COCOP: steel pilot case

SIDENOR, MSI, TECNALIA

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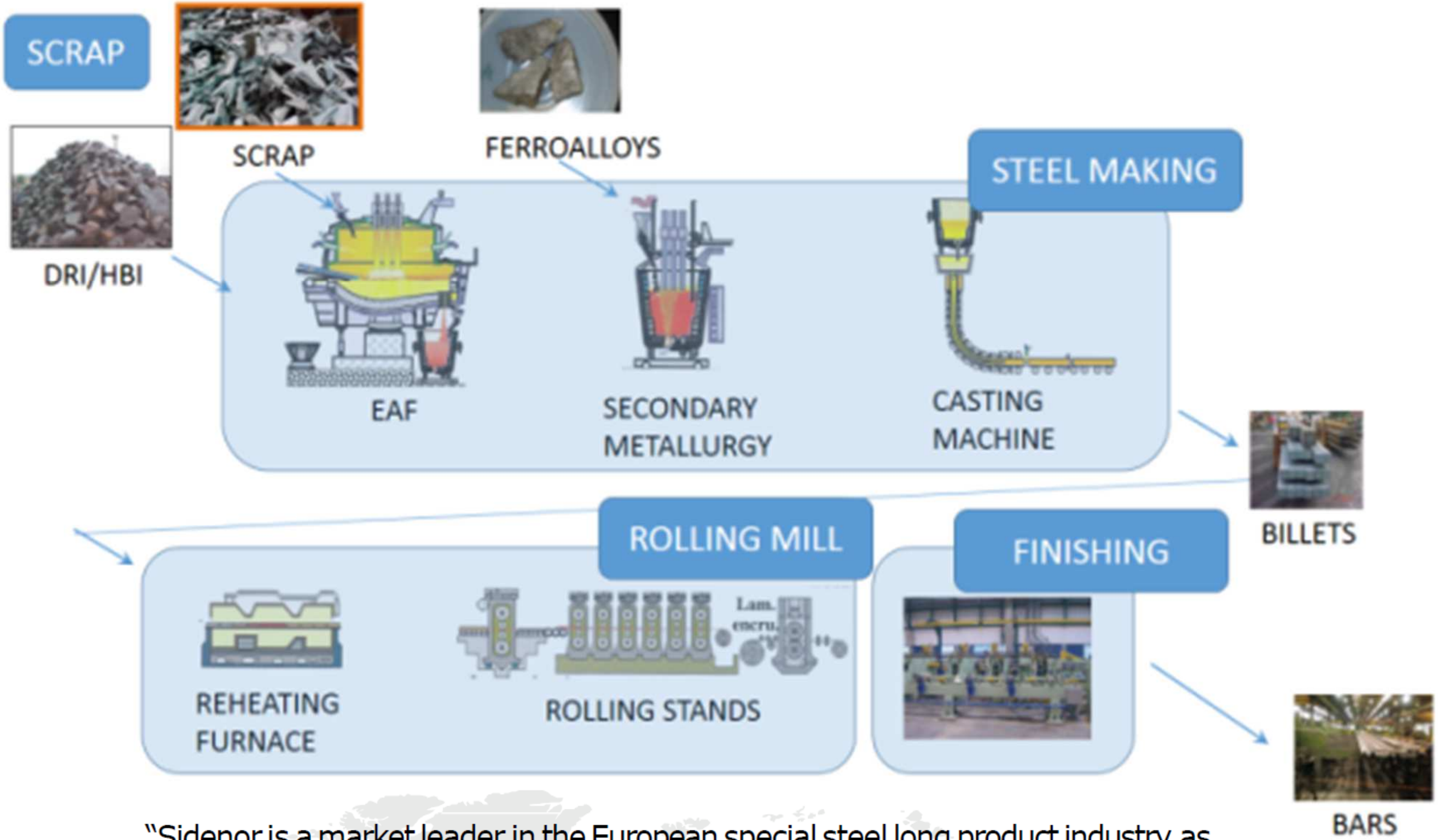
Steelmaking process in SIDENOR plant

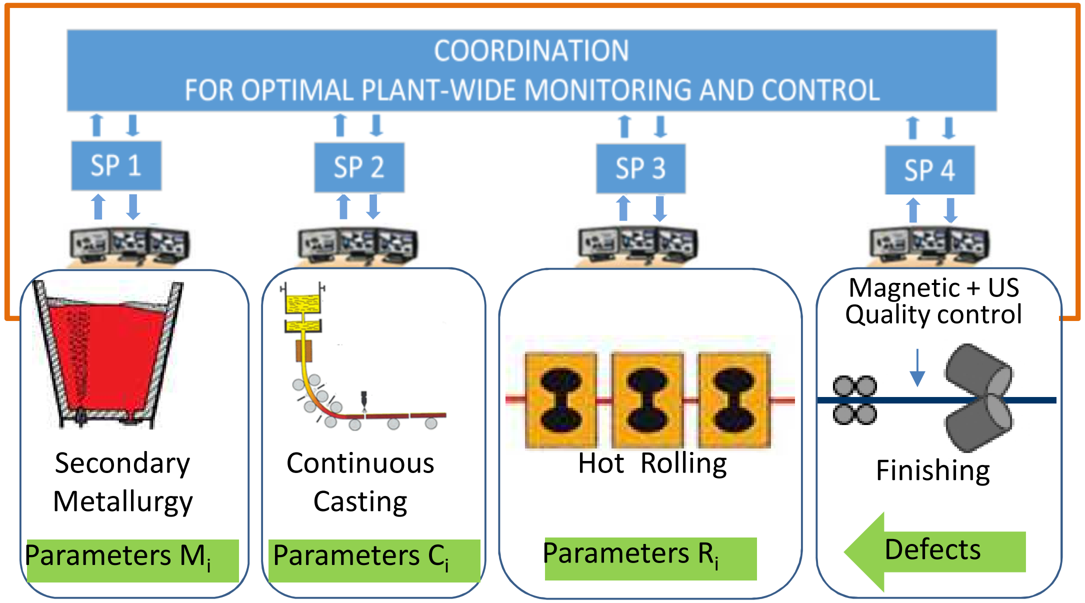


"Sidenor is a market leader in the European special steel long product industry as well as an important supplier of cold finished products in the European market"

Steel pilot case: goal and KPIs

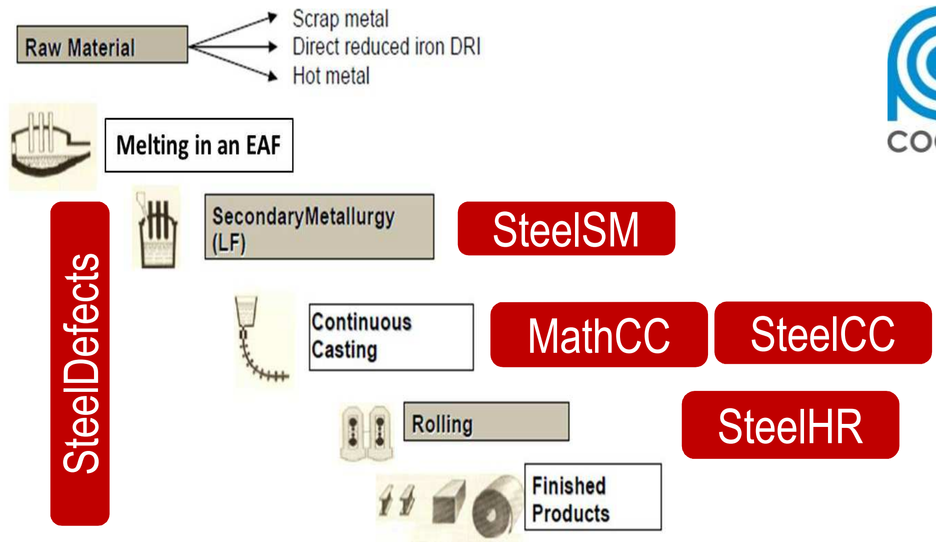
- **Target**: To develop a steel manufacturing plant-wide monitoring and advisory tool in order to reduce the number of surface and sub-surface defects at the final product, ensuring a good performance of the related sub-processes (secondary metallurgy (SM), continuous casting (CC) and hot rolling (HR))

  - Defects can be generated during the SM, CC or HR sub-processes but they are detected at the end of the manufacturing process
  - They are dependent sub-processes



- **Focus** on: micro-alloyed steels in as-rolled condition
- **KPIs**:
  - KPI-T1S: reduce the rejection on the finishing line due to surface defects relative to baseline
  - KPI-T2S: reduce the reworking on the finishing line relative to baseline
  - KPI-T3S: reduce the rejection on continuous casting due to surface defects relative to baseline

Steel pilot case: models



To reduce the number of surface and sub-surface defects at the final product (micro-alloyed steels), ensuring a good performance of each sub-process (SM, CC, HR)

Model Steel SM
(data based model)

Simulation model of the Secondary Metallurgy process: *castability index*

Model Steel CC
(data based model)

Simulation model of the Continuous Casting process: *temperature of the billet before the straightener*

Integration with **MathCC** (Mathematical Model): *predict thermal & solidification evolution*

Model Steel HR
(data based model)

Simulation model of Hot Rolling process: *minimum and average temperature of the billet before the continuous rolling mill*

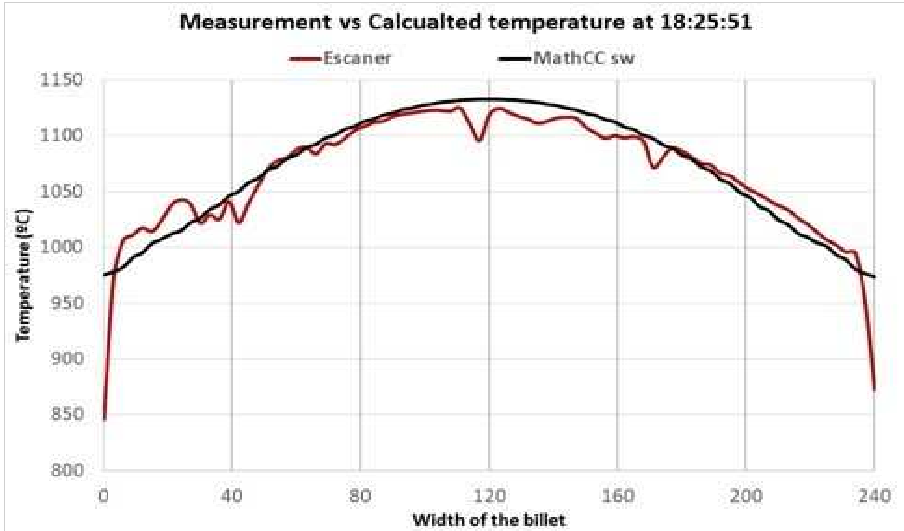
Model Steel Defects (data based model)
Defect predictive model with the key parameters of SM/CC/HR involved in the defect generation

Steel pilot case: models

- The data based modes (*SteelSM, SteelCC, SteelHR and SteelDefects*) were developed following the steps:
  - Descriptive analysis of the data for process understanding purpose,
  - Data cleansing and outliers detection,
  - Feature engineering,
  - Modelling for regression to predict the target variable. Here different techniques were tested such as neural networks, random forest and gradient boosting. Finally, the gradient bosting was selected.
  - Performance evaluation using a 10-fold cross validation approach and calculating the root mean squared error normalized to the magnitude of the variable (NRMS) and the Mean Absolute Error (MAE).
- During the testing phase, the value of the target variable (castability index, temperatures of the billet or number of defects) estimated by the new models was compared with the actual value of the variable, obtaining similar errors to those obtained during the performance evaluation.

Steel pilot case: models

- The mathematical model (*MathCC*) predicts the temperature distribution, the shell thickness and the metallurgical length during the solidification process of the steel, considering steady or transitory conditions.
- It solves a transient two–dimensional model in which several cross sections of the billet move through the continuous caster, exchanging heat with the mold wall, secondary cooling system, rolls & ambient.
- The model was validated using temperature measurements with a scanner placed on the top face of the billet before the straightener. The temperatures calculated by the new model are in a good agreement with the measured temperatures, with an average difference in the temperatures of about 11ºC (considering the temperature in this zone, it means an error about 1%).



Comparison among temperatures measured by the scanner (red) and calculated by the model (black) along the cross line of the upper face of the fillet. Values at the point "120 mm" correspond to the middle point of the billet. The jumps in the chart of the measured temperatures are due to the presence of scale on the surface of the billet, which lead a decrease in the temperature, and they should not be considered in the analysis.

Steel pilot case: optimization

To find the best combination of values for the key defect-related parameters of the three sub-processes (SM, CC, HR) that minimize the generation of surface defects in the final product.

Target: Good performance of each sub-process

Coordination Layer to assure a good global performance

1. Use *SteelDefect* model in order to get the optimal values of the key defect-related parameters for each sub-process that **minimise the defects**
2. Optimize the parameters of each sub-process (using the models *SteelSM*, *SteelCC* and *SteelHR*) **to obtain a good performance**, considering as constraint the optimal values of the key defect-related parameters

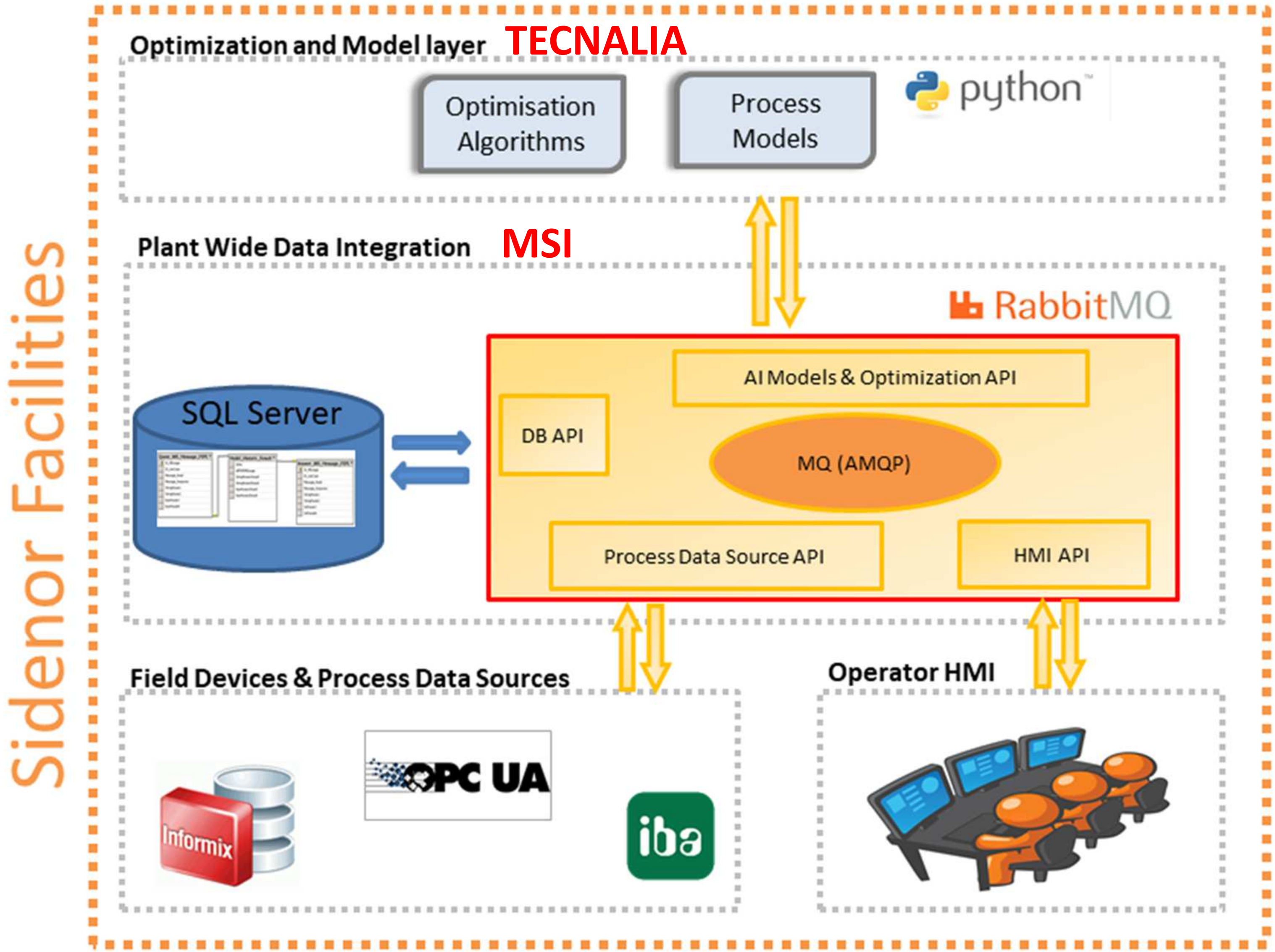
Model SteelSM
(data based model)
Optimisation:
Maximise the castability index

Model SteelCC
(data based model)
Optimisation:
Achieve the target temperature of the billet before the straightener

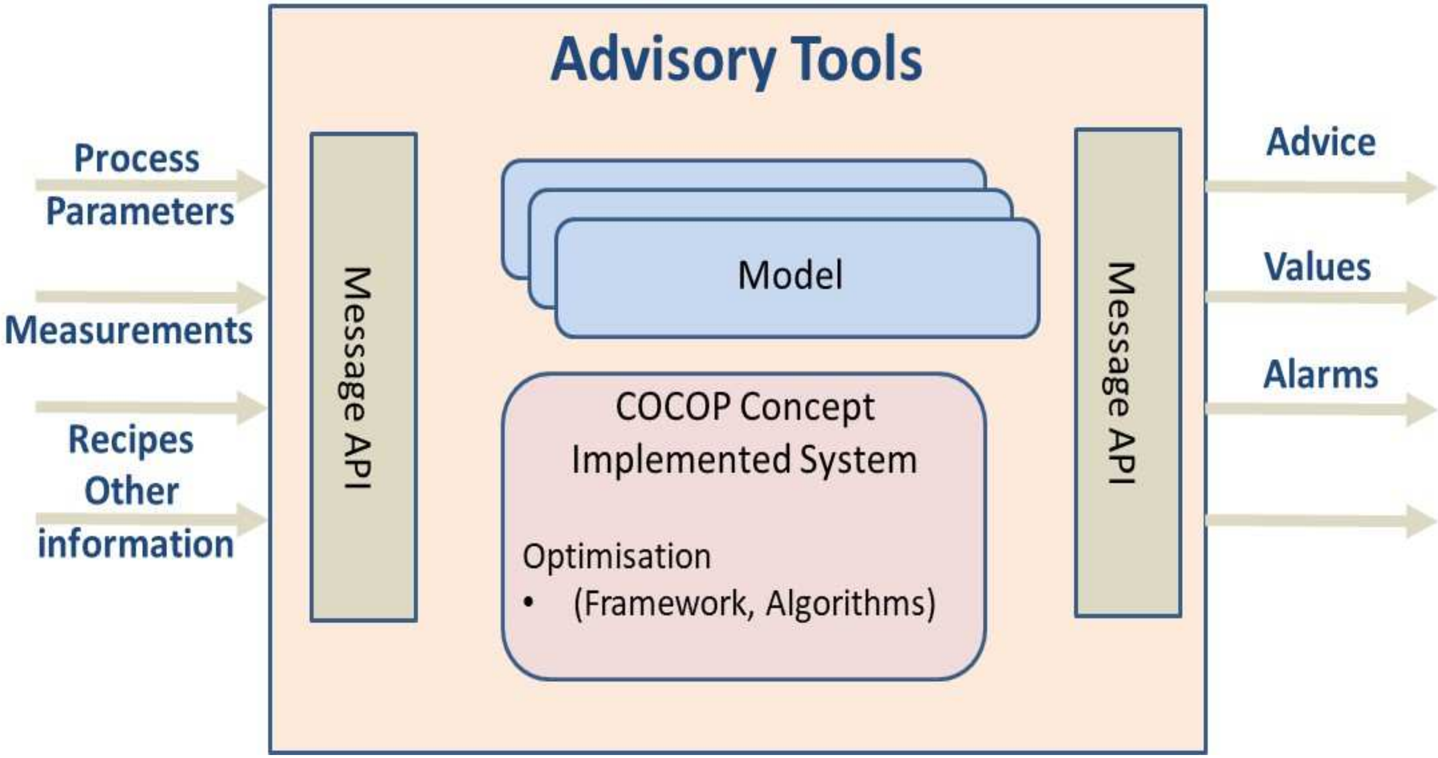
Model SteelHR
(data based model)
Optimisation:
Achieve the target temperature before the continuous rolling mill

Model SteelDefects (data based model)
Optimisation: minimise the number of surface defects

Steel pilot case: architecture



Steel pilot case: advisory tools



- Advisory Tools are implemented to provide processes advisory information based on all available processes information sources.
- The input data are used by a process model (mathematical or data-based model) to calculate some relevant output information of the process.
- The model may also be linked to optimisation algorithms to calculate the optimal set-up of the process.

Steel pilot case: advisory tools

- **Optimisation tools:** to find the optimal parameters to achieve a good performance of each process (good castability index in SM and good temperature of the billet in the CC and HR) and to find the optimal values of the defect-related key parameters of each process (SM/CC/HR) to minimize the number of defects in the final bar
- **On-line monitoring and alarm tools for the SM and CC process:** to provide values of relevant parameters of the process that are not measured and warn in case of risks (alarms)
- **Off-line prediction tools:** to analyse the influence of the different parameters of the process (SM, CC, HR) on its performance and on the number of defects in the final bar, i.e. how the performance or the number of defects varies when a parameter is modified
- **Quality report tool:** to generate a report after finishing a heat with the analysis of the SM and CC process performance and the prediction of the number of defects in the final product

Steel pilot case: example of an optimization tool (SM)

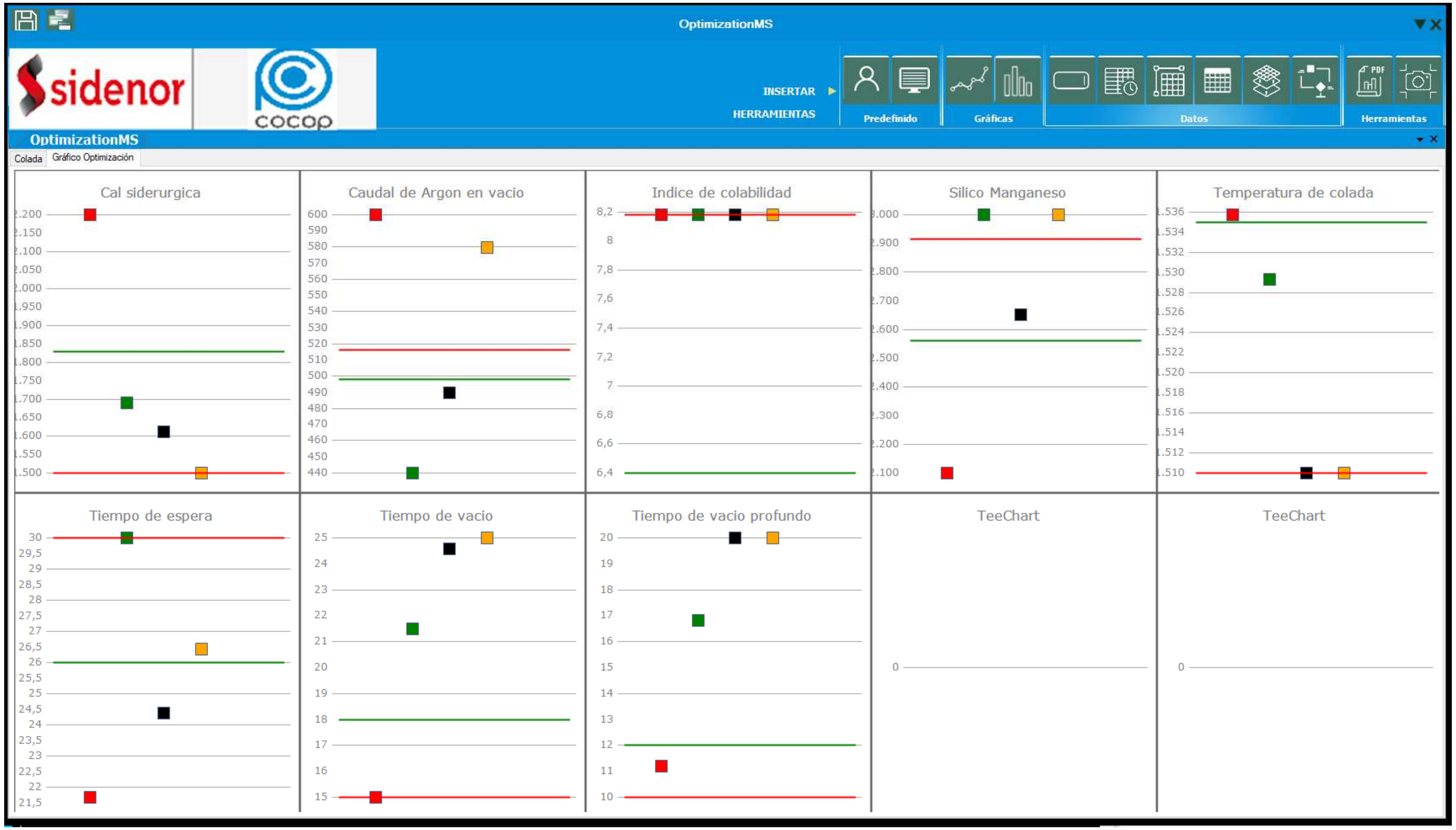
Find the optimal values of the SM to get a good castability index

- First the user has to define the optimization problem: indicate the value of the objective function, select the variables to be optimized, define the range of values for these variables and define the value for the fixed variables
- The tool provides a set of values with an optimal performance

Steel pilot case: example of an optimization tool (SM)

Find the optimal values of the SM to get a good castability index

- Five simulations are run together → provide information about the range of optimal values obtained for each variable
- This allows the user to apply the optimal values chosen by the tool or select other optimal values depending on what is most suitable at that time



Steel pilot case: example of an on-line monitoring tool (CC)

Get on-line relevant information of the process

During the solidification process of a billet in the CC there are two relevant parameters difficult to measure: i) the shell thicknesses at the end of the mould to avoid break-outs and ii) the temperature of the billet before the straightener to avoid cracks. This tool calculates these parameters on-line with the actual process parameters and provides alarms when there is a risk.

Alarms for:
- Tª of billet at the straightener
- Thickness at the end of the mould
- No. of defects on final product
- Secondary cooling parameters

Evolution of Tªs of the billet before the straightener

Solidification front profile at the end of the mould

Evolution of shell thickness at the end of the mould

Steel pilot case: example of an off-line tool (SM)

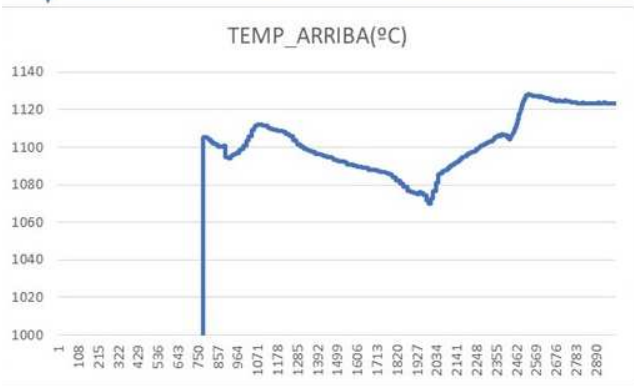
Analyse the influence of some parameters in the performance of the processes

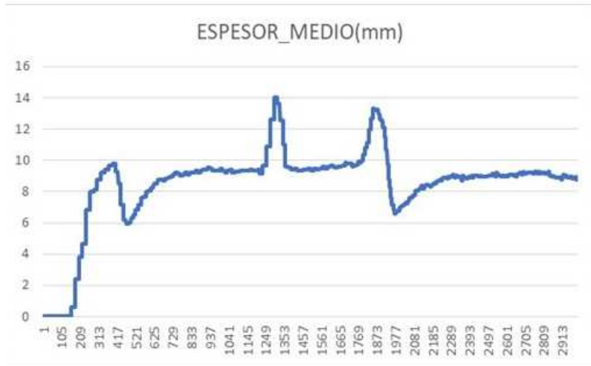
Steel pilot case: quality report

After finishing a heat, analyse actual performance and predict the number of defects in the final product with actual parameters of SM and CC

- Castability Index value
- Prediction of the number of defects / Ton in the final bar:
  - for a diameter of 30 mm (the min diameter → the best case for the surface generation)
  - for a diameter of 70 mm ((the max diameter → the worst case for the surface generation)
- Information on the relevant parameters predicted by the new COCOP tools: temperatures before the straightener and shell thickness at the end of the mould
- Information related to "transitory" behavior of some relevant variables of the process (casting speed, liquid steel level, etc): length of the heat with oscillations, number and amplitude of jumps and peaks

Evolution of Tªs of the billet before the straightener





Evolution of shell thickness at the end of the mould

This information facilitates the making decision about the actions to be done: nothing, scrap a billet or reserve the billet to orders with high tolerance for the defects or low diameter of the bar

Steel pilot case: testing and KPI evaluation

Tools development

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Offline testing: Developers & SIDENOR researchers

↓

Online testing

↓

KPI evaluation

On-line tools installed in the SM and CC control rooms

- It is user friendly, easy to use, not requiring additional workload
- It offers innovative data to support the production work and has a high potential the workers could benefit from.
- Additional functionalities are suggested

Steel pilot case: testing and KPI evaluation

Based on KPI monthly measurements and theoretical calculations, the estimated KPIs improvement are:

- KPI-T1S: rejection index in the finishing line → **improvement of 20%**.
- KPI-T2S: re-working index → **improvement of 11%**
- KPI-T3S: rejection index at the end of CC→ **improvement of 20%**

Thank you for your attention!

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