SCOOP (STEEL COST OPTIMIZATION) – PROFIT MAXIMIZATION THROUGH RAW MATERIAL PURCHASING AND PROCESS PARAMETERS OPTIMIZATION

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Abstract
SCOOP is a tool based on mathematical models allowing to calculate the cheapest raw material mix for a given quality of steel and compatible with each specific process. As opposed to the existing conventional tools, SCOOP takes into account the entire set of production steps, from Coke Plant to Steelmaking Shop, and computes an integrated technical-economical optimization. In this context, the main objectives from SCOOP implementation are to reduce raw material costs and improve information exchange between the different production Units. As final result, SCOOP reduces the total production costs of steel. SCOOP can also be used in order to justify the investment for some projects.
Key words: Modeling; Simulation;, Controlling; Automation**.**

MAXIMIZAÇÃO DE LUCROS ATRAVÉS DA REDUÇÃO DE CUSTOS COM COMPRA DE MATÉRIAS PRIMAS APOIADA PELA OTIMIZAÇÃO DE PARÂMETROS DE PROCESSOS

Resumo
SCOOP é uma ferramenta baseada em modelos matemáticos, permitindo calcular a combinação de matérias primas de menor custo para uma dada especificação de qualidade do aço, e compatível com cada processo específico. Contrariamente às ferramentas convencionais existentes, SCOOP leva em consideração o conjunto completo das etapas de produção, da Coqueria à Aciaria, e calcula a melhor solução técnico-econômica integrada. Nesse contexto, os principais objetivos da implantação dessa ferramenta são reduzir os custos de matérias primas e melhorar a troca de informações entre as diversas Unidades de Produção. Como conseqüência, SCOOP reduz o custo total de produção de aço.
Palavras-chave: Modelagem; Simulação; Controle; Automação.

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INTRODUCTION

N-SIDE is a company specialized in Operations Research - models, simulation and optimization. One of N-SIDE's key solutions is called SCOOP (Steel Cost Optimization) and is used at different integrated steel making companies in the world, IN Europe, North America and Brazil. The objective is to optimize the choice of raw materials and technical parameters (thermodynamics, capacities, productivities…) in order to optimize the profitability of the steelmaking operations.

The choice of the SCOOP (Steel Cost Optimization) software

When Steel companies have a look at the SCOOP solution, they found obvious interest since most of them are already familiar with models and simulations. As a matter of fact, some companies already had very good and detailed models for their Blast Furnace, Coke plant, Sinter Plant and steel shop, but those models are usually run independently from each other. The main interest of the SCOOP tool is that it is now possible to run most of those models all together, including the steel shop. As the optimum of a global integrated model is always better than the sum of the optimum of the models run independently, additional savings are possible.

Perimeter of the application

The optimal mix of raw material for a yearly, quarterly or monthly budget, must take into account all the technical characteristics of a production site. In the case of ArcelorMittal Dunkerque, the coke plant, the sinter plant and the three blast furnaces are modeled in the system from a chemical balance point but also from a thermo-dynamical and logistical point of view. The tool considers the main flows and engines but also all associated possible bottlenecks such as coke or sinter production, as well as all factors impacting the productivity. For instance the oxygen blown at Blast Furnaces and the pellets impact on productivity are taken into account.
The tool consist on many min/max types of constraints on raw material or semi-finished products quantities such as rates of use, availability, usage by families of raw materials/blending, coke, sinter and hot metal quantities, chemical composition of quality constraints. Many technical parameters are also defined with min/max constraints: temperatures, flows of air, slag basicity (at blast furnaces and BOF's)…
The optimization can be done on each plant individually (coke plant alone for instance), or for a combination of 2 or 3 plants (for instance, blast furnace and sinter plant with internal coke fixed as an input) or for all the plants together, from the coke plant to the steel shop, which takes all the optimization levers into account. Many cross-plants parameters are used in the optimization such as the coke quality impact (Drum Index) on the coal injection rate at the blast furnaces.

Profit Maximization / Optimization of all costs

The tool can be run in profit maximization mode (typically impacting the productivity) or, if the quantity of steel is fixed, the optimization is equivalent to a cost minimization mode.
All the costs are optimized during the solver calculation, and not only the raw material costs. SCOOP takes into account all kind of fixed and variable costs (per ton of steel or per year) such as labor, electricity, refractories, maintenance but also all additional

elements such as nitrogen or oxygen, as well as all revenues (negative costs) from co-products like slag, tar, coke oven and blast furnace gases … It is possible to take into account that some semi-finished goods (sinter, different sizes of coke, hot metal) or co-products (sludge and dusts) are partially or completely sold externally. Finally, CO_2 (as well as NO_x and SO_x) emissions are calculated thorough the entire process and a cost can be associated to the CO_2 (green certificate to purchase for instance).

SCOOP Implementation

SCOOP implementation usually takes between 6 and 9 months. The first 3 months have been dedicated to the Blueprint and the set up of a prototype with first sets of simulations. During the next months, the SCOOP tool is fully implemented, customized and calibrated.
The Blueprint is the process of collecting all the data from the customer, concerning the 4 main plants (coke, sinter, BF, steel shop) but also for the IT department (to interface SCOOP with existing systems in order to avoid any data redundancy between systems, such as raw material or grade compositions), logistic department or purchasing department. From a technical point of view, the models available in SCOOP are compared to the models in used at the customer and decisions are made regarding which parts of the models will be modified, added or removed, to best match the site's existing knowledge and data availability.
Decisions are made regarding which data would benefit to the global optimization but are not currently collected by the customer. If the impact of those data is significant enough, the customer will start a campaign to measure them.
Some parts of the models have been adapted. For instance, the cold test for coke quality that was available in SCOOP was compliant with the IRSID typical parameters used in Europe (I10, I20, I40) while Brazilian companies are more used to measure the Drum Index (DI) or the M10, M40 parameters. For a specific customer, the model for Drum Index prediction and its impact on the coal injection (typically calculated from empirical regressions) have been added in SCOOP instead of the IRSID indexes.

Example of simulations done at customers

1. Optimal cost for increased production levels

One of the first usages of SCOOP N-SIDE did with one customer concerned a sensitivity analysis on the production levels and associated costs. Since many companies have been operating at a low production level during the crisis, with only one Blast Furnace instead of two for instance, increasing the production involved re-opening other Blast Furnaces.
The Figure 1 below represents the evolution of the marginal cost (the cost of the next ton of steel, represented by the blue line) and the global profit of the plant when we increase the production rate. The price levels (slab cost and sales price) are given as an example that does not correspond to current economical conditions (costs and sales prices are lower than that in Brazil, currently).This example is not representing any existing customer, for obvious confidentiality reasons. Each point on the cost line is the result of an optimization run of SCOOP which means that it represents the minimum achievable cost for that production level. As the graphs shows, at low

production level, it is possible to operate at low costs, well below the steel prices, until about 3.600 thousand tons per year.
Note that the when the marginal cost line meets the slab sales price, we reach the maximum profit.

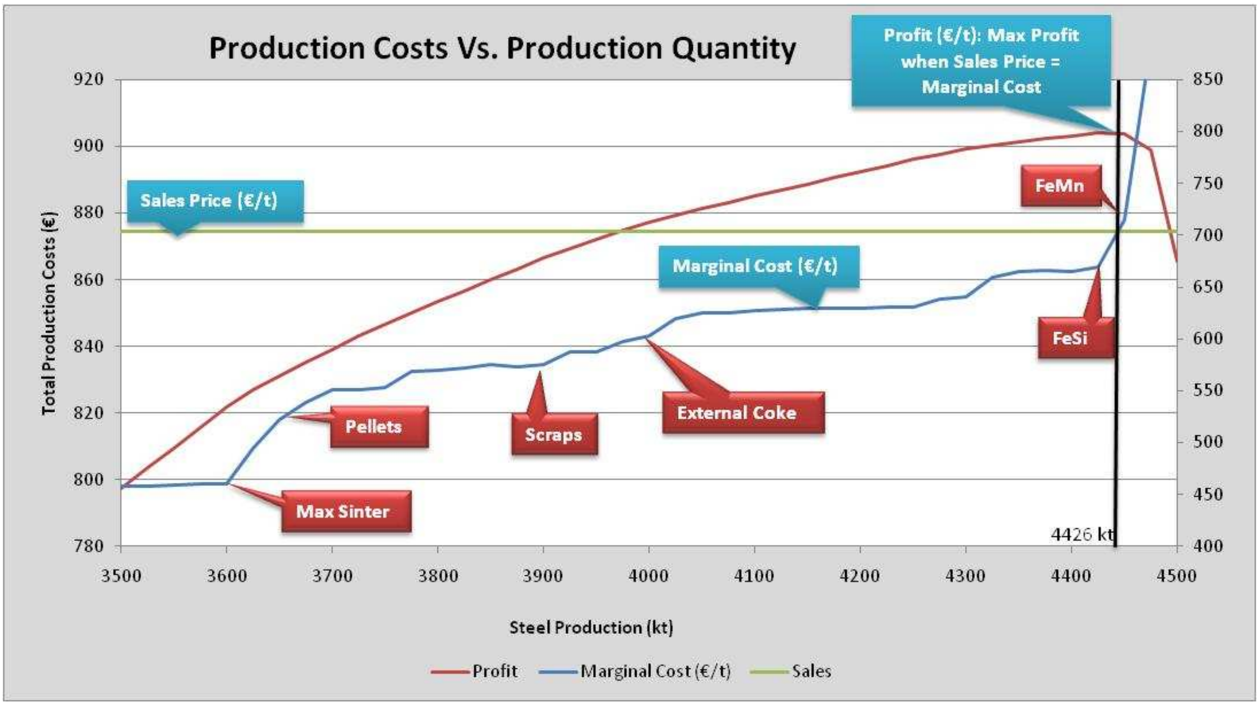

Figure 1: Production levels and costs.

The Figure 2 represents the usage of the different families of raw materials when we increase the production. It is used as a support to explain the cost line of the figure 1.
From around 3.600kt/y, we reach the maximum capacity of the sinter plant. As we can see on Figure 2, the sinter production reaches a maximum. In this case, we have removed the different productivity impacts such as the lime impact, the iron content, percentage of fines, the rakes or the sinter bed height. When those effects are included in the model, the sinter production is not flat around its maximum production but vary based on the changes of mixes used to optimize the productivity, if relevant to the total production costs. At 3.650kt/y, the rate of pellets increases, which increase the production costs.
After 3.900kt/d, there is a compromise to make in order to be able to increase the production at the lowest possible cost: extend the hot metal production and/or use some scraps at the steel shop. As we can see on the figure 2, the optimal cost is reached by starting to use scraps, while extending further the production of hot metal, mainly by using more productive pellets and less lump ores. This basically means that for such a cost of hot metal, scraps usage become interesting from an economical point of view.
At around 4.000kt/y, we use the full capacity of the internal coke produced at our dummy site, and we need to start using expensive external coke, which explain the cost increase at this production level. Note that the increase in production cost at this point depends a lot on the difference between the internal coke production costs and external coke prices.
When approaching the 4.500kt/day, costs increase to a prohibitive level, well above the slab selling prices, and causing the global profit to decrease rapidly. At this

production level, we reach a very expensive level of hot metal with blast furnaces running at very high productivity, thanks to the usage of expensive pellets and reduced lump ores. Scraps are necessary at a greater rate causing 2 consequences. The first one is the temperature decrease that causes some usage of expensive FeSi. The second one, as the grades we produce in this case have a minimum requirement in manganese, causes a dilution of the Mn in the hot metal and this means that very expensive FeMn are required to boost the Mn content in the steel grades.

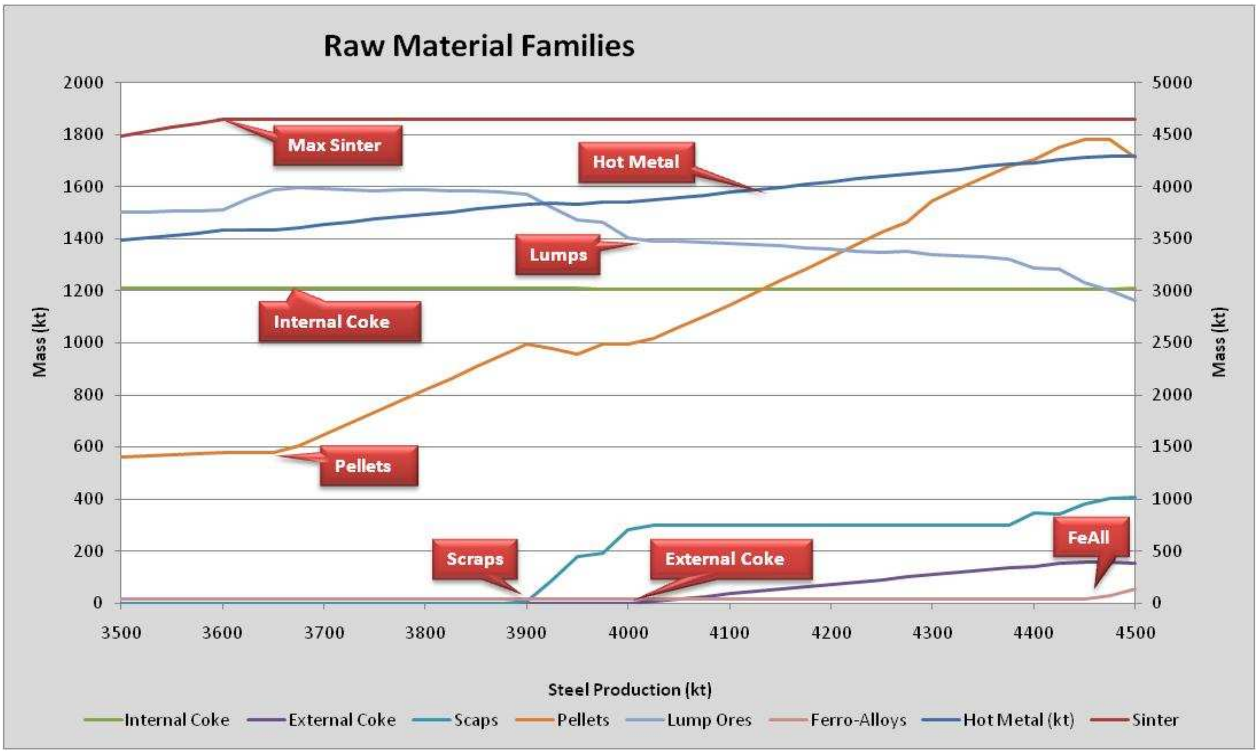

Figure 2: Production levels and raw material families' usage.

Note that interpretation of the production cost curve requires some advanced skills and the above scenario is rather simplified. We already mentioned the effect of the productivity at the sinter plant, not taken into account in this example. Also, the curve here does not take into account the fact that the production level increase causes a reopening of a blast furnace, but in that case, a minimum production level is required on the 2 or more blast furnaces. In this simplified example, a second blast furnace would be allowed to run a very low level, not realistic. However, N-SIDE has studied some production curves with more realistic assumptions.

2. ROI justification for the purchase of a 1 million $ machine to measure the Si content in the Hot Metal.

Si content in the hot metal has an impact on the costs at the hot metal and at the Steel shop. Typically, if we increase the content of the Si in the Hot Metal, it is the Fe content that decreases which means that more scraps will be necessary at the Steel Shop, which means increased costs. However, it will also have an impact on the expensive Ferro-Silicium required at the Steel shop that will decrease. Other effects will be measured and simulated in SCOOP in order to establish the impact of the Si content in the hot metal on the total production costs. This should allow justifying if

the investment in a machine to measure precisely the content of Si in the Hot Metal is justified or not.
First of all, we make the assumption of various Si content in the Hot Metal, ranging from 0.35% to 0.55%. At the same time, the Fe content decreases in almost equivalent proportions, from 94.5% to 94.3%.
The different effect interacting with each other and modeled by SCOOP are the following:

- More Si content in the hot metal means that the un-oxidized proportion of Si is greater, supplying less chemical heat to the process. The result is an increase of the coke equivalent (coke or PCI) required in order to heat the hot metal and slag, hence extra costs for Hot Metal.
- Less Iron content in the Hot Metal means that more scraps are required at the Steel Shop in order to obtain the target Fe content in the steel grades, which means higher costs as well
- More Si content in the hot metal causes more additions (lime) to maintain a certain basicity index, causing an increase in the convertor slag. This means more energy is required but most of it is coming from the extra Si content in the hot metal.
- The extra Si content in hot metal allows reducing greatly the quantity of FeSi required at the Steel Shop, which has a positive impact on the costs.
- Globally, if we consider all the costs impact, we see that we reach a minimum for a certain Si content in the Hot Metal.

Table 1: cost impact for different Si contents in Hot Metal

						Average
Hot metal composition	**Si**	**0.35**	**0.45**	**0.55**		**0.10**
	Fe	94.50	94.40	94.30		-0.10
Coke equivalent		500.44	501.47	501.97		0.77
HM Prod. Cost	**R$/thm**	**414.23**	**415.37**	**415.72**		**0.74**
CNV Slag	**kg/tst**	155.63	155.04	182.53		13.45
Scraps	**kg/tst**	**22.54**	**23.77**	**27.69**		**2.58**
Additions	**kg/tst**	**58.77**	**58.76**	**67.41**		**4.32**
Iron yield		1.0712	1.0698	1.0654		-0.003
FeSi	**kt**	**8.263**	**2.093**	**0.340**		**-3.962**
Steel Prod. Cost	**R$/tst**	**491.98**	**490.12**	**492.58**		

The following graph contains several measures done with the sensitivity analysis tool of SCOOP where the Si content in hot metal varies from 0.35 to 0.55. We can see the impact on the cost of steel at two different values of rates of hot metal (911 kg of hot metal / ton of steel and 920 kg of hot metal / ton of steel). We can see that the production cost curve has a minimum at different Si content levels (0.39% of Si for 920 kg hm/tst and 0.46% of Si for 911 kg hm/tst). The more hot metal we use, the less Si content we can have to maintain the minimal cost.

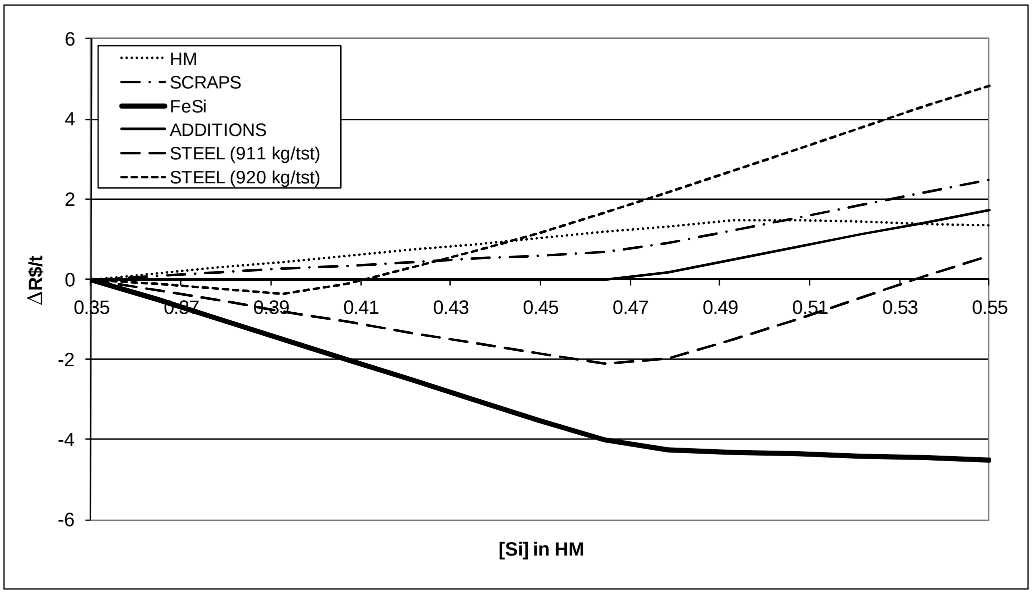

Figure 4: Cost impact for different Si contents in Hot Metal.

The conclusion is that the impact on the Si content in steel cost can be of up to 1 dollar per ton of steel. This justifies the investment of the 1 million $ machine to measure precisely the Si content in the Hot Metal.

3. Impact of the Fine Ore quality (SiO2) on the production costs.

One of our customers uses fine ores where the SiO2 content can vary between 4.7 and 5.4%. The objective of the simulation was to measure and understand the impact of the various contents in SiO2 on the production cost.
For the simulations, all other contents in the sinter feed are diluted accordingly to the increase in SiO2 content. Also Pellets and Lump Ores are used at a constant rate.

Table2: Cost impact for different SiO2 contents in Fine Ores

Sinter feed	**SiO2**	**4.70**	**4.90**	**5.10**	**5.30**	**5.40**		**Delta 1%**
	Fe T	64.60	64.40	64.21	64.01	63.92		-0.98
	kg/tsi	840.76	837.92	835.10	832.29	830.90		-14.09
Limestone	**kg/tsi**	189.78	209.09	223.72	238.22	245.45		79.52
Sinter	**Fe T**	58.50	58.17	57.85	57.52	57.36		-1.63
	SiO2	4.69	4.85	5.01	5.17	5.25		0.80
	CaO	9.14	9.45	9.77	10.08	10.23		1.56
	BI	1.95	1.95	1.95	1.95	1.95		0.00
	Volume	13.83	14.30	14.78	15.25	15.48		2.37
	R$/t	**62.00**	**62.12**	**62.24**	**62.36**	**62.42**		**0.59**
	kg/thm	**1193.15**	**1199.96**	**1206.81**	**1213.71**	**1217.17**		**34.32**
Slag BF3	**kg/thm**	246.91	254.85	262.85	270.90	274.96		40.07
Coke Eq BF3	**kg./thm**	**503.24**	**503.92**	**504.61**	**505.30**	**505.65**		**3.44**
HM	**R$/t**	**427.96**	**429.19**	**430.43**	**431.67**	**432.29**		**6.19**

We can observe the following elements from the simulation of various SiO2 content in the sinter feed:

- The content in Fe is reduced accordingly to the increase of SiO2 (to keep the mass balance). This will causes a requirement for more sinter to bring the same quantity of Iron.
- The additional SiO2 content causes the requirement for more lime (CaO) to keep the same basicity index (BI). The additional content in CaO as well as the additional quantity of Sinter required in the Blast furnaces, means more slag, hence additional coke equivalent required to heat the slag and then extra costs.
- The global impact on the cost of hot metal is 6.19 R$ per ton of hot metal if the SiO2 content in the fine ores increases by 1%, which is quite significant.

Expected Return on Investment

SCOOP customers have experienced a return on investment of several dollars per ton of steel, which means that the SCOOP tool is paid in a few weeks only. The ROI comes mainly from the following areas:

- Global optimization of the cost that looks for the global minimum instead of considering the cost minimum at each production plant.
- Better understanding of the processes and the complex impacts involving several production departments. Decisions can be made accordingly in order to reduce the costs
- SCOOP allows quantifying the impact on the different production decisions and facilitates the decision making by providing objective information.
- Additional negotiation power in order to estimate the value of the raw material in comparison with their purchase price.
- Help with some investment decision in additional capacities, measurement devices with technical and economical justification.

Conclusion

The SCOOP tool is a strategic tool that is used to make key decisions about raw material purchases and process parameters setting that will minimize the production cost. It enables aggregating the data and the knowledge available at customer sites in order to provide quantitative and qualitative information that is necessary to make key decisions.