D1.4: Recommendations for HyperCOG solutions from the operators’ point of view

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1. Introduction

The aim of Deliverable 1.4 – Recommendations for the HyperCOG solutions from the operators’ point of view was to collect information and make recommendations about:

- User activity for the three industrial partners use cases (Sidenor, Çimsa and Solvay);
- Needs of operators in the digital field.

Throughout this study, our goal was also to compare the operators’ point of view regarding the use case proposed by each company for the HyperCOG project.

To collect this information, two methodologies were proposed: Observations and Semi-structured interviews. 5 interviews were conducted with Sidenor (face to face), 6 with Çimsa (remotely) and 5 with Solvay (face to face). Due to covid-19, field observations were carried out only for Solvay.

The data collected during each interview was analysed by using the thematic analysis method, which is one of the most common analyses in qualitative research. Throughout these interviews, the final goal was to make recommendations for the HyperCOG solutions from the operators’ point of view.

The document is structured as follows: First, the methodology used is described (part 2.). Second, the analysis of each company is presented (part 3, 4, 5). Recommendations are detailed following the analysis in each section.

Due to privacy concerns, some information had to be removed for this public version.
2. Overview of the methodology

The main objective of HyperCOG is to demonstrate the innovation potential of the Cyber-Physical Systems (CPS) and Data Analytics to transform the process industry and business models. To achieve these objectives, HyperCOG aims to develop systems in the value chain to different industrial sectors: steel, cement, and chemical sectors. These systems can be greatly improved by applying HCD (Human Centered Design) approach. The HCD method suggests “to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors and ergonomics”, as described in the norm ISO 9241-210:2010. This approach integrates the end users from the beginning to the last iteration of the problem-solving process that shall serve as a backbone to the projects, to shape the system in function of the end users need and requirements (and not the opposite).

In the first step of the HCD method, the goal is to conduct semi-structured interviews and observations. These two methodologies are important and should be deployed together. In this way, it will be possible to collect information and makes recommendations about operators needs and gaps in the digital field. This work will be also helpful for the WP6: Learning resources development.

2.1. Semi-structured interview

For this study, we will conduct semi-structured interviews. That means the interviewer follows an interview guide. An interview guide is composed of different themes. It takes place between an interviewer, who asks the questions, conducts the interview, and an interviewee, who answers the questions. All questions must be asked most faithfully as provided in the interview guide. Depending on what the participant says, the interviewer can detach himself from the guide by making reminders deepen certain points. The interviewer should not ask a question that the participant has already answered. If needed, the interviewer can suggest new questions but not remove them.

For this study, the themes covered in each interview guide were:

- Task, tools, work environment
- Technology used
- Organisation between operators
- Operators needs

Before interviews, the HyperCOG project must be present to the participant. A little speech was writing (Annex 1). The interview must be conducted in native language (Spanish for Sidenor’s operators, Turkish for Çimsa’s operators and French for Solvay’s operators) to facilitate communication. Then, the interview must be recorded in audio. The interviewer must acquire supervisors’ and participants’ consent. The recording authorisation (Annex 2) must be signed by each participant.

The data collected during each interview were analysed with the thematic analysis method which is one of the most common analyses in qualitative research. The method allows patterns of meaning or “themes” in datasets to be identified, analysed, and interpreted. Qualitative data are segmented, categorised, summarised, and reconstructed in a way that captures the important concepts within the dataset inside a grid.

In this document, essential verbatim are provided in italics and blue. A verbatim transcript captures every single word from an audio file in text, the same way those words were originally spoken during each interview.

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2.2. Observation

Observation is a “field” method, which consists of collecting observable data from operators. The data collected are behaviours, verbalisations, interactions with colleagues and with manual and technological tools. The aim is to understand the working environment of operators, without interfering. Indeed, there is always a difference between what an individual claim to do (the task: what is to be done) and what he does (the activity).

2.3. Road map

The initial roadmap planned for 2020 is described in the figure 1:

Due to COVID-19, our approach has not been changed, but rescheduled:

- The exploration phase took place in September/October 2020
- The validation phase in November/December 2020
- The finalization phase in February 2021, for a rendering of the deliverable on February 12, 2021
3. Steel Case: SIDENOR

3.1. Company profile

Sidenor, founded in 1878, is a steel company, leader of the European production of special long steel products. The production of the company is based in Basque Country, Cantabria, and Catalonia as well as business delegations in Germany, France, Italy, and the U.K.

The company has highly specialised facilities offering solutions for all industrial sectors requiring high quality steel services. Sidenor’s steel production capacity exceeds one million tons annually, primarily destined for the automobile, machinery, capital equipment, railway, energy, mining, and petrochemical industries. In all these sectors, Sidenor’s special steel is used to manufacture reliable products.

The project takes place in the Basauri factory (figure 2), founded in 1967. In 2017, the plant had 744 employees. They are specialised in the production of round steel bars (from 30 to 100 mm round). The Basauri factory rolling mills and finishing units produce 400000 tons of round bars (melting capacity = 850,000 t, rolling mill capacity = 360,000 t, light bar capacity = 75,000 t, heat treatment = 115,000 t).

The factory produces more than 400 styles (grades) of different steels. The raw materials are scraps and ferroalloys. A significant amount of other auxiliary materials is also used such as slag formers or refractory materials. In the Basauri plant, the production cycle is planned for one week from Thursday to Wednesday. The plant is open 24/7. It allows about 24 heats per day or about 140 heats per week. The heat is the basic production unit in a steelmaking shop.

3.2. Presentation of Interviewees

Before starting the interviews, it was necessary to identify operator profiles involved in the use case. Four profiles were identified with Sidenor:

- Production coordinators
- Production managers
- Field operators
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- Employees in the company planning department

Interview guides were proposed to each profile. The following topics were discussed getting the opinions of the interviewees:

- Production line management and planning
- Production chain and disruptions
- Tools used
- Steel making melt shop and tundish change
- Coordination between each department
- Training
- Future needs

Due to the particularly difficult social conditions produce by the COVID-19, there was a working time reduction (full or partial) affected SIDENOR team. Despite the difficulty to cross the frontier, ESTIA were able to conduct face-to-face interviews. The following analysis presents the supervisors’ vision and summarises their specific needs. The methodology used to analyse the activity and identify operator practices was partially deployed as this analysis is based on semi-structured interviews and no field observations could be made. But this study allows to take a starting “photo” of the current situation. It is a valuable input for the development of the technological solutions.

In total, 5 interviews were conducted between November 26 and 27, 2020. Each interview was recorded and afterwards transcribed into Spanish, before being translated into French for analysis.

3.3. Basauri process

The steelmaking plant process can be divided into six steps:

1. Scrap and ferroalloys storage

The raw material arrives by truck to the steelmaking plant. Then it is received and classified in a register called PDA. The scrap combination is made at the scrap yard. The crane operator is responsible to collect the scrap types that make the recipe that will be delivered to the furnace.

2. Furnace

The raw material (scrap and ferroalloys) is melted in an electric arc furnace (EAF). The steel needs around 1600°C to melt.

Secondary metallurgy

When the scrap is melted it is tapped to a container called ladle then the composition of the steel grade is reached by adding the missing alloys and subtracting elements.

3. Casting

Once the desired composition has been obtained, the liquid steel must be given a first solid form, an intermediate step before its final shaping. The liquid steel contained in the ladle is solidified in a caster machine. The molten steel flows continuously. The heat is the basic production unit in a steelmaking process. First heats are grouped in “sequences”. This sequence (the group of heats) is cast into the tundish which is made of refractory material and which can resist high heat. Each sequence shares the same set of casting machine refractory materials (tundish lining, stopper rod, SEN or nozzles). Then, it passes through the mould, the flow of steel meets the water-cooled walls and begins to solidify. The moulded metal goes down, guided by a set of rollers. There are three different main shapes depending on the desired bar size: “billet continuous caster”, “bloom continuous caster” and “round continuous
caster”. When the metal comes out, it is solidified at heart. The result is called: “billet” (square section long bars) or “bloom” (square section long bars or rounds bar).

4. Hot Rolling

Before rolling, the semi-product is reheated in a furnace to make the metal more malleable, easier to stretch and shape. Then the semi-product pass through the rolling mill to produce the final product: Round bars from 30 mm to 100 mm diameter.

5. Heat Treatments

The heat treatments are only applied to some steel grades. It alters the metallurgical properties of the bars produced in the rolling mill by controlled heating and cooling operations. The final process is the finishing units. They make the final preparations and quality measurements of the bars to prepare them for the expedition to the customers.

The figure 3 describes the process since the raw material to the semi-product.

3.4. Use case reminder

The use case covers the transformation of liquid steel into solid semi-products. Basauri plant produces specialty steel for many customers and different steel grade orders. The difficulty for the steelmaking shop is to combine different grades, not too long sequences, optimize the losses coming from mixed steel scraping, production shutdown due to a new sequence start and internal customer needs. The decision about how to group heats in sequences and the order inside them is an activity that is done by humans (implicit knowledge required, frequent adaptations and rescheduling due to production incidents very difficult to preview). The decision has important effects over material losses, productivity, quality implications and constrains. There is therefore a need to create a decision-support system. The problem includes all the constraints generated by the rest of the installation in a steelmaking shop (secondary metallurgy and ladles, electric arc furnace and, of course, both casting machine casters) as all the steps relate to each other.

The following scopes for improvement have been identified in the deliverable D1.1 regarding the use case:

1. The scheduling of heats itself in some of its phases is hand made as it has many constrains that are not easy to implement and important complexity is handled by human actors. Translating it to the digital knowledge to feed a CPS is a challenge.

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2. Rescheduling operations in production is also manual but with the difficulty of the lack of time. The number of possible problems and incidents that can alter the scheduling is high.
3. In the previous cases the interaction between humans and CPS systems is clearly described. Several gaps appear here as the menace for the jobs or the communication between humans and machines.
4. Several aspects and systems are part of the scheduling, some of them with less data. Data integration is always difficult in production areas where the main focus is not to stop production or alter production systems.
5. Cybersecurity is a growing concern in industry. The former isolated control systems are more and more interconnected and are more vulnerable as they are becoming a more sought target for cyber-attacks. The lack of secure design is widely present in industries like steel that started early to get automation of systems and do not change frequently tools that work.

In the next part, the goal is to highlight positive points as well as the limitations and needs expressed by the operators related to the use case but not only.

3.5. Interview analysis

3.5.1. Positive feedback

R&D and Improvements

HyperCOG is not the company’s first European Project. Sidenor participated in the COCOP project (end of March 2020) which is also about Industry 4.0 and some others. The company is part of the Research Fund for Coal and Steel (RFCS) which supports research and innovation projects in the coal and steel sectors. The company also participates in other programmes with external clients. Improvements are therefore under way at each stage of production and supervisors seem to be involved in these evolutions.

“We contribute with the support of our department in the investment’s definition, in engineering, in the execution, in the implementation, we are very involved which contributes powerfully to the investments’ success.”

At the scrap storage, a software called SDA (internal name for the MES system) is currently optimising. The improvements are suggested by operators, then their needs are prioritised and sent to the IT information department. Operators’ needs seem to be considered, which is very positive.

“Crane operators detect improvements while carrying out their work. They realise that some functionalities do not work correctly so they give their suggestions to the manager. Then it is in the other way, the improvement is made, and the operators can test them.”

Preventive Maintenance

Preventive maintenance seems to be for the company a strong point for the company. Many investments have been made to considerably reduce the number of failures and avoid production interruptions.
“Preventive maintenance is optimal, it works very well in this factory because we have few failures, so the productivity is constant.”

“We have a very powerful maintenance cell reorganised over the last ten years so today, this maintenance cell is able to drive and guide investments’ execution.”

Training
It seems that when new tools are put in place for employees, training sessions are suggested (theoretical training and field training). This approach is a good point since it allows to overcoming employees' reticence and fears. Employees’ reluctance to integrate new tools into their daily work is normal and common. The importance is to be able to guide employees by suggesting training.

“...There is a period of testing and training and once these steps are successfully completed, the implementation is established.”

“There is a training that takes place on two levels: one to explain the fundamentals and another in the field. Supervisors are very close to the employees to train them in the field.”

“We had some reluctance, but we never had any frontal refusals or opposing attitudes at the end: Some of them accept it with optimism and hope, others with scepticism, but in the end the employees in a global way, they end up collaborating, accepting willingly and admitting the benefits of the implementation posteriori.”

Communication and collaboration
On all interviews carried out, the participants generally consider that communication and collaboration between each department is good (between the scrap storage and the furnace, between planning, Central office, and production, etc.). This is particularly important since the production chain is a continuous process in which each department depends on each other (once the scrap is in the furnace, the process cannot be stopped. Production shutdown is a very costly and time-consuming process. However, this only concern communication and collaboration between supervisors. The quality of communication/collaboration with operators has not been studied.

“The communication is very fluid with both managers and operators.”

“Finally, there must be coordination, there is a good communication between departments.”

“We have good communication: it is fluid, and you can ask for advice from everyone. So, communication is not something that I have a problem with.”

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3.5.2. Specific limitations and Needs

Scrap and ferroalloys storage

The first difficulty of the process is the heterogeneity of the raw material. The scrap or ferroalloys used come from different sources and maybe constitute of different residues: copper, tin, molybdenum, and nickel. Each casting has requirements regarding residues. According to the requirement of residual, it belongs to a family that has a standard. The standards define the quantities of residues not to be exceeded. All raw material arriving at the plant must be received and classified with a software called PDA. But most of these tasks are manual such as taking pictures and characterising the quality.

“Our greatest uncertainty is the heterogeneity of our raw material.”

A first need emerges regarding the classification of raw material arriving in trucks. They need a support to detect non-ferrous materials (residues that do not contribute to the process and may produce an invalid casting due to poor quality.) (i.e., identification of material whose copper rate exceeds established limits).

“The scrap metal classification could be improved.”

Two interviewees spoke also about the need to improve the SDA software (internal name for the MES system) that is used for casting request programming. This tool is appreciated, but it should be updated. In addition, the register could be more reliable and could be partially automated. However, this point seems already take into consideration by Sidenor since improvements are currently in progress.

“We do not have all the data quickly. The registry could be better or more reliable...I think it would be to optimise the production process, to automate it.”

A second need arises regarding the weighing of the raw materials in the preparation of the steel mixture at the crane (i.e.: Ostrende crane). Currently, the mixing is carried out with the unaided eye by the crane operator. This can have an impact on the quality of the final product and generate stock or waste.

“The steel mix, for example, an improvement would be to have a weighing scales in the crane, in the crane of Ostrendre, which is the alloy. There, if we had a weighing system, the mixing would improve, because right now we are doing it with the unaided eye. If we had a weigh-in, it would be reliable.”

Heat Planning

Once the fabrication orders (OF) are provided, a casting order is created. From there, the planning is done manually on an Excel (figure 5) by a supervisor.
It is necessary to organise and create the sequence (create groups and classified heats) considering the constraints to improve both quality and losses. The constraints for the operator are many:

- Fabrication orders (OF) that come from the central office → very short-term overview that generates a lack of agility and overlord in work for the operator.
- Availability of raw material.
- Manage with deadlines.
- Emergency.
- Process constraints → optimise the cost of the steel plant in the manufacturing process.

The last one, “Process constraints” is related to two other constraints:

1. **Steel bars variability**

   The particularity of Basauri concerns the variability of production. Unlike an ordinary steel plant which produces a low amount of different steel grades (type), Basauri is specialised in special steel. It produces for many customers, each with specific requirements and in small quantities. This difference sets the factory apart, but it is also an important constraint in terms of productivity.

   The factory’s goal is to avoid products stock and melt only what is necessary. All of heats produced must be brought together to create sequences in the programme. If the sequences created have different grades casting, the intersection between each casting will have to be thrown out, which is a significant cost and productivity loss. The difficulty is therefore to know how to combine heats and avoid different grade sequences (SDC or SMC) in the planning.

   "The reality is that we have to manufacture a lot of steel grades, so our variability is much greater than those who decide to manufacture only one steel grade… If we had, for example, two or three customers asking us for fifty thousand tons of same grade, we would always make the same steel with which we would gain in productivity because we would always do the same thing, we would gain in order because we could do a lot of castings of this sequence and we would gain in quality because we would repeat the same thing."
Another programming constraint concerns bar size (diameter) because **not all size can be produced together in one week**. Basauri can make three sizes of small billets (155, 185, 240), each for different production line, to make blooms of 350x 470 and round blooms of 410 and 525. However, they must choose in the programme which sizes will be manufactured each week.

“Our first decision is therefore to tell the steelworks which sizes we are going to use for this cycle.”

2. **Tundish’s change**

This is an important element, in fact, with the heat of the liquid steel, the refractory materials (tundish lining, stopper rod, SEN or nozzles) must be changed regularly (exchange time = 40 min). Studies have shown that the tundish must be changed at least every 5 series to meet quality requirements. Each sequence shares the same set of refractory materials. The refractory materials must be changed more often if the composition of the steel changes. However, it is sometimes more cost-effective and time-effective to produce steel bars and then to throw them, as the composition is not the right one, rather than change the tundish. Changing the sequences generate a non-productive time due to the restart of the machine. This time can be long or short depending on the operation to use. Modelling tools are used to calculate and estimate if the tundish should be changed or not. However, **the optimisation of sequence development and tundish modification are mainly decisions taken by experience.**

“When you plan the loads, you take them into account so that there are no sudden changes, because you don’t change a tundish that has a lot of cooper to another that doesn’t have, for example. This is part of the programming: coordinate and juggle with the distribution.”

“We have a limitation in which one, in short sequences of two flows, you do not have to heat the next tundish. The tundish has a minimum heating time. I mean, it has to do with programming. Because... it must be considered that the short sequences must take place either before a bloom sequence or after it, because of the heat time of the tundish.”

“The sequence can contain only heats of the same composition or heats with small changes in composition.”

**Most of the constraints presented are informal knowledge.** Currently, the operator used only Excel and SAP. SAP is appreciated but it is not sufficient to meet the operator’s needs. SAP does not integrate all the information that comes from the production, which is particularly limiting. At the end, a central office will collect the Excel that was generated to check the programme and make new proposals. However, these annotations are not plotted in a specific tool.

“I have no tools to tell me what those constraints are, I’m based on experience, on the annotations that are made, with the papers that are created. It is a whole jumble of situations that you collect to try to order it.”

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“Today, we do everything by hand, there are dozens of inputs that govern our mental equations that we manipulate to make this ordering…. You understand? It is a little complicated. We are based most of experience. What happened to us last time? How’s it going?

There is therefore a real need to improve the planning which is currently create manually (transferring information from SAP to Excel and then to the central service). This can be done by optimizing SAP or developing another tool that would consider the constraints mentioned below.

“The first handicap that I have is not being able to visualise what is the best programme for my needs.”

“My main problem is that I only work on SAP. I’m going to explain to you how we do this, to show you that this programming system is very manual… SAP seems to me to be a very good tool: versatile and able to adapt to needs, but Excel is only a spreadsheet that is to say… Excel doesn’t help me in this process.”

“So you can see that this translates into an Excel spreadsheet, but the steel plant's limitations criteria are actually in my head.”

Decision making during the production process

The steel works schedule must be followed but, regularly adaptations are necessary. Reprogramming is frequent due to unpredictable production incidents. The operators on the production line are not directly involved but alert in case of problems. Incidents that could disrupt the initial programming come in many ways:

- Quality deviation (due to residues or scrap metal, deviation in the process in the furnace).
- Equipment failures requiring corrective maintenance.
- Timing problems. The steel works must have a rhythm because it is a continuous process (the furnace cannot be ahead or behind the process).

The reorganization of the program is usually carried out by a working group. This group use different tools such as: MES system (Manufacturing Execution System), PLC (Programmable Logic Controller), SCADA (Supervisory Control And Data Acquisition), Mix Steel Calculation Tool, Ladle Thermal State, etc. But these tools do not facilitate the decision-making work of operators. Depending on production incidents, different decisions can be made:

- Continue production.
- Stop the furnace.
- Change the quality of the cast part or replace it with a part that can fit in the sequence.

Each of these solutions have an impact on quality, productivity, and cost. In addition, these decisions depend on multiple factors:

- Ambient humidity has an influence on decision-making process for setting the programming time (i.e.: weather).
- Heating time of the tundish.
• Continuity of the process. Once the scrap is loaded into the furnace, the process cannot be stopped. Production shutdown is a very costly and time-consuming process.
• Etc.

For each incident, a solution can be found but the decision is currently taken manually, without any help besides experience. Supervisors try to increase their knowledge but most of the situations are different and new. Developing a tool to improve decision making and therefore improve the quality, the safety and the productivity is undeniable.

“If you have a tool which tells you which is the best melt or which melt to replace that does not influence the operation, that would be a help.”

“The expectation is very concrete; an algorithmic solution to help us make decisions in the manufacturing software.”

“A good improvement would be that, to have support, support when helping us to make decisions which must be immediate; this decision-making should be limited. A tool that tells us that between this change, this one and that one, we can choose the one we want.”

3.5.3. General limitations and needs

Technology intelligence

According to a supervisor, an important comment and complex point concern technology intelligence implementation. To be able to improve production, safety, environment, cost, efficiency, etc. a permanent technology watch group should be suggested. This work should be done by a technical support such as specialized engineers.

“It is true that technological intelligence is beginning to become a very difficult task. The staff of the company must include electronic engineer, another nuclear physicist, who will constantly participate in fairs or congresses, travel, look at the internet, search, etc.”

User Centered Design

As we have seen in positive points, operators’ needs seem to be considered. Nevertheless, it seems supervisors are not involved during the design process while the user centered design approach (UCD) is essential to avoid operator’s refusals. The User-centered design (UCD) process outlines the phases throughout a design and development life cycle all while focusing on gaining a deep understanding of who will be using the product. Design is based upon an explicit understanding of users, tasks, and environments; is driven and refined by user-centered evaluation; and addresses the whole user experience. The process involves users throughout the design and development process, and it is iterative. This process shall serve as a backbone to the project to shape the system in function of the end users’ needs and requirements (and not the opposite way). Users should be included in the whole process and not just at the beginning.
“In the design phase, employees don’t participate in the design process. Supervisors are obviously protagonists in the design and the implementation phase. If we are talking at the working-class level (operators’ level), no, they are not involved in this design phase.”

Cybersecurity
Currently, the systems used in the steel plant combine different ages and maturities as the system is complex. For this reason and the industrial reality, the vulnerability to cyber-attacks is more and more present. The tools that we be developed in the HyperCOG project will have to take into consideration cybersecurity, which is a growing concern in industry and particularly at Sidenor.

3.6. Recommendations
The use case covers the transformation of liquid steel into solid semi-products and more particularly tundish’s change. For Sidenor, the main goals of this project is to provide operators with a decision support system in order to optimise as much as possible the sequence programming. Due to the heat of the steel grade, the tundish must be changed several times a day. The aim is also to automate production planning. Through the interviews, we were able to identify that many needs were revealed in all the processes, since the scrap and ferroalloys storage to the semi-product production. The need related to tundish’s change is a topic within a larger topic.

“In other words, we have no problem with consumption of tundish. We are more limited by quality than by tundish.”

At the first step, an important need concerns the identification of the raw materials quality. For this specific point, new tools can be proposed to help the classification of raw material. Another solution will be to improve the current software tool that is used for casting request programming.

At the second step, the needs are at the planned heats level. Basauri produces specialty steel for many customers and different steel grade orders. The difficulty for the steelmaking shop is:

a. Consider steel bars variability: to combine different grades (shape and size), not too long sequences to avoid different quality sequences, optimize the losses coming from mixed steel scraping, avoid products stock and melt only what is necessary.

b. Organize tundish’s change.

The optimisation of sequences development (to group heats in sequences) and tundish change are mainly decisions based on experience. Most of these constraints are informal knowledge. This point is particularly important, since in the event of employees' departure (retirement, resignation, etc..), the knowledge acquired could disappear.

“If, we were computerised, automated, that would be a great achievement, but it doesn’t exist, and we are based most of experience.”

D1.4. Recommendations for the HyperCOG solutions from operators’ point of view
Public
Different solutions can be proposed to meet these needs:

- **Tool optimisation or tools development:**
  - SAP optimisation.
  - Creation of a decision-making support system to help heats schedule considering the constraints.
  - Metal casting optimisation to reduce the tundish’s change: Increase the tundish lifespan to obtain longer sequences or reduce nozzles wear.

- **On the commercial level,** negotiate new markets with much more order quantities to avoid multiplying customers and producing different steel grades.

During the production process, different incidents can occur. In this case, important decisions must be made that can impact quality, productivity, and costs. Currently, most of these decisions are made with implicit knowledge. To help employees in these decisions, several solutions can be imagined:

- Use continuous casting sensors to detect irregularity in the process that could cause a failure which in turn would cause tundish’s change.
- Creation of a decision-making support system to reschedule the production.

Three general limitations were also found and should be considered in the HyperCOG project:

- Technology intelligence implementation.
- User centered design approach.
- Cybersecurity implementation.

To help HyperCOG project partners, several recommendations were suggested. In the light of the analysis, the priority recommendations would be:

1. Creation of a decision-making support system to help heats schedule (production planning) considering the constraints.
2. Use continuous casting sensors to detect irregularity in the process that could cause a failure which in turn would cause tundish’s change.
3. Creation of a decision-making support system to define how to reschedule the production.

Two precautions must be taken regarding the improvements that will be proposed in the project for Sidenor:

- All the stages of the production are interrelated. The proposed improvements will have to analyse the impact on the entire production process.
- Strong expectation from employees who would like to be involved into the solution design process.
4. Cement Case: CIMSA

4.1. Company profile

Çimsa, a subsidiary of Sabancı holding, was established, in 1972, in Mersin (figure 6). Currently, it is carrying out its operations with its 6 integrated plants in Turkey. As one the first two brands in the world in white cement, Çimsa is an international cement manufacturer with its terminals in Germany, Italy, Spain, etc. It meets the product and service needs of its customers in full and in a timely manner with its market-oriented approach and wide distribution network. As a reliable business partner of its shareholders, Çimsa provides the required materials for living areas, and their infrastructure, reaching next generations.

The plant, by manufacturing special type cements like white cement and calcium aluminate cement besides grey cement, leads the Turkish cement and building this approach in the future as well.

Çimsa focuses on profitable growth that will add value to all its shareholders, with the aim of maintaining this approach in the future as well.

The project takes place in Mersin plant. The plant is open 24/7. 500 employees work there, and three types of cement are produced: grey cement, white cement, and calcium aluminate cement. To ensure the continuity of operations on the lines, operators work in 3x8, 6 days a week, and 7.5 hours a day.

The plant has 4 production lines: 1 grey cement production line, 2 white cement production lines and 1 calcium aluminate cement production line. For control and monitoring, each line is divided in 2 sections: kiln section and mill section.

The good maintenance of operations is ensured by a set of people: field operators, automation operators, supervisors, the maintenance planning department, and the cement quality control department.
4.2. Presentation of interviewees

As the ESTIA team was unable to travel to Turkey and conduct interviews in Turkish. The Ekodenge team was our intermediary between Çimsa and ESTIA. As a reminder, Ekodenge is a team of sustainability experts which seeks solutions and strategies that minimise the urban and the industrial footprint with holistic life cycle thinking, taking advantage of information technologies and deliver convenient, innovative, cost-effective, and applicable solutions for sustainability. Ekodenge is the SW integrator of the use-case 2 (cement use case, WPS).

To support Ekodenge in this approach, a methodology and interview guides were provided. In total, 6 interviews were conducted by Ekodenge remotely: 4 in September and 2 in December. The interviews were recorded and afterwards transcribed into Turkish, before being translated into English for analysis. All transcriptions and translations were done by Ekodenge team.

During the interviews, the following topics were discussed gathering information and get the opinions of the interviewees:

- Operators’ activities and work organisation
- Production chain monitoring
- Cement quality control
- Equipment maintenance
- Disruptions
- Technological tools
- Future needs

Despite sanitary conditions difficulty produced by the COVID-19, ESTIA were able to train Ekodenge team to the semi-structured interview method. Six interviews were conducted remotely by Ekodenge.

4.3. Mersin process

HyperCOG project is involved in one of the white cement production lines. It concerns the whole of this production line. The aim of the project is to optimise the monitoring of the production line with new systems to improve cement quality control and equipment maintenance.

4.3.1. White cement production process

The cement manufacturing process is described below (figure 7).

1. Quarrying limestone: the materials necessary for the manufacture of white cement are extracted from open-cast quarries by electronic firing.
2. Crushing limestone: cement limestone is transported to the crusher, the materials are then reduced to a maximum size of 80 mm.
3. Storage and prehomogenisation: the materials are stored in the form of strata to mix the different geological veins.
4. Raw mill: the raw materials are then dried and ground very finely.
5. Preheating: the product is reheated to around 750°C-900°C.
6. Kiln: the material is brought to about 1300°C-1600°C, the flame is around 2000°C.
7. Cooling: the cooled material is called “clinker”, it comes out at max. 300°C with 0-10% humidity and 75-88% whiteness (whiteness target min. 85%).
8. Clinker storage.
9. Cement mills: the clinker (92%) is ground very finely with other additions (5% gypsum, 3% marble) to obtain standardised qualities of cement. The size of the clinker particles should not exceed 5 microns. Water is added to the mill at a rate of 0 to 5 m³/h, with the aim of working in ranges of 100 to 115°C without exceeding this temperature.
10. Storage and dispatch: the products thus obtained are stored before being shipped in bulk or in bags.

![Cement manufacturing process diagram](image)

**Figure 6.** Cement manufacturing process description (for white cement production iron is not used between steps 3 and 4).

### 4.3.2. Production chain monitoring description

The production line is monitored by the **automation operator from the control room** using his screens. He ensures the proper functioning of the equipment and the good quality of cement.

From his screens, he follows several parameters:
- Temperature
- Vibrations
- Humidity
- Pressure
- Gas (O₂, CO, SO₂, CO₂)
- Cement quality
- Equipment state (mill, kiln, cooler, clinker transport lines, etc.)
Some data (temperature, vibration, humidity, pressure, gas) are obtained online using sensors installed on the equipment, while others (cement quality) are taken manually.

Moreover, visual checks are carried out by field operators to control the equipment state, such as the presence of cracks. During these interventions, the field operators are guided, by radio, by the automation operators. Automation operators are sometimes required to go to the field to better understand the problem. Each intervention in the field requires obtaining a work permit. The operator must be equipped with PPE (Personal Protective Equipment): mask, glasses, and helmet.

The automation operator reports his activity to the supervisor. The supervisor is responsible for the production outcome: the quantity and the quality of cement produced. He is also responsible for the health of operators, occupational safety, and equipment maintenance. He oversees field operators, automation operators and the maintenance planning unit. He is present on site during the day from 8 am to 6 pm. When taking up the post, he checks and examines production data, cement quality parameters and overnight accidents. If a major malfunction occurs during his absence, he is still notified by his colleagues.

4.3.3. Cement quality control description

The plant seeks to produce cement with the best quality. For this, throughout the production chain, from the raw material to the final product, samples are taken every hour manually by field operators. Over the entire installation, there are over 800 measurement points. For example, in the kiln, samples are taken from 30 different points.

Once collected, the samples are sent to the cement quality control department for analysis. The process takes a total of 2 hours: sampling, analysis, obtaining the results and communication to the target operators. During this analysis, the whiteness, the fineness, the amount of free lime, the moisture, the compressive strength, and the setting time of the cement are checked. For each parameter, thresholds, defined by the laboratory, make it possible to say whether the product is of good quality or not. A good quality cement is very fine and very white at 86-87%, below 85%, it is bad. The PSD (Particle Size Distribution) is also an important parameter.

If the poor quality of the raw material is detected, it is put aside so that it does not mix with other products. If the samples taken from the mill are of poor quality, the mill must be emptied. If the cement obtained from the production line is of poor quality, then it is not sold.

4.3.4. Equipment maintenance description

Equipment maintenance is carried out by the maintenance planning department with the assistance of electrical, electronic, measurement control and mechanical services.

The life of the equipment varies between 6 months and 1 year. Routinely, maintenance activities are planned to check the condition of the equipment. For example, the mills are checked once a week. During maintenance, operators follow a checklist on tablet or smartphone, which includes questions about the equipment: “Is there an oil leak?”, “Is there a problem with the sound?”, etc. The operator successively answers the questions by carrying out checks.

The maintenance planning unit can intervene urgently in the field at request of the supervisor, in the event of breakdowns or major problems with equipment, such as sensors or engines. The maintenance operator is guided by radio by the automation operator, so that the malfunctions detected on the screens are resolved.
The total shutdown of the production for overhaul is scheduled twice a year: once during the summer holidays and once during the winter holidays. During these shutdowns, all equipment will be checked, especially those requiring maintenance for 15 days. The plant operates year-round except during overhaul periods, i.e., 20 to 30 days per year.

4.4. Use case reminder

Today, in Mersin plant, the production is continuous. The line is equipped with sensors to measure certain parameters such as temperature, but there are no online sensors to measure cement quality parameters. Cement samples are taken manually and then analysed by the laboratory. The results are examined by the automation operators who control all the process parameters and ensure the continuity of the production chain.

The following scopes for improvement have been identified in the deliverable D1.1 regarding the use case:

1. To cool the clinker, water is introduced. The amount of water to be introduced should be kept at optimal level. For this aim, it needs to be monitored continuously. By installing temperature and humidity sensors on the clinker pan conveyor, with the feedback of the sensors to adjust the cooling system, optimum amount of water can be ensured, while optimum cooling is maintained.
2. Amount of free lime and whiteness are critical parameters for clinker quality. Free lime depends on the kiln process and quality of the raw meal. Whiteness depends on the cooling of clinker. By installing adapted online camera sensors on the pan conveyor, clinker can be continuously monitored, and the amount of free lime estimated.
3. The temperature of the clinker entering the mill is important because high temperatures change the additive structure and make grindability of the clinker difficult. By installing a heat sensor on the clinker silo discharge gates, with the feedback of the sensors, it will provide clinkers which have optimum temperature to enter the mill.
4. By installing PSD mechanical equipment and soft sensors on the exit of the separator, cement particle size distribution will be analysed. This will help production process to have more stable outputs. While stabilising the quality, the production tonnage in general will be increased, and energy will be saved.
5. Analytics-Driven prescriptive maintenance by equipping all crucial equipment with sensors that would monitor metrics like pressure, temperature, and heat and analysing the obtained data. Performance thresholds can be used to trigger a warning when sensors report a value greater than threshold value or machine learning algorithms can be used to analyse historical data and predict risk of failure for each equipment. For critical equipment like system fans, main drives, and separators with additional sensors. With prescriptive maintenance many failures can be predicted before it happens. By implementing this measure, it is possible to decrease the maintenance cost and down time of the factory.
6. Optimisation via digital twin, there are many different variables and steps to consider in cement production like quality of raw material, type of fuel inside the kiln, quality and chemical properties of coal and limestone, desired cost, and quality of the final product, etc. As optimisation across all steps and variables is difficult, systems and processes of company can be modelled in digital environment and machine learning algorithms can be used to enhance steps and optimise variables. Main KPI values like specific energy usage, quality values or calorific values may be simulated. Additionally, raw material and their respective ratios, resource use including water use and supply chain management could also be simulated and optimised resulting in more sustainable and efficient production.
In the next part, the goal is to deal with the need previously mentioned in the use case in depth thanks to interviews. We will also highlight the other needs mentioned by the interviewees as well as the positive points.

4.5. Interview analysis

4.5.1. Positive feedback

The plant has many technological tools and procedures that are used both for monitoring and maintenance of the production line and for communication between teams.

**Software**

To manage the cement production lines, the plant has 30 computers connected to the Internet and equipped with several software.

PLC (Programmable Logic Controller) software is used for programming field devices. Once completed, these programmes are transferred to the SCADA (Supervisory Control and Data Acquisition) software. This software is used to design and view automation pages, control field equipment and view sensor values (temperature, vibrations, pressure, etc.). This allows operators to follow variations in data. For example, having the humidity level live makes it possible to adapt in real time the consumption of water and energy and therefore to reduce costs. Additionally, if an indicator crosses the threshold value, the software automatically triggers an alarm to alert the operator about the problem.

During maintenance operations, the automation operator can see on his screens when the last maintenance took place. It allows to compare equipment data between the faulty state and a previous normal state.

“We look at the previous data of the equipment, such as a weekly or a monthly basis, such as maintenance, temperature, pressure. Thus, we can compare its normal stable state with its problematic state.”

For risk monitoring, the plant has QDMS (Quality Document Management System) software which lists all corrective and preventive action procedures.

“We have a Quality Document and Management System (QDMS), we have quality targets.”

Operators also use Microsoft Office 365. For example, for each shift, the operators enter in an Excel table the quantity of fuel consumed, the tonnage produced (quantity of cement produced), the number of defective products and set aside, and who was responsible for this shift.

“I also have an excel sheet on the computer.”

D1.4. Recommendations for the HyperCOG solutions from operators’ point of view

Public
Disruption process

During each disruption of the production chain, the following procedure is applied. The maintenance planning department is alerted. With the team leaders, they try to understand the causes of the incident and fix it. Any malfunction, interruption, shutdown, failure on the production line is reported and recorded in data history. Thus, in case of new malfunctions, this history can be consulted to see if the problem has already occurred before and how it was solved.

“We also learn from disruptions due to past malfunctions. So, we also use historical data.”

In the event of a kiln shutdown, a Root Cause Analysis (RCA) is carried out within 24 hours between the maintenance planning unit, the electrical and electronic services, and the cement quality control unit, to take the appropriate measures. Restarting the kiln can take 5 hours. In addition, to better understand possible kiln shutdowns and prepare for urgent restarts, RCA meetings are organised every Wednesday.

“We have regular meetings on root cause analysis (RCA) on Wednesdays. If necessary, we can also make instant meetings. For example, there are meetings for an occupational accident, an operational kiln stops, or an opened Corrective Preventive Action. Normally, we gather in the first 24 hours for the kiln stop and take actions.”

Communication

To facilitate the change of shift, automation operators have a shift book in which they note the work performed, the problems encountered and how these problems were managed. This shift book allows the operator on shift to find out about the events that took place during his absence.

“We take our notes about this problem, we report the problem. We report it so that the next shift or other shifts do not have the same problem.”

“I am reading the shift book.”

In addition, many communication tools are in place to facilitate coordination between the different units in post: radio, telephone, email, and meetings. Each shift begins with a 15-minute meeting to relay information from one team to another.

“I reach my colleagues in the field via radio.”

“I usually communicate by mobile phone.”

D1.4. Recommendations for the HyperCOG solutions from operators’ point of view

Public
New tools implementation

Before new tools implementation, operators were consulted to obtain their opinions.

“They do not do anything without our opinion.”

“They operators helped to put these and similar software into operation. I can say they look positive. They participate in the process and they are trained.”

Moreover, operators appreciated that their opinion is considered for the HyperCOG project.

“It is very nice to have the opinions of the operators.”

“I like that you care about the operators.”

This point underlines the importance of carrying out interviews with end users, to know their needs, before implementing new solutions.

4.5.2. Limitations and needs

SCADA software

Although SCADA software has advantages, operators would like some aspects of the software to be improved.

As seen previously, the software automatically triggers an alarm to alert the operator if an indicator crosses a threshold value. However, operators would like to be warned in two stages: having a first level of alert that serves as a warning and then having a second level of alert that corresponds to current alarms.

“It would be better if there were such devices, if they gave us the warning earlier, and gave us a pinpoint. There is awareness, but investment is needed.”

In addition, the SCADA software keeps in memory only data of the last month. To have an expanded history, the data are saved for 3 years in the Qualist Bridge software. However, operators would like to see from recent years directly accessible from the SCADA software. This would save time and make it easier to visualise the data to better understand past variations.

“If we could put data for the last 2 years, not a month, like our other facilities do, then it would be better if we could see the past trend.”

D1.4. Recommendations for the HyperCOG solutions from operators’ point of view
Sensors

Although the plant has already sensors to measure temperature, pressure, etc., operators suggest that number and precision of these sensors could be increased:

- **Having more precise sensors** would optimise the plant’s production. Indeed, although the temperature is measured by sensors, it is also measured manually by operators. However, sometimes there is a 6/7-degree difference between sensor measurements and manual measurements.

  “Sensors, temperature terminates can be further developed and be much more precise.”

- **Having more sensors** would improve equipment maintenance. This would provide a better representation of the condition of the equipment. Please note that the installation of these sensors must consider the location of the equipment in the field: the sensors are quickly damaged by the dust present in the factory.

  “We monitor the equipment with sensors. We can optimise it by increasing the number of sensors.”

  “To monitor the health of the working equipment, a suitable device must be selected by considering the location of the equipment in the field.”

Cement quality control

Cement quality control is a major issue. For the plant, obtaining poor quality cement is a big loss of:

- **Product**: Production targets are not being met.
- **Time**.
- **Energy**: Although the amount of material is reduced, machines still use just as much energy. To reduce the plant’s CO2 emissions, machines should be able to adapt their energy consumption according to the amount of material present inside.

  “When we reduce the tonnage, we lose energy. Because the same devices, same machines, same furnace, same fuel but low production. So high energy consumption but low tonnage.”

- **Economy**.

Operators raised some points about the cement quality control process:

- **The samples taken for analysis are small**. They do not reflect the entire volume of products to be analysed.
“We cannot analyse a huge bulk at all. Sometimes the raw material analysis cannot fully reflect the whole bulk.”

- If the analysis results take a long time to arrive and if there is any doubt about the quality of the product, the automation operator asks the field operators to perform visual checks. However, these checks are not 100% reliable. The operators do not have any real training. They learn from experience and from their colleagues. These controls still make it possible to give an idea and to decide whether the product should be put aside or not.

“Visual tracking does not give 100% accuracy, but still gives an empirical idea, helping us decide whether to ship the product of the stock hall, especially if the analysis has not arrived yet.”

To optimise the cement quality control, operators would like sensors to be installed along the production chain to have online monitoring of the various parameters: whiteness, fineness, PSD, etc. The installation of these numerous sensors would make it possible to avoid multiple manual sampling, to intervene quickly in the production chain and minimise the production out of quality targets.

“If these analysis values come to us continuously online, not in two hours, the interventions to be made in production would be faster, more active, and even proactive.”

Maintenance equipment

Operators mentioned that the maintenance of certain equipment is more critical than others: equipment failure which causes the production chain stop, equipment that must be dismantled and then reassembled, recurring breakdowns, etc. For example, the press, a machine that refines materials before putting them into the kiln, often breaks down. It is therefore checked 2-3 times per shift unlike other equipment which is only checked once per shift.

“In the press system, we need to pay more attention because the separators work with a hydraulic pressure system. Since it is an external part joint to the mechanism, it must be kept under constant control. I can say it is a complex system.”

“If other systems are checked once per shift, presses and separators are checked 2-3 times.”

In addition, if an engine breaks down, the entire production line stops. But the factory activity cannot be stopped for more than 8 hours. Changing the engine should therefore not take too long at the risk of causing a large loss of production. Some equipment, such as the reductor, comes from abroad. If their changes were not anticipated, it could strongly impact the production chain. As for equipment that can take up to 15 days to maintain, its maintenance is performed when the plant is closed during the winter and summer holidays.

D1.4. Recommendations for the HyperCOG solutions from operators’ point of view
“Critical equipment is large engines. They are the equipment that will stop the production when it fails. They are equipment that takes a long time to change and supply. For example, it can be the reductor of the mill. The reductor comes from abroad; it does not arrive immediately when ordered.”

Breakdown
General failures can occur due to a process problem, an electrical or mechanical problem. Operators report that energy cuts are quite frequent, especially in winter. In addition, the devices are connected to each other by a direct current. Thus, if a device at the start of the chain breaks down, the others will not work.

“In addition, although energy cuts are rare, they are slightly more in winter. Maybe we can say fluctuations instead of interruptions.”

“The mill is the final line in our production system. There are many systems before it. There are systems such as silo, fans, elevators, separators on the silo. When there is a problem in these systems, the mill is deactivated. If the front fan stops, the mill stops. If the elevator or separator is deactivated, the mill stops.”

In summer, some equipment overheats due to high temperatures. They are cooled by external fans.

“The biggest problem we encounter in summer is the temperature. Since the air temperature in summer is very high, especially if you are in a place like Mersin, the air temperature is already 35-40 Celsius degrees. In a working system, oil temperatures can reach 75-85 Celsius degrees. Therefore, there is a need for cooling, there are cooling equipment. We use external fans.”

Communication and training
Though communication tools are in place, operators believe that communication could be improved, which would solve the problems faster. For example, directing field operators by radio during maintenance operations is difficult work. Automation operators find it is difficult to direct staff to the malfunction and to explain it precisely. In addition, it happens that the radios do not work, which causes delays in interventions.

“The hard part is directing people, that is, directing the staff on the field to the malfunction and explaining the malfunction is a bit difficult. Sometimes I think it would be better to do it myself instead of explaining.”

“We can delay the intervention when there is a problem with the radios.”
Although trained in the use of software, operators feel that they do not master it 100%. They would like to be more trained in the use of software so that they can increase their skills. These training could take the form of a meeting, so that operators can discuss the use of the software with each other.

“It can be improved by training. We are not 100% competent on many pages in programmes like Qualist that we use on computers. There may be training for them. It is possible to exchange ideas with other operators by holding meetings with other central control operators.”

4.6. Recommendations

In the short and medium term, the plant has several objectives to achieve:

- Increasing the quality of the cement.
- Increasing production.
- Reducing the consumption of energy and electricity, to reduce the impact on the environment.
- Reducing the number of disruptions in the production chain.
- Reducing the number of human actions, to reduce the number of work accidents and improve the health and safety of operators.

As operators have pointed out, to achieve these goals, the plant must invest in new technologies and improve those already present.

“There is a need for a much digitalised and much online system. Because a field that works 24/7 should always be monitored.”

Following the analysis carried out, the following recommendations can be made:

1. Quality sensors must be installed along the production line. Operators will be able to monitor the cement quality parameters online (whiteness, fineness, etc.). High priority.
2. The number and precision of sensors, which are used for monitoring equipment, must be increased. High priority.
3. SCADA software needs to be improved, so that operators can access to data history of several months.
4. Operators need to be better trained in the use of software, to master all aspects of them.

Two precautions must be taken regarding the improvements that will be proposed in the project for Çimsa:

- For the installation of new sensors for monitoring equipment, the location of the equipment must be considered. Dust in the factory can cause premature degradation of the sensors.
- Strong expectation from employees who would like to be included in the process of designing and improving new solutions.
5. Chemical Case: SOLVAY

5.1. Company profile

Solvay, founded in 1863, is a Belgian chemical industry company. In 2019, the group employed 24,100 people spread over 115 sites in 64 countries. Its turnover is 10 billion euros. As a global leader in materials, chemicals and solutions, Solvay brings advancements in planes, cars, batteries, smart and medical devices, water, and air treatment, to solve critical industrial, social and environmental challenges.

The project takes place in the La Rochelle plant, founded in 1948, part of the Solvay group since 2013. This plant is dedicated to the manufacture of products formulated with rare earths. It has recognized expertise in the separation and purification of these rare earths, and the manufacture of high-tech products. The site has also a research and innovation department.

The La Rochelle site is international: it imports rare earths from Asia, receives them and exports 90% of its finished products. This site is classified Seveso 3, high threshold. The site has a unique production, it is the only one to own this kind of separation battery and works globally on organic chemistry with different fields of application such as: automotive, electronics, medical, etc. Traffic is marked as the 40 ha site and 320 employees include pedestrians, bicycles, cars, trucks and trolleys.

Three weeks of downtime for maintenance are planned each year on the site, two weeks in summer and one week in winter. The maintenance is done by an external company. Alongside its activities, Solvay is also investing in its territorial integration, notably with the financing of certain sports activities (Football, Rugby, etc.).

The following figure shows the organization chart of the site.
The study of the hierarchy allows to know the different actors around the batteries but also to understand their links. Starting from the batteries, we find the roles of roundsman and operator in the control room who are the actors most physically close to batteries and those who act directly on them. Above them, the shift supervisor is their team leader, supervises them and transmits instructions to them. The day supervisor gives the instructions to the shift supervisor and receives the instructions of the chief engineer of the battery part. It is dependent on the manufacturing manager. Finally, the site manager supervises the entire site.

5.2. Presentation of Interviewees

HyperCOG project is involved in extraction liquid-liquid process of rare earths. The aim of the project is to optimize the control of the battery separation process with systems. Members of ESTIA team was able to visit the site of Solvay three times between September and October 2020.

It allows to determine operators concerned by the use case:

- First: control room operator, shopfloor operator, shift foreman, who are the people directly impacted because of their proximity with the batteries.
- Then: day foreman, manufacturing engineer and process engineer are also impacted.

After determining people to encounter and spread over the different days of visits, it was possible to observe, interview and record several people:

- 2 day foremen
- 3 shopfloor operators
- 3 control room operators
- 3 shift foremen

We followed the people on their activities, observed and asked them questions related to their work.

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Also, we had the chance to follow a quick formation on the batteries process, in order to understand it and a meeting with 3 engineers from the process support part allowing us to collect their needs.

Table 1 recapitulates the visits of the Estia team on the Solvay site:

<table>
<thead>
<tr>
<th>Name of the phase</th>
<th>Source of data collection</th>
<th>Duration of the phase</th>
<th>People from Estia</th>
</tr>
</thead>
<tbody>
<tr>
<td>First contact phase</td>
<td>General observations Meetings Documents</td>
<td>One day</td>
<td>5</td>
</tr>
<tr>
<td>Observations and interviews</td>
<td>Direct observations Semi-structured interviews (individual and collective)</td>
<td>Two days, one night</td>
<td>3</td>
</tr>
<tr>
<td>Second observations and interviews</td>
<td>Direct observation Semi-structured interviews (individual and collective) Meeting</td>
<td>Two days, one night</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1. Details of the visits.

5.3. Solvay process

HyperCOG project is involved on the batteries workshop. It concerns the whole batteries part. The aim of the project is to optimize the monitoring of the production line with new systems to improve separation of rare earth quality control.

5.3.1. Separation of rare earth process

Thanks to the explanations of the quick formation of day supervisors, we are able to draft the process of the batteries. With our understanding, we can say that there are three workshops in the company: ores, batteries and FCE and electronics. The ore comes in solid form to the ore workshop, it is attacked with nitric acid which makes it liquid and forms a solid pulp which is a waste. The liquid part is recovered by the battery shop. After processing, rare earths are stored in storage tanks or “cigars”. The FCE and 5x8E workshops, which are in fact the customers of the battery workshop within the company, use these reserves in order to produce. The battery shop must ensure that the available stock meets the needs of its customers. This stock is checked every morning by the batteries. There are currently 4 batteries operating in the following order: C2, C4, C3, C5. In January 2021, the C5 battery will disappear and the C3 will run continuously to produce enough 99.99% pur rare earth. The batteries run continuously 5 days a week, which means started on Monday and stopped on Friday and the employees work in 3x8, 5 days a week, and 8 hours a day.

For the batteries process, we take the example of C4. First, a battery is made up of several floors that the ores will pass through in order to be extracted. C4 is composed of 87 stages.
1- A solvent - or organic phase - is composed of a diluent and an extractant. This solvent runs in a closed circuit through the batteries and is therefore reused continuously. It is injected in the battery at the beginning.

2- This solvent is directly loaded with Rare earth A at a fixed concentration. In fact, the solvent has an extractor power to capture rare earths with a maximum loading capacity given. This maximum loading allows the solvent to be full of rare earth and protect the exit of Rare earth A at the start of the battery.

3- An aqueous phase, that is to say the ores in liquid form, is sent on a specific floor to travel through the stages of the battery in the opposite direction of the solvent. From the feeding step, the solvent and the aqueous phase are mixed by stirrers and then left to settle in each stage.

4- As the solvent travels through the floors, is mixed and decants, it exchanges the Rare earth A with Rare earth B, which it prefers as it goes along. The total separation takes place in a stage called "sensitive stage".

5- At the decant, the solvent goes up while the aqueous phase goes down. This process allows the two liquids to be reinjected separately on the next floor by opposite side to be remixed.

6- Finally, the solvent, completely filled with Rare earth B, is separated from it. The solvent goes back into the circuit after a regeneration process that allows it to retrieve its original characteristics and via a washing process that eliminates any impurity. At the same time, the Rare earth B is stored in a tank while the Rare earth A has been deposited throughout the process in the aqueous phase and returned in the opposite direction. The solvent washed restarts the process from the beginning.

Not all floors have the same function. Those at the beginning and in the middle of the battery will be used to receive the components and start the process, while those at the end will be used for cleaning and storage. These very specific and complex stages are the most dangerous for safety and generally where problems arise. However, the vast majority of stages allows the separation of rare earth with mixing and settling phases of liquids. Let's describe more specifically this type of battery floor. One floor consists of two parts: a motor stirrer and a settling tank. The first part receives the two liquid components in opposite entrances and mixes them so that the solvent takes with it the rare earth B contained in the aqueous phase. During settling in the tank, the solvent is recovered by overpouring while the aqueous phase is recovered by underpouring. Each stage has two canes that allow the recovery of both liquids. The solvent cane has an upward opening and receives the solvent as the liquid rises. On the other hand, the aqueous phase flows into the next stage through a cane with a downward opening. These rods are adjustable by the shopfloor operators who act on them when a problem is detected. In particular, they allow the solvent to be collected more quickly by lowering the solvent cane or to allow the solution to settle for a longer period of time by moving the entry points away from the liquids. The figure 9 shows what happens in a floor.
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Figure 9. Description of a floor process (picture recovered from Solvay).

The following figure 10 shows the functioning of batteries in general.

Figure 10. The circuit of battery from the separation of ores (document recovered from Solvay).
The batteries have different functionalities: C2 separates the exogenous from the rare earths, C4 separates the Rare earth A and the Rare earth B, C3 and C5 have the same function which is to purify the Rare earth B but at a different quality.

5.3.2. Production chain monitoring description

From its screens, the console operator has access to a system of monitoring, DeltaV, which receives measurements from an online analyzers and sensors. The two analyzers measure the rare earth concentration on a specific stage of the battery (sensitive stage) for driving assistance and concentrations and densities in feed streams and concentrated tanks. Four types of sensors are also required for battery control:

- Temperature
- pH
- Pressure
- Level in the tank

DeltaV is connected to the batteries and allows the operator to act on the parameters of these. For instance, it can open valves or decrease a flow. Very visual, this software represents the circuit in the batteries with its components such as the solvent tanks or the evaporators. This software is used to place alerts on the parameters to be monitored by the console operator. The circuit elements are green when the values are those expected and requested by the operator panel and gradually change to orange and then to red if there is a problem.

On the specific functioning of the C4 battery, heat and acidity are the two parameters that facilitate settling. However, the solvent degrades itself because of these same parameters and reaches its illuminating point (explosion). The heat in the workshop must be regularly controlled.

The solvent, and the associated tank movements, are the first vigilant points for console operators. If it heckles, then the operator will check its other parameters. The priority parameters for him are the concentrations in the tanks and the pH which indicates whether his solution is acidic or basic. The pH is regulated by the addition of base. It is therefore necessary to monitor both its value for the reasons mentioned above but it also provides information on other data and the detection of problems. This information is accessible to the operator from its screens. He must report them for each battery in operation on a sheet of records at specific times, at the start, middle and end of shift.

The role of the operator is also to carry out histories. These curves give the value of certain parameter as a function of time. Consulting these curves is necessary by the operator to be aware of and understand the actions carried out by the previous control room operator and when they were taken. Indeed, the actions have delayed repercussions that the current lectern will have to take into account in his decisions.

In short, to have control over the batteries, the parameters necessary for the teams on each of the batteries to work are:

- The movements of the solvent tanks
- The histories
- The flows
- The concentrations
- The pH
- The temperature into the tank
- The forehead
- The reflux
5.3.3. Problems on the batteries

An usual problem is encountered by the service on batteries. It is the drift. It is a gap between the value wanted by the operator and the real value. It breeds an emulsion which is a bad decantation. When it occurs, it must be corrected as quickly as possible so that it does not spread to other floors. To do this, the batteries have to run low, which has an impact on production or worse, can stop it.

The front or sensitive floor is a stage where the separation between the Rare earth A and the Rare earth B takes place. This is the floor that needs to be watched the most because this is where emulsions can occur. The control room operator sees this floor very clearly on his screens and is able to detect a problem on it. The shopfloor operators are also able to detect that problem visually. On the other hand, to do this, he must be in the exact place where the emulsion occurs and see it, “lift the right bonnet at the right time”. Batteries are well known to every roundsmen, so they usually know how to look at the right floors to detect the problem.

The start is also a critical activity. It requires attention and experience because that is when problems can occur. All batteries must be started one after the other. For instance, an emulsion can occur at the beginning of the operation or a battery that has not worked for a long time can cause problems. The start process begins with the activation of process alarms, cascading of several components such as valves, agitators, flow meters, pH meters, starting the stirrers and finally opening of the valves. All this process is done by the control room operator via DeltaV but is accompanied by a manual opening of the valves, visual checks and the installation of pH probes carried out by roundsmen. This tedious coordination is necessary for the correct starting (or stopping) of the batteries.

5.3.4. Analysis of the people close to the batteries

As close as possible to the batteries are shopfloor operators and control room operators. The shopfloor operators are in charge of carrying out the patrols on the batteries in order to check their operation and detect any anomalies. It is a very physical and varied task which requires knowledge of the batteries workshop and chemical handling. The control room operator designates the person supervising the screens and the different parameters during the 8 hours of work. It requires a lot of attention and vigilance. These two jobs are totally complementary because the shopfloor operators, on the batteries field, need to be guided, there are the hands and the eyes of people in the control room. Each other can talk via talkie walkies to transmit information and act. In the control room, some data are not available on the several screens. The data have to be collected manually with tests and samples by the roundsmen. Thanks to this collaboration and good communication, the operators can go beyond the problems encountered on the batteries.

Complex battery drift situations can only be managed if the operator has already experienced and faced these issues. It is therefore necessary to experience a start, a stop, a battery drift to understand its operation and the management of the parameters.

The shopfloor operators and the control room operators have the common role of retrieving the information and processing it to make decisions which will have consequences on production. It is therefore important for them to make the right decisions, each according to their experience and sensitivity to regulate and ensure production and even anticipate future problems.

Encounter people on the site and their work environment allows us to understand how that the work in 3.8 promotes links between individuals, which unites teams and leads to work in a good atmosphere.

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5.3.5. Equipment maintenance description

Technical problems are solved by people from Electric Instrumental Automation, electrical part or from Instrument Analysis Maintenance, the mechanical part. They take care of the problem reported by the shop floor operators in the field or the control room operators in the control room and intervene as quickly as possible if it threatens production.

Two major maintenance issues were discussed with the operators during our visits. The first is the replacement of a porthole and the second is the replacement of an agitator motor.

The temperature variations between the batteries on and off are quite significant. Thus, the seals around the portholes tend to retract during periods of site downtime and therefore cause the tank to leak. The window must then be changed as soon as possible in order to resume production. For this, two operators are necessary. They use cubitainers to extract all the liquid from the tanks. The huge volumes in the tank and the type of maneuver are very risky. It takes about 3 hours for the shopfloor operators to solve the problem.

As for the agitator motor, the shopfloor operators generally detect a suspicious noise upstream of the failure. These agitators are changed by the shopfloor operators, supported by the AIE support. It has spare motors available which they load on lifting equipment and allows the agitator motor to be raised. They come and fix it on the floor and then wait for the AIE service who will electrically disconnect the engine and who have the necessary authorization to do so. Once reconnected, the motor is tested, and its operation verified. The operation takes around 30 minutes for the shopfloor operators.

Finally, in general, a technical problem in the field is reported to the electrical and mechanical teams who are authorized to intervene in the field.

5.4. Use case reminder

The ESTIA and Solvay teams were able to make contact during a first telephone meeting on April 3, 2020, during the lockdown. During this exchange, the teams introduced each other and expressed their expectations. Solvay wants to become the leader of the specialty chemicals market, and this involves optimizing production. Vision La Rochelle 2022 is the name of Solvay’s horizon 2022 digitization objectives, it is within this framework that the HyperCOG project is part of to contribute to this digitization.

Then, the team ESTIA conducted a first interview of one hour with the person in charge of Operational and Digital Excellence in April 2020, to understand more precisely the needs of Solvay on this site. The subjects aborded were first, the site of La Rochelle and its history, its situation to the city, its business culture, and the state of mind of the employees. Then, we asked him about his job and his course on the company, as well as his experience with change. The exchange became a little bit more technical then, with precisions on the jobs related to the batteries, precision of the physical and human perimeter and the jobs impacted by the system.

These exchanges allowed ESTIA team to understand the needs of Solvay in this project. First, the site wants to evolve through digitization. Also, the company desires change management in order to perfectly coordinate the new system with the company business culture.

The following scopes for improvement have been identified in the deliverable D1.1 regarding the use case:

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1. The liquid-liquid extraction process consists of a series of 6 sub-processes called “Batterie”. The purpose of each batterie is to separate rare earths nitrates using the capability of specific solvents to have selective affinity for the different rare earth elements.

2. The aqueous phase containing the rare earths nitrates is fed continuously through the batterie while the solvent is circulating counter currently in the batterie. When the solvent is loaded with the selected rare earths, it is finally “regenerated” by unloading the nitrates in aqueous phase (extracted rare earths). At the other end of the batterie, one obtains the non-extracted rare earths.

3. Process control is done by measuring flows, pH at specific points as well as rare earth concentration in the extraction zone to insure good separation between the elements. Reaction plan to disturbances (poor separation, emulsion between aqueous and organic phase) is rather manual and depends on operator experience.

4. The objective of the project is to have more sensors (as interface quality, solvent degradation follow-up, etc.) together with the correlation of current process parameters to be able to anticipate problems and run steadily at the maximum capacity. The expected benefits are: increased productivity, less quality defects, optimized steam usage for the nitrates concentration, longer life expectancy of the solvent (less waste), optimization of parameters to business needs (running rate).

5.5. Analysis of collected data

5.5.1. The perimeter of the project

According to the previous analysis, the physical perimeter of the project is located in two buildings in Solvay. It includes the control room, the shift supervisor’s room on a first building and the batteries field, disposed on several floors and a laboratory in the middle of that on a second building. Both are linked by stairs. The control room is shared between the batterie and 5.8 Electronical workshops. The four lines of batteries are concerned, C4, C2, C3 and C5.

As for people concerned by the project, the closest people to the batteries are the first impacted by the new system. It means: control room operators, shopfloor operators, shift foremen and day foremen.

5.5.2. Feedback from observations and interviews

The communication

The communication is a very important part of the different roles of the company. In fact, due to their complementarity, shopfloor and control room operators are connected from the control room to the field with talkie walkie and cannot go on their activities without communication. The shopfloor operator is the eyes and hands of the control room operator who controls the parameters from the control room. He cannot act without this link. In the same way, the shopfloor operator has to control certain floors or take precise readings at the request of the console operator who guides him. All ensure the smooth running of the production process and exchange information.

"The eyes and hands of the control room operator." "I don't have all the info, it's data I'm going to get from those in the field."

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Decisions are taken jointly. The control room operators consult the shopfloor operators but also their supervisors. Whether they are in training or not, certain actions, such as calling the maintenance department at night, must be reported to the foreman and are taken by the latter.

"I'm waiting for him to confirm a setting so I can make an action and get back into my range."

For the instructions, previously transmitted on paper, they are now on a Drive accessible from an office computer in the control room. They also receive e-mails and information about the company on it.

"I also have the life of the factory, so communication with the hierarchy".

Paper media are preferred because they are stored and can be consulted later by everyone. It is possible, for a comparable situation already managed, to go and find the document and consult it to see the steps taken. In the same way, the control room operators fill in a sheet of readings several times during the course of their shift, which allows the most important parameters to be noted. This sheet is accompanied by comments left by the control room operators in order to specify to the person who will follow him the actions carried out to reach these parameter values.

"I'll tell my colleague what I did and at what time."

The portholes

Each battery level has a window. This normally allows a person to read what is in the tank and see if the stage is in emulsion. However, because of the material used for these windows, namely polycarbonate, the use of windows is often made impossible because of its opacification over time. It is necessary to go on site to check their condition and see that taking information through this window is made difficult. The information is therefore taken in another way: by pegging. In fact, the shopfloor operator dip into the tank of the floor they wish to observe and can thus see the state of the settling through a glass instrument called a rod.

"I'm going to pick up the battery, I'm going to dip the cane in to see the interface."

Determining the pH

As we have seen above, acidity is a parameter that helps the settling of the solvent and the aqueous phase. The pH is therefore read by the growers to determine if it is in the right range of values. The test is carried out using pH paper directly in the tank to be measured. However, due to the low luminosity of the room, the precision of the paper and the sensitivity of everyone to the colors, this measurement is only indicative.
"It's not very accurate, it's with a paper test, but it's to make sure it's within the range."

The pH is regularly checked. It is a value on which the console operator sets alerts to be warned of its evolution.

The ambiance on the field

The room containing the batteries is maintained at a very high temperature due to the separation process explained above and to the release of heat that this produces. The room can go up to 45 degrees in summer.

"When it's 40-41, it's mainly on the C5 side, we're at more than 45° on the C5 side"

Personal protective equipment, PPE, consisting of boots, gown, glasses and helmets, are compulsory in this area. The wearing of earplugs is recommended because of the movement of the mixers that makes this room a noisy environment. They have thermoformed earplugs which pick up tiring and harmful noises.

"It'll pick up the sounds that are most harmful to the ear"; "We know that with all the motor-agitators, on the ears, after a while it creates a noise that tires"

For laboratory handling, latex gloves are available. They are provided with more specific gloves for opening valves and collecting samples. This atmosphere within the batteries as well all the safety equipment is heavy for the shopfloor operator. Indeed, wearing glasses and helmet narrows their field of vision. We felt a real work habit on their part to carry out their work activities in these conditions. Also, some types of solvent used have a strong smell, that sometimes give headaches. To all this equipment is sometimes added a mask if the grower feels the need. However, everyone gets used to this smell.

"At the beginning, you have to admit that it's very complicated on drums. You have to get used to the solvent"; "the masks have to be closed and not to get the smell of hot solvent in your nostrils"

The control card

The main role of the control card is the on-line detection of manufacturing process drifts and standardizing the corrective actions to be carried out by operators. Equipped with a low and high range, this system determines solutions when the parameters go out the ranges and gives instructions of good actions to do and on the behaviour to adopt at the operator.
"It’s a control screen. So it’s going to give us solutions. Like when we’re out of range, then we have our range which is set as soon as our data comes out, it changes colour, and we have the corrective applications here."

Sometimes, the control card is not readable because parameters are too low or too high. The control room operator then calls the shopfloor operator to retrieve the information and guide him since he is then acting blind.

The data is updated only every 15 minutes and must be found manually by the console for a specific time. This is a rather tedious process that requires time and organisation from the console operator.

"If I want the new data, I have to reset, search for the date, search for the parameter that I want to follow"; "After the idea it would be to have the data on the fly. It would avoid us having to navigate, to go around the screens all the time”.

Finally, much information provided by this software is also provided by DeltaV where it is possible to consult and intervene on the parameters.

**DeltaV**

DeltaV is the software used by control room operators to consult operating parameters and act on the batteries. By default, DeltaV sets thresholds at which it acts autonomously. Control room operators have to set limiters to block the action of the software that makes decisions. This manual work alleviates the problem but adds work to the console operators instead of making their activity easier.

An overview of all the screens and parameters is made when the station is taken and then every 20 to 30 minutes. Generally, the control room operator is in the habit of linking turns as long as there are no problems. This enables the console operator to complete the sixteen hours that have elapsed and to understand the actions carried out during this time, in particular thanks to the curves of the history curves.

"It's a bit of a ritual"

"Every 20-30 minutes"

"If there's nothing else specific, it's what we do"

"It's the shape of the curve that makes you say that"

To do this, the information must be coherent and synchronised with reality so that the operator has all the elements at his disposal to make the right decisions.
5.6. Recommendations

Regarding the recommendations, several aspects stand out. First, from a work of ESTIA perspective, access to the plant is essential. This allows us to work from real working situations that we have observed in context. In fact, the difference between the prescribed and the actual work is important to understand. The cyber physical system will consider all the parameters that the operator must have available and provide him with the information in a legible manner.

In addition, the cyber-physical system will have to take into account the aspects mentioned above, i.e. the corrosive products used for the extraction of rare earths, the attenuated vision of the operator by the protection equipment and the environment in which the batteries are located (especially the heat).

Then, due to groups of work already engaged with people concerned for an intern project, the entire people seem favorable to the project.

Therefore, the daily work of Solvay’s teams is based on decision making. In fact, everyone is working towards the goal of controlling the batteries to produce rare earths. Analysis shows that what they are doing is simply making decisions to achieve this end. To do this, the team members therefore work to prevent and avoid the drifts that slow down or stop production. Drifts can be linked to different parameters throughout the process. They can be managed in different ways by the team. In all cases, when a drift is detected, the reaction time, i.e. finding the fault and adopting the corrective action that allows the system to return to equilibrium, is crucial. Today, this reaction time can take several hours to days and can lead to a production stoppage. The implementation of a Cyber-physics system to assist in this decision making, a particularly sensitive point, could be a useful support for the teams.

Another possibility would be to facilitate the reading of the portholes. As we have seen above in this document, the visual is very important for the shopfloor operator and the portholes do not always allow a good reading of the tank. The installation of sensors to improve the taking of measurements and their analysis could be suitable for the team.
6. Conclusion and Lessons learned

The aim of this deliverable called “Recommendations for the HyperCOG solutions from operators’ point of view” was focus on collected information and make recommendations related to operators’ needs. To identify operators’ needs, semi-structured interviews (remotely for Çimsa) and field observations (only for Solvay) were carried out with employees of each company. A total of 17 interviews were conducted.

These works ensured that the use cases proposed by each company for HyperCOG project were in line with operators need. However, the study also highlights other opportunities with recommendations that are not related to the use cases. Those recommendations present many of the challenges faced by the CPS systems in the industrial context. They can be technical (i.e., CPS interaction, decision-making support system, sensors, technology intelligence), but also social (i.e., communication, collaboration, training, User centered design approach) or even related to security (i.e., cybersecurity) according to the plant and these specificities.

Through this study, employees were able to express their point of view. They particularly appreciated being allowed to share their work and their needs and to be listened to. For this reason, there is a strong expectation from employees of the three plants that would like to be involved in the HyperCOG project.
Annex 1: Interview Introduction

Hello Mrs/Mr, ... *(interviewer presents himself)*

Today, I am here for the European project HyperCOG. Do you know this project? If yes, what do you know about this project? What do you think about this project?

The goal of this project is to develop new solutions for industrial production chains. Before implementing new solutions, we need to understand how you work, to know your opinion on how you work (what is ok, possibly what is wrong, what could be improved, what could be the new solutions for you) and your needs in general, in terms of tools, etc. For that, we will ask you some questions.

The interview will take about 40 minutes. Is it ok for you? Because it is difficult to take notes and conduct the interview, we need to make an audio recording, it is anonymous. The recording will not be released, it will be kept for the time of data analysis and deleted. If you agree, please sign the recording authorisation *(Beware the recording authorisation must be signed).*
Annex 2: Recording authorization

I agree to participate at the European project HyperCOG.

I voluntarily participate at this study. I understand that my participation is not compulsory, and I can stop my participation at any time without justification and responsibility.

My consent does not remove organizers responsibility and I conserve all my rights guaranteed by law. During this interview, I accept to be recorded and that data are collected with my answers. I understand that information collected are confidential and just for the study use.

I am informed that data are treated anonymously.

I accept that data can be conserved for 6 months.

Date:

Name and interviewee signature (preceded by the words “read and approved”):

Name and interviewer signature: