caster scheduling is to produce orders on time, that is, to minimize order earliness and order lateness . The desired production time for each order at casting is usually given by some higher level production planning function, which balances order loads across the entire plant. Planners try to respect this requirement by scheduling each order for production on the day that it was requested. If orders are produced too early, unnecessary inventory may result. If orders are produced late, customer delivery performance suffers and unnecessary expediting costs may be incurred.

The second goal of melt shop and caster scheduling is to maximize tundish utilization . For each steelmaking grade, there is some maximum number of heats that can be cast using a single tundish. When the maximum is reached, the tundish must be switched out and relined with new refractory. Maximizing tundish utilization reduces operating cost per ton, minimizes the number of "top" and "bottom" slabs (or blooms, or billets) as a percent of total production, and helps keep liquid steel flowing for as much calendar time as possible. The Czech plant has several casters, and some portion of the order book is often considered to be "swing orders," able to be produced at alternative casters. Tundish utilization can normally be improved by intelligent allocation of swing orders to casters during the caster scheduling process.

The third goal is to minimize grade and width transitions within the tundish. Minimizing grade transitions improves prime yield, as material from the chemical transition zone may have limited usefulness for customer orders. Reducing the number and severity of slab width transitions is important for flat products producers, as it reduces wear on both casting and hot rolling equipment, reduces breakout risk, and can improve prime yield.

The fourth goal is to minimize the amount of stock within the melt shop and caster schedule, and focus production on current demand. As manufacturing orders are combined into heats, and heats into tundish sequences, stock (or "open order") material must sometimes be inserted, to fill out a heat or extend tundish length. Production of stock is usually a waste of precious manufacturing time, since it cannot be converted immediately into revenue, but lingers in inventory.

The fifth goal of melt shop and caster scheduling is to minimize over-grading. Each customer order has alloy requirements that must be satisfied. In order to fill out heats, extend tundish length or avoid grade transitions, orders are sometimes "over-graded," that is, a more expensive chemistry is used to satisfy an order than is actually required by the customer. Thus minimization of over-grading reduces alloy costs.

For integrated steelmaking plants—those with blast furnace operations—there is a sixth goal: control of liquid iron inventory. In every such plant, the fleet of torpedo cars that transport liquid iron from the blast furnace to steelmaking (see Figure 7) is finite: there are only a certain number of cars available at any given time. Ironmaking is the input to this liquid iron inventory, and steelmaking consumes it. Steelmaking production volumes are driven by caster schedules—wide schedules consume more iron, narrow schedules consume less. Since blast furnace production is difficult to modulate rapidly, caster schedules must be continuously adjusted to control the amount of liquid iron "on wheels." This helps avoid costly or environmentally irresponsible methods of disposing of excess iron.
For those steel plants that are capable of significant amounts of hot charge rolling, two additional goals help define the quality of integrated casting and rolling schedules: material charge temperature into the reheat furnace, and hot mill asset utilization. Retaining as much heat as possible in the semi-finished product reduces fuel costs per ton, and increases throughput for furnace limited mills. Hot mill utilization improves when rolling campaigns are planned at the maximum length for each campaign type, minimizing the number of required roll changes.

All of these goals exist in a complex tradeoff relationship (see Figure 2).

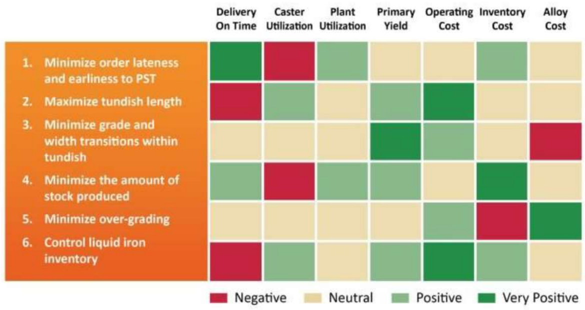

***Fig 2** Six key goals of melt shop and caster scheduling*

Minimizing order earliness and lateness supports good customer delivery performance, but may hurt tundish utilization and increase operating costs. Maximizing tundish length reduces operating costs, but may result in stock production and over-grading. Maximizing hot charge rolling may reduce tundish utilization, etc. The complexity of balancing above-mentioned goals taking into account specific technological constraints and rules prevented for a long time companies from achievement of efficient results in the area of melt shop and caster scheduling. Existing methods usually targeted only one of the goals. There was no method available for complex and efficient balancing of all the goals. The necessity for development of such a method was obvious for specialists at the Czech steel maker.

2.3. The key provisions of a new method

The complexity of melt shop and caster scheduling problem defines necessity to apply a decomposition method to it. Using problem structure this scientific method allows decomposing original problem into set of small interrelated and more simple tasks.
The main idea of the new method is as follows: a) proper decomposition of the problem into layers; b) application of the most useful optimization techniques for each layer; and c) rapid iteration between layers until the model converges on a solution that respects the planner's business goal priorities. The proposed method solves the problem using three layers of optimization (see Figure 3).

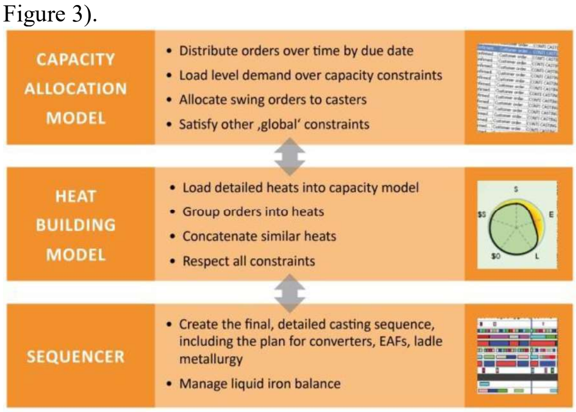

***Fig 3** Decomposition of melt shop and caster scheduling problem*

The first layer handles capacity allocation. This layer distributes orders over time by due date at casting, levels casting demand loads respecting major capacity constraints, allocates "swing orders" to multiple casters, and generally satisfies global constraints.
The second layer is the heat building model, which combines orders into heats, loads heats into available capacity, and concatenates similar heats, while respecting the next level of capacity constraints.
The third and final layer creates the detailed production sequence at steelmaking, ladle treatment and continuous casting, manages the

liquid iron inventory balance, and respects the most detailed constraints.
The optimization layers iterate until the total KPI balance is achieved. The first layer executes, and control is passed to the next level down. If infeasibility is detected at the second or third layer, control is returned to the next level up for resolution. The model cycles up and down between layers until the total KPI balance requested by the planner is achieved.
Thanks to the decomposition of the scheduling problem into layers and the usage of the best fitting combinations of solvers for each layer the computations are executed as efficiently as possible.
Scheduling information system
The new method of scheduling was used as a base for development of a solution for the Czech production company. Also the Czech company specialists and LOGIS project team members defined a set of key requirements for a new solution.
Whether assessing the relative merits of multiple scheduling scenarios, or reacting to shop floor problems that require immediate schedule changes, model execution speed is simply fundamental, and must be accomplished without compromising schedule quality.
No model, however sophisticated, can fully represent the richness and variation of physical reality. Therefore the planner must be able to easily make manual adjustments, with complete visibility to any potential constraint violations.
The quality of any melt shop and caster schedule can be measured along vectors that correspond to the goals for scheduling. The planner must have real-time visibility to the full set of Key Performance Indicators that reflect the value of the schedule, after every model run and after every manual adjustment.
The goals for melt shop and caster scheduling can have different relative importance for different steel plants, and can vary for the same plant as business conditions change. For example, when alloy prices are high relative to steel prices, it's more important to control over-grading. The planner must be able to adjust the priority of caster scheduling goals, and have the model produce schedules that comply.
The planning environment evolves constantly: new facilities added, new products introduced, changed commercial priorities, etc. The melt shop and caster scheduling model must represent constraints in a way that allows planners to make model changes without long IT wait times. Constraints should be represented in the model as data and the planner should be able to add, change or delete constraints as needed.
To implement these and other requirements LOGIS specialists developed a new solution. During the implementation project the model of melt shop and caster scheduling was set up in the solution.
To solve a complex problem, one must be able to represent the problem. The UI representation of scheduling data structures, constraints, and the schedule itself is another critical component of usability. The developed solution has a number of standard reports that characterize the schedule, including views of tundish utilization, over-grading, production to stock, and order earliness and lateness.

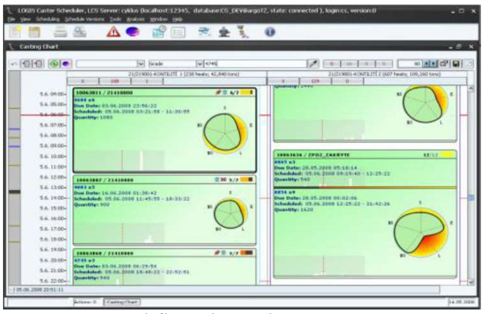

Fig 4 *Material flow through casters*

The system was developed in C++ and it uses memory resident architecture which means that the solution doesn't use hard drive during calculations and thus it has high performance. The system uses for modeling constraint satisfaction programming algorithms including linear and mixed integer programming, constraint-based search, heuristics and other OR algorithms (Taha H., 2005).
The key results of the implementation of the developed system are: significant rise in speed of calculation (it takes minutes not hours now); improvement of schedule quality thanks to detail modeling of steel making rules, application of contemporary optimization algorithm and friendly user interface for manual changes of a schedule.

3. Results and discussion

The process of melt shop and caster scheduling was completely renewed at Trinecke Zelezarny thanks to implementation of the new solution. Today casting requirements are generated automatically based on a valid calendar production plan. This allows a planner to work on the complete calendar production plan horizon – up to 4 months. Currently melt shop and caster schedules are created for 40 days. The first 14 days of the horizon are planned in detail. The schedule is updated regularly based on real situation in production. The visibility of schedules and wide planning horizon significantly improved economic and technological reasonableness of planners' decisions.
The result of new process implementation was efficiency improvement not only in melting and casting but also at the company in general. One of the key performance indicators of steelmaking is the level of wasted tundish life at continuous casting. An improvement of this indicator enables a decrease in the costs of production, with simultaneous increase of the total performance of the steel plant. The achievement of a good level for this indicator is especially difficult due to the following factors: necessity to produce a large variety of steel grades, taking into account special requirements of individual customer orders; high share of small orders in proportion to one heat, let alone to the minimal size of a tundish lot. The level of wasted tundish life at continuous casting is evaluated as the difference between the theoretical maximum and the planned sequence length for individual steel grades, where the theoretical sequence length derives from the maximum length of sequence given by the technology of production and the planned sequence length derives from the casting schedule at the continuous casters. Statistics of average tundish continuous casting is provided on Figure 5.

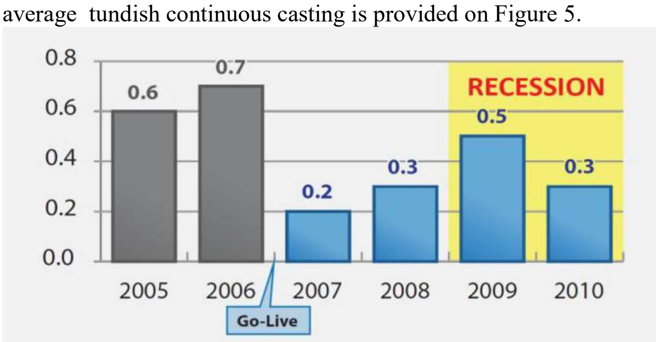

Fig 5 *Statistics of wasted tundish life at continuous casting*

In 2007 when go-live of the solution started the company was able to lower tundish life wasting at continuous casting to 60% comparing with 2006. Although crisis happened in 2008 the indicator was improved by more than 70% comparing with 2006. It is worth mentioning that using specialized solution in crisis period allowed the company using achieved additional competitive advantages to get leading positions on the market in its segment. Thus the implementation effect was obvious even during the uneasy period when supply on the steel market was much higher than demand.
In general the integration of the new process of melt shop and caster scheduling into the process of order fulfilment planning significantly improved quality of customer service. In 2007 the company was able to achieve due date performance (daily accuracy) of 91% keeping high operational excellence. Then the indicator only improved though significant increase in number of

products and in number of steel grades (see Figure 6).

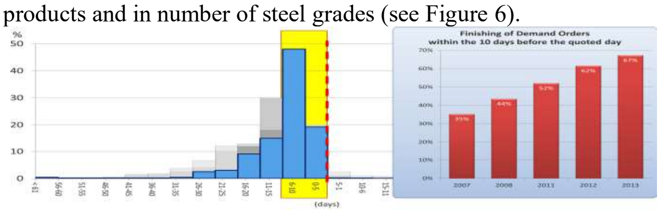

***Fig 6** Finishing of Demand Orders in relation to the Quoted Day (2013)*

4. Conclusion

The quality of melt shop and caster schedules has a profound effect on competitive advantages of a steel company and in most aspects defines its financial performance. Steelmaking constraints are specifically important in order fulfilment planning for companies which have hundreds and thousands grades of steel.

The developed method and the solution help planners to effectively solve problem of melt shop and caster scheduling in short time. These method and solution were implemented at a set of international industrial companies. They proved their efficiency and they are recommended for use at similar companies.

Grant information

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5. Literature

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