capri

Cognitive Automation Platform for European PRocess Industry digital transformation

Deliverable

D3.3 CAPRI Industrial Analytics Platform and Data Space

Deliverable Lead: Nissatech

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Title	CAPRI Industrial Analytics Platform and Data Space
Lead Beneficiary	Nissatech
Description	This deliverable of type OTHER presents the implementation results of the data-driven Reference Architecture for Cognitive Plants in the process industry, with Smart Events Processing, as developed in T3.2. Part of the final outcomes will be provided in the zip file to be submitted together with the present deliverable For each Cognitive solution the following details will be provided: • **Text document** (Word/Pdf): explaining the work done, introduction to video, user manual of the apps, including the available links, data and metadata description, description of everything else in the ZIP. • **Executable of the program/app**, if any • Any kind of **data** that can be publicly shown (full data, sample data, metadata, surveys results, …) • **Video** used to explain "physical" results, as sensors.
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EXECUTIVE SUMMARY / ABSTRACT SCOPE

D3.3 – "CAPRI Industrial Analytics Platform and Data Space", is a deliverable of type OTHER that, together with D3.2, D3.4 and D3.5, targets the so-called 'MS4' milestone, regarding technology validation of different cognitive solutions at M24, and describes the concrete achievements in the development of the Smart Events Processing in Cognitive Processes, leveraging the CAPRI reference Implementation described in D3.1, and particularly state of the art open standards such as OPC UA and MQTT for data ingestion and NGSI-LD for data representation.

After an introductory on document scope, audience and structure, a section that describes the distribution of the various developed CSs in the D3.2, D3.3, D3.4 and D3.5 deliverables is followed, with the used content structure to make easier to find the relevant information.

Next, for each domain, a summary view of cognitive solutions at control/sensor level is explained, then an extensive list of evidences are detailed to better shape the achievement obtained. For each cognitive solution are provided a text to explain the work done until M24, an introduction to a video showing the cognitive solution in laboratory environment if available, data and metadata description, sample data used for testing, user manual of the applications if any, and any other element that might go along the CS development description. Some of these contents cannot be included in this document, so they will be uploaded in a separate file.

The final section offers some recommendations to address next Work Packages (WP4 and WP5) on the best integration approaches with the CAP, or features to be evaluated in next phases that could bring improvements on the functional side, or can constitute innovative aspects to be followed up in future research projects.

1 Introduction

1.1 Scope of Deliverable

D3.3 – "CAPRI Industrial Analytics Platform and Data Space", is a deliverable of type OTHER aiming at describing the practical results of the data-driven Reference Architecture for Cognitive Plants in the process industry, with smart IoT cognitive components, as designed in T3.1. The CAPRI Reference Implementation, as described in D3.1, has been materialized by Open Source environments such as APACHE and FIWARE, supporting state of the art open standards such as OPC UA and MQTT for data ingestion and NGSI-LD for data representation. What will be presented in this deliverable corresponds to achievement of milestone MS4 of technology validation of different cognitive solutions, with a focus on the control/sensors' solution components.

Part of the final outcomes will be provided in the zip file to be submitted together with the present deliverable. For each Cognitive Solution the following details will be provided:

- **Text document** (Word/Pdf): explaining the work done, introduction to video, user manual of the apps, including the available links, data and metadata description, description of everything else in the ZIP.
- **Executable of the program/app**, if any
- Any kind of **data** that can be publicly shown (full data, sample data, metadata, surveys results, …)
- **Video** used to explain "physical" results, as sensors.

Finally, D3.3 aims at providing some recommendations to related WP4 and WP5, with suggestions on the best integration approach with the CAP, or features that could further evaluated and improved in the next steps and could be conceived as brand new and innovative aspects and to be followed in future research projects or moved to other process industry domains.

1.2 Audience

D3.*3* – "CAPRI Industrial Analytics Platform and Data Space", is a deliverable of type OTHER that presents the implementation results, targeting the Alpha release of the CAPRI implementation, that represents the standalone implementation of cognitive solution. In this deliverable the practical details of the smart IoT cognitive components will be provided, with textual information explaining the work done, introduction to videos or screenshots, user manual information on apps used to showcase results, data and metadata description, to better explain the zip file contents.

For this reason, while D3.3 is conceived to be a report accessible to all partners, it is addressed mainly to a reader with a technical background related to Control Technologies and Data Architecture:

- For the three pilots, it is a technical description of the Smart control cognitive components that will be installed in their environment and that will be integrated with existing assets and solutions;
- For technology providers involved in WP4 and WP5, it represents a reference to drive the control solutions integration with CAP implementation and verifying compliance with requirements as described in deliverable D2.2

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1.3 Relationship with other deliverables

How cognitive control solutions have been split in the deliverables:

D3.3, together with D3.2, D3.4 and D3.5, trace a continuation line after D3.1. While the latter D3.1 describes the Reference Implementation of the Cognitive Application Platform (CAP) to support the integrated implementation of the four cognitive layers, D3.3 describes in details the standalone development of the control based solutions, to be integrated in the final plants in the different domains.

At the same time D3.6 will describe the overall picture of activities performed within WP3, presenting the openness approach on cognitive solution and investigating the generation of Open Data, whose specific results at sensors, Control, Operation and planning level are documented in D3.2, D3.3, D3.4 and D3.5.

On the other hand, final results in WP3 will feed the integration step to be covered in WP4, paving the way to the final demonstration in WP5 tasks at plant level.

1.4 Document Structure

This document is organized with three main chapters (Section 2 – Section 4), in addition to the introductive chapter (the current one, which describes the scope of the deliverable, audience, relationship with other deliverables and the structure are described) and the conclusive one, which summarizes main achievements and shaping next steps.

Section 2 – Attachment Structure Description explains the distribution of all developed CSs in D3.2, D3.3, D3.4 and D3.5 deliverables, with the used content structure to make easier to find the relevant information. Since there will be a unique zip file collecting all contributions of the four deliverables, this section will be the same in all four deliverables.

Section 3 – Smart Event Processing Cognitive Solution Overview provides a summary view of cognitive solutions at control level, split by domain.

Section 4 – Smart Event Processing Cognitive Solutions Results aims at reporting the detailed description of what is going to be included in the zip file. Sample data and data format will be provided through .csv files, demonstrative screenshots will be .jpg file, videos will be .mp4 files, and Applications used to showcase particular features will be .exe files or any other necessary file format.

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2 Attachment Structure Description

The objective of the current chapter is twofold: first of all it aims to provide an overview of the structure of the four deliverables of type OTHER, including the current one; secondly to provide the list of the documents attached to the present report, including the Zip folder, the Zenodo folder and any other external link.

Actually, at month M24 (March 2022), WP3 is delivering four deliverables of type OTHER to summarise and provide evidence of what has been implemented so far; each deliverable consists in a textual part (the present document) and a set of attachment, which is the core of the deliverable.

This section aims at providing a summary picture of the structure of the four documents and of the attachments to make easier to find relevant information, since the subjects presented in each report may overlaps with the others and it is not straightforward for the reader to understand what he/she can find where. Hence, the objective of this chapter is to provide support in orientating inside them.

Since it deals with the four deliverables, it will be replicated almost the same in all of them:

- Deliverable D3.2 – “CAPRI Industrial IoT Platform and Data Space” as output of Task 3.1;
- Deliverable D3.3 – “CAPRI Industrial Analytics Platform and Data Space” as output of Task 3.2, the current one:
- Deliverable D3.4 – “CAPRI Smart Knowledge and Semantic Data Models” as output of Task 3.3;
- Deliverable D3.5 – “CAPRI Smart Decision Support” as output of Task 3.4.

As mentioned above, each deliverable is related to a specific Task, but the activities performed in WP3 can’t be siloed per Task since they involve more than one at the same time. Actually, the CAPRI Cognitive Solutions are 19 assets implemented at laboratory level, split by the three domains (Asphalt, Steel and Pharma) and encompassing the four layers of WP3 (Sensor, Control, Operation and Planning, corresponding to the four Tasks). It means that each CS is developed within one specific use case, but it presents features that cross more than a layer, so practically, it is part of more than one Task.

To overcome this situation and the fact that each CS should be described in more than a deliverable, it has been agreed to include in the report an initial section (Chapter 3) to describe the activities associated to the Task. So, Chapter 3 is at Task level and takes care only of the CS’s component related to the task, even if it means to depict it only partially.

Conversely, Chapter 4, that is the core of the deliverable together with the set of attachments, provides the overview at CS level, in order to avoid jumping from a document to another to find information. Each Chapter 4 (of the four deliverables) contains only a subset of CSs but they are fully described: for each cognitive solution, the main achievements are presented.

The following table shows in which way the 19 Cognitive Solutions encompass the four WP3 layers and so, also the four WP3 Tasks (in bold, the percentage that drove the choice of the deliverable where the CS has been assigned).

Table 1 CAPRI CSs encompassing the four layers/tasks

DOMAIN	CS'S NAME	CS'S CODE	T3.1 Sensor	T3.2 Control	T3.3 Operation	T3.4 Planning
ASPHALT	Sensor for bitumen content	CAS1	**50%**	50%		
	Sensor for particle size	CAS2	**80%**	10%		10%
	Control of the asphalt drum	CAC1		**85%**	15%	
	Predictive Maintenance of baghouse	CAO1	10%		**30%**	60%
	Planning and control of asphalt production	CAP1		10%	10%	**80%**
STEEL	Sensor for product tracking	CSS1	**70%**	30%		
	Sensor for Solidification	CSS2	20%	**80%**		
	Sensor for Product temperature	CSS3	20%	**80%**		
	Scale sensor for scale build-up	CSS4	20%	**80%**		
	Sensor for risk and anomalies	CSS5			30%	**70%**
	Digital twin architecture	CSO1		10%	**60%**	30%
PHARMA	Sensor for blend uniformity	CPS1	**80%**	20%		
	Sensor for granule quality	CPS2	**80%**	20%		
	Sensor for product moisture	CPS3	10%	30%	**60%**	
	Sensor for prediction of dissolution	CPS4		40%	**60%**	
	Sensor for fault detection	CPS5		10%	**60%**	30%
	Cognitive Control Concept	CPC1		**70%**	30%	
	Cognitive Operation Concept	CPO1		10%	**70%**	20%
	Cognitive Planning Concept	CPP1		10%	10%	**80%**

All project partners have agreed to assign each CS to a specific deliverable, even if it encompasses more than a layer (and so, more than a Task) to ease and speed-up the reading of the document and to show all the information related to a Cognitive Solution in a single report.

Hence, the 19 CSs have been split in the four deliverables as follow, according to the most relevant layer:

Figure 1 The 19 CSs into the deliverables D3.2, D3.3, D3.4, D3.5

In this way, the four deliverables are well balanced: 5 CSs are described in D3.2 and D3.3, whose main component is the Sensor and the Control, respectively; 6 CSs are described in D3.4, focused on Operation and finally, 3 CSs are described in D3.5, about Planning. In each deliverable, Asphalt, Steel and Pharma domains are always represented.

Namely, the current deliverable contains the following 5 Cognitive Solutions:

- CAC1 - Control of the asphalt drum [Asphalt]
- CPC1 – Cognitive Control Concept [Pharma]
- CSS2 – Sensor for Solidification [Steel]
- CSS3 – Sensor for Product temperature [Steel]
- CSS4 – Scale sensor for scale build-up [Steel]

Since we are talking of deliverables of type OTHER, each Cognitive Solution listed above is equipped with:

- A number of attachments of different nature (video, data, metadata, application, code, …), containing additional information that helps to better understand the final output of the CS and to provide a concrete evidence of what has been implemented in WP3;
- A textual part, available in Chapter 4 that complements the “physical” content in attachment, explaining what it is and how to exploit it.

The attachments are available in the Zip Folder, in Zenodo repository. Due to limitations of space (52Mb) in EC portal not all the assets could be included into 1 single file. That is the reason we have decided to include all files into CAPRI’s Zenodo account and CAPRI YouTube channel video for the videos showing specific demonstrations. The table below lists all the links (zenodo and youtube) of the different files described in the present report.

Table 2 D3.3 – List of attachments

Cognitive Solution	Content	Type	Location
CAC1 - Control of the asphalt drum	CAC1_Data_1.mat	Example dataset	https://doi.org/10.5281/zenodo.6397356
	CAC1_IDSS_MODEL_MPC_CONTROLLER_v5.slx	Model	https://doi.org/10.5281/zenodo.6397356
CPC1 – Cognitive Control Concept	A3_DAT_CPC1_20220223	Process data of an experimental run including the granule size control	https://doi.org/10.5281/zenodo.6397370
CSS2 – Sensor for Solidification	CSS2_video_1.mp4	Video	https://doi.org/10.5281/zenodo.6397377
	CSS2_model_description.docx	Text	https://doi.org/10.5281/zenodo.6397377
CSS3 – Sensor for Product temperature	CSS3_video_1.mp4	Video	https://doi.org/10.5281/zenodo.6397384
	Capri CSS3 Temperature Model Work description_final.docx	Text	https://doi.org/10.5281/zenodo.6397384
CSS4 – Scale sensor for scale build-up	CSS4_video_1.mp4	Video	https://doi.org/10.5281/zenodo.6397399

It is worth to mention that each data file shared is accompanied by the corresponding data management plan file (DMP file) to comply with the F.A.I.R.[1] principles as CAPRI project is part of the open research data pilot of H2020[2].

Finally, an overview of each Cognitive Solution is available in the CAPRI website, at the “Use Cases” section[3].

If you are interested in the details other CSs different from the five associated to the current deliverable, please refer to related deliverable according to the structure shown in Figure 1.

[1] Under these principles, each data file must be Findable, Accessible, Interoperable and Reusable. http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf

[2] https://www.openaire.eu/what-is-the-open-research-data-pilot

[3] https://www.capri-project.com/technology

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3 Smart Event Processing Cognitive Solutions Overview

3.1 Asphalt sensor/control solutions

To understand this cognitive solution is important to consider that the asphalt product is a recipe obtained by mixing aggregates, bitumen and additives and the asphalt plant has 9 important parts, the cold aggregates bins feeders, the dryer drum, the baghouse filter, hot aggregates bins, system of filler input, line of RAP, bitumen tanks, fuel tank and, the mixer.

The asphalt production process begins when the stockpiled aggregates in the cold feeders are metered and conveyed to a dryer drum where they are heated to a specific temperature. A first collector removes large dust particles from the gases before entering the bag house, which removes fine particulate matter (filler) before they are released into the atmosphere where is located the sensor solution CAS2 (cognitive sensor of amount of filler). Hot aggregates are elevated to a vibrating screen where they are classified by size and stored in different bins. These hot aggregates, filler and other additives (RAP) are scaled and mixed with the hot bitumen in the mixer producing the final asphalt mix. Specifically, in the rotary drum the drying and heating of the aggregates is carried out.

CAC1- Cognitive control of Dryer Drum

The control solution objectives are to obtain a dry product at an optimum temperature for the next process and fumes (combustion gases) at the possible lowest temperature, on one hand not to damage the bag filter and on the other to minimize energy consumption, thus increasing the efficiency of the drying process. The main objective is to decrease the consumption of electricity, recycled fuel and diesel. This way knowing the humidity and temperature in the input of the drum, adjustments will be made to obtain the best conditions of output, avoiding overheating of aggregates.

This solution has been developed based on a control algorithm where sensors and actuators are used to calculate the optimum values for the different variables that run the drum. Actually a dynamic modelling of the rotary drum is being created through model-based identification methods running several experimental tests performed at the asphalt plant taking into account some of the main variables: temperatures, humidity, load to dry, burner, drum speed, combustion gas flow. This identified model will be required like an input for the Model Predictive Control (MPC), advanced method of process control that is used to control a process while satisfying a set of constraints. It is in this control solution where the rotary drum optimized control calculations are performed.

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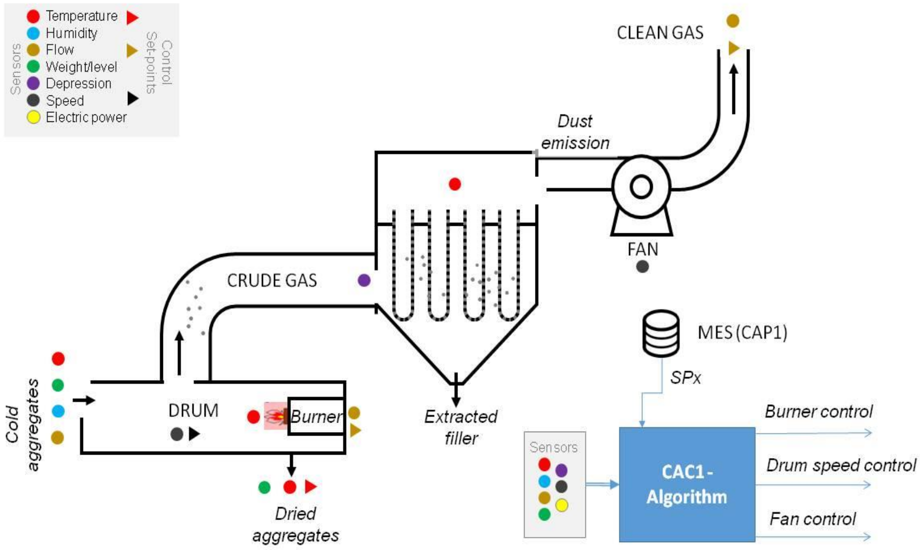

Figure 2:CAC1 Basic Architecture

The Cognitive Algorithm will be executed in real time by providing the setpoints: drum burner power (%), drum rotation speed (%) and exhaust damper opening (%), to obtain the optimal temperature of the hot aggregates coming out of the drum and to guarantee in this way the desired temperature of the final asphalt mix and also the gas combustion temperature. In addition, this is intended to minimize the combustion gases temperature and to improve energy efficiency and reduce pollution.

A more detailed description of this Cognitive Solution can be found in the following deliverable: D2.2 Use Case Requirements.

3.2 Steel smart sensors/control solutions

Three steel-domain solutions are presented in this report, all of which are soft sensors (pure software solutions). The steel solidification sensor (CSS2) deals with the continuous casting of billets, the temperature (CSS3) and scale sensor (CSS4) are concerned with the hot rolling mill, where billets are rolled and finally cut into bars, and the subsequent cooling bed for the steel bars. The three sensors consist of physics-based simulations that enhance the existing process data by generating additional data of potential relevance to the surface quality of the steel bars, the final products of our processing chain. Their results will hence be used by the risk and anomalies sensor, which is described in another project report (D3.5). Besides this usage, the three soft sensors also generate some intrinsic benefits related to the improved observability of the production processes that they provide. For instance, the solidification sensor calculates the crater end position within the casting strands i.e., the position where the originally liquid steel has fully solidified. Since the liquid core of the strands is completely covered in a solid shell right below the mould, this information is not easily accessible from direct measurements.

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Figure 3: Overview of the steel production chain, with the position of the solidification (CSS2), temperature (CSS3) and scale sensors (CSS4), as well as the two risk estimators.

CSS2: Solidification sensor

The solidification sensor consists of a state-of-the-art numerical temperature and solidification model based on the 3-dimensional heat flow equation with reasonable simplifications that enable the real-time operation of the process simulation. Boundary conditions are calculated from available online measurements, for instance of the steel temperature in the tundish (the vessel from where the liquid steel flows into the casting mould), temperatures and flow rates of mould cooling water, as well as flow rates of spray water loops applied in secondary cooling zones.
These calculations have been calibrated to fit historical datasets with measurements of strand surface temperatures.

CSS3: Temperature sensor

The temperature soft sensor is a software solution that tracks the temperature development of steel billets and bars in the hot rolling mill and the following cooling bed. The temperature evolution of billets and bars during and after rolling can have a great impact on their quality, which is why we aim to correlate this information with the surface quality assessment data that is recorded for the steel bars at the end of the process chain considered in the project. Also, the build-up of scale depends strongly on the temperature, see CSS4 description below. Another potential application for a cooling bed temperature soft sensor is the optimization of the cooling bed occupation, although this is not planned in the project.

In our demo site, a couple of temperature measurements of the steel surface are made by means of pyrometers, installed at fixed locations in the rolling mill. The soft sensor interpolates the product temperatures to time intervals where no measurements are available, in our case the time spent on the cooling bed.

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CSS4: Scale sensor

The scale sensor is a soft sensor that estimates the amount of secondary scale i.e., iron oxides, that forms on the surface of the hot steel billets, resp. bars, during and after the hot rolling process. Since scale may impact the surface quality of the bars, we aim to correlate this information with the quality assessments in the risk and anomalies sensor. Since the main impacting quantities for the scale formation are the surface temperature of the steel items and their chemical composition, this soft sensor relies on the results of CSS3.

3.3 Pharma smart sensors/control solutions

The smart sensor/control solutions developed in the pharma use case aim at improving the quality of the final product and the reduction of waste material. Therefore, the CPC1 control concept is realised. It contains two main aspects: (1) A process control concept, which aims at keeping critical quality attributes of the pharmaceutical intermediate and final product close to their desired value. (2) A quality control concept, which ensures that only in-specification tablets are being produced and that the amount of waste material is minimised at the same time. To accomplish the two mentioned tasks, real-time information about the (critical) quality attributes (CQAs) is needed. An overview of the investigated manufacturing line and the developed solutions are shown in Figure 4. A high-level description of the two CPC1 concepts including their relationship to the sensor solution is given below.

CPC1-process control: The process control concept aims at producing granules of a precisely defined size and moisture content. These two properties can be influenced by adjusting the granulation settings (solids and liquid mass flow rates) and the dryer settings (drying time, dryer inlet temperature, dryer inlet air volume flow rate). In order to implement a process control concept, the relevant quality attributes need to be known. For that purpose, CPS2 (granule size) and CPS3 (granule moisture) have been developed. CPS2 is described in deliverable D3.2. CPS3 is described in deliverable D3.4. The control concept uses the model predictive control (MPC) approach, which requires the availability of suitable process models. The granulation has been modelled by means of the local linear model tree (LOLIMOT) algorithm, which is a data driven modelling approach. The model of the dryer is based on mechanistic equations.

CPC1-quality control: To ensure in-specification tablets, it is essential to monitor critical quality attributes during production and to perform necessary discharge actions, in case the materials do not meet the required specifications. In the investigated manufacturing line, such out-of-specification (OOS) material can be discarded before it enters the tablet press. In order to perform a precise discharge action, the timely alignment of monitored quality attributes to the material portion in question at the discharge point, needs to be established. A simulation model for material tracking, as well as an algorithm considering the residence distribution of the tablet press for making the discharge decision, have been developed.

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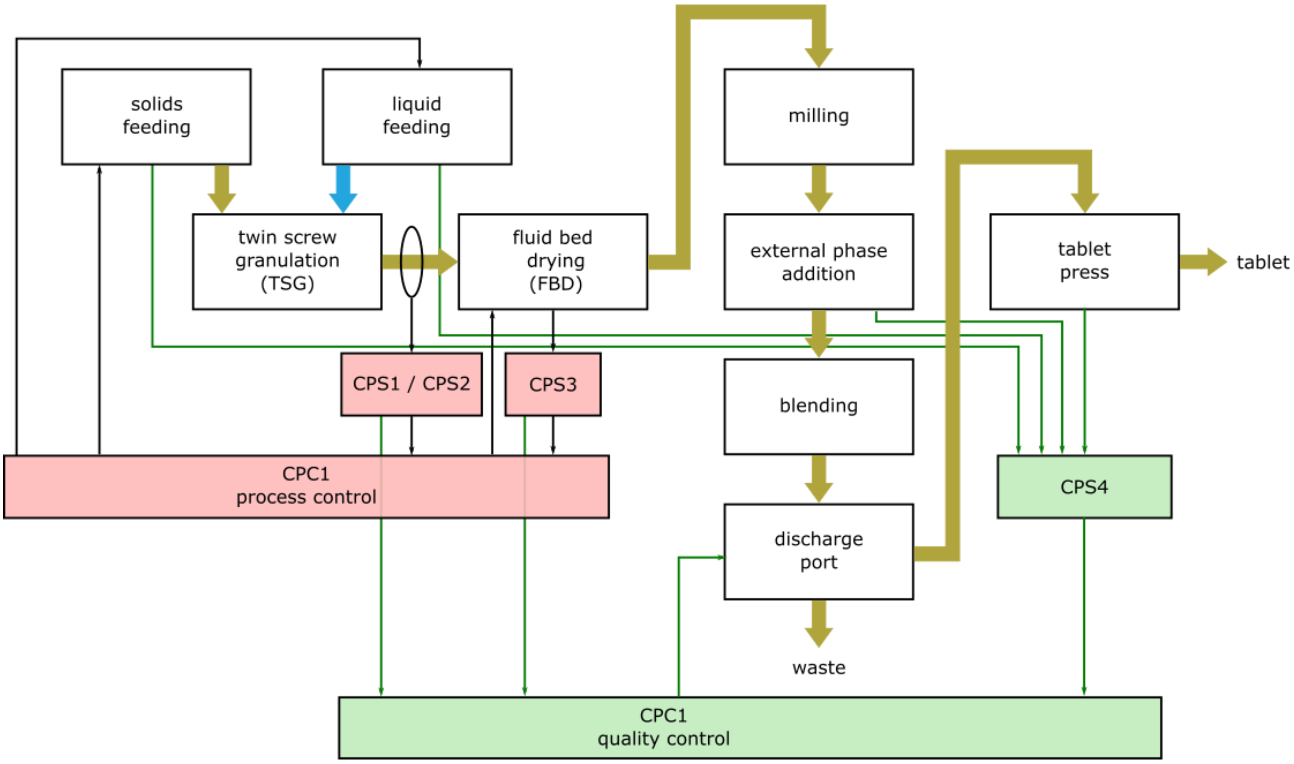

Figure 4: Overview of the pharma smart sensors and control solutions

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4 Smart Event Processing Cognitive Solutions Results

4.1 Asphalt domain

4.1.1 CAC1, Control of the asphalt drum

DATA FILES

File **CAC1_Data_1.mat**

Example dataset containing sample data that can be run and tested in current version of the CAC1 solution. Sensors data is made up of real production data from EIFFAGE Gerena asphalt plant on the 3rd and 4th of February 2022.

General technical specifications of the data according to the DMP can be seen in “Technique Dataset” Table 3.

The dataset example is made up of the following variables (sensors measurements and generated setpoints):

It is divided in two timeseries variables named **u_** and **y_**. They are matrices whose columns correspond to the following data (from column 1 to the last one):

U:

Input data for the CAC1 CS solution:

- 'rcvTime' – Time stamp of the received data at the CAP platform (format yyyy-MM-dd'T'HH:mm:ss,SSSZ) – Datetime data type
- 'Cburner_RPA1300' – Rotary Dryer Drum Burner Power (%) – Numeric Data Type
- 'Fproduction_RPA0700' – Production Flow Rate (Tn/h) – Numeric Data Type
- 'Pdryer_RPA2000' – Pressure drop at rotary dryer drum (Pa) – Numeric Data Type
- 'Pfilter_aggr_RPA2100' – Pressure drop at baghouse filter (Pa) – Numeric Data Type
- 'Crotating_dryer_RPA1900' – Rotary dryer drum speed (%)– Numeric Data Type
- 'DrumFuelVal' - Consumed fuel at dryer drum burner (kg) – Numeric Data Type
- 'TemperatureDoseur1' - Cold Aggregates Hopper 1 (sands) Temperature (ºC) – Numeric Data Type
- 'TemperatureDoseur2' - Cold Aggregates Hopper 2 (sands) Temperature (ºC) – Numeric Data Type
- 'Tmixture_RTA1300' - Mixture temperature (ºC) – Numeric Data Type
- 'MetTemperatureExt' - Weather Station External Temperature (ºC) – Numeric Data Type
- 'HumiditeDoseur1' - Cold Aggregates Hopper 1 (sands) Humidity (%) – Numeric Data Type
- 'HumiditeDoseur2' - Cold Aggregates Hopper 2 (sands) Humidity (%) – Numeric Data Type
- 'MetHygrometrie' - Weather Station Humidity (%) – Numeric Data Type
- 'O2' - O2 concentration at baghouse filter (chimney) (%) – Numeric Data Type
- 'PPMPrefitre' – Particles Concentration at baghouse filter inlet (ppm) – Numeric Data Type
- 'Tout_dryer_RPA1000' - Outlet Rotating Dryer Temperature (ºC) – Numeric Data Type
- 'Tfilter_in_aggr_RPA1400' - Inlet aggregates filter temperature (ºC) – Numeric Data Type

Y:
Output data generated by the CAC1 solution:

- 'C_Burner_SP' – Rotary Dryer Drum Burner Power Setpoint (%) – Numeric Data Type
- 'C_Drum_SP' – Rotary Dryer Drum Rotation Speed Setpoint (%) – Numeric Data Type
- 'O_Exhaust_SP' – Exhaust Damper Opening Setpoint (%) – Numeric Data Type

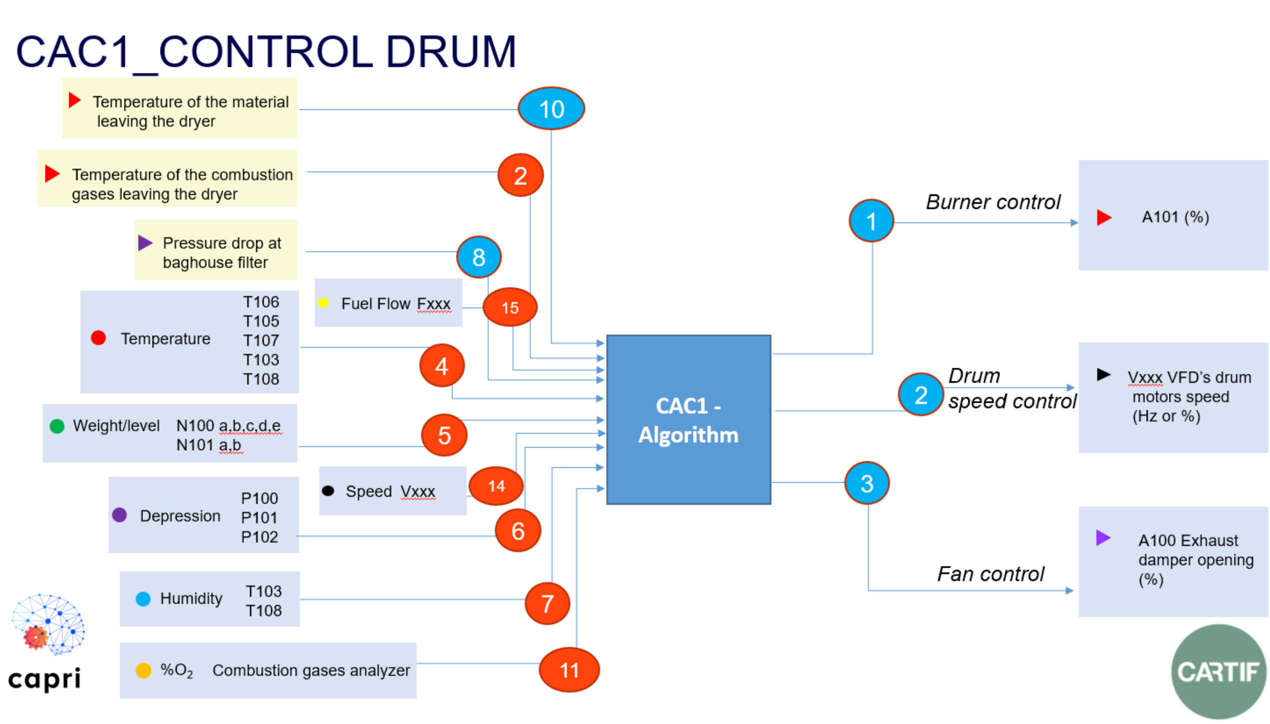

Figure 5: Data concerning CAC1 dataset

Table 3: CAC1 technique dataset specifications

Technique Dataset	Value
Structure	Data available as numeric and alphanumeric data order by acquisition time stamp (variable *rcvTime*)
Type and Format	.mat format (binary files used in MATLAB to store workspace data)
Data Size	~ 2.75 MB
Data Rate	~ 2.75 MB/day
Communication protocol	Data comes from sensors connected using 4-20 mA or 0-10V connected to plant PLC or directly to WAGO plant datalogger. Also data as a result of CS outputs.
Edge or embedded	Edge and remote
Tools to access	Dataset accessible through MATLAB environment (but used by CAC1 in a direct way)
Name of the system	CAC1 Cognitive Solution
Visualisation	Currently through MATLAB plotting modules
Technology	.mat file (MATLAB storage files)
Source	Sensors connected to the plant PLC and the WAGO datalogger and sent to the CAP platform at CAPRI server side (located at CARTIF facilities) and store in a MySQL database (using FIWARE based architecture).
Destination	Dataset example for CAC1 Cognitive Solution
Archiving	MySQL database in the CAPRI server located at CARTIF facilities

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CAC1 Data Model and Algorithm

CAC 1 algorithm consists of an identified data-based model and an MPC (model-based predictive controller) programmed in MATLAB environment using both MATLAB scripts and SIMULINK function blocks.

In order to run the solution, the CAC1 solution is a **MATLAB/Simulink** simulation environment where the algorithm requires the installation of the **MATLAB** tool alongside **Simulink** and the following toolboxes: **System Identification** Toolbox, **Control System** Toolbox and **Model Predictive Control** toolbox.

Regarding the *Cognitive Algorithm that CAC1* is based on, the following applies:

AC (cognitive algorithm) based in an experimentally data-based identified model, from all sensor measurements (mainly concerning those ones of the material (aggregates) and combustion gases, see previous variables list) and the dynamics (data-based model) in the production chain and related process variables it will calculate the setpoint SP1 of the drum temperature controller.

The setpoint of combustion gases temperature controller leaving the rotary drum dryer SP2, modulating the speed of rotation of the drum will also come from this AC algorithm.

The setpoint SP4 `‘O_Exhaust_SP’` of the depression controller C4 is constant in any scenario and can be changed by the operator if it is necessary.

The MPC (Model Predictive Control) calculates and changes in real time the setpoints of the slave controllers C1 and C2 from the setpoints SP1 and SP2 generated by the CAC1 algorithm. SP1 and SP2 are inputs to the MPC control algorithm where:

R1: Variable setpoint `'C_Burner_SP'` of the slave PID controller C1 (of the burner), calculated in real time by the MPC.

R2: Variable setpoint `'C_Drum_SP'` of the slave PID controller C2 (of the drum speed VFD), calculated in real time by the MPC.

U1: Burner power control signal (%).

U2: VFD control signal that modulates the rotation speed of the drum (%).

CAC1 FILES

To run the CAC1 algorithm that is included in the .zip file, the following instructions must be followed:

- Install the MATLAB environment alongside the above mentioned toolboxes:
  - Simulink
  - System Identification
  - Control System
  - Model Predictive Control
- Unzip the corresponding zip file in one folder. Leave the following files (corresponding to the CAC1 solution) that have been unzipped in the same folder, including de .mat data file:
  - **CAC1_Data_1.mat**
  - **CAC1_IDSS_MODEL_MPC_CONTROLLER_v5.slx**
-

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- Load in the Matlab Workspace the data file CAC1_Data_1.mat
- Open the Simulink simulation environment from within MATLAB and open the previous .SLX file. From there, the algorithm can be run and through several scopes, their outputs can be calculated and analysed.

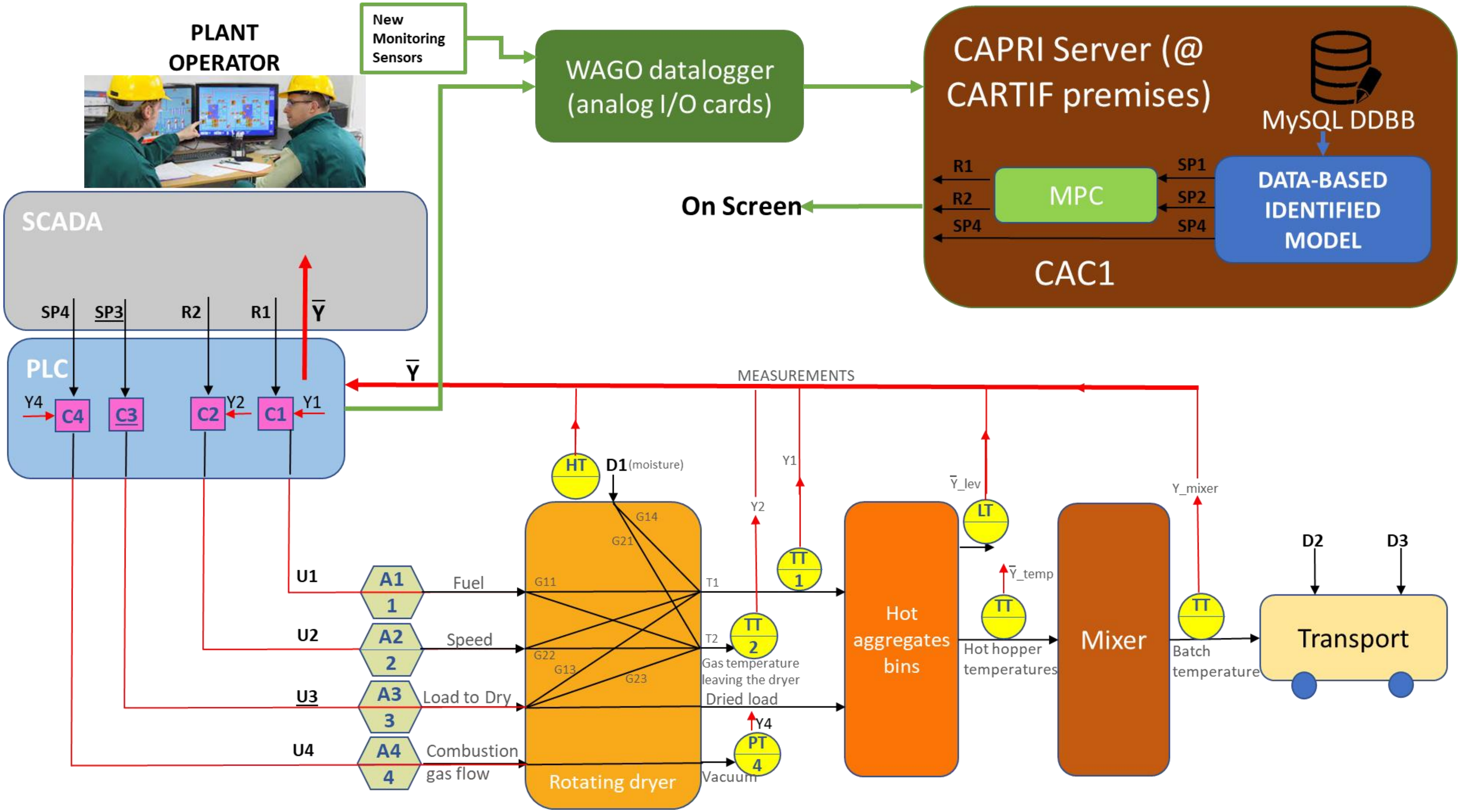

Figure 6: CAC1 CS diagram

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4.2 Steel domain

4.2.1 CSS2, Sensor for Solidification

CSS2 Video

The video for CSS2 gives a short introduction into the algorithm (cf. paragraph below) and shows the graphical user interface developed for user interaction with the solution. The latter has multiple panels, one showing the input data and sensor results per heat, another one that shows a replay simulation of the casting process, including the surface temperature field, crater and position and the virtual billet boundaries as they proceed in time. Finally, there is a panel that allows running the model for a particular heat and casting strand.

CSS2 Algorithm

Introduction

DynSolidCC – the Dynamic Temperature and Solidification Model for Continuous Casting Processes set up by BFI - can be used on-line for monitoring and controlling the solidification process, and off-line for analysing different process conditions, getting a better understanding of the related solidification behaviour and for improving the layout of the process and the design of the casting machine. The program has been implemented object orientated with C++. It calculates the temperature field and solidification front of the strand using a mathematical model based on the heat flow equation. Initial, boundary and process conditions have to be given - for example the temperature of the steel poured into the caster, the cooling water data from the mould, the casting speed or the amount of spray water used in the secondary cooling zones.

The calculation domain is three dimensional (thickness, width, length). Thickness and width can be time and space dependent, e.g. for width reduction in the mould or thickness reduction at the end of the solidification process (soft reduction).

Calculations can be performed

- for round or rectangular strands,
- in 2- or 3-dimensional mode,
- with stationary or variable casting conditions
- and symmetric or asymmetric boundary conditions.

Boundary, initial and process conditions needed as model input comprise

- composition of steel which is poured into the mould
- temperature of steel which is poured into the mould
- casting speed
- heat transfer coefficients, e.g. calculated within related boundary condition models from
    - cooling water flow and temperature increase in mould
    - spray water amounts in secondary cooling loops

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On the other hand, the model provides output data like

- shell thickness (solidification front) along the casting direction
- crater end position
- temperature field on lattice across the strand
- liquids temperature along the casting direction.

The temperature dependent thermophysical parameters (like density, thermal conductivity, specific enthalpy and liquid/solid fractions) of the steel are calculated from the composition of the steel poured into the mould.

The model application within the CSS2 sensor gets for each heat additional information about essential secondary metallurgical process steps, like

- deoxidation additions,
- degassing and
- final stirring durations.

This information together with characteristic data from the casting process are tracked for each strand slice moving through the caster and then assigned to the cut billet. The characteristic casting data tracked by the model comprise

- superheat at mould entry
- casting speed
- mould cooling water flow
- mould cooling water temperature increase
- spray water flows
- shell thickness, surface and centre temperatures at
    - end of mould
    - end of each spray water loop
    - at position of installed temperature scanner
    - before cutting torch.

<u>Mathematical model</u>

There are three different mechanisms of thermal energy transport:

- convection, i.e. transport by movement of matter,
- conduction, i.e. transport by random molecular collisions,
- radiation, i.e. transport by electromagnetic fields.

Radiation plays a role at the surface of the metal, only. It is taken into account by the boundary condition models. The heat flow equation is based on the energy conservation law and a second

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principle, called Fourier's law of heat conduction. According to this law the conductive heat current density is proportional to the temperature gradient.

For modelling the casting process, the following two approximations have been made:

- The conductive heat transfer in casting direction is much smaller than that by convection or that by conduction in the other directions. Therefore, it is neglected.
- The convective heat transport in the liquid part perpendicular to the casting direction can be taken into account via an effective thermal conductivity.

These approximations decouple to some extent the system of partial differential equations to be solved and allow for fast numerics which can be applied in real time for on-line purposes (see below). Regarding the velocity field in cases without strand deformation, it is a good approximation to assume only a velocity component in the longitudinal casting direction, which is equal to the casting velocity.

Taking into account a deformation of the strand - either by width adjustment in the mould or by thickness reduction in the secondary cooling zone - the strand geometry becomes a function of space and time. There are mainly two locations where thickness reduction can take place: in the segment neighboured to the mould - the intention is to get thinner slabs; in the segment where the strand section becomes solidified completely - the intention is to improve the steel quality by adjusting the volume reduction caused by solidification (soft reduction).

There are two main principles from which the equations for the velocities can be derived:

- Mass conservation, i.e. the rate of mass change in a given volume is given by the mass flux over the surface volume.

- The stress velocity in the direction of deformation is proportional to an empirical function (e.g. linear with respect to the liquid phase fraction).

For solving the equations for the temperature and velocity fields, appropriate boundary and initial conditions have to be given. An exact determination of all boundary conditions is an impossible task, because accurate temperature measurements at the surface of the strand are not available. Instead, one has to calculate the boundary conditions from the positions and diameters of the rolls, the amount of spray water and mould water used for cooling the strand and from the temperature difference to the environment. The formulas in these boundary condition models contain several parameters which have to be tuned for each specific casting machine:

- For the mould, one can assume a heat flux q across the surface exponentially decreasing along the casting direction (z). The maximum heat flux q_0 (at z=0) can be calculated from the average one. The latter can be estimated from the width W and the length L of the mould, the primary cooling water amount per time w_p and the temperature increase of this water ΔT_{wp}, which leads to the equations

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$$q(z) = q_0 e^{-\alpha z}$$

with $$q_0 = \frac{a_c c_{pw} w_p \Delta T_{wp} \alpha}{W(1 - e^{-\alpha L})} \qquad (1)$$

where c_{pw} is the specific heat of water and a_c, α are model parameters. Then the heat transfer coefficients in the mould amount to

$$h(z) = \frac{q(z)}{T_{surf} - T_{env}} \qquad (2)$$

where T_{surf} is the surface temperature of the strand and T_{env} the environment temperature.

- For the secondary cooling zones with spray water amounts per time w_i in loop i the heat transfer coefficients can be described by

$$h_i = a_i (b_i w_i + c_i w_i^{0.31}) + d_i w_i^{n_i} + f_i \qquad (3)$$

where the coefficients a_i, b_i, c_i, d_i, n_i, and f_i (i = 1, ..., number of loops) can be approximately calculated from the caster design data (width, roller distances) and empirical data (comparison with coefficients for known casters).

- For the domain behind the secondary cooling zones one can assume electromagnetic radiation according to the 'T^4-law' and an additive term for other heat transport across the strand surface leading to a heat transfer coefficient

$$h = a_r \sigma \frac{T_{surf}^4 - T_{env}^4}{T_{surf} - T_{env}} + b_r \qquad (4)$$

where $\sigma = 5.67 \times 10^{-8}$ W/(m²K^4) is the Stefan-Boltzmann constant and a_r, b_r are model parameters.

For most applications (e.g. regarding control of the crater end position) it is sufficient to assume an average heat transfer coefficient for each secondary cooling loop. But also, high-resolution boundary condition models can be used taking into account the variations of heat transfer coefficients depending on:

- position and diameter of single rolls
- position and spray characteristics of single nozzles can be used.

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The main features of the used mathematical model are described in more detail in this bibliography[4]. The model has been discretized by means of finite difference methods[5]. It has been shown to be quite successful, i.e. it is simplified enough such that the calculations can be performed on-line, and it is exact enough such that the results agree sufficiently with the real state of the strand.

For the billet casting process, all calculations are performed 3-dimensions. The 2-dimensional problem can be achieved by assuming negligible heat flux with respect to width, e.g. for slab casting. Then only one longitudinal section through the strand centre with zero heat flux in width-direction can be calculated.

Extensibility of the model

The currently available dynamic temperature and solidification model does not take into account all aspects of continuous casting processes, e.g.

- segregation phenomena, e.g. in the centre of the strand before complete solidification
- electromagnetic stirring of the liquid part of the strand
- thermomechanical properties of the strand.

For that purpose

- appropriate sub-models for such inhomogeneities in the composition of the steel,
- more complex velocity field (mass flow) equations
- appropriate thermomechanical sub-models

have to be included.

The implemented software structure (described in the next section) is compatible for such extensions, but they are not intended within the current project.

OO-implementation of the model

For implementation of the DynSolidCC model kernel an object-oriented (OO) design has been chosen. On the top level there are classes for management of the different events for model calculations with related input and output data (see Figure 7):

- EventManger: Calling of model calculations for different events (e.g. startCasting, nextTimeStep, newSteelAtMould, cutStrand, …)
- InputManager: Management of model input data (dummy bar position, initial steel temperature and analysis at mould level, casting speed, primary and secondary cooling water data, …)

[4] K.-H. Spitzer, K. Harste, B. Weber, P. Monheim, and K. Schwerdtfeger: Mathematical Model for Thermal Tracking and On-Line Control in Continuous Casting, ISIJ International, Vol 32 (1992), No. 7, p. 848
[5] S.V. Patankar, Numerical Heat Transfer and Fluid Flow, Hemisphere Publishing Corporation, New York (1980)

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- OutputManager: Management of model output data (temperature field, shell thickness along strand, crater end position, …)

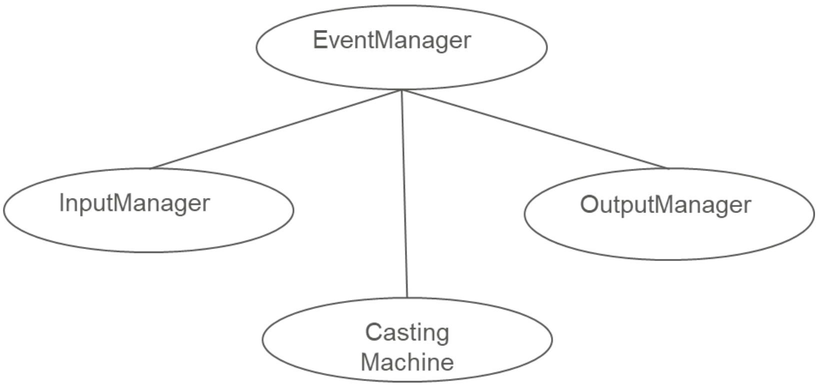

Figure 7: Top level design of DynSolidCC kernel model

The EventManager calls the different model calculations via the main inner kernel class CastingMachine. Figure 8 sketches the design of this class with its relations to other inner kernel classes.

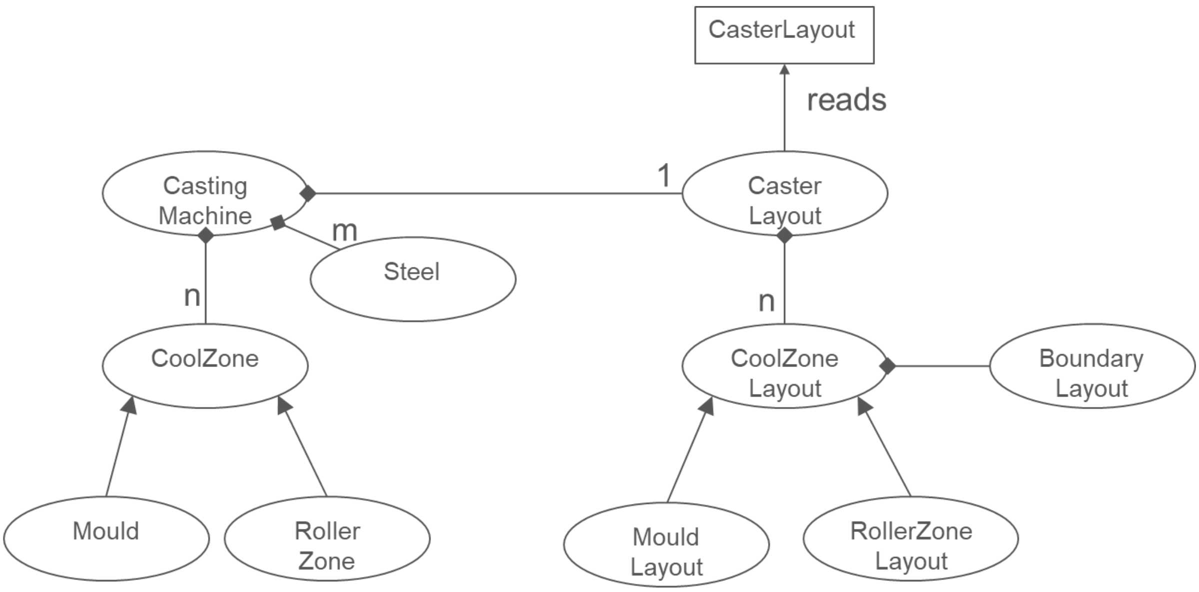

Figure 8: Design of main inner class CastingMachine of DynSolidCC kernel model

In detail, there are involved 10 inner kernel classes:

- The CastingMachine consists of n CoolZone objects.
- The CastingMachine has m Steel objects providing the information about the steel at the m lattice points in casting direction.
- The CastingMachine has one CasterLayout object specifying the caster design regarding geometry, mould, segments, cooling loops etc. This has to be configured within a related ASCII file.

- The CasterLayout consists of n CoolZoneLayout objects.
- The CoolZoneLayout has one BoundaryLayout object providing the information about the types of boundary conditions (mould, spray water zone or radiation zone) associated with the cool zone.
- Mould and RollerZone are CoolZone types.
- MouldLayout and RollerZoneLayout are related CoolZoneLayout types.

The class CoolZone contains all classes necessary to solve the problem of simulating a continuous casting process (cf, Figure 9).

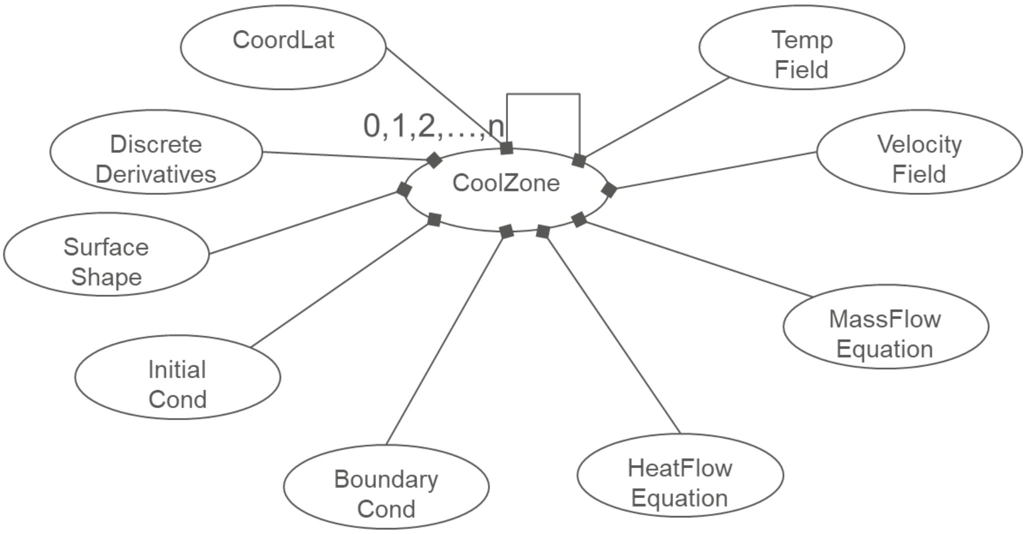

Figure 9: Design of class CoolZone of DynSolidCC kernel model

- CoordLat provides the information about the lattice where the fields are defined on.
- Discrete Derivatives are implemented in the classes DiscMatrix for discretization of second derivatives and DiscVector for discretization of first derivatives.
- SurfaceShape provides the information about the cross-section perpendicular to the casting direction.
- InitialCond provides the information about the initial conditions.
- BoundaryCond provides the information about the boundary conditions.
- HeatFlowEquation implements the heat flow equation.
- MassFlowEquation implements the velocity field equations.
- VelocityField provides the information about the velocity field on the lattice.
- TempField provides the information about the temperature field on the lattice.

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Integration of the model into on-line- and off-line applications

The developed DynSolidCC model kernel is provided as dynamic link library (DLL) with a C++ application programming interface (API) in order to integrate it within a model shell for related on-line or off-line applications.

For each sequence, the on-line model shell has to track the start of casting, acyclic events (like new steel grade at mould entry) and cyclic measurements (e.g. of casting speed, mould cooling water data, spray water flows) by usage of appropriate interfaces to basic automation, production control and manufacturing execution systems and to supply the model kernel via an instance of an API class with the respective input data for the process monitoring functions. Then the kernel returns the calculation results by the output data structures defined within the API. For offline recalculations of the casted sequences, validation and tuning of the model functions, the kernel logs all necessary process data into suitable protocol files.

Configuration of the model for billet casting process at Sidenor

Based on the plant and process data provided by the industrial partners, BFI has configured their DynSolidCC model for simulations of the billet casting process at Sidenor. For that purpose, the configuration files for the Sidenor caster (cf. Figure 8) as well as appropriate ASCII files providing input data for a typical stationary casting process have been set up, including the steel grade, its initial superheat, casting speed as well as primary and secondary cooling water data.

Figure 10 shows the results from the model simulations with these casting conditions. Here, the strand thickness at the end of the mould (at 0.78 m) amounts to about 10 mm and the complete solidification of the strand is calculated at a metallurgical length of 16.2 m, which is in reasonable agreement with the expected values of the Sidenor caster. The reduced cooling in the spray water zones as well as in the subsequent radiation zone lead to initial increases of the surface temperature in these zones.

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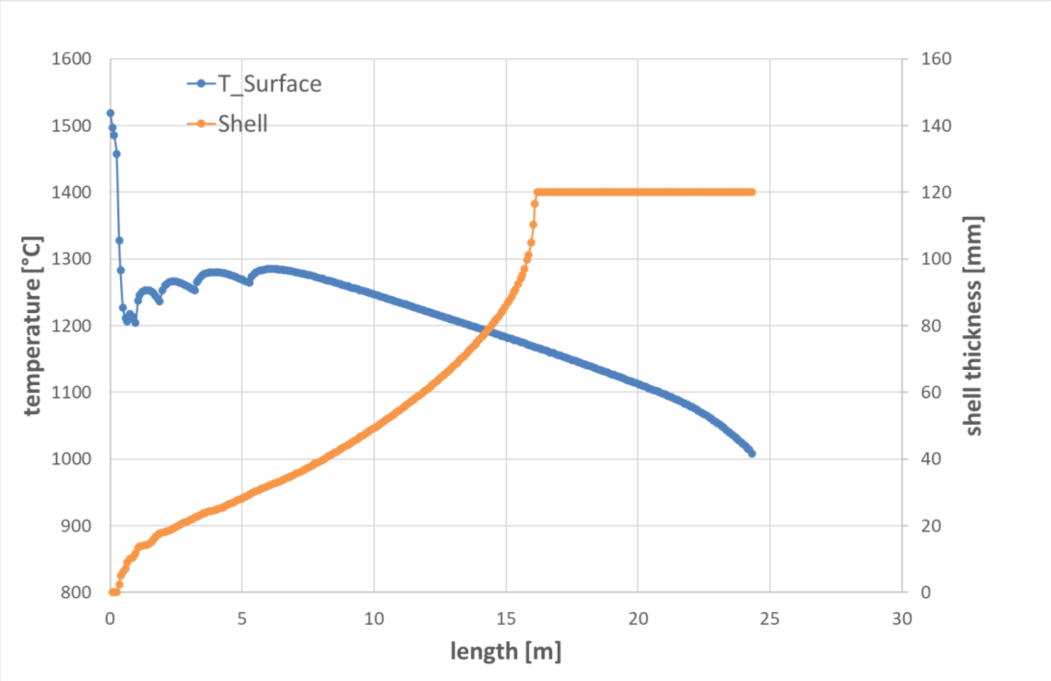

Figure 10: Surface temperature and shell thickness for mid of strand top side simulated with DynSolidCC for billet casting at Sidenor with typical stationary casting conditions

The results proved the general validity of the temperature and solidification model DynSolidCC for simulation of billet casting processes at the Sidenor plant. Further validation and tuning of the boundary condition models based on infrared camera measurements of stand surface temperatures at the steel plant are described in the following section.

Model tuning based on infrared camera measurements of strand surface temperatures

Sidenor collected the process data for 39 heats casted in March 2021 within csv-files which were provided to BFI for evaluation. The files also contained data from a temperature scanner (infrared camera) which has been installed 9.9 m below the meniscus to measure the temperatures in the middle of the top surface of the strand (with an assumed emissivity of 0.8).

BFI has preprocessed the provided data to generate appropriate input files for offline simulations with the DynSolidCC model adapted to the billet caster of Sidneor. Based on these simulations, a regression analysis with least-squares optimisation could be performed to adjust the parameters a_i, a_r and b_r of equations (3) and (4) for the heat transfer coefficients in the secondary spray water and subsequent radiation zones to the measured surface temperatures.

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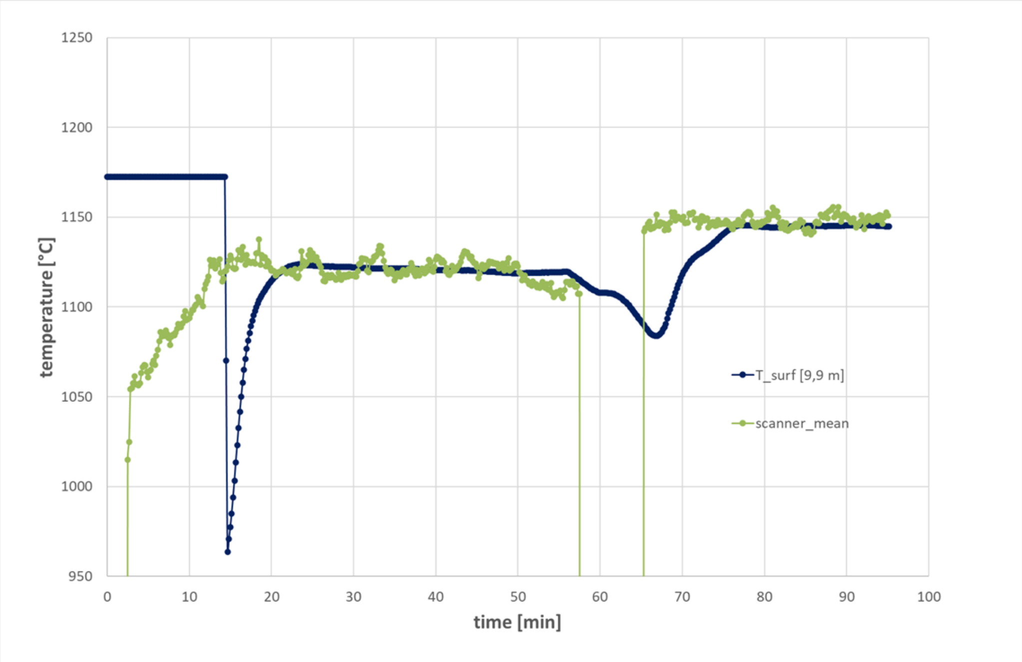

Figure 11: Simulated (blue line) and measured (green line) surface temperatures 9.9 m below the meniscus at SID billet caster

Figure 11 shows the measured and simulated evolution of the strand temperature in the middle of the top surface 9.9 m below the meniscus for a sequence of 2 heats. After about 15 minutes, the dummy bar has passed the measurement position and the temperature values achieve a first stable level. Then, about 57 min after start of casting, there has been a change in the casted heat and an increase in casting speed by 0.1 m/min resulting in a transition to another stationary strand state with a higher level of surface temperatures. Both stable levels of measured surface temperatures are reproduced by the tuned model simulation very well.

The statistics of simulated compared to measured strand surface temperatures for all measurements of the 39 heats under stationary casting conditions is shown in Figure 12. The data measured by the temperature scanner have higher variations for each stationary state whereas the model simulations show more smooth temperature behaviours. This results in an overall model error with a mean value of -0.1 K and a standard deviation of 8.2 K, which confirms a reasonable accuracy of the simulation model. There are only few heats with simulated temperatures below 1095 °C which show systematic underestimations of the model calculations by about 5 – 20 K.

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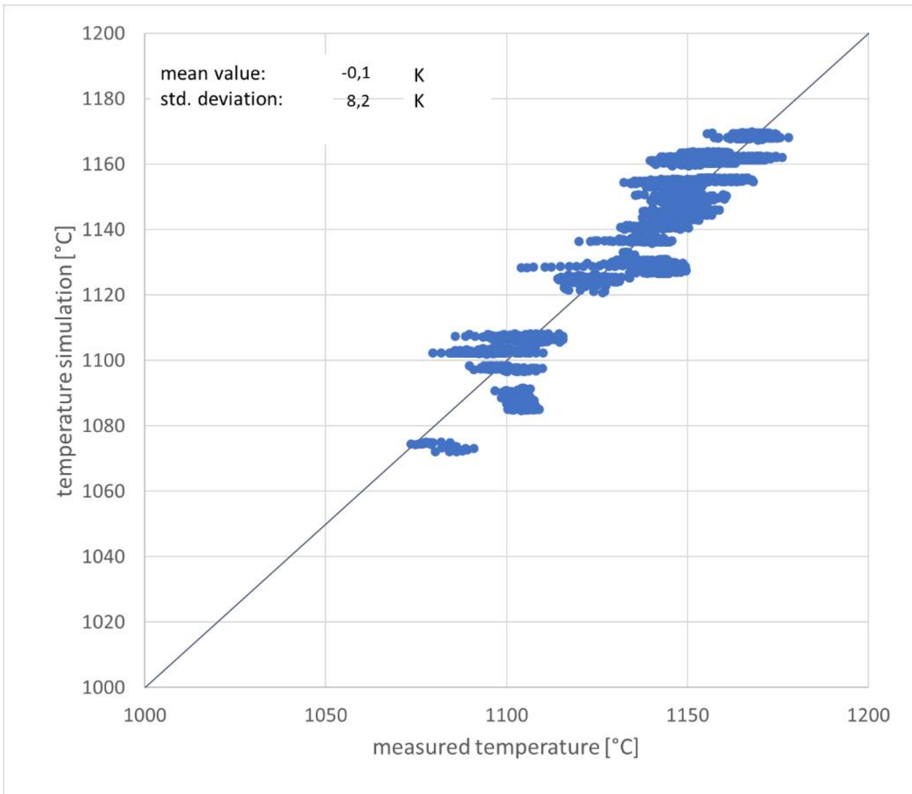

Figure 12: Simulated vs. measured strand surface temperatures for all relevant measurements of 39 heats casted at Sidenor

4.2.2 CSS3, Sensor for Product temperature

The CAPRI CSS3 temperature soft sensor is a software solution that tracks the temperature development of steel billets and bars in the hot rolling mill and the following cooling bed. A video explaining the concepts and presenting the user interface of the sensor is attached.

The temperature evolution of billets and bars during and after rolling can have a great impact on their quality, which is why we aim to correlate this information with the surface quality assessment data that is recorded for the steel bars at the end of the process chain considered in the project.

On the surface of hot steel in ambient air the growth of iron oxides, the so-called scale, can cause surface defects in later processing steps. Primary scale develops in the reheating furnace at the beginning of the hot rolling mill and is subsequently removed in a descaler, whereas secondary scale develops thereafter in the rolling processes before the units are cooled down to approximately 500°C. Then the growth of scale stops, which is why the hot rolling mill and the cooling bed are the crucial places where secondary scale build-up takes place and where we want to track the temperature curve of our steel products.

Another potential application for a cooling bed temperature soft sensor is the optimization of the cooling bed occupation.

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In our demo site, a couple of temperature measurements of the steel surface are made by means of pyrometers, installed at fixed locations in the rolling mill. The soft sensor interpolates the product temperatures to time intervals where no measurements are available, in our case the time spent on the cooling bed.

For the development of the soft sensor two months of temperature measurements have been collected from the production system, including the pyrometer data, furnace temperatures, and partly also the material properties and casting data. The data was made available as a process timeseries and needed to be converted to product-centric datasets by means of the tracking codes recorded by the furnace automation system, in line with the Digital Twin approach pursued in the project.

For the development of a temperature model several parameters need to be known: the contour of the product, the start temperature of cooling, the material parameters, and the ambient conditions. Some of them are known exactly, such as the geometry of the round bars and their chemical composition, others are estimated or could be calibrated by means of actual surface temperature measurements, such as the heat loss coefficients.

The modelling is done by an FEM-analysis, using a partial differential equation toolbox for the heat transfer. For each diameter a 2D-mesh for the cross section is generated, a reasonable maximum start temperature is selected, material and boundary conditions are defined, and the model is run.

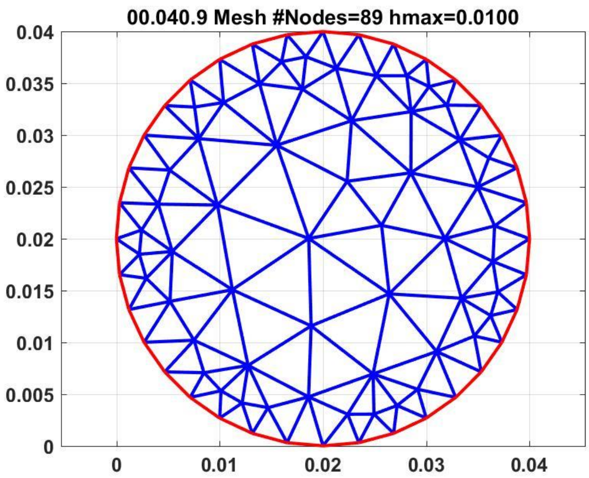

Figure 13: A sample mesh for the temperature model.

The model simulation is executed for a certain timespan, for example 150 minutes, with variable timestep, for example 30 seconds.

The result of the temperature model is a cooling curve, including the two-dimensional temperature field in the product cross-section and the mean temperature at the bar surface over time. These model results are stored as templates in the database. For every billet that is rolled in the hot rolling mill, the temperature at the end of the process will be used as a starting point where the template cooling curve for the respective diameter will be attached.

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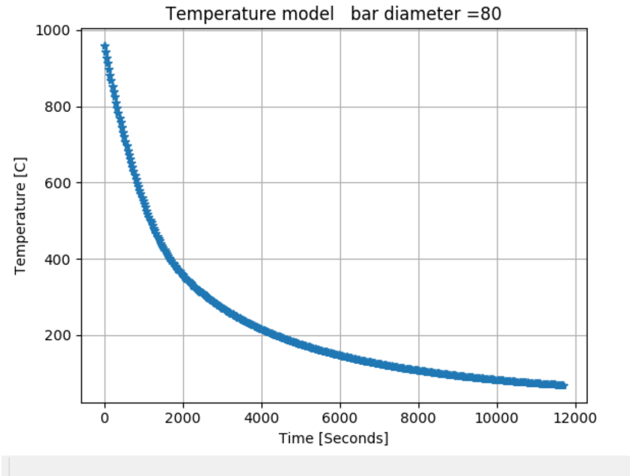

Figure 14: Cooling curve for a round steel bar.

A web-based user interface provides access to both the raw data and the results of the soft sensor. This user interface is presented in the accompanying video. It has two panels, the first one shows the raw data as it is received from the automation system for a selected timespan. We can see the temperature recordings at three different positions in the hot rolling mill, and additionally the billet tracking code of the last billet leaving the reheating furnace.

The second panel shows the same data in a product-centric way, using the API provided by the digital twins of the billets. We can see the temperature recordings for one or more billets. The difference is the perspective, no longer time-related but product-related. Addionally here we see as result of the model implementation the forecast of the temperature development of the billet after rolling.

4.2.3 CSS4, Scale sensor for scale build-up

CSS4 Video

The video for CSS4 gives a short introduction into the algorithm (cf. paragraph below) and shows the graphical user interface developed for user interaction with the solution. The latter provides a view of the scale thickness of a billet, respectively the bars cut from it, as a function of time.

CSS4 Algorithm

The formation of scale on the surface of a steel product is a complex chemical reaction. It is a high temperature oxidation build-up of three kinds of iron oxid: FeO, Fe3O4 und Fe2O3. The composition and thickness of the oxidation layer strongly depends on temperature, and the steel composition also plays a role.

In this scale sensor the secondary scale is of interest. This scale grows during and after rolling, when bars are air cooled on the cooling bed, in a temperature range from 1100°C down to 500° C. Scale growth effectively stops at temperatures below 500°C. Temperature information comes from the hot

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rolling mill data and CSS3, the steel composition is recorded originally as input data for CSS2. The scale soft generates an estimate of the secondary scale thickness as a function of time.

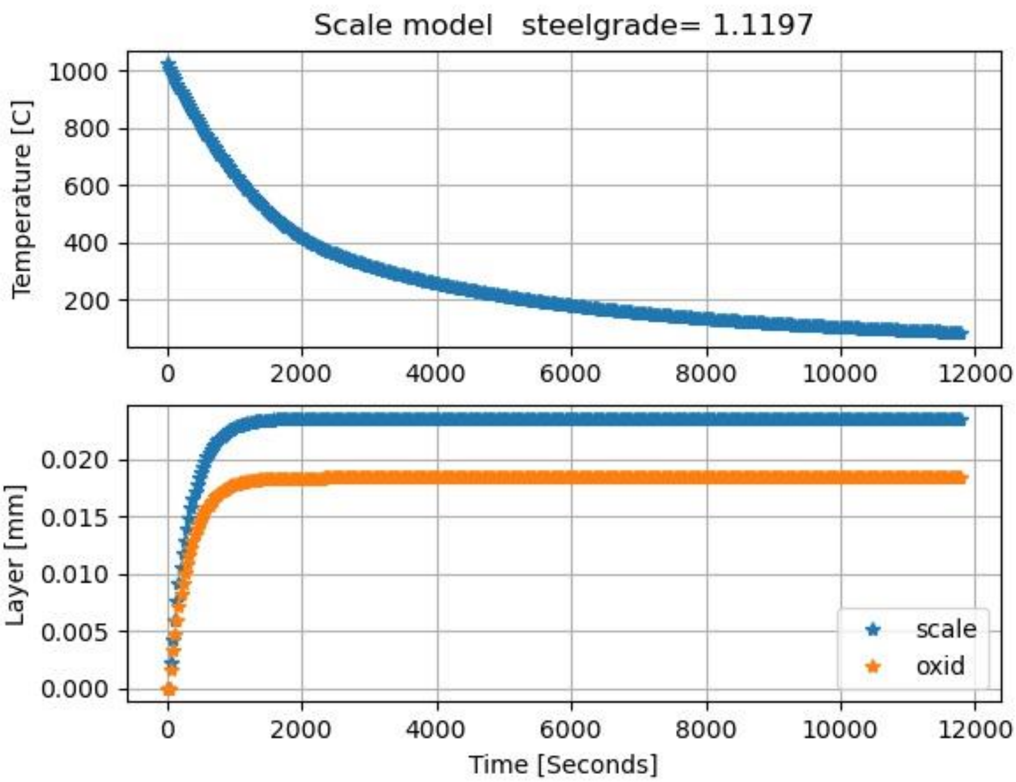

Figure 15: Scale thickness as a function of time.

4.3 Pharma domain (RCPE/AMS)

4.3.1 CPC1, Cognitive Control Concept

The first part of CPC1 (process control concept) is based on model predictive control (MPC). From the measured particle size distribution, characteristic size values of the granules are computed (CPS2). These size values (e,g, mean value of volume based particle size) are considered controlled variables. The main process inputs affecting the size are the solids and liquid flow rates at the granulator inlet. Their ratio (liquid to solids ratio, L/S) is considered the manipulated variable. The process model required by the MPC concept has been created using the local linear model tree (LOLIMOT) approach. For that purpose, dedicated experiments exciting the granulation process inputs were executed and the response in terms of mean granule particle size was measured. This data was then used to train the process model. Finally, a model of the form

$$\hat{y}_k = f(u_{k-1}, u_{k-2}, \dots, u_{k-3,}\ \hat{y}_{k-1}, \hat{y}_{k-2}, \dots, \hat{y}_{k-3})$$

was implemented.

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The optimisation problem, which is the core component of the MPC was formulated as follows:

$$\min_{\mathbf{u}=[u_k,\dots,u_{k+n_c}]} \sum_{i=0}^{n_p} (r_{k+i} - \hat{y}_{k+i})^2 \; Q \; + \; (u_{k+i} - u_{nom,k+i})^2 \; R + \; (u_{k+i} - u_{k+i-1})^2 \; R_\Delta$$

$$\text{s.t. } \Delta u_{min} \; \leq u_{k+i} - u_{k+i-1} \leq \Delta u_{max}$$

$$u_{min} \; \leq u_{k+i} \leq u_{max}$$

$$u_{k+i} = u_{k+i+1} \quad i \geq \; n\_c$$

$$\hat{y}_{k+i} = f(u_{k-1+i}, u_{k-2+i}, \dots, u_{k-3+i,} \, \hat{y}_{k-1+i}, \hat{y}_{k-2+i}, \dots, \hat{y}_{k-3+i})$$

The controller parameters (prediction horizon n_p, control horizon n_c, weights Q, R and R_Δ) have been iteratively selected via simulation runs.

In Figure 16 the results of a simulation run with CPC1 active are shown. After activation of the MPC, the controlled variable mom1 correctly tracks the corresponding reference profile. Constraints on the process input LS are taken into account by the controller. Figure 17 Figure shows the experimental results of a test run carried out on the manufacturing line. The zip-archive A3_DAT_CPC1_20220223.zip contains a dataset that has been captured using CPC1 (see Table 4).

Table 4: Contents of the CPC1 zip-archive

Filename	Description
A3_DOK_CPC1_process_data.xlsx	Process data of an experimental run including the granule size control.
Explanation.txt	Textual description of the process data contained in A3_DOK_CPC1_process_data.xlsx

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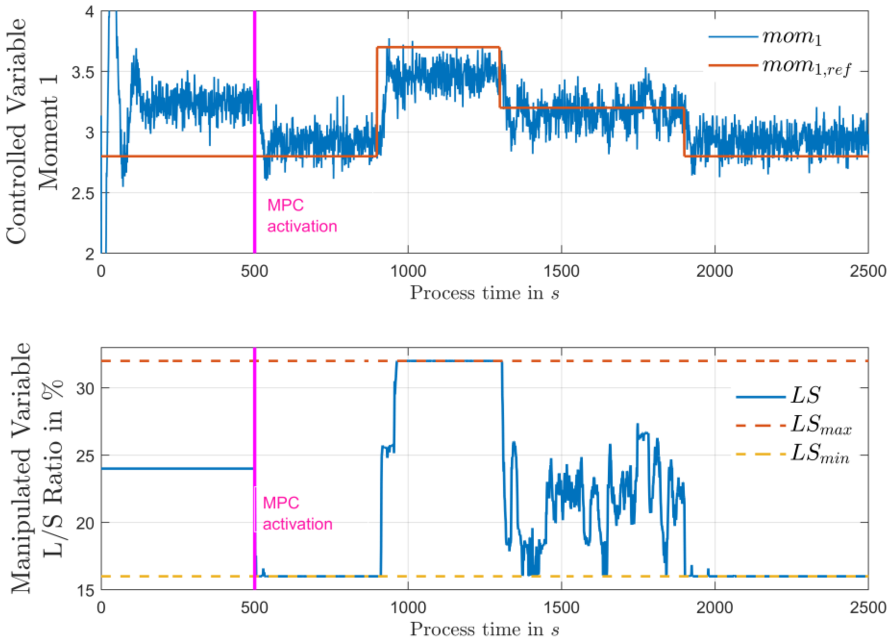

Figure 16: Simulation study of MPC control of the mean granule size. Top: controlled variable mom1 (mean particle size), bottom: manipulated variable liquid to solid ratio (LS)

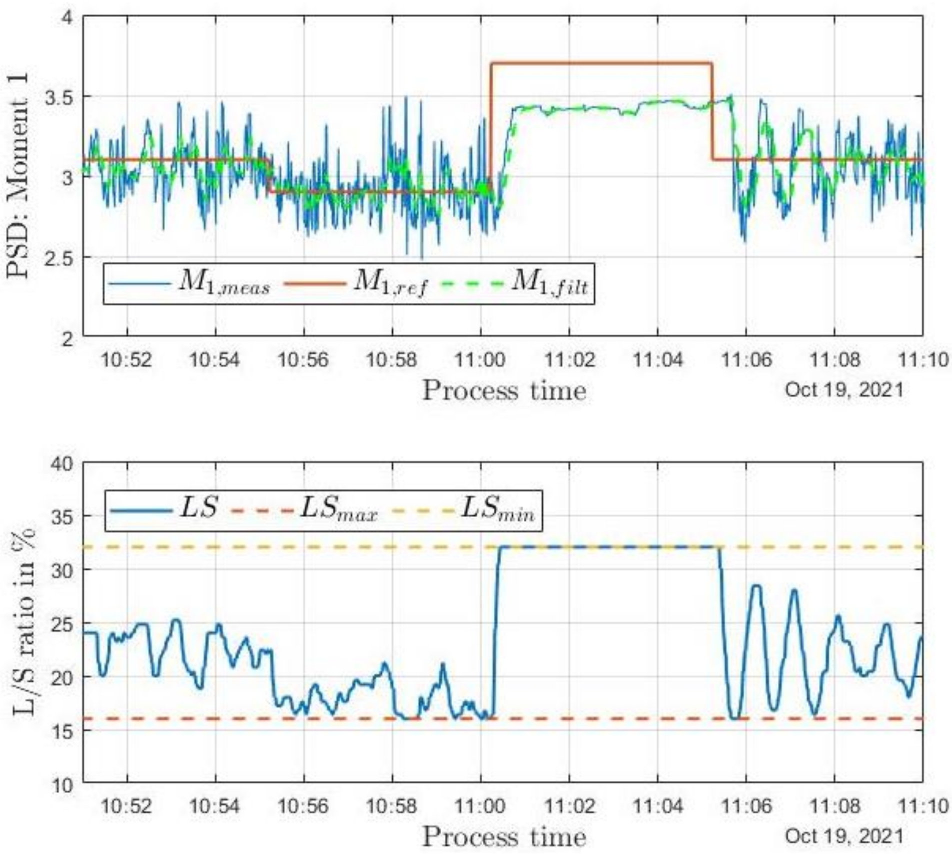

Figure 17: MPC control of the mean granule size. Top: controlled variable M1 (mean particle size), bottom: manipulated variable liquid to solid ratio (LS)

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In terms of dryer control, the dryer model developed in CPS3 (see deliverable D3.4) is used to predict the granule moisture in real-time. Based on that information, the drying is stopped as soon as the desired value has been reached.

The second part of CPC1 (quality control concept) takes information from CPS1 and CPS3, as well as from other available process data (e.g., solid feed rate, scale at external phase dosing), feeds this into a material tracking model that has been developed for the manufacturing line. A screenshot of the Simulink implementation of the material tracking model is shown in Figure 18.

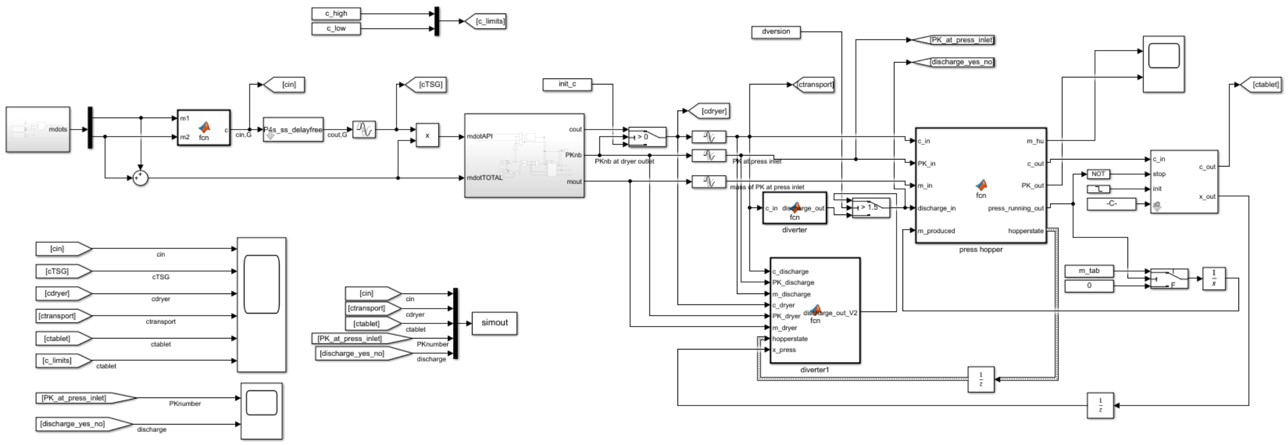

Figure 18: Simulink block diagram of the material tracking model

5 Conclusions and Next Steps (NISSA)

D3.3 – "CAPRI Industrial IoT Platform and Data Space", is a deliverable of type OTHER that, together with D3.3, D3.4 and D3.5, targets the 'MS4' milestone related to technology validation of different cognitive solutions at M24. The document has described the concrete achievements in the development of the smart control/sensors cognitive solutions, leveraging the CAPRI Reference Implementation described in D3.1. Main practical results have been detailed for each domain and cognitive solution, providing algorithms, sources, data format, data samples, and videos showcasing the implementation done in laboratory activities in WP3.

The output of WP3, starting from the control/sensors based cognitive solutions described in this deliverable, will be integrated with the CAP platform in order to satisfy the needs of the three CAPRI domains (i.e., Asphalt, Steel, and Pharma) supporting all use cases and covering the entire life data cycle from the data ingestion to the data presentation. The algorithms, already analysed in terms of rationale, technology, and intellectual property, will be integrated into the CAP platform for implementing the processing layer. After the integration of the cognitive modules, the platform will be tested and tuned, thus feeding the validation scenarios in the three plants, to be addressed in WP5 through two iterations. WP4 will pave the way to ultimate objectives of quality, flexibility and performance. On the other hand, a toolbox of cognitive solutions for sensing, control, operation and planning will be developed to help the adoption of the CAP for batch, continuous and hybrid process industry plants. The final validation will take place in WP5, addressing manufacturing challenges in industrial operational environments of the three chosen process sectors, and providing useful feedbacks and lessons learnt.

Next steps will be in T4.1 (on Cognitive sensor solutions for process industries) and T4.2 (on Cognitive control solutions for process industries), where cognitive control/sensors developed within WP3, will be integrated with the CAP following a modular and iterative approach, to provide a holistic solution, managing the cognitive functions embedded in cognitive control/sensors. At the same time, the integration will enable a higher level of intelligence exploiting the vertical integration of such sensors with other processing modules, at both edge and cloud level, delivering the cognitive applications towards the appropriate user role (e.g. planners, managers, workers), with first deliverables due by M28.

The "Sensor Layer" and the "Control Layer" Reference Implementation of the CAP will be developed and will enable further customizations for the implementation of the three tailored instances of the CAP for the three pilots. This layers will provide features and capabilities to enrich physical sensors with soft sensors and digital twin representations required for further control and business services.

The progression in the maturity of the cognitive solutions will enable an in-depth analysis in WP7, for the shaping of the exploitation opportunities of the different CAP layers and the CAP platform as a whole, as well as opportunities for replicating cognitive solution in other sectors of process industry.

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