A FIWARE-based IoT platform for enabling digital twins in a greenfield smart factory: an application study on a repurposed manufacturing line

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Abstract: The recent advent of novel concepts and technologies, such as the Internet of Things (IoT), Big Data, Augmented Reality, Cloud Computing, and Artificial intelligence is transforming industry and society as a whole. Today, the large amount of data generated requires the design and development of new schemes for extracting valuable information. At the same time, The COVID-19 epidemic is posing unprecedented challenges for businesses, governments and companies around the world. This article refers to a company in Southern Italy that has decided to repurpose its production line to manufacture surgical masks. The situation is completely new for the firm, which does not have historical data. Therefore, the aim is to propose a FIWARE-based IoT architecture for supporting real-time data acquisition and enabling the creation of a digital twin. Preliminary results show that the proposed solution effectively helps the company in starting the new business. Furthermore, the use of digital twin-based real-time dashboards enables continuous and agile improvement in the management of warehouse, production and maintenance activities.

Keywords: Industry 4.0, FIWARE, Digital Twin, Internet of Things, COVID-19 Pandemic

1.Introduction

In the context of Industry 4.0, the use of emerging technologies and concepts such as the Internet of Things (IoT), data analytics, cloud computing, digital twin, artificial intelligence provides new opportunities to make manufacturing processes more efficient, collaborative and flexible (Lu, 2017). Basically, with the Fourth Industrial Revolution, physical and digital world are more and more integrated and connected, then new challenges arise (Longo et al., 2017). In the smart factories, smart sensors and devices continuously generate a large amount of data that can be profitably used to monitor, manage and maintain the production line (Klingenberg et al., 2021). Extracting valuable information from data becomes a key aspect for business development. However, data is usually ubiquitous and heterogeneous because can derive from multiple sources, then today there is a strong need to use a common standard to gather, extract, process, and store it, especially in manufacturing field. Another crucial issue is interoperability (Xu et al., 2020): sharing data between multiple stakeholders offers many advantages, but trusted and secure platforms are necessary, when personal and/or industrial data are exchanged. Essentially, the IoT is creating a demand for new system architectures, infrastructures and platforms, with the aim of fulfilling the requirements of multiple distributed smart applications. Different IoT platforms are available, both open-source and commercial (Guth et al., 2016). Recently, FIWARE, an open-source and cloud-based infrastructure for IoT platforms, funded by the European Union, has attracted considerable interest from academics and practitioners. The main reason is that it offers some Enablers, developed for generic or specific use in different domains (e.g., manufacturing, energy, agri-food), that are reusable and composed by modules which enable interoperable interfaces (Corista et al., 2018).

At the same time, The COVID-19 epidemic is posing unprecedented challenges for businesses, governments and companies around the world (Kumar et al., 2020). Companies are reacting in different ways to ensure business continuity, improve the resilience of their supply chain or move towards innovative ways to generate revenue. A key challenge in the current crisis is the spike in the daily demand for medical consumables such as masks, disinfectant, visors and swabs. In many sectors and countries, companies are repurposing their production lines from making perfumes to producing hand sanitizer, textile companies are making masks, distilleries are creating alcoholic disinfectants and automotive companies are evaluating the options for making medical devices such as ventilators. The repurposing helps companies keep production lines active in periods of low demand, generate moderate revenues and positively affects their reputation.

In this paper, we refer to a company located in Southern Italy, which produces sofas and has decided to reconvert its production line to manufacture surgical masks, thus taking advantage of the business opportunities offered by the ongoing pandemic. The market analysis, regarding the convenience of this decision is out of the scope of this paper. Considering that this a completely new business for the company, no historical data is available. We aim to design a FIWARE-based IoT architecture to facilitate the company in real-time data acquisition and enable the creation of a digital twin, based on a multi-paradigm simulation model. In this particular case, the acquisition of data in real-time is crucial to bridge the knowledge gap that the company has regarding the new business. At the same time, digital twin technology is extremely useful for simulating different scenarios in terms of production and maintenance programs in a digital environment, therefore at the minimum expenditure of cost and time, and identifying the most profitable configurations, to be implemented in the physical environment.

The remainder of this paper is organized as follows. Section 2 presents a literature review on digital twin technology and IoT platforms, with a focus on FIWARE. Section 3 is devoted to the description of the case study, while Section 4 presents the proposed FIWARE-based IoT architecture and discusses its main benefits. Preliminary tests and results are presented in Section 5, while Section 6 shows the conclusions.

2. Literature review

2.1 Digital twin technology

With the recent advance of the Industrial Internet of Things (IIoT), cloud computing, big data, artificial intelligence, wireless sensor networks, deep learning algorithms, a new data-driven paradigm, called Digital Twin (DT), has emerged and is receiving considerable attention from both academia and industry (Nguyen et al., 2020). The use of the "twin" concept dates back to the 1960s, when National Aeronautics and Space Administration (NASA) built two identical space vehicles for the Apollo program. The ground vehicle was used to replicate and simulate the vehicle-in-flight conditions and assist astronauts in orbit as precisely as possible. However, only in this millennium, the concept has spread significantly, taking on different denominations such as digital mirror, digital copy and the currently widely used "digital twin". One of the most recognized definitions of DT was provided by Glaessgen and Stargel, (2012): "an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin". However, today it has evolved into a broader concept, which concerns the virtual representation of multiple manufacturing elements such as personnel, processes, assets and products, which is continuously updated as the physical counterpart changes, with the aim of representing, in real-time, working conditions and resources state (Lu et al., 2020). Basically, DT implies the existence of a physical space and a virtual space. The virtual space must be as synchronized and accurate as possible with the physical space (Tao et al., 2018). In this context, Qi and Tao, (2018) highlight three main concepts:

- The virtualization of physical entities: the physical activities are analysed, monitored, predicted, optimized in the virtual world;
- The materialization of virtual process: after the simulation and optimization phases, the physical process executes the optimized solution;
- The process of interaction between virtual and reality: such a process takes place within a closed-loop; the data generated from the physical world are transmitted to the virtual entities via sensors. They are optimized and fed back to the physical world, with the aim to improve the current operating conditions. This continuous interaction needs technologies and networks, capable of guaranteeing high reliability, limited latency (i.e., end-to-end delay), low energy consumption, and represents the main motivation behind the recent evolution from 3G/4G wireless systems to the fifth generation of mobile and cellular technologies, named 5G.

For more information about digital twin and relative applications, the reader is referred to some recent literature reviews (Negri et al., 2017; Agnusdei et al., 2021), which shows that the interest of the scientific community towards this topic is undoubtedly growing.

2.2 IoT platforms for smart applications: Focus on FIWARE

An IoT platform implements an architecture, which provides a set of building blocks such as device management, data analytics, security, data management, aimed at the development of IoT smart applications. The main reason behind the growing interest in IoT architectures is that a complete solution for smart applications requires hardware, software and communications technologies to work together and be able to integrate a set of platforms, components and services (Zyrianoff et al., 2020). Currently, there are numerous IoT platforms, which can be classified and compared, based on different parameters (Hejazi et al., 2018). The main purpose of researchers and developers is to address crucial challenges, such as interoperability, scalability, security, cost-effectiveness, openness, modularity. This paper focuses on FIWARE.

FIWARE is an open-source and cloud-based infrastructure for IoT platforms, funded by the European Union, aimed at building open and sustainable ecosystems for the development of smart solutions (Guth et al., 2016). It contains a library of components, called enablers, which can be catalogued as generic and specific. Generic Enablers (GEs) are independent on the domain area. Specific Enablers (SEs) are instead designed to be used in specific industrial areas such as manufacturing, agri-food, energy. The enablers can have different purposes: cloud hosting, data management, internet of things (IoT), 3D graphics, security. Basically, FIWARE provides a set of public and royalty-free Applications Programming Interfaces (APIs), which can ease the development of new smart applications. Moreover, for each component, an open-source reference implementation is made available (Corista et al., 2018; Coma-Tatay et al., 2019).

In Table 1, we explain the main reasons behind the choice of FIWARE for the IoT architecture proposed in this paper.

Table 1: Why FIWARE

Feature	Description
Openness	There is a worldwide community that constantly helps software architects and developers. In this way, any errors and bugs can be identified quickly and effectively compared to what happens with proprietary solutions. Essentially, maintenance costs are shared between all those who use this open-access infrastructure. Moreover, it should be highlighted that an open-source reference implementation is provided for each of the FIWARE components.
Easy testing	With the aim to make available an environment for testing and experimentation for developers, the European Union has created the FIWARE Lab, where stakeholders can easily implement their own solutions. Here, some virtual resources (e.g., computing power, disk, cloud storage, memory) ease the development process.
Interoperability	FIWARE makes APIs available, then developers can effectively merge IoT data with data from other sources (e.g., mobile apps, CRM systems, social networks). Data management is simplified and continuously improved. Moreover, FIWARE is not an all or nothing solution. In fact, FIWARE GEs can be combined with third-platform components to design hybrid platforms.
Context Management	Among the GEs made available by FIWARE, Context Broker (Orion) has a main role as it allows to model IoT data as context entities. It is extremely important to retrieve data in real-time, in fact it provides an API, which allows the registration of context producers updates, and queries and notifications that enable context consumers to access available information.
Standardization	FIWARE provides multiple IoT agents, that can be used as a bridge between an existing protocol (e.g., JSON, Ultralight, LoRaWAN) and NGSI Context Broker. They can ease the interface with machines, robots and Third-party systems.

At the same time, it should be noted that, with the spread of the IoT and the interconnected devices, the opportunities for cyber-attacks are increasing significantly, especially in the manufacturing sector. Therefore, alongside the advantages of an open and interoperable platform, cybersecurity issues must be seriously taken into consideration (Wu et al., 2018).

2.3 FIWARE-based smart applications

In the following, the main FIWARE-based smart applications, with reference to the manufacturing area, are reviewed. Sang et al., (2020) focus on predictive maintenance. In this case, the use of a FIWARE-based framework enables a data-driven approach, where maintenance plans are made effective and flexible. The modularization of multiple functions and security requirements allows collaboration between different organizations. Munoz-Arcentales et al., (2020) design and implement a FIWARE-based architecture to offer a comprehensive solution for guaranteeing access and usage control in industrial data ecosystems. With the aim to validate the proposed architecture, they develop a use-case in the food industry, with good results. Multiple GEs and open-source tools are used in the implementation phase, such as Orion, Cosmos, Wilma, Draco. Alonso et al., (2018) propose the implementation of a Reference Architecture, created by the Industrial Data Space (IDS) Association, based on the GEs of FIWARE. The validation of the proposed solution concerns a real use-case, where the manufacturing processes of a factory are gradually improved, by analysing the data retrieved from their systems. Two types of machines are taken into account (i.e., milling machines and coordinate-measuring machines): each can improve its performance by exploiting the data generated by the other, in the context of Zero-Defects/Breakdown Manufacturing. Access and usage control of data are guaranteed. Schroeder et al., (2016) propose the use of AutomationML to model the attributes related to the concept of digital twin, at high level. In this context, FIWARE is adopted as a middleware, to guarantee the effective data exchange between different systems. A case study, where an industrial component (i.e., a valve) is modelled, is presented to validate the methodology.

Our literature review shows a very recent interest in FIWARE-based applications. However, although FIWARE includes a number of advantages (openness, royalty-free, standardization, interoperability, etc.), its use in the scientific landscape is still very limited, especially with reference to the manufacturing context. There is only one document, whose purpose is the creation of a digital twin, while currently there are no papers, which deal with pandemic situations. Therefore, our main contribution is to propose a FIWARE-based IoT architecture to help an Italian manufacturing company, which wants to repurpose its lines to produce surgical masks. In this context, the main aims are: (1) supporting the company in the critical task of acquiring data in real-time from the physical environment. (2) Enabling the creation of a digital environment to allow the efficient simulation of multiple scenarios and the consequent application in the physical world.

3. Case study: Production line repurposing in the event of pandemics

In light of the strong demand at the national level, a Calabrian company has decided to reconvert its production line for the creation of surgical masks. However, approaching for the first time to the production of masks, the company needs to assess different potential production scenarios.

A typical surgical mask has a rectangular shape (180x95mm) and is made by the following raw materials:

- Rolls of non-woven fabric (TNT);
- Rolls of filter paper;
- Elastic ties;
- Semi-rigid coil for the nasal bridge.

Therefore, the following raw materials are necessary for 1 mask:

- 2 sheets of non-woven fabric (TNT) of 180 mm in length each;
- 1 sheet of filter paper 180 mm long;
- 2 laces;
- 1 nose piece from the semi-rigid coil which is 160 mm long.

The production department of the company, located on the ground floor, is represented in Figure 1. On one side, there is a gate for the entry of raw materials and/or exit of the finished products. The filter area (on the left) is used as a storage area of both raw materials and finished products. The masks production area is instead located on the right.

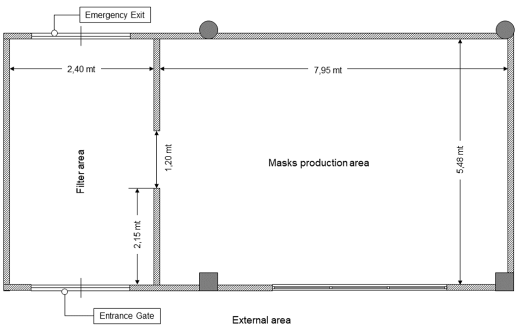

Figure 1: Production department

For the storage of raw materials and finished products, some shelfs are located in the filter area. The handling of the materials is carried out by a warehouse operator, which has also to ensure that there is always at least one raw material roll, the laces or a reel in correspondence of the load area of the production line. An automatic production line and two machines for packaging and sterilization are used to make the masks. In particular, the automatic production line for surgical masks consists of a roll loading station, a roll cutting machine, a machine for cutting the nasal profiles, an ultrasound welder, a mechanical arm that distributes the masks on two belts conveyors that carry the welded masks at two welding machines for the elastic bands, as shown in the 3D reconstruction in Figure 2.

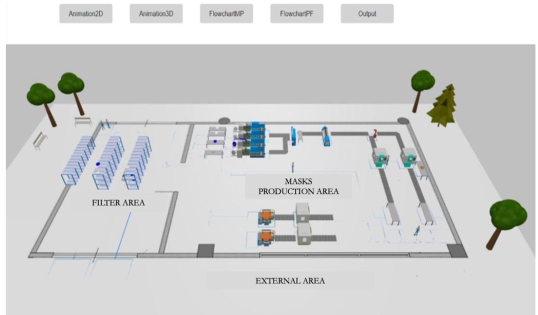

Figure 2: 3D reconstruction of the production department

The overall mask production cycle can be divided into 8 main phases, as shown in Figure 3.

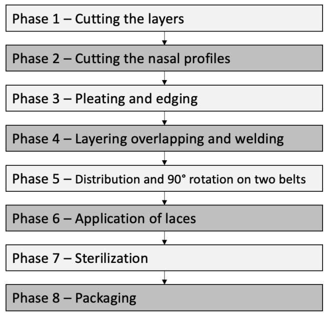

Figure 3: Mask production cycle

The cutting phase is carried out both for the TNT roll and for the filter paper roll with three roll cutting machines that work in parallel on the same line. In the material loading area, there are three aligned rolls of material (2 TNT rolls for the upper and lower layer and 1 roll of filter paper) which feed the machine. In addition to these, the machine is also powered by a semi-rigid coil for the nasal bridge. Layers of tissue and nasal profile are cut, edged, superimposed and welded. The mask body is welded on both sides (on the long side), using ultrasonic welder and two continuous welding rollers. The nasal bridge is conveyed simultaneously to the welding on both sides. The masks are then distributed on two different conveyor belts, for the welding of the laces and, finally, they reach the operators. They carry out a quality control (i.e., a visual inspection), in which they check the quality of the masks and discard them if they do not reflect the quality standards of the finished product, in terms of shape and size. The two sterilizing and packaging machines are located at the exit of the belts of the automatic mask production line. On exiting the belts, the line stacks the masks one on top of the other in a batch, which is then transferred by the operators themselves to the input belt of the sterilizing and packaging machines, which envelop the masks and pack the batches of masks in cardboard packs. The cardboard packs coming out of the packaging machine are therefore picked up by the warehouse operator who brings the finished products to the warehouse and places them on the shelves.

4. A FIWARE-based IoT architecture for real-time data acquisition and digital twin

Since the company in the case study is repurposing its production line, no historical data is available neither for production nor for sales. Before starting production, the company wants to analyse in detail the stochastic characteristics of manufacturing and identify the best configuration (e.g., batch size, line balancing), based on several scenarios. However, after starting production, it is extremely important to acquire and analyse data in real-time in a safe and efficient way in order to analyse it and fill the knowledge gap related to the production of surgical masks. In this regard, we have first developed a multi-paradigm (i.e., agent-based and event-driven) simulation model, the details of which are not the focus of this paper. Then, we have designed a FIWARE-based conceptual IoT architecture, which has two main aims:

- Collect, process and efficiently store data in real-time from the production environment;
- Align the simulation model to the real environment, in order to enable the creation of a digital environment.

In order to make the characteristics of our architecture as clear as possible, we describe it as an instance of an IoT reference architecture well-known and recognized in the literature (Guth et al., 2016), that is shown in Figure 4.

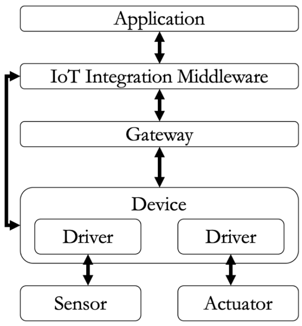

Figure 4: IoT reference architecture by Guth et al. (2016)

Our proposal is instead represented in Figure 5.

Basically, the proposed architecture consists of three main environments or layers. The physical environment represents the production area, where the data are acquired. The sensors located on the machines are used to measure the parameters of the physical environment and are connected to a device to which the gathered data are sent. Moreover, the operators can acquire production data and store them into a device (e.g., smartphone, tablet), based on their activity (e.g., quality control, machine supervision). A device is not always capable of communicating directly with other systems or environments. Therefore, very often a gateway is used. In this case, we propose the use of a FIWARE IoT Agent, which can translate different communication protocols to the one used within the cloud environment.

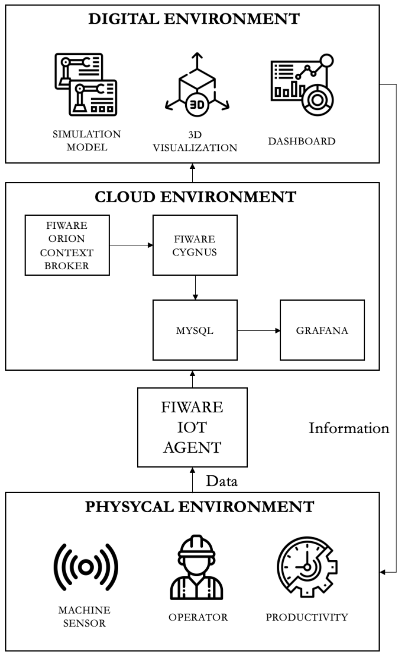

Figure 5: FIWARE-based IoT conceptual architecture

In fact, one of the strengths of the FIWARE accelerator is that it makes available multiple IoT Agents, in an open-access format. They can be adopted according to different needs, then act as a bridge between a protocol (e.g., JSON, LoRaWAN, Ultralight) and NGSI Context Brokers. The cloud environment can be considered as the IoT Integration Middleware of our architecture because it is responsible for receiving data from the connected devices. Then, data are processed and provided to the connected application, represented by the digital environment. In the cloud environment, we propose the use of a GE named FIWARE Orion Context Broker, which can manage context information in a large-scale manner. Basically, the entire lifecycle of context information can be managed, including changes, queries, subscriptions and registrations. FIWARE Cygnus is a connector between Orion Context Broker and other external systems, such as databases. It can be used for big data analysis, therefore to discover trends. With the aim to store the updated information, we propose the use of MySQL, that is an open-source relational database management system (RDBMS). Then, Grafana is an open-source monitoring solution, aimed at creating dashboards to visualize data in an effective and useful manner. The last layer of the proposed architecture is the digital environment. It is designed to exploit the data collected via IoT and return useful information for improving operations in the physical environment. Through the collection of data and context management enabled by FIWARE components, it is possible to align the simulation model to reality and have a 3D digital copy of the physical environment.

5. Preliminary tests and results

The experimentation involved two main steps:

1. Creation of an agent-based and event-driven simulation model by AnyLogic.

2. Linking the simulation model to the digital twin, in order to enable what-if analyses and real-time support.

Basically, first of all a simulation model was built to start an initial phase of study. In fact, the company does not have historical data regarding the new business, which concerns the production of surgical masks. For this reason, an analysis was carried out to determine how the use rate of machinery varies with the number of operators employed. For clarity reasons, Figures 6-7 show how the number of warehouse and production operators impacts the mean use rate of the machines for roll cutting and sterilization, respectively.

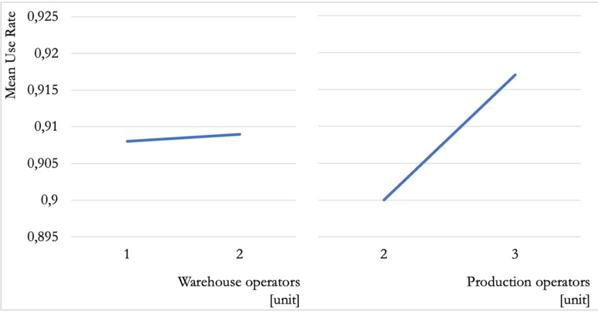

Figure 6: Mean use rate of the roll cutting machine by varying the number of warehouse and production operators

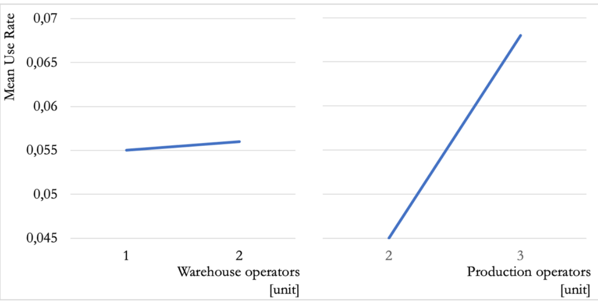

Figure 7: Mean use rate of the machine for sterilization by varying the number of warehouse and production operators

Basically, the simulation model supported decision making on how to start the production of surgical masks. Secondly, it was connected to a digital twin, in order to carry out what-if analyses and to support the company in production planning, in balancing production lines and in maintenance activities. Before repurposing its production lines, the company was greenfield, in fact it did not use any protocol for the acquisition and analysis of real-time data from the production department. Then, FIWARE was chosen and the architecture represented in Figure 5 was adopted. FIWARE acquires real-time data about order and warehouse management from the management software, while from the machines in a smart way as they are connected to the network. Through the use of the digital twin, a continuous and agile adaptation is possible for the company. In particular, real-time dashboards are made available (see Figure 8), with the aim of supporting the company in the following main fields:

Production planning: the production plan can be simulated, assessed, optimized in the virtual world. Then, the best solution is delivered to the physical world for the start of production. However, while manufacturing is underway, data from the physical world are continuously acquired and transferred to the virtual world for monitoring and control purposes. In the event of deviations from the plan, digital twin technology enables the rapid assessment of multiple scenarios and strategies in terms of processes and resources to be assigned (e.g., further workers and/or machines) to correct production activities in real-time; this is a very critical task, especially considering that the company has no experience with manufacturing surgical masks.

Maintenance: each fault can be viewed, diagnosed and analysed through the virtual model. Furthermore, it is possible to simulate and optimize different maintenance plans (i.e., response strategies). The use of the digital twin reduces maintenance time and costs. Furthermore, the digital twin-big data integration enables a set of predictive analyses about the health status of each asset, its remaining life and the probability of failure. Considering that the machines have been repurposed, the collection of data in real-time and replication in a virtual environment are extremely important tasks, in order to identify the relationship between the different parameters and the occurrence of failures.

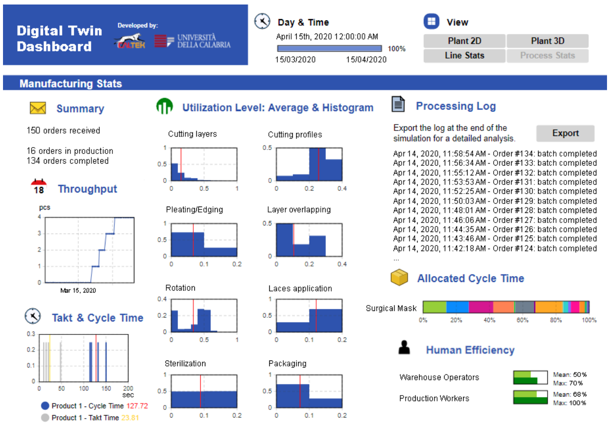

Figure 8: Digital twin dashboard

Experimentation in the use of the digital twin is still ongoing, but the first results are encouraging and promising. Through the use of real-time dashboards, the company is gradually improving the parameters related to warehouse management and production planning & control. Then, the new business looks profitable.

6. Conclusions

With the Fourth Industrial Revolution, the physical world and virtual world are increasingly integrated and connected. The advent of new technologies and concepts such as big data, cloud computing, artificial intelligence, digital twin poses new opportunities and challenges. Basically, the IoT is creating a demand for new system architectures, infrastructures and platforms, with the aim of fulfilling the requirements of multiple distributed smart applications. At the same time, the COVID-19 pandemic is leading many companies to change their plans to be able to survive. In this paper, we have focused on an Italian manufacturing company, which aims to repurpose its production line, to make surgical masks. The company has no historical data or experience regarding the new business. Therefore, we have designed a FIWARE-based IoT architecture to ease real-time data acquisition and enable the creation of a digital twin. The main benefits of our proposal were discussed and concern the support in the production and maintenance plans, and the assignment of the right workload to the operators. FIWARE looks very promising, however it has not yet had a large-scale deployment in the manufacturing sector. Its openness poses cybersecurity challenges, but its standardization and interoperability properties promise greater deployment in the near future. Furthermore, it sets no limits from a sectoral point of view, considering that Specific Enablers are offered for each scope (e.g., manufacturing, agri-food, energy).

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