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# Cost optimization system for an integrated steel mill

*Kostenoptimierung für ein integriertes Stahlwerk*

**Kimmo Kanninen and Jarmo Lilja**

Professionals world-wide are struggling to improve cost efficiency at integrated steel plants. A wide range of theory and practice exist for optimizing sub-processes. However, the market is lacking tools to analyse and optimize integrated steel mills as a whole. SSAB and SW-Development Ltd have taken steps towards overall optimization of steel plants. The model is capable of analysing complex material and energy flows at steel mills giving answers to questions like “What is the Value-In-Use of a cheaper coal in the mix?” Target for the optimization model is to find the most cost-effective way of producing a mix of steel grades in conditions defined by chemical analysis of input materials, limiting values of impurities in steel grades and range of permissible values of user-defined parameters.

*Weltweit versuchen Experten, die Kosteneffizienz bei integrierten Stahlwerken zu verbessern. Für die Optimierung von Teilprozessen gibt es eine breite Palette von Theorie und Praxisanwendungen. Auf dem Markt fehlen jedoch Werkzeuge zur Analyse und Optimierung zur ganzheitlichen Analyse und Optimierung von Stahlwerken. SSAB und SW-Development haben Schritte zur Gesamtoptimierung von Stahlwerken durchgeführt. Das Modell ist in der Lage, komplexe Material- und Energieflüsse in Stahlwerken zu analysieren, um Antworten auf Fragen wie z. B. „Wie groß ist der Nutzwert einer billigeren Kohle in der Mischung“ zu finden. Ziel des Optimierungsmodells ist es, die kostengünstigste Herstellungsmethode zur Erzeugung eines bestimmten Stahlsorten-Portfolios zu finden. Rahmenbedingungen sind hierbei die chemische Analyse der Eingangsmaterialien, die Grenzwerte für Verunreinigungen in Stahlsorten und der Bereich der zulässigen Werte von benutzerdefinierten Parametern.*

Traditionally integrated steel mills tend to have optimization tools for sub-processes like the determination of a blast furnace charging program. Target of the cost-optimization system is to avoid sub-optimization and visualize total cost and effects of decisions for the complete steelmaking process, figure 1.

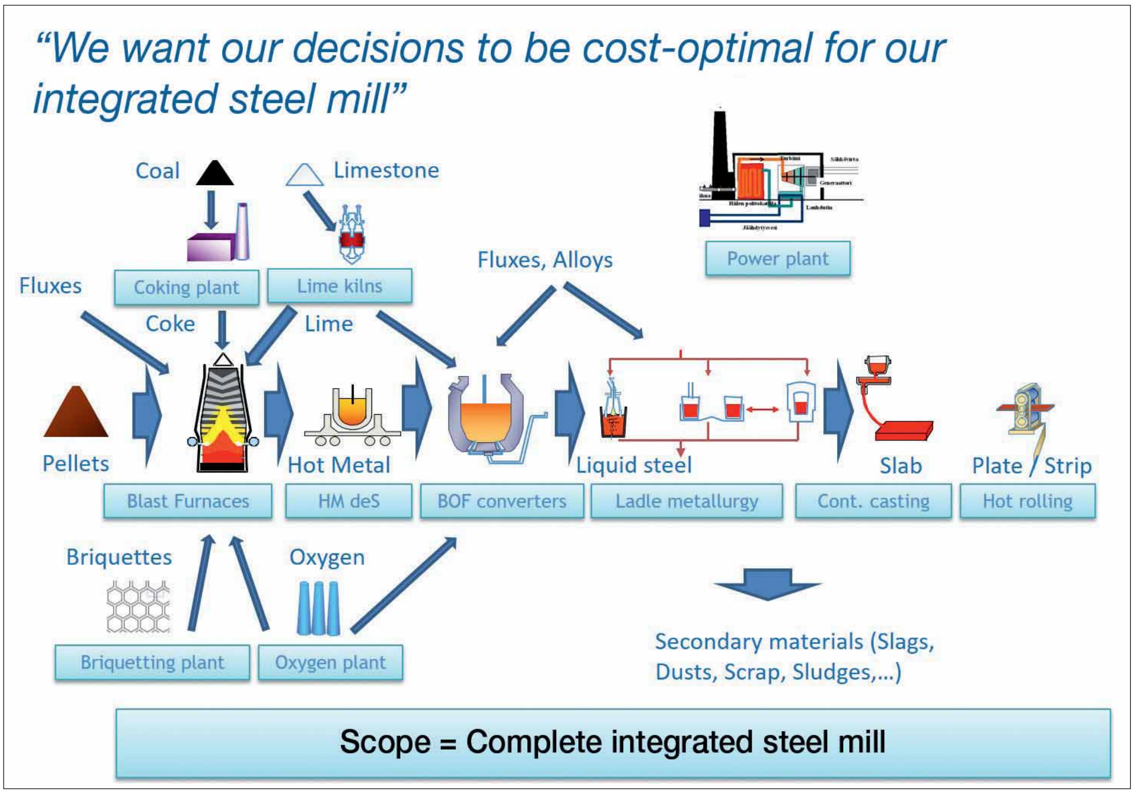
The major amount of total steelmaking cost is related to raw materials and energy. Even relatively small improvements on yield and usage of a more cost-efficient mix of raw materials will result in major savings. Better decisions based on fact-based analysis will result in improved cost-efficiency, figure 2.

## Scenario-based decision making tool

The cost optimization system is designed to facilitate fact-based decision making. Any change in raw material and energy prices or mix of steel grades to be produced may cause a need to adjust material usage or process control in the steelmaking process. The system provides cost-based analysis having the complete steelmaking process involved. This approach provides a wide range of possible use cases for the system. Some examples:

- ▷ Effect of introducing new coking coal to the coal mix: What is the value-in-use of a cheaper coal in the mix? Can we still match the target impurity levels at continuous casting?
- ▷ Effect of volatile raw material prices: Should we change the hot metal/scrap ratio at BOF steelmaking? Can we replace or reduce the use of expensive raw materials by process modifications?
- ▷ Effect of increased recycling: Can we still match the target impurity levels without changes in usage of other raw materials? What is the effect on composition of other secondary materials and their usability?

The system supports scenario-based analysis with a comparison of total cost and wide range of other, more detailed results. Following the shown use case examples alternative scenarios may include e.g. a

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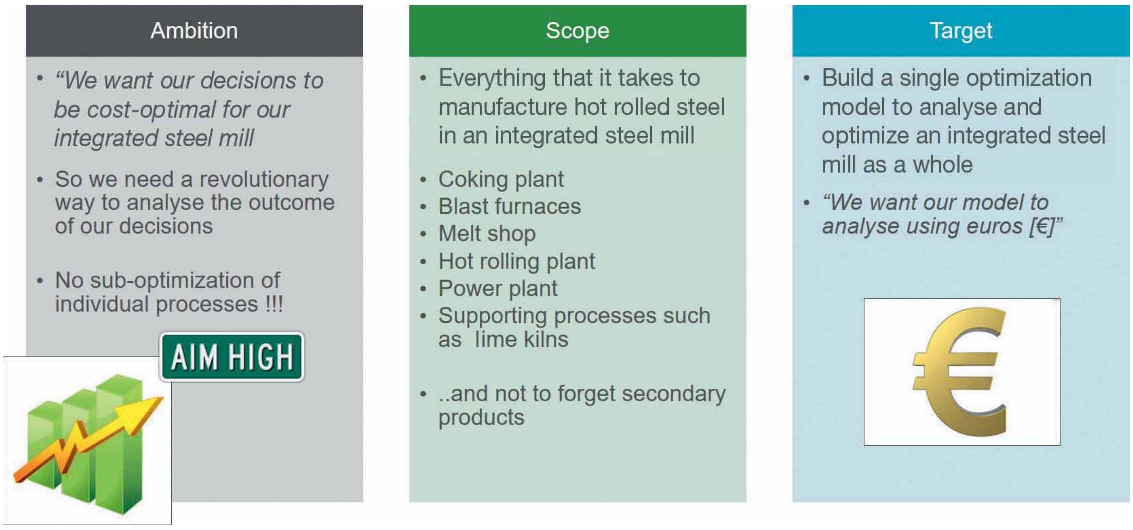
**Scope for the cost-optimization system**
*Umfang für das Kostenoptimierungs-system*

different hot metal/scrap ratio. Alternative scenarios can be set up manually or by using optimization.

▷ Example of manual approach: compare two different coal mixes by exchanging the model inputs for different scenarios
▷ Example of using optimization: give a range of allowed hot metal/scrap ratio for the model and let the model find the cost-optimal ratio for each steel grade and/or as a whole.

## Mass balance and energy balance

The process model consists of "blocks" that represent sub-processes at steelmaking such as blast furnace, converter and ladle treatments involving secondary metallurgy. Materials flowing in the process move solidly from one sub-process to another. Each material has a chemical composition that involves metallic and oxide phases. Conversion from sub-process inputs to sub-process outputs is defined by a common mechanism that is applicable to any sub-process. Mass distribution coefficients are used for the purpose. This principle is called *'mass balance'*. In addition to the common coefficient-based calculation mechanism some sub-processes include process-specific functionalities. Some examples of such functions are hot metal – scrap ratio at converter and alloying rules at secondary metallurgy processes.

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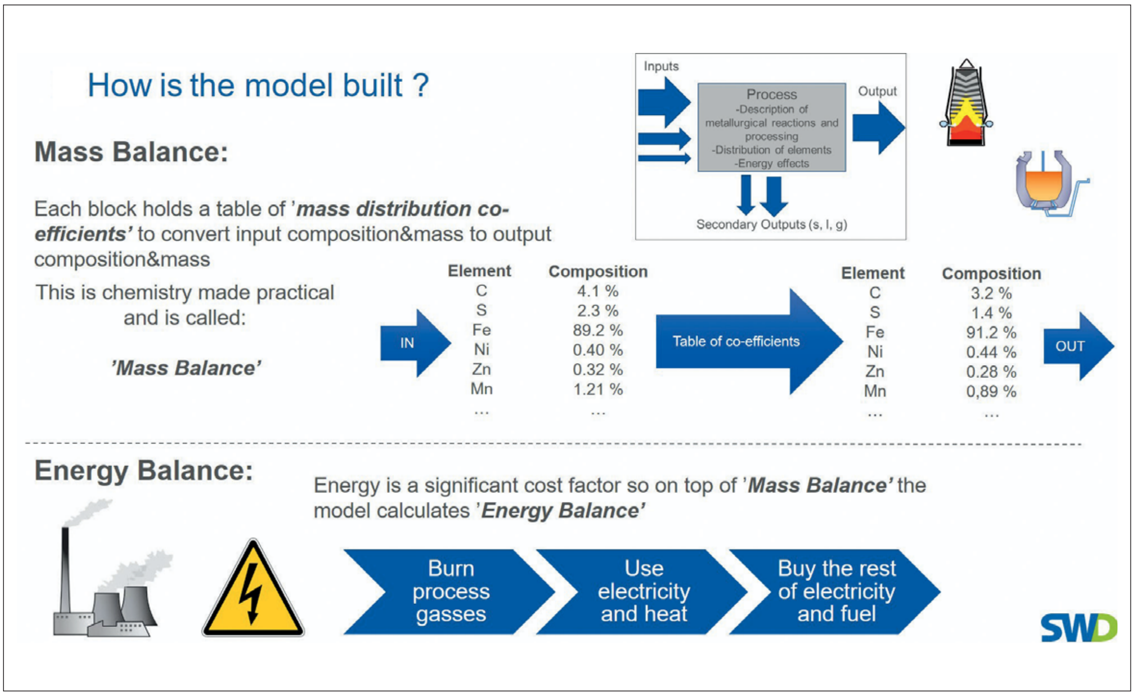
**Ambition level and targets**
*Vorgaben und Ziele*

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**Mass balance and energy balance**

*Massen- und Energiebilanz*

The model also works on "energy balance", figure 3. Process gasses are used for slab heating and running a power plant to produce vapour, electricity and district heat.

Energy from process gases replaces LNG and other purchased fuels. Also depending on the setup energy may be a sold product generating income instead of cost. Each sub-process contains parameters that define electricity and vapour usage. Power plant sub-process contains turbine models that enable modelling of efficiency and electricity-vapour power ratio.

## Mass distribution coefficients

To manage the extreme complexity of iron and steelmaking processes the model relies on mass distribution coefficients that define transition from a sub-process input to a sub-process output. The coefficients are defined by history data from the process. Basis for the coefficients are:

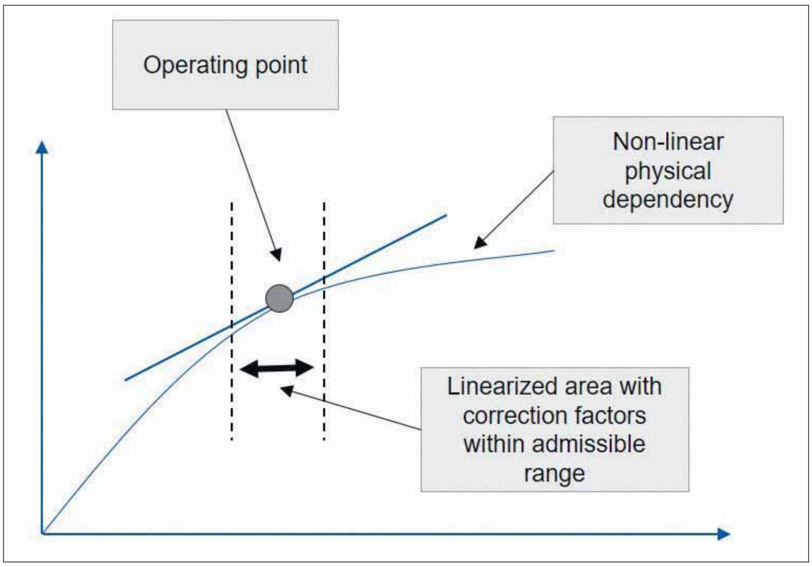
- ▷ Volumes of input and output materials and their relations in the process
- ▷ Chemical analysis of each material.

Depending on exact scope the model needs several thousands of individual calculation parameters. The mass distribution coefficients and factors distributing materials into primary and secondary flows are required for each sub-process – material pair. To provide a 'kick-start' to the implementation of the system provides functionality to define initial set of parameters based on history data.

Linking and using more sophisticated external sub-process models is a potential way of further developing the main model. Physical behaviour of sub-processes may be approximated to adjust the coefficients in the main model.

## Linearization and scenarios

Target amounts for each steel grade are defined by input data for each scenario. To enable a valid comparison of scenarios the model must make exactly the amount of each steel grade described in the given input file. Underlying calculation principle in the model is forwards calculation downstream the process. Forwards calculation will result in having

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**Linearization and operating point** | *Linearisierung und Betriebspunkt* final products' amounts close to the given targets but not with 100 % precision.

An important target for the model is to enable reliable comparison of alternative scenarios. At each scenario the produced amounts of steel grades must be 100 % equal to guarantee valid comparison of total cost. The model balances the gap between target and actual amounts of steel grades using iterative calculation. The gap reduces to a correction factor defined by the targeted and actual production amount. Initial amounts of main input materials are scaled with the correction factor for iterative balancing. Using correction factors for balancing requires linearity from the model.

Given the circumstances of using history process data for initial model setup and approximation of physical phenomena with linear modelling the model's reliability can be guaranteed within an operating point relatively close to the initial situation. In case values of correction factors grow excessively high depending on the case there may be need to adjust the initial model setup to form a proper operating point for the model, figure 4.

## Optimization aspects

Model's target is to find a cost-optimal solution within a given set of variables and restrictions. Restrictions include e.g. target impurities of steel grades. Variables may depend from case to case, figure 5. Some examples:

▷ Scrap – hot metal ratio in steelmaking
▷ Blowing practice: target endpoint for carbon
▷ Blast furnace material selection and relative amounts of selected materials.

## Application aspects

Applying the model requires a solid set of data from the underlying physical process. Modular structure and standardized formats of input data enable a straightforward start for the implementation. However, some case-specific rules related to model behaviour are expected to rise from any process where the model in applied. An example of this type of rules is alloying rules at ladle treatment.

To enable valid scenario comparison any non-linear phenomena should be approximated with linear modelling. A key strength of the system is the capability to cover the complete steelmaking process. However, practical applications may also be found in a more limited scope like secondary metallurgy.

Coefficient based modelling method enables a fast and relatively easy start for model deployment. Process characteristics are derived from historical data which makes model configuration semi-automatic in case needed data is available. For different operating points alternative sets/timeframes of history data should be used to formulate initial set of coefficients appropriately.

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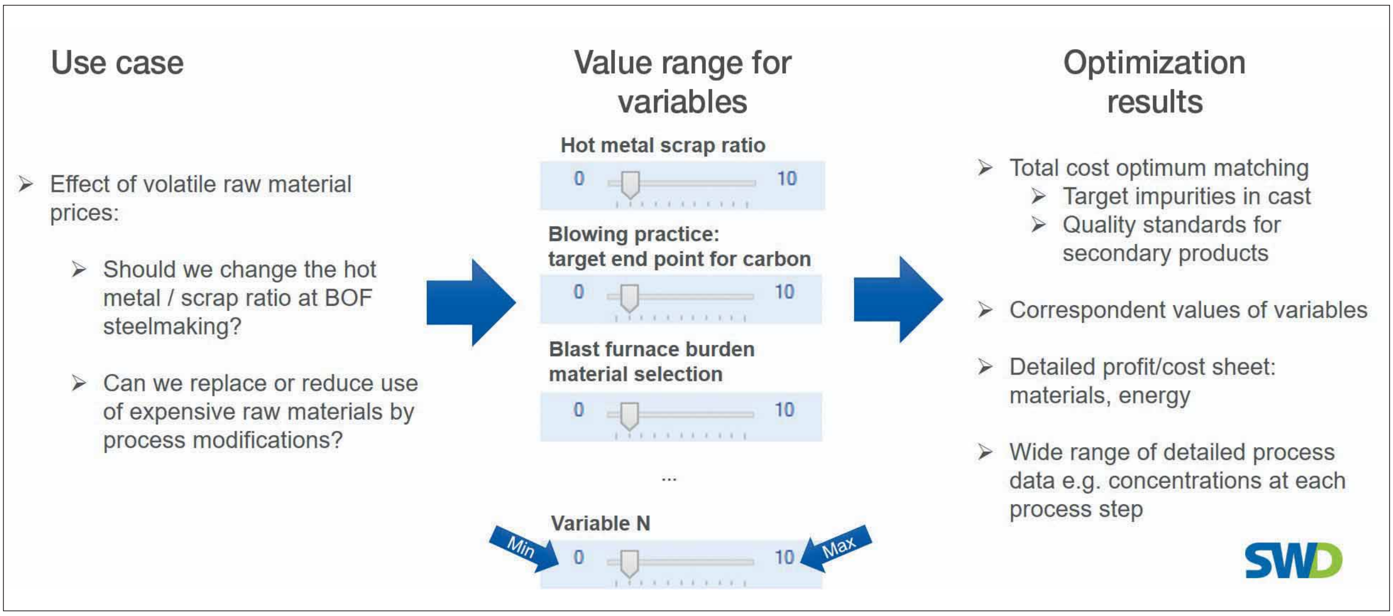


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**Optimization use case** | *Optimierter Anwendungsfall*