Digital-twins for PPE manufacturing

Monitor and improve the efficiency of production processes.

The Challenge

The company is a FFP2 mask producer. His aim is to create a digital-twin of their process in order to better understand how they can improve both the production processes and the product itself.

Industry Sector:
IIoT

Challenge classification:
Real-time process monitoring and optimization; Detection of early signs of equipment malfunctions, allowing maintenance personnel to prevent further failure; Improving personnel working conditions based on real-time temperature, humidity and other environmental data

Time for Project Completion:
3 months

Main Requirements

- Monitor the Production flow;
- Optimize the production planning and scheduling;
- Create Alerting and notification system;
- Improve machine utilisation;
- Optimize the supply chain based on climate parameters.

Other Requirements

N/A

Key Performance Indicators

N/A

Other informations

Use manufacturing execution systems (MES) or enterprise resource planning (ERP) systems?
Yes

Type and operation of the MES or ERP system used?
tracking

Use of any existing cloud vendor (AWS IoT, Microsoft Azure, etc.)?
Yes

Cloud vendor and the services used on this cloud service:
cloud storage

Number of machines to be connected:
25

Configuration of each machine and the operation of each:
not clear

Machines are equipped with PLC/PAC or CNC controllers and can provide data?
23

Machines are not equipped with any digital controller (Legacy Machines)?
2

Communication protocols, sensors or devices with which the solution needs to integrate?
Modbus RS485, Siemens S7

Research Phase

Taking into account the challenge description, its requirements and its information, elaborate at least 5 questions that can lead your research for a solution.

Research questions:

1. What is the purpose of the Digital-Twin? Will it be used for analysis, for predicting, for prescribing, for actuating..
2. What is the scope of the Digital-Twin? What parts of the processes of the company do you want to include (priorities)? The level of granularity for each "monitorization"?
3. What is your budget and time to be delivered?
4. What is your current situation in terms of digitalization? Especially regarding sensing and automation capabilities
5. What technologies should be used for deploying the Digital-Twin?

Given the questions and the main requirements of the challenge previously listed:

- *identify possible technologies using the Planet4 Taxonomy Explorer;*
- *identify and analyze the sources (papers, articles, etc.) of those technologies that best suit the challenge;*

Technologies identified in the taxonomy:

- Digital Twins

Sources of those technologies that best suit the challenge:

1. Predictive maintenance/retrofitting, ejector https://www.mdpi.com/2071-1050/13/2/646 (Arduino, Deep learning, Optimization algorithms, Real-time web frameworks)
2. Smart scheduling / equipment health predictions, laboratory assembly line environment https://www.sciencedirect.com/science/article/pii/S2405896319308791?via%3Dihub#! (Genetic algorithms, Cyber-physical Systems)
3. smart Control Engineering / Realtime vision feedback infrared temperature uniformity control https://ieeexplore.ieee.org/document/9262203 (Raspberry Pi, Arduino Leonardo, Matlab Simulink and Simscape, Lattepanda board, Pulse Width Modulation)
4. Fully automated facilities, predictive maintenance https://ieeexplore.ieee.org/document/9367549 (Robotics, Edge Computing)

5. Floor plant energy consumption https://www.sciencedirect.com/science/article/pii/S2351978918313763 (Data models, ontology, DT simulations)
6. Energy-efficient Manufacturing https://www.sciencedirect.com/science/article/pii/S0360835219300324 (Cloud, data models, cyber-physical systems)
7. Quality control / Performance control / Turbine blades / geometries https://www.sciencedirect.com/science/article/pii/S2405896320335746 (Computer-aided engineering, Finite Element Method model, digital shadow, 3D modelling)
8. prevention, prediction and control of nano-forms airborne emission and worker exposure https://www.researchgate.net/publication/352657484_Digital_Twins_applied_to_the_implementation_of_Safe-by-Design_strategies_in_nano-processes_for_the_reduction_of_airborne_emission_and_occupational_exposure_to_nano-forms_Digital_Twins_applied_to_the_i (ISO 23247, safe-by-design)
9. aluminium anomalies detection / extrusion process / cost reduction / production efficiency https://www.mdpi.com/2071-1050/13/18/10155/htm (Gaussian process, DT procedure model, UC template)

In light of the discoveries made:

- *report the answers for the questions above;*
- *compare 2-3 of the more common solutions identified in the sources (how would they change the approach to the solution? What are the possible benefits/issues in such a use of these technologies?);*
- *draw initial conclusions on which path you want to take in proposing a solution.*

Answers:

1-2-3. The conception and implementation of a DT strategy are a complex and interdisciplinary development process. Even for just one single use case, a systematic approach is needed in order to keep track of all necessary tasks and to execute a project as efficiently as possible. In the first step of the model, relevant actors of the system should be identified, a common understanding of the term “Digital Twin” should be communicated, an overall DT strategy formulated, and a set of relevant use cases would be derived. These use cases should be then analyzed and assessed regarding their value proposition and the estimated effort for their implementation. For example, effort could be assessed in three categories: simulation, phase data and network; and the value could be evaluated with respect to quality improvements, time, and/or cost reductions. By doing so, a roadmap for the implementation of the use cases can be formulated based on their prioritization. Consequently, these activities aim at answering the question of where to start. Without this first step, the threat of not meeting your needs would be quite high.

4. After the scope of the project is set, the current situation needs to be analyzed. To implement the use cases as efficiently as possible, it is crucial not to start from scratch but to carefully assess the possible areas for implementing the DT module. For example, the already used software and the produced data could be documented to define where the data interface for the DT module could be. Furthermore, the selected process should be analyzed to assess where the DT, based on its analyses, could automatically cause a change in the production process to improve it. This activity also reflects the maturity of the company regarding the implementation of a DT, which is vital for conceptualizing the target state.

Target conception is the main task of the procedure model. Here, based on the documented initial situation of the use case, a target area is identified. In this part of the current process, the DT can add the most value, by creating an additional service, increasing quality, lowering costs, etc. For the different options, based on the process model and with respect also to further production steps, it is evaluated where the most significant improvement can be achieved. Subsequently, the required tasks of the DT are derived and implemented in the process model. At the end of this third step, a first specification of the DT can be documented to hand over to the supplier or the internal person responsible for implementing the use case.

5. Many technologies could be used in the implementation of a DT (which is already considered as a technology in itself). But what is most important, there is a lack of standardization in the definition and implementation of DTs. Of course, simulation, storage and computation, and communication and networks are key technological aspects to any DT, and many solutions in these regards are available in the literature, as well as for the DT data models required to link these technologies with the sensing and automation and predictive capabilities required by the selected use cases in the most optimal way.

Comparison:

Regarding the definition and implementation of DT many references can be found related to Industry 4.0. The problem is that each of them presents the deployment of a particular instance of a DT for a particular product, machine, scope, etc. Indeed, even if many references exist, it is impossible to find a DT development of a FFP2 producer with the (so broad) scope defined in this challenge, and of course even if this existed, the starting point would be of course different and thus the implementation would not be the same. For this reason we selected [8] and [9] as the most interesting works, because they provide a general solution useful for any DT strategy, and Industry 4.0 scenario. In particular, we believe that [9] is most suitable because the standard presented in [8] is not free and would be more difficult to replicate but this would of course depend on the budget and priorities of the company.

Conclusions:

DT is indeed the best solution for optimising production processes and products. Nevertheless, it is a quite new technology, and as such, there is a lack of standardization in its implementation. The heterogeneity of machines/sensors, protocols, and of course use cases makes the conception and implementation of a DT strategy a complex and interdisciplinary development process. In order to address it we need to reply to the proposed research questions together with all the stakeholders of the DT, and follow a systematic approach to guarantee that the real needs of this company are covered. We based our solution on the work presented in [9].

Proposed Solution

Making use of the technologies identified after the analysis of the sources, describe a possible solution to the challenge. Also, do not forget the constraints (time, number of devices to produce/connect, etc.): the solution must be applicable to the real context of the company that commissioned the challenge.

Solution Summary

Brief description of the solution (1-2 paragraph + 1 image)

The proposed solution consists of following a systematic approach for the conception and implementation of a DT. Indeed, the granularity of the sensing, the level of automation, the specific technologic solution for the simulator, sensors, protocols, etc. will depend on a more detailed analysis of the scope and objectives of this DT, as well as on the particular starting point of the company in this regard. Thus, the following procedure model for the conception and implementation of a Digital Twin extracted from [9] is our proposed solution.

The following Figure presents de the Procedure model to follow (and described in the answers of the research questions):

Procedure model for the conception and implementation of a Digital Twin in industry [9].

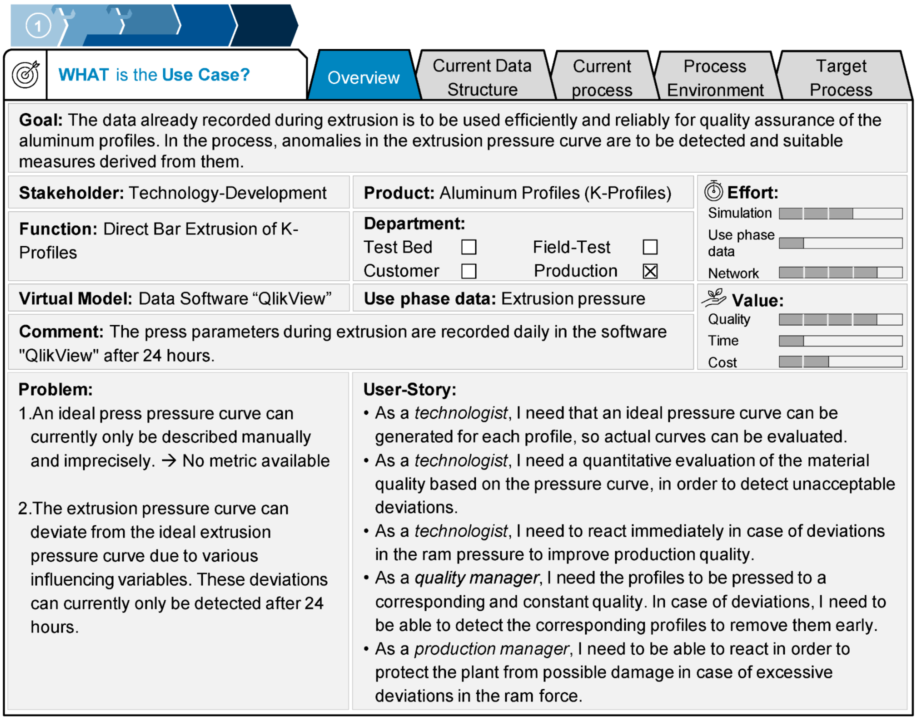
Solution Description

Describe the solution and its details

As stated before, the solution for this Company would be based on many factors currently unknown. Through the application of the presented model and a use case template, we believe that the project would be at least structured, and all boundary conditions and requirements, as well as the clear goal, would be defined. The following use-case related to anomaly detection in aluminum production (provided by [9]), could guide the Company through the first three steps of the DT procedure model presented at the beginning of this section.

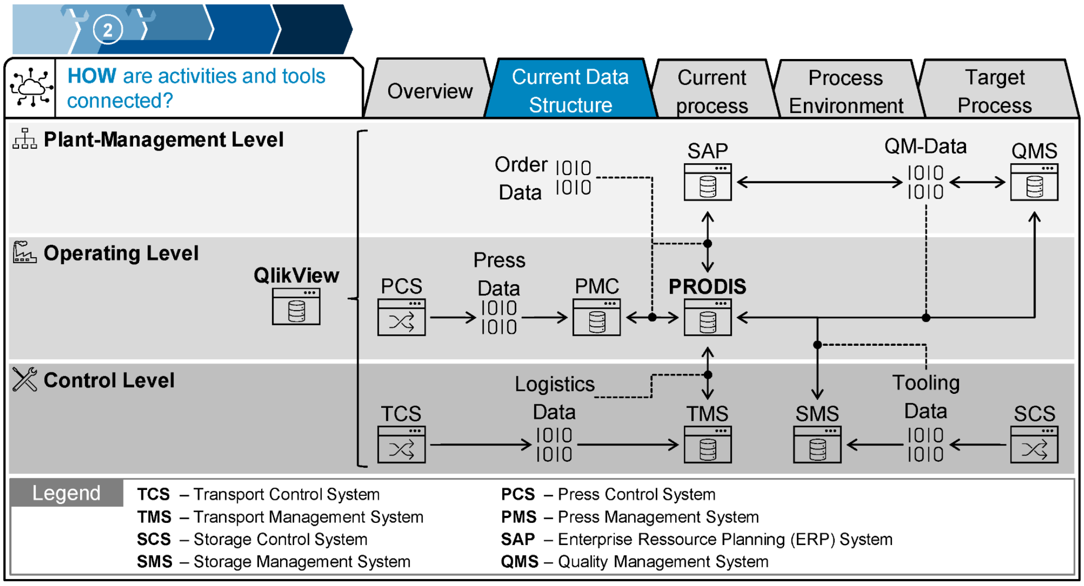
<u>Use-case sample of the application of the "Procedure model for the conception and implementation of a Digital Twin in industry"</u>

In the first step of the procedure model, relevant stakeholders from engineering, quality production, and IT are identified. With the stakeholders, a use case description is formulated and documented using the use case template (see next Figure).



For several years, the Company had already been collecting data from their extrusion plants, including ram pressure, extrusion speed, container temperature, billet temperature, and much more. However, to date, the production process could only be improved based on retrospective, manually derived, and imprecise analyses, but not on active and predictive approaches. Therefore, the goal for this use case was formulated as, *“The data already recorded during extrusion are to be used efficiently and reliably for quality assurance of the aluminum profiles. In the process, anomalies in the extrusion pressure curve are to be detected and suitable measures derived from them”*. To achieve this goal, user stories were formulated, stating the needs and requirements of the case study partner. The partner wanted to have an ideal pressure curve generated, which can be used to evaluate the material quality of a produced profile quantitatively and qualitatively. Moreover, once an anomaly is detected, an immediate reaction should be triggered to increase production quality and to protect the press from severe damage. Based on the goal and the user stories, the effort and value of this use case were assessed qualitatively. Effort was evaluated using the dimensions simulation, use phase data, and network. The first dimension considers effort related to the development of the algorithm. As applications of anomaly detection for production control already exist in the literature, it was rated only as medium high. Gathering the use phase data was unproblematic, as all sensors and data management systems were already in place. The network aspect, however, is extensive. So far, there was no interface allowing for automated, real-time analysis of production data. The value is assessed by the three factors: quality, time, and cost. As the major focus of this use case is to improve production quality, this dimension was rated high. Time was rated low, as detecting faulty products does not have a major effect on the cycle times. However, costs were rated higher, because identified, defective profiles can be discarded early in the production process and no further resources will be wasted on them.

In Step 2 of the procedure model, the situation analysis, the current data structure and the current situation of the production process needed to be analyzed as a starting point. The analysis of the current data structure is necessary to identify the interface that can be connected with the developed DT solution. See next Figure.

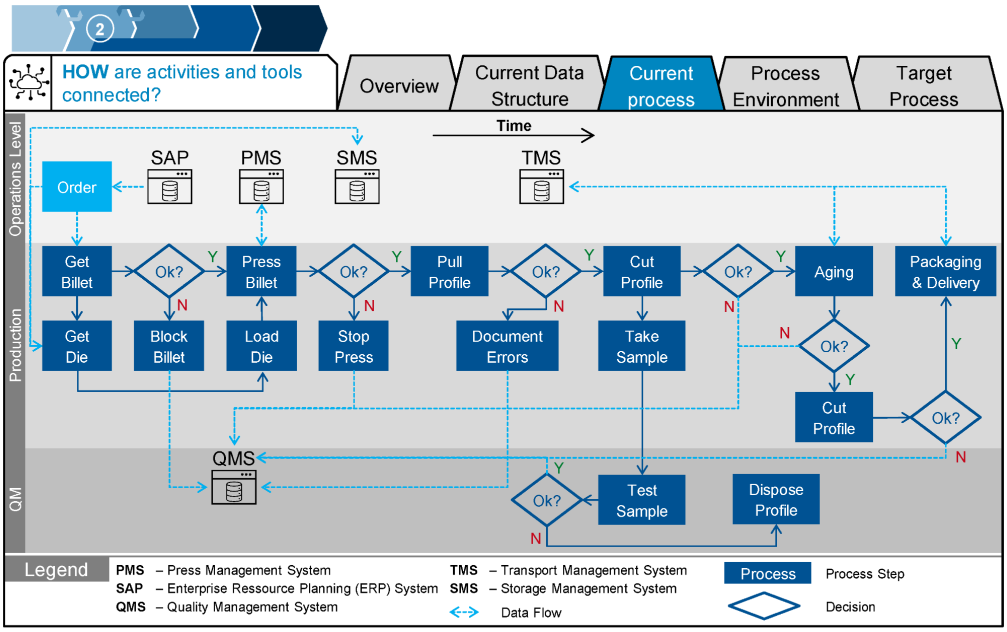


At the bottom, the control level is depicted with press control, control for the transport control system, and control of the die storage. These systems transmit press, logistics, and tooling data to the respective control station. The control level provides communication between the various control systems and enables a coordinated material flow in the technical process. The press management system (PMS), transport management system (TMS), and the management control system (SMS) forward the process data to the "PRODIS" software on the operating level, which is central to the data structure. It contains enterprise resource planning (ERP) data from SAP, quality-management data, tooling data, manufacturing data, and logistics data. This software is used for production flow and capacity planning in production. Subsequently, the relevant order and quality data are summarized at the plant management level and forwarded to the quality management system (QMS) and the corporate level.

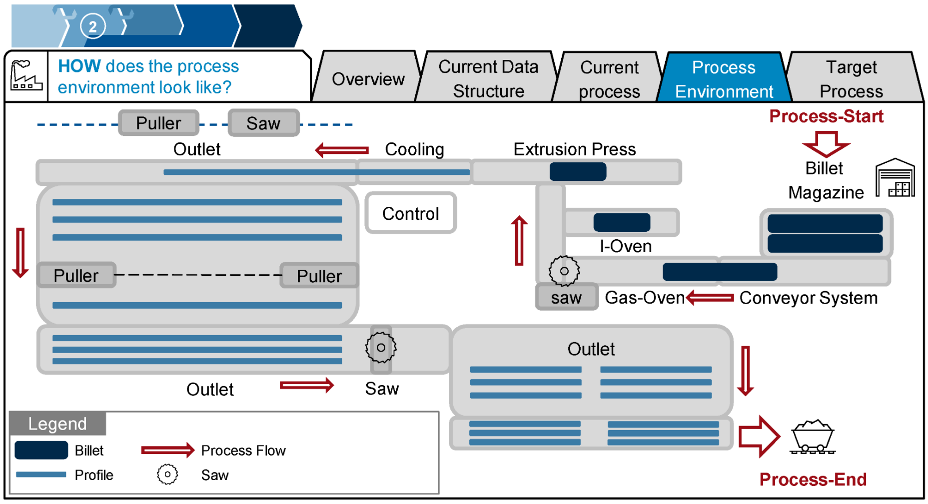
In addition, a system for data visualization, "QlikView" is implemented. As all relevant data for this use case, namely ram pressure, cycle time, ram velocity, and logistics data, are sent to QlikView, this is the system identified as the data source for this use case.

The structure of the current process is depicted in the next Figure. This case study is on improving a direct bar extrusion process. At the Company, first. a billet is taken from stock. After a first inspection, this billet and the die are transported to the press. Pressing entails preheating the material and the tool, as well as pushing the billet through the die and disposing of the remaining material of the billet. Next, the extruded material is stretched in order to avoid thermal displacements and to ensure dimensional accuracy.

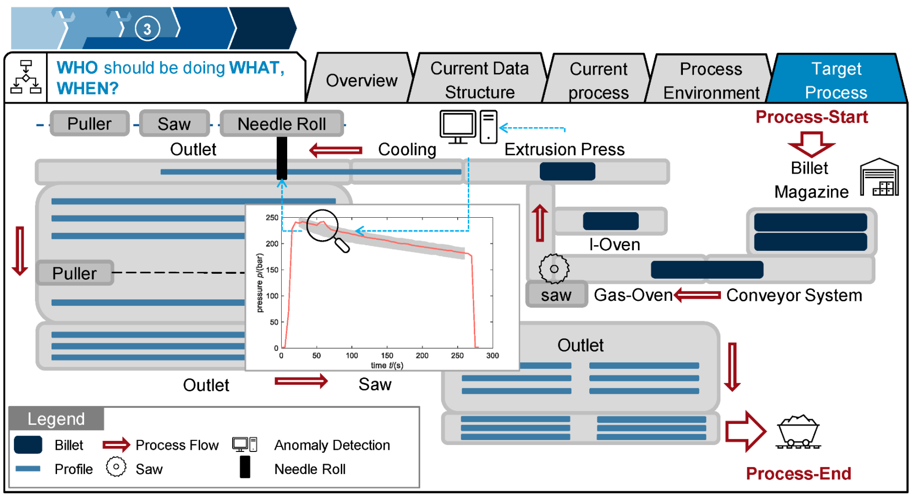
Subsequently, the ~50 m long profile is cut into ~3 m long pieces, which are transported to the aging oven. Here, small samples are taken for quality analysis. The samples can be traced back to the production order, but not to the billet or the final profile, which makes it hard to analyze correlations between process parameters and manufacturing errors. The processed profiles are then cut into the final, desired length, transferred to storage, packed, and delivered to the customer. It is important to cover the whole production process, not only the process step, where errors might occur (namely in pressing). There are two reasons for this. First, actions might need to be taken “outside” the process step to ensure the greatest process improvement. Second, it is necessary to analyze all steps in order to investigate the resulting changes that need to be taken for the following process steps and to quantitatively evaluate the success of the solution.



For an engineering twin, the current process was sufficient to identify the system’s structure. However, for a production use case, the physical layout of the process is important. Therefore, a section for documenting the “process environment” was added to the use case template. For this model of the physical layout, it was necessary to zoom in and focus just on the important areas of the process to keep it comprehensible. The respective process environment is shown in the next Figure. After the outlet and process end, the profiles are transported to the aging ovens, which is not depicted here, as only the first part of the process could be adapted.



In the third step of the procedure model, the target process is developed. As described in the user stories of this use case, the case study partner wants to quantitatively evaluate product quality based on the pressure curve. In detecting anomalies in the curve, there should be the possibility of immediately reacting and removing the defective item. As the machine does not provide the possibility of spontaneously adapting the process parameters while pressing, it should be ensured that the defective product is discarded and recycled as early as possible and not sent to the customer. One simple idea to do so is to mark the profile as faulty, so it can be excluded from further process steps after sawing (see the previous Figure). With the current plant layout, no other low-cost possibility could be identified to exclude the defective material earlier in the process. To mark the detected product, a needle roll can be applied. Such a needle roll is already placed in some production sites, but only actuated manually. The resulting target process is depicted in the next Figure. Consequently, once an anomaly is detected using machine learning algorithms, the needle roll will be activated to mark the defective profile. At the outlet, marked material will then be separated from the proper products and recycled in the billet casting. Therefore, costs for subsequent manufacturing steps are avoided, and the overall quality of the batch delivered to the customer will increase.



Implementation Plan

Describe the solution implementation plan considering among other things: Gantt chart with milestones, high-level cost analysis, possible difficulties (at least 3 major issues or difficulties) and additional opportunities (at least 2 extra benefits).

It would be difficult to implement a DT in 3 months, but considering a possible "small" instance of a DT only for monitoring a process, a possible plan could be the following:

- STAGE 1 (2 weeks): Project Initiation and Goal definition. At this stage the relevant stakeholders from engineering, quality production, and IT are identified. With the stakeholders, a use case description is formulated and documented using the use case template. Moreover, based on the defined goal and the provided user stories for addressing this goal, the effort and value of this use case are assessed qualitatively.

Milestone 1: Use case defined and documented.

- STAGE 2 (2 weeks): Situation analysis. The current data structure and the current situation of the production process need to be analysed as a starting point. The analysis of the current data structure is necessary to identify the interface that can be connected with the developed DT solution.

Milestone 2: Current system structure described.

- STAGE 3 (1 week): Target process conception. At this stage, the target process is developed, by defining who should be doing what and when. At the end of this stage, the first specification of the DT can be documented to be handed over to the supplier or the internal person responsible for implementing the use case.

Milestone 3: First specification of the DT documented.

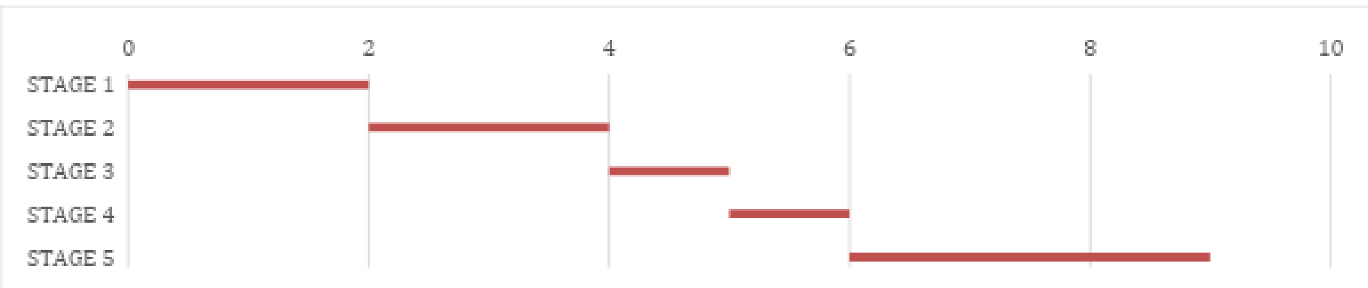
- STAGE 4 (1 week): Suppliers analysis. (OPTIONAL) In case

Milestone 4: Supplier selected.

- STAGE 5 (3 weeks): Implementation. In this stage, the DT designed in STAGES 1,2 and 3 is implemented.

Milestone 5: DT implemented.

Gantt chart:



High-level cost analysis:

Implementation of the Stage 1 – Personnel costs (5 employees x 2 week)	10.000 €
Implementation of the Stage 2 – Personnel costs (2 employees x 2 week)	4.000 €
Implementation of the Stage 3 – Personnel costs (2 employees x 1 week)	2.000 €
Implementation of the Stage 4 – Personnel costs (2 employees x 1 week)	2.000 €
Implementation of the Stage 5 – Personnel costs (2 employees x 3 week)	6.000 €
TOTAL	24,000 €

Possible issues:

1. Any update on the Company must be reflected in the DT. Need of an expert on DT in the Company or continuous subcontracting for its maintenance.
2. As a novel technology, better solutions may arise in the following months/years.
3. As a novel technology it can be difficult to find expert and cheap IT providers for its implementation.

Extra benefits:

1. The standardized procedure of implementing this DT could be used for any other use cases that one could imagine, facilitating the scalability of this DT in the mid-long term.
2. Many other digitization initiatives in the Company could be evaluated (both at an economic and performance levels) before affecting any real production unit or process.
3. The use of DT is a clear proof that this Company is ahead of its competitors on innovation and technology, which could be used for convincing possible customers.