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Optimization of Manufacturing processes in Steel Industry: An Industrial Case study

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Abstract: *"This paper presents an integrated, optimization model that aims at helping steelmakers to make strategic decisions and improve overall profitability by optimizing raw material procurement and adjusting sales and operation planning based on ever changing market conditions. Successful implementation of this model at a steel company can achieve annual benefit of several Euros per ton of steel. The benefit is demonstrated through two real-world case studies.*

Keywords: iron and steel, process modelling and simulation, profit optimization and cost reduction.

Introduction: While there are signs that the global economics is slowly improving, the world steel industry still faces significant challenges. According to recently published market research [1], excess capacity remains the biggest threat to the steel industry. The industry is straining under the relentless pressure caused by years of excess steelmaking capacity and low margins. Under this situation, the only sustainable strategy for a steel company is to become a low-cost producer. One way to achieve this is to continuously optimize iron and steel making processes. In this paper, an integrated, optimization-based strategic decision tool, named SCOOP (Steel Cost Optimizations) is presented. It aims at helping senior managers of steel plants improve profitability or reduce production cost by optimizing the purchasing of raw materials, adjusting the operating parameters, and identifying value creating investment opportunities while matching all quality and operational requirements. SCOOP considers both technical and economic aspects. It takes into account chemical equilibriums, process thermodynamics, productivity constraints and materials availability, and it includes all costs involved in the steelmaking processes. By using the concepts of limit marginal price and marginal cost introduced in this tool, one can perform various scenario analysis or sensitivity analysis regarding process, material, or cost parameters. Given the fact that many steel companies already have very good and detailed models for each operation units (e.g., blast furnace, coke plant, steelmaking shop, etc.), but most of these models are run independently in a "silo" mode, steelmakers will likely have difficulties to find the global solution for company-wide profit maximization or cost minimization. SCOOP differentiates itself from the above existing models in the plant by a complete integration of all the processes from raw material purchasing to the production of end products.

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This brings a significant benefit that all important management decisions are simultaneously taken into account in one single model, which enables new, eye-opening improvement levers. In this paper, the optimization technology utilized in SCOOP system is discussed in Section 2, followed by two real-world industrial case studies, where the first example discusses optimal cost as a function of steel production level and the second example shows how this tool can be used to evaluate impact of newly available raw materials on production cost. The paper is concluded by a summary of benefits of using SCOOP system as well as the estimated cost savings per ton of steel. 2 Integrated Optimization and Its Applications Integrated optimization is the most important feature of SCOOP system. As illustrated in by considering almost all possible flow sheet configurations in an integrated steel plant, the SCOOP system is able to optimize each individual operation unit as well as their interactions. For example, some interesting questions involving cross-department decisions can be answered: Fig. 1 Complete process scope of SCOOP system

• what will be the optimal sulphur content in hot metal? Should cheaper coal be used to make high coke at low cost and thereafter leading to high-S hot metal, or vice versa to reduce desulphurization cost at steelmaking? How will this optimal sulphur content be changed with different end product mix determined by market demand?

• what will be the best allocation of hot metal between multiple steelmaking shops depending on their different production capacity, steel grade mix, scrap price and availability? The mechanism behind the scene to answer these questions is a well-defined, large-scale non-linear optimization model, in which the objective function is to maximize the overall company profitability, i.e., revenue generated from end product sale minus all fixed and variable costs, including raw material cost, by-product credit, energy and operating cost, etc. The key technical constraints and decision variables are defined as follows:

• raw material availability in market;

• charging rate and blend ratio of raw materials at each operation unit;

• chemical composition, quality and production volume of intermediate products, such as coke, sinter, hot metal, etc.;

• mass and heat balance of each operation unit, e.g., coke / PCI / natural gas usage at blast furnace are determined based on thermal balance requirement;

• productivity and capacity of each operation unit;

• market demand for each end product group. For a typical 5MT carbon steel plant, there will be more than 500 decision variables in SCOOP optimization model, and the total number of linear and nonlinear constraints is beyond 25,000. There are mathematical challenges to solve such an optimization model in a few minutes, although it is out of the scope of this paper. Once the model is solved, it can be used to calculate limit marginal price (LMP) of raw materials, marginal cost of end products, and to perform sensitivity analysis and scenario study. All these analysis can be great help for steelmakers to make right decisions and respond quickly to changing market conditions. Some typical SCOOP applications in different functional areas include:

• procurement: use LMP to evaluate the true value of available raw materials in the market and determine the optimal purchase. LMP can also be used to negotiate price or volume with suppliers.

• Production planning: optimize production of end product group and focus on the most profitable products based on calculated marginal cost.

• Strategic study: identify process bottlenecks and calculate ROI for new process improvements.

• process / operations: decide the optimal process parameters, such as sulphur content and silicon content in hot metal, coke quality (with impact on PCI usage and productivity of blast furnaces), etc.

• last but not least, collaborative management: acting as a collaboration platform across the company, SCOOP model will significantly enhance communication between people from different functional departments (e.g., purchasing, cost, operations and so on) and quickly form the resultant force to break down operation "silos" and improve the overall performance. Over the past ten years, SCOOP system has been successfully implemented in more than 15 steel plants (including Arcelor Mittal, Thyssenkrupp, ERDEMIR, ESSAR, Usiminas, CSN, Gerdau, Severstal, etc.). In the next Section, two industrial case studies are studied.

Methodology: Optimal decision on production level during the economic crisis over the past a few years, many steel companies had to reduce production. With recently improving steel demand in America market, Company "A" started to plan increasing production. But this time, the top management put more focus on profitability rather than volume. They wanted to know what would be the optimal production level for the given market conditions. To answer this question, a task force was formed to conduct analysis using SCOOP model. Marginal cost of steel slab (i.e., the cost of next ton of steel slab produced) was calculated and compared with the slab sale price, as shown in Fig.1. Each point of the marginal cost curve (blue line) is the result of one optimization run of SCOOP model, which represents the minimum achievable cost for given production levels. As indicated by the plot, this plant was able to operate at constantly low cost when the production is less than 3.6MT.

Sulphur content(%)	BF#1	BF#2	BF#3
Base case without CPATE	0.041	0.040	0.044
NEW case with CPATE	0.081	0.079	0.082

Once above it, the marginal cost was increased significantly, and finally met the slab sale price at the production level of 4.4MT. At this point the maximum profit was achieved. F Marginal cost of steel slab calculated by SCOOP (all numbers are revised for confidentiality reasons) what are the reasons causing continuously increased marginal cost? SCOOP model also provided the detailed answer. The consumption of each family of raw materials was plot with the evolving production level. It can be seen clearly that, for this particular example, the maximum capacity of the sinter plant was reached at the production level of 3.6MT and as the result, the consumption of pellets started increasing, causing high production cost. Around 3.9MT, the usage of scraps kicks in and pushes the production cost higher. At the production level of 4.0MT, the internal coke plant was running at the full capacity and high-price external coke was required. When the production level passed 4.4MT, marginal cost was way above the slab sale price, resulting in the overall profit decreased rapidly. At this stage, hot metal production was very high, requiring usage of more expensive pellets and less lump ores.

Impacts	Difference
Impact on hot metal production cost	-8.71€/thm
Impact on desulfurization cost	+0.66€/tsl
Impact on slab production cost	-7.34€/tsl

Scrap consumption was also high, which brought two consequences: (1) usage of expensive FeSi to prevent temperature decrease; and (2) in this particular example, the steel grades produced has the minimum requirement of manganese. Due to the dilution of the Mn in hot metal, a very expensive FeMn was required to boost Mn content in the liquid steel. Fig.3 Consumption of each family of raw materials In this case study, an optimal decision on production level was made based on the marginal cost of steel with comparison to the current market conditions. When market conditions (slab sale price) are changed, Company "A" is able to quickly adjust production plan to maximize overall profitability. Evaluation of impact of new PCI on slab cost In this case study, Company "B" has a possibility to use a low-price petroleum coke PCI, named CPATE. Of course this is a good opportunity to reduce the production cost of hot metal. However, CPATE has relatively high sulphur content (i.e., 4.57%), and therefore it will have a big impact on sulphur in hot metal, which may lead to higher cost of desulfurization at steelmaking shops. The question is: should CPATE be used and if so, what will be the impact on slab cost?

Results: It involves two different operation units: iron making and steelmaking. SCOOP model is a perfect tool to answer this type of question because of its feature of integrated optimization. To do it, CPATE was added into the model as a newly available raw material, together with its detailed chemical composition, physical properties, market price and availability. SCOOP model had given the following results:

• A new optimal blend ratio of PCI, which includes CPATE. This implies CPATE has positive impact on overall profitability.

• The maximum PCI rate was calculated as 150kt/thm.

• And most important, SCOOP calculated the economic impact of CPATE on slab cost. As shown in Table 2, the overall slab production cost was reduced by 7.34 €/t of steel, which is mainly contributed by decreased hot metal production cost of 8.71 €/t of hot metal and increased desulfurization cost of 0.66 €/t of steel at steelmaking Table 2. Economic impact of CPATE Impacts Difference Impact on hot metal production cost - 8.71 €/thm Impact on desulfurization cost + 0.66 €/tsl Impact on slab production cost - 7.34 €/tsl It can be concluded that CPATE is a very attractive PCI, which can make a significant improvement on the overall profitability. In addition, a sensitivity analysis was conducted using SCOOP model. Fig. 4 shows the slab production cost with various consumption of CPATE. It clearly shows the optimal usage of CPATE is 367 kt/yr. This will be the target set for procurement department to purchase from the market. In this case study, SCOOP model was used to assess newly available raw material to make the tradeoff between decreased cost of blast furnace operation and increased cost of desulfurization at the steelmaking shop. This can only be achieved by the integrated optimization.

Conclusions: SCOOP has made significant contributions to many steel plants and achieved annual benefit of several dollars per ton of steel. The benefit comes mainly from the following areas:

• Integrated optimization of entire steelmaking process from raw material purchasing to downstream facilities instead of considering local optimization of individual operation "silos".

• Better understanding of processes and complex impacts involving multiple operation units. As the result, decisions can be made accordingly to achieve maximum overall profit.

• Additional negotiation power gained by assessing true value of raw materials in comparison with their purchase price. In summary, SCOOP model is a strategic tool that can be used to make key decisions about raw material purchases, production planning and operations that will maximize company's overall profit. It enables aggregating the data and the knowledge available at steel plant in order to provide quantitative and qualitative information that enhance decision-making process''.

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