COGNITWIN

Cognitive plants through proactive self-learning hybrid digital twins

DT-SPIRE-06-2019 (870130)

Deliverable Report

Deliverable ID	D6.1	**Version**	V1
Deliverable name	T0 baseline measurements of the KPIs		
Lead beneficiary	SINTEF (SINTEF AS)		
Editor	Stein Tore Johansen (SINTEF)		
Contributors	Are Dyrøy (Hydro), Iñigo Unamuno Iriondo (SIDENOR), Mika Liukkonen (SFW), Kjetil Hildal (ELK), Ulrike Faltings (SAG), Aylin Demircioglu (NOKSEL), Peter Singstad (CYB) and Stein Tore Johansen (SINTEF)		
Report review	Kjetil Hildal (ELK) and Iñigo Unamuno Iriondo (SIDENOR)		
Due date	29.02.2020		
Date of final version	28.02.2020		
Dissemination level	PU		
Document approval	Frode Brakstad	28.02.2020	

The COGNITWIN project has received funding from the European Union's Horizon 2020 research and innovation program under GA No. 870130

Executive Summary

This report, the first deliverable from COGNITWIN WP 6, Impact and Exploitation, focuses on the impact expected from the project partners that provide pilot case studies. Each of the “pilot partners” have provided a description of their respective cases, provided a number of Key Performance Indicators (KPIs) and devised how to measure or quantify those. Then, for each pilot, baseline values of the KPIs are determined. The baseline KPIs will be the reference for assessing the progress and success of COGNITWIN.

Table of Contents

Acronyms

GTC	Gas Treatment Centre
HSE	Health, safety, and environment
KPI	Key Performance Indicator

1. Introduction

This report is the first deliverable from COGNITWIN WP 6, Impact and Exploitation. It summarizes the results from Task 6.1, "Conduct the baseline KPI measurement based retrospective data". The scope of this work package is to maximize the impact generated by the project, in different communities and on different aspects; in improved operations, reduced emissions, improved energy efficiency, creating business opportunities, new jobs, improved education as well as other socio-economic benefits. An important part of the expected impact will come at those of the project partners that provide pilot case studies. In order to measure that impact, each of the pilot partners have provided a description of their respective cases, and

- Provided a number of Key Performance Indicators (KPIs)
- Devised how to measure or quantify those
- Determined baseline values of the KPIs – based on historical data up to the time of project start-up.

This report summarizes this work. It also contains objectives for improvements in some of the KPIs. There is one chapter for each of the pilot industry partners.

2. Pilot 1: Hydro Gas Treatment Centre

2.1 Short intro to pilot case

In aluminium plants the electrolysis cells (pots) are fed with primary alumina (raw material) which has been used to adsorb and clean HF from the off-gas leaving the cells. In this way valuable F is recovered and the off gas is cleaned. The primary alumina becomes secondary after it has picked up HF from the off gas and is next transported to the cells and fed into the electrolyte. The quality of the primary alumina impacts both the operation of the cells and the operation of the Gas Treatments Centre. The pilot deals with optimization of the Gas Treatment Centre and the interplay with the pots in the electrolysis halls.

2.2 Baseline KPIs

Since the pilot is divided into several cases, in which all aim to increase the raw material stability to the electrolysis and energy consumption of the GTC, each of the cases (numbered 1-3) are set up with a tangible KPI's. These KPI's will play into the overall KPI's in the application.

1. Matched and even distribution of HF to primary alumina feed, by demonstrating primary feed matching HF mass flow (calculated from logged operational data).
2. Keep constant temperature for best possible adsorption, i.e. 90°C ±5°C (from logged data)
3. Reduce the power consumption on the 3x 1 200 kW fans by 5%, measured by logged energy consumption from fans before and after activation of Case 3.

3. Pilot 2: SIDENOR – Cognitive digital twin of steel ladle

3.1 Short intro to pilot case

In the COGNITWIN project, the main focus for Sidenor is on the refractory linings of the ladle and the objective is to predict when the refractory lining in the ladle need to be replacement (or repaired).
Ladle refractory wear problem is the combined effect of thermo-physical-chemical processes activated by working conditions. The understanding of the whole process requires splitting the different stages:

Tapping → Liquid Steel → Casting → Cooling and Burner Heating

These steps are repeated for each heat although the numeric aspects may vary greatly as the times of the processes for the ladles are not necessarily regular; ladle operations are usually affected by any operational incidence or even decision in the steelmaking shop.
The extent of refractory degradation during ladle operations depend on physical-chemical conditions imposed by the process, and by mineralogical, micro chemical and technological characteristics of the refractory.

3.2 Baseline KPIs

3.2.1 Justification and short description

The Cognitive Digital Twin will help to reduce refractory wear and increase operational ladle lifetime. The goal is to increase ladle refractory lifetime to 80 heats for full relining and 40 heats to partial relining. As part of this the ambition is to reduce the critical refractory depth for renewing the refractory lining

3.2.2 Methods of estimation, time period when KPIs were measured

The data set to be used in the frame of COGNITWIN project is based on mainly from two data sources. One of those sources will be the measurements of the refractory remaining thickness measured during the repairing and demolition phase of the ladle, an on the other hand, the second data source will be obtained from all available steelmaking process parameter measurements during the working period of the ladle.

3.2.3 Numerical values

- Timelife of refractory lining: Reference of 80 heats for total ladle relining and partial relining (slag line) at 40 heats. The goal of the project will be to increase a 5%
- Reduction of the critical refractory depth for renewing the refractory lining: Initial refractory has 6 or 7 inches (155 mm or 180 mm) in different parts of the ladle. Final value of 50 mm is considered safe.

4. Pilot 3: Elkem - Optimization of silicon process

4.1 Short intro to pilot case

Elkem produces silicon in large (up to 45 MW) electric furnaces at process temperatures above 2000 C. The silicon is tapped from the furnaces into ladles and is a highly manual process performed in an environment with extreme heat and dust exposure. Today tapping conditions are measured using either manual sampling in the liquid silicon in the ladles or weighing the full ladles after the tapping, which has a high HSE risk. Elkem wants to develop remote operation of the tapping process, and online sensors will be giving information about furnace production rate. Similarly, real time data for the incoming metal can give information regarding temperature and composition to be used later in the process. The silicon furnace process is the core of the silicon plant, where raw materials, electrode materials and electric current in fed into the furnace. Out of the furnace comes off-gases from which heat is recovered, and dust is removed before the gas is released to the atmosphere. Slag and metal is tapped batch-wise into ladles. The ladles are transported to refining stations where the metal is refined and chemical composition adjusted as needed. Upon completion of the refining process, the metal is cast, the ladle is cleaned and the cycle starts again.

4.2 Baseline KPIs

The most important KPI`s are

1. Post-taphole yield (tonnage cast/tonnage tapped). These values are measured for each batch.
2. Hit-rate on chemical composition (intended product/actual product)
3. Specific energy use (kWh/tonnage cast). The energy is the electrical energy fed to the submerged arc-furnace.

As all of these values are sensitive information, and it will therefor be applied a relative value, set to 100, for the last 6 months of production for each of the variables. Improvements resulting from the project implementation will be calculated and normalized. Thus, the goal of the project is to:

- Increase PTH yield from 100 to 102
- Increase hit rate on intended products from 100 to 102
- Reduced energy consumption from 100 to 99
- Increase lifetime of ladles from 100 to 105

As of today, there are no good dust measurements taken in the plant. Thus, there is no way for the project to properly evaluate the reduction of dust emissions. In addition, none of the actions described in the proposal are aiming to reduce dust emissions. Therefore, there will be no further attempts to quantify improvements in this area. Similarly, there is no good way of measuring product quality variations (chemistry, microstructure, particle size) so this is not a convenient KPI for determining the success of the project. Elkem will be focusing on KPI 1-3 as described above.

5. Pilot 4: Sumitomo SHI FW – Boiler operations

5.1 Short intro to pilot case

Boilers are a critical element in the current energy industry and will play an important role in the coming green energy technologies. The Sumitomo pilot case deals with optimization of operation of boilers, designed and delivered by Sumitomo and aiming to be fast adapting to new and variable energy sources. Input to the plant is both developed technology (design and operation), combustible raw materials with a large variety in chemical composition, energy contents, and air that is sucked in, to support the combustion. Specific challenges are variations in fuel feed rate, corrosion and fouling. Output from the process is energy, combustion products and ash. The pilot case deals with the complete plant.

SHI FW customer’s business requires high flexibility in their operation, e.g. amount of energy produced together with new and more challenging fuels. These challenges are a consequence and necessity from the decarbonation targets in EU, and the consequent transition of the energy sector to renewables, especially solar and wind. To enable that transition, other power plants must assure highest flexibility. As usual, this EU environmental target will eventually extend worldwide. Customers face challenges in both plant operation, maintenance and asset management. The plant operators may struggle with the optimal operation when the fuel is continuously changing, especially when firing challenging renewables such as biomass and bio-residues. The fuel quality may be decreasing, and new challenges are set to maintenance and equipment lifetime as the harmful components in fuel are increasing.

5.1 Measurable KPIs and expected impact

5.1.1 Measurable KPIs

For the Engineering Pilot, SFW has identified some Key Performance Indicators (KPIs) to evaluate and measure the success of the development efforts. The original set of the measurable KPI targets were selected in order to highlight the various overall aspects of the plant operation performance:

1. Technical performance
2. Reliability and availability
3. Operation economy
4. Environmental performance
5. Safety

The technical performance of the boiler is measured by boiler operating efficiency which is believed to be improved by cognitive systems by enabling the operators to use optimal operating parameters and set values for each precise fuels, including the process controls, such as O2 set values, the usage of additives and steam coil air preheaters as well as to optimize the boiler cleaning practices by optimizing the boiler sootblowing frequency directly based on the fuel quality. The overall boiler reliability and availability are improved by cognitive methods both directly, by decreasing the bed related process disturbance and erosion/corrosion related pressure part defects, and in-directly, by minimizing factors that may cause or accelerate the boiler ageing or degradation, such as variations in process conditions or forced emergency shut downs.

Operation economy will improve together with the technical performance and reliability by lowering the operating costs related to consumption of fuels, additives and auxiliary power as well as the maintenance costs for repairing the boiler damages and restoring the boiler back to normal operation. Environmental issues related to the boiler are mostly related to boiler flue gas emissions. The improved boiler monitoring means and predictive controls decrease the variations in the combustion process and help to optimize the combustion temperature dependent NOx and CO emission, especially emission peaks in load change situations and disturbance events. Last but not least, the operator and environmental safety will be improved, as a combination of improved emission controls and the avoidance of process problems and unintended and unexpected shut downs of the plant.

5.1.2 Current situation of KPIs – initial values

The original measurable KPIs were defined based on average performance of an average plant (in the SFW customer fleet with various unit sizes and fuels) that has been in operation for several years, experienced some degradation and is not operated in the optimal way anymore. The original KPIs were defined as follows:

1. Improved boiler operating efficiency, target 0.05-0.10 % improvement on average
2. Lower operating costs, target 100-200 k€ saving in annual boiler O&M cost
3. Smaller emissions, target to decrease emission peaks and overall levels up to 30 %
4. Improved reliability and availability, target 0.5-1.5 % improvement in plant availability
5. Improved safety, target incident rate in process disturbances causing Lost Time (LTI) is ~ 0.00

Nevertheless, the piloting plant has a new boiler unit that will be handed over to commercial operation in spring 2020. Thus, it has not been experiencing any natural degradation, the used fuels are according to contract specs and the operations is more optimized as the boiler process controls have been tuned by experts right before the hand-over. Therefore, the improvements in the piloting project are expected to be somewhat lower than in an average unit in the SFW fleet.

The current situation of the KPIs is partly not known, as the unit has not been in commercial operation yet. Some of the KPIs can be estimated based on the design and guarantee values of the boiler, but not all. For example, the O&M costs are confidential business figures of the end user (i.e. the customer company) and can be only estimated by SFW. The current safety figures from customer’s other units are not available from the customer and the current status cannot really be estimated by SFW.

The current status of the measurable KPIs is (design or contractual guarantee value / range):

1. Boiler operating efficiency: Typical ~89.5-92.0%
2. Operating costs, boiler O&M cost / year: Typical 600-700 kEUR/year (first 5 years)
3. Emissions, peaks as hr-avg, overall day-avg: Permit NOx and CO both 100-150 mg/m3n (fuel)
4. Reliability and availability: Typical ~ 98.2-98.3%, estimated by SFW
5. Safety, Lost Time Incident Rate (LTI): Status not available from customer’s other units

5.1.3 Future situation of KPIs – calculations and target values

The improvements in the selected KPIs will be calculated after two years warranty period i.e. during spring 2022 by comparing the measured performance (KPIs) after the implementation of the cognitive systems to the measured performance prior to the implementation. This measured performance type of evaluation will be available for Technical performance, Environmental performance and Operation economy (if figures available from the end user).

Technical performance will be evaluated by calculating the average plant efficiency in normal commercial operation, not in a specific performance test. Normal EN stardards will be used for the calculation (DIN1942 etc). For the evaluation, 6-months periods for ‘before’ and ‘after’ will be specially selected in such a way that the fuel and load conditions of the boiler are as similar as possible. Some correction curves can be used for fuel quality, if the fuel quality is not similar during the measurement periods.

Also the ***Environmental performance*** will be evaluated by calculating the average performance in normal commercial operation, not in a specific performance test. The performance will be evaluated by two key factors:

- Number of the short emission peaks when exceeding the emission limits for hourly average given in environmental permits (hourly average limits) for CO and NOx separately
- Overall emission limits over the 6-months periods as long average for CO and NOx

Correction curves can be used for fuel quality if the fuel quality is not similar during the measurement periods.

The ***Operation economy*** will be evaluated in similar 6-months periods based on the direct impacts:

- Efficiency improvement and it’s effect to boiler operation economy (fuel consumption)

- Improvements in other operation economy, such as additive consumptions etc
- Possible effect of the avoided downtime during the period, if the availability can be measured

The overall effect to O&M costs, especially the maintenance cost and any indirect cost savings, will be anyways measurable only after several years in operation, i.e. is longer than the program timeline.

Availability will be measured by comparing the plant operation hours and load levels compared to the ones required by customers power and district heating demand. Only the unavailability incidents will be counted to the evaluation, that are both attributable to the equipment delivery and related to the fuel quality, process controls or can be or could have been detected by cognitive systems.

Typically, the ***Safety*** KPI would be measured by interviewing the customer plant management and the number of reported and recorded incident would be the measured value. The improvement evaluation would be made by comparing recorded number to customers records of previous years. This improvement evaluation is, anyways, consent to customers willingness to provide the details also from the other units, so it is possible that we may not have access to these data. Therefore, we will not evaluate the safety KPI further.

Based on these marginal conditions, the measurable target improvements of KPIs are set to:

1. Improved boiler operating efficiency: +0.05-0.10 % in average as cont. performance
2. Lower operating costs, boiler O&M cost: -100 k€/year during the first 5 years
3. Smaller emissions, decrease emissions: avoid limit exceeding: overall levels -20%
4. Improved reliability and availability: +0.3-0.5 % in plant availability

6. Pilot 5: Saarstahl AG – Tracking system for rolled bars in the rolling mill

6.1 Short intro to pilot case

The primary goal is to track individual billets in the Nauweiler rolling mill train, thus providing a linkage between various sensor data as well as other relational data on individual billets collected before and after the non-continuous part of the mill train. Another benefit of the computer vision tracking system will be to detect deviations and erroneous billets. The overall goal is to link data collected throughout the production process to an individual steel rod, thus obtaining a digital twin of each produced rod. To meet this goal, a necessary step is to close the missing link in the Nauweiler rolling mill train. The digital twin in return can then e.g. be used to optimize production processes, recognize causes for deviations and, depending on the specific situation, react in real time to prevent deviations from occurring.

6.2 Baseline KPIs

- Improve rolling line efficiency by 15%
    - By identifying and reacting to situations likely to cause erroneous bars, the rolling line efficiency is improved already. Additionally providing a linkage in data associated to individual billets throughout the production process will allow SAG to use advanced analytics to identify other causes for deviations in the production process and react to

- these by e.g. adapting rolling parameters for individual billets. Moreover, the final version of the tracking system should allow for further automatization of the rolling process in the blooming train altogether [although this will most likely exceed the scope of COGNITWIN project].
    - **Methods of estimation, time period when KPIs were measured**: efficiency measured as amount/tons of non-first-grade products shipped to customers in assigned timespan. E.g. for one year and in relation to overall amount of billets entering Nauweiler oven in assigned timespan
    - scaled present situation, based on 2018 values: efficiency = 1
- Reduce energy consumption (15%) and process emissions (15%)
    - Each occurrence of an erroneous bar means a new billet needs to be cast and rolled, leading to additional energy consumption and process emissions. Moreover, the return transport to the steel mill for remelting has further impact on process emissions. Thus by identifying and reacting to situations likely to cause erroneous bars, this additional impact can be reduced. Moreover, providing a linkage between data associated to individual billets over the entire process will allow SAG to use advanced analytics to identify other causes for deviations in the production process and react to these to reduce the level of scrap from the production goods even further [i.e. the level of billets/rolled bars with too severe deviations to be sold to the costumer that are remelted].
    - **Methods of estimation, time period when KPIs were measured**: energy consumption & emissions measured as amount of gas and electricity needed. E.g. for one year and in relation to amount/tons of non-first-grade products shipped to customers in assigned timespan. As energy consumption is linked to produced tons, will be measured indirectly by ratio of non-first-grade products as compared to all products, same as for rolling line efficiency.
    - scaled present situation, based on 2018 values: Energy consumption=1, Emissions = 1
- Automatic error detection
    - At present, there is no automatic detection of situations in process that will likely lead to e.g. bent bars or of erroneous bars in assigned section. The target is to identify over 95% of erroneous bars automatically and to identify over 90% of situations likely leading to erroneous bars automatically. As to the tracking: At present, around 95% percent of all billets enter and leave the mill train sequentially, however, since there is no tracking system installed so far, it is not possible to safely link the sensor data obtained in and after the mill train to data associated to a particular billet ID obtained earlier in the production process. The goal is to track at least 98% of all billets successfully throughout the mill train and recognize when tracking failed such that at most for the two billets in the non-continuous mill train section at that time data from later in the process cannot safely be linked to one of the two respective billet IDs, only to the two IDs together/two-ID-tuple.
    - At present, there is no automatic error detection installed in assigned section
    - Zero automatic detections at present

7. Pilot 6: Noksel – (Cognitive) digital twin powered condition monitoring (and control) in steel pipe manufacturing industry

7.1 Short intro to pilot case

Noksel's pilot case project is creation of a cognitive digital twin for an SWP machine in steel pipe production. The digital twin will collect and analyze multiple sensors' data in real-time, and enable a smart condition monitoring system for predictive maintenance. Smart components that use sensors to gather data about real-time status, working condition, or position will be connected to a cloud-based system that receives and processes all the data the sensors monitor. This input will be analyzed against business and other contextual data through smart visualization systems. The digital twin model will allow joining physical and virtual worlds to create a new networked layer in which intelligent objects interact with each other to virtualize the steel pipe manufacturing process on the SWP machinery. The aim of the project is to support predictive maintenance and thus increase total equipment performance, reduce energy consumption per ton, and decrease average machine downtime by analysing operational and automation data received from different sensors with digital twin supported condition monitoring platform to be developed in serial production of steel pipes.

7.2 Baseline KPIs

The KPIs to be used are: Type I and Type II errors in anomaly detection, and reductions in machine downtimes and energy consumptions. Since Type I and Type II errors in anomaly detection system don't exist in our current system, the most important KPIs in NOKSEL use case are reductions in SWP machine downtimes and energy consumptions.

7.3 Justification and short description

The Cognitive Digital Twin will improve to reduce both energy consumptions and SWP machine downtimes. By decreasing number of downtimes; our aim is to decrease number of start/stop of the SWP Machinery so that energy consumption amount during starts which requires more energy will be prevented. Moreover by enabling efficient running of SWP machinery (with lower number of downtimes) will increase production amount so that energy consumption produced by electrical systems of the SWP Machinery will also be prevented which results in total energy consumption decrease and at the same time increase in production amount.

By means of a successful implementation of a predictive maintenance system, it is expected that the machine downtimes to be less than the current number of downtimes, because the number of machine downtimes to due machine failures related to maintenance activities will be minimized.

7.4 Methods of estimation, time period when KPIs were measured

Electric consumption data has been started to be recorded daily since November 2019. Before this date, electric consumption data was recorded monthly. Therefore; the current figure is set from SWP machine real recorded data. These figures are calculated from following formulas;
If **X** represents the current energy consumption of SWP to produce 1 ton of steel pipe and **Xt** the energy consumption to produce 1 ton of steel pipe after implementation of ideas from COGNITWIN. For both **X** and **Xt** the unit of measurement is KWatt/ton.

Xo = Total energy consumed (KWatt) per time month/ steel pipe produced (ton) before COGNITWIN per month
Xt = Total energy consumed (KWatt) per time month / steel pipe produced (ton) after COGNITWIN per time month
Xt <= Xo x 0.90

Yo = average total machine downtime duration per month in m months / total machine working time per month before COGNITWIN
Yt = average total machine downtime duration per month in m months/ total machine working time per month after COGNITWIN
Yt <= Y0 x 0.90.
m: number of months 0 →a and t -> a+n