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Research Article

An Industry 4.0 Case Study in Plastics Manufacturing: Bridging the Gap Between the Current State and Future Trends

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Abstract: The paper presents detailed research on bridging the gap between the theoretical and practical approach of Industry 4.0, considering a use case of the manufacturing company working in plastics production. In particular, we study an established Greek company in the textiles and plastics industry to present the current industry's technological status. Initially, we focus on the industrial process of a plastic manufacturing plant presenting the processes, methods, and equipment classification of such a factory. Subsequently, we focus on a novice method for developing or upgrading factories specializing in textiles and plastics and showcase its operational procedures. Lastly, after identifying the current state of affairs, we further expand on the key points that need change to develop the technological operations of an industry plan from Industry 3.0 to Industry 4.0. Specifically, to achieve this, we provide a detailed techno-economic proposal that suggests a trade-off between optimal quality and continuity of operations for an Industry 4.0 level factory. The technical novelty of this article lies in taking a step back and providing a top-down technological approach to the current state of affairs in machinery, supply chain, and factory operations level while suggesting cost-effective methods to increase productivity, reduce production errors and pave the way for smart manufacturing techniques.

***Keywords*:** Industry 4.0, digital transformation and society, digital business, financial manufacturing categorical framework, Internet of things (IoT), industry plant factories automation systems

***JEL codes*:** F63; L11; O14; L65

1. Introduction

Since the first Industrial Revolution (Industry 1.0) to date, the production process has undergone significant changes due to the development of technology, which has led to greater complexity and automation [1]. The first industrial revolution took place in the late 1700s when humans exploited the power of steam in such a way that led production into industrialisation. From the mid-1800s on, the second industrial revolution resulted from mass production, which was inaugurated by electricity and assembly lines. In the 1970s, the third industrial revolution came about when electronic and information technology combined with globalisation, which accelerated industrialisation [2, 3]. This revolution is

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currently progressing towards its end. This era is characterised by the automatization of production, placing emphasis on informatics and computer systems in general, as means to enhance and accelerate production. The next major development is the so-called "Industry 4.0" which is expected to bring extensive and fundamental changes to the tech industry. Moreover, recent studies suggest that many fields of computer science and thus manufacturing will be crucially affected by this evolution, with the most obvious being cloud computing, cyber security, artificial intelligence, big data, and analytics. All of these areas are closely connected to the everyday operation process and flow of manufacturing industries from acquiring material, optimising work-in-processes, assisting operators, monitoring types of machinery, and engineering planning. It is noted that this era is not a cure-all, but it will introduce decentralised decision-making, full information transparency, and interconnectivity between informatics and its procedures in manufacturing, commerce, and several aspects of everyday life [4].

Industry 4.0 is a complex process characterised by a constant interaction between man and machine. More specifically, Industry 4.0 is characterised by widespread cyber-physical system (CPS) digitisation, in which interconnected human and machine networks interact and collaborate with the information they share and analyse [2, 5]. Additionally, Industry 4.0 is supported by big data and cloud computing across industry-wide value chains. The interaction of the three main industry components of 4.0 is illustrated below (Figure 1).

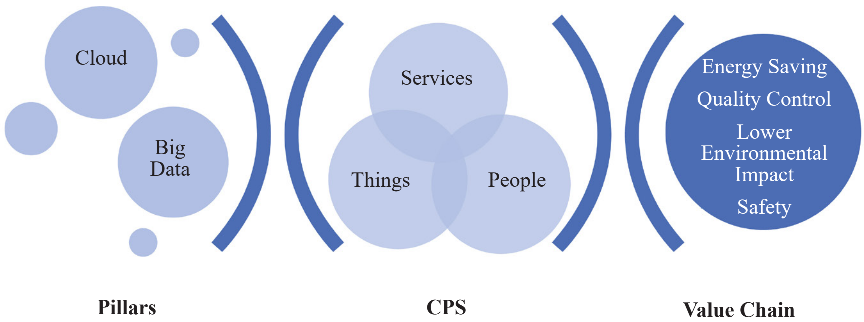

Figure 1. Interaction of the major three Industry 4.0 factors

Flexible and efficient production is possible with Industry 4.0, as it reduces production costs while simultaneously increasing time efficiency and improving production quality through technology, methods, and tools. As a result, Industry 4.0 has the potential to accelerate industrial production to achieve unprecedented levels of operational efficiency and productivity gains [5]. In the smart factories of the future, people will control processes and make decisions based on data coming from factory equipment and information about the availability of raw materials and energy costs. Taking all these factors into consideration will result in increased productivity with reduced costs in an environmentally sound manner [6].

In this paper, we first define what is "Industry 4.0", what are its elements, and how it is categorised (Section 2). Then, we focus on presenting the key features composing the current state of affairs as well as suggesting new smart manufacturing systems (Section 3). Specifically, we propose a framework for the manufacturing industry that categorises the Industry 3.0 and 4.0 characteristics based on their necessity and difficulty of implementation. Secondly, we expand on the usage of this conceptual framework by presenting in detail a plastics and textile manufacturing factory. Analytically, we use as a case study, a plastics company in Greece and explain in detail its modus operandi based on 3 areas: machinery, production, and factory field (Section 4). Thirdly, we provide our suggestions and an estimate of their cost on how to expand the capabilities of current Industry 3.0 implementations to 4.0, i.e., harvesting the advantages of Internet of Things (IoT) interconnectivity, smart devices, predictive production monitoring processes, and smart error detection systems (Section 5). Lastly, we conclude our research and summarise our findings on the proposed techno-economic solutions to advance to Industry 4.0.

2. State of the art

Recent advancements in technology, specifically following Moore's Law, which states [7]: "while computer systems processing power and thus capabilities annually increase, the cost of their components is gradually reduce," have enabled the manufacturing industry to rapidly adopt emerging technologies regardless of the end product (casting/moulding, machining, joining, or shearing/forming) [8-10]. Specifically, the fourth industrial revolution (Industry 4.0) that is taking place today refers to the organisation of production processes based on technology and devices that communicate autonomously with each other in the value chain [11]. Industry 4.0 is characterised by the digitisation and integration of horizontal and vertical value chains for the creation of intelligent products, by digitisation of goods and services, as well as by more customer-oriented digital business models [12-14]. It is highly related to the following technologies [15]: information systems [16], IoT [17, 18], blockchain [19, 20], CPS [21, 22], information and communication technology (ICT) [23], enterprise architecture (EA) [24], and enterprise integration (EI) [25, 26]. Increased competitiveness, exploitation of opportunities (e.g., consumer data analysis), risk reduction, and personalisation of products and services are some of the benefits of Industry 4.0 [27, 28]. An important asset is also the opportunity to strengthen sustainable innovation [29].

However, the implementation of Industry 4.0 also has limitations as part of overall business activities. One of them is the lack of digitalisation skills [30] and of trained staff [31], while another is the centralisation observed in the context of interoperability [1, 32, 33]. The volume of data and its real-time availability create new requirements in terms of technology, business management, and infrastructure [34-36]. In addition, a clear picture has not yet emerged of what is included in the concept of Industry 4.0 [37, 38]. Similarly, extensive knowledge, understanding, and utilisation of current technology, such as big data and deep learning [39], is required. Finally, another crucial factor to take into consideration is the high cost per unit that limits the growth of a company to full implementation of Industry 4.0 [40]. Nevertheless, Industry 4.0 will help manufacturers produce better-quality products with low-cost and sustainable solutions with less time, effort, budget, and general resources.

Regarding Industry 4.0 and its implementation, we can categorise its use case according to the following governing principles [5, 41]:

1. **Interface**: Machines, devices, and sensors will use wireless communication technologies to communicate with each other via the IoT. Communication standards play an important role in interconnection [42]. Cyber security issues will therefore become increasingly important as the number of harmful attacks increases when valuable information is transferred to the network and stored in the cloud.

2. **Transparency of information**: By linking objects and people, more information will be available. By accessing all the information, a virtual copy of the natural world can be created [43]. Equally important to receiving information is providing the information to the right destination.

3. **Decentralised decisions**: When objects and people are interconnected and information is transparent, decentralised decisions can be made [44].

4. **Technical assistance**: Due to the increased complexity of production, technical assistance will be of major importance. There are two main types of help systems. Firstly, decision support systems aid people in decision-making by gathering and visualising information. Secondly, help systems exist that aid in various everyday activities [45]. Advances in robotic technology will allow new forms of assistance to be created at the factory.

3. A categorical framework of manufacturing for Industry 4.0 and beyond

3.1 *Features under consideration*

The analysis of the Industry 4.0 model has shown that industries are at a rather early stage of development. This means there are still a number of issues to solve in order to be successful in a full transition from theory to practice. From this analysis, it was also found that Industry 4.0 was introduced as yet another industrial revolution along with new concepts [46, 47]. These concepts set the requirements for Industry 4.0, which means they are considered fundamental [48] and are summarised in two major categories. The two categories are thus interoperability and awareness. The first category includes decision-making, timely self-awareness, self-optimisation, and self-configuration, and refers to concepts that exist exclusively in Industry 4.0. The second category of awareness consists of the concepts of digitisation, communication, standardisation, flexibility, real-time response, predictive maintenance, and personalisation of systems, and refers to concepts that are attributes and systems belonging to Industry 3.0.

According to the literature study and taking into account the two categories, a framework has been created that includes eleven features under consideration [49]. The eleven selected cases are not mutually exclusive nor are the result of a thorough study of the system. Nonetheless, they are representative of the Industry 4.0 approach. Importantly, the framework makes it possible to apply it to all companies, rather than those that tend to approach Industry 4.0. This gives it a fair result [50, 51]. They, therefore, allow the reader to apply this framework to any industry (the following study applied to this categorisation framework may well inform the reader).

For the purpose of this research, there are eleven characteristics that are taken into consideration, analysed, and evaluated in order to complete categorisation. The features of the industrial revolution are described as follows [52]:

• **Digitalisation** - (Industry 3.0): The process of converting data from analogue to a digital format for import into a computer so that it can be stored and edited by the user. New sensor technologies allow digitisation of operating conditions, including the identification of all materials in the factory and warehouse. Technologies such as barcodes, QR codes, and RFID tags offer traceability, which is a precondition for self-handling materials.

• **Communication** - (Industry 3.0): Hierarchical connectivity and defined functions. It is limited within the enterprise in the production process.

• **Standardisation** - (Industry 3.0): The use of standards that are necessary to identify parameters that cannot be identified or studied during design. In particular, Standard Operating Procedures (SOPs) are explicit instructions describing the tasks, conditions, and steps to be taken to achieve the operation of a unit or the application of a method.

• **Flexibility** - (Industry 3.0): The ability to have a system respond to changes that lead to external factors at the level of connectivity and automation. To address the increasing complexity and speed of processing, smart support systems are introduced. Support systems are implemented in a variety of processes, providing operators with standard operating procedures, technical maintenance instructions, and inspectors supporting decision-making on production quality. Information is automatically provided to people with the help of screens, smart glasses, and tablets.

• **Customisation** - (Industry 3.0): It combines the benefits of mass production and personalised production by setting the foundation for the production of new smart products that are tailored to the customer's quality financial and operational requirements. The intelligent product delivers decentralised coordination and production control. In addition, smart products require their own processing requirements, which are directly communicated to the machines.

• **Real-time Responsibility** - (Industry 3.0): It is critical that data is collected and analysed in real-time so that the system can respond and react in time with minimal impact. In this study, real-time management of systems or processes refers to the collection and processing of KPIs (key performance indicators) in real-time, since KPIs play an essential role in controlling production. Different types of KPIs such as Overall Equipment Efficiency (OEE) can be measured.

• **Preventive Maintenance** - (Industry 3.0): The main objective of predictive maintenance is to provide a break before it appears. By equipping sensing machines, it is possible to monitor the state of a machine and predict when maintenance needs to be carried out. This approach promises cost savings. Predictive maintenance also contributes to the manufacture of additives that provide a more resource-efficient way of producing components by allowing spare parts to stand alone. To date, additive manufacturing has been mostly used as a prototype in product development, however, there are also areas of application in the industry.

• **Decision Making** - (Industry 4.0): The process of identifying alternatives and decision making. Applications of virtual reality and simulation are expected to increasingly grow here. Applications will be used to introduce new products to simulate material flow and factory designs. The main benefit is that it offers a cheaper and faster way of working, as the number of natural experiments can be reduced.

• **Early Aware** - (Industry 4.0): This concept includes accurate self-assessment with the ultimate goal of solving problems according to the system's capacity and limits.

• **Self-optimisation** - (Industry 4.0): The system has the capability for all components and systems to continually seek opportunities to improve performance and efficiency. It achieves all of this by utilising big data analysis systems and artificial intelligence (AI). It is imperative to equip machines with sensors and systems capable of storing a huge amount of data. Machines can optimise themselves in terms of order delivery time or cost of production.

• **Self-configuration** - (Industry 4.0): The system is trained to fully adapt to new conditions. Through cyber feedback in the physical space, there is a seamless inspection that leads to corrective and preventative decisions.

3.2 *Proposed framework to define the gap*

In terms of establishing a framework, there is a table (Figure 2) that includes all those characteristics that compose the necessary features to make it possible to ascertain the current situation and estimate the impending gap. As mentioned, some of the attributes are related to Industry 3.0's domains (the industry-specific systems belong to Industry 3.0) and are prerequisites that must be met to enable a system to move to the industry level of Industry 4.0 [53]. In addition, they are classified with a certain weight in order to highlight the difference between the technologies of the machines or systems. The significance of each feature is given by the condition that its existence sets in relation to the next one. For example, communication between machines as a feature requires the digitisation of information. A level above digitisation is thus classified.

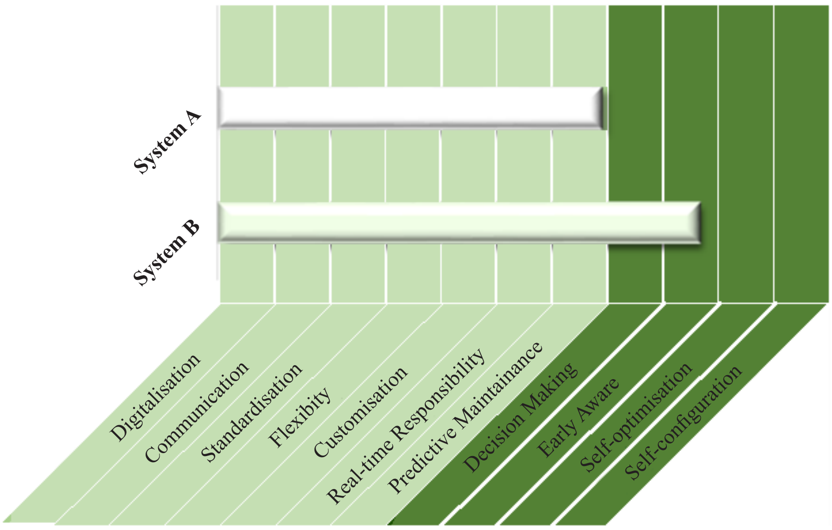

Figure 2. Table of the core eleven characteristics of the industrial revolution for 2 systems

According to this table, a framework occurs that develops a roadmap for the implementation of Industry 4.0. In its implementation, the developed framework complements the empirical data in order to analyse the information, identify the gap, and present proposals for its coverage. In order to obtain tangible results and, by extension, make identification possible, there are scales created considering the level of maturity for each feature. The maturity in coverage of a single feature is estimated with a score from zero to four (Figure 3). In particular, for the maturity scale, the systems with the highest maturity are characterised by four (4). This indicates that it has been fully implemented, while zero (0) indicates that there is no possibility.

Maturity Scale

0	1	2	3	4
No possibility to implement	There is an implementation plan	A relevant project has been presented	Partially applied to the plant	Complete application in the factory

Figure 3. Scale to determine the maturity of implementing Industry 4.0 solutions

When all cases are evaluated for all systems studied, a table is developed for each of the features. The scale of maturity and the system that are under consideration are placed on the two axes of a Cartesian coordinate system. This table was developed to provide data for Industry 4.0 maturity analysis.

The scoring process for Industry 4.0's level of implementation was calculated for each machine, process, and factory in total. The total score for each system was calculated by adding the maturity scores of each of the eleven features. Finally, empirical findings were analysed.

The table in Figure 3 will emerge through this process by considering that a characteristic is "covered" when the conditions set by it are fully or even partially met, as in the case of maturity.

4. Implementation of plastics manufacturing

4.1 *Case study – plastics company in Greece*

For our case study, we have studied one of the most promising and established companies in Greece, i.e., Thrace Nonwovens & Geosynthetics S.A., with a market capitalisation of over 200 million euros [54]. Specifically, this company was created in 2010, undertaking all the activities related to the technical fabrics and yarns made of polypropylene of Thrace Plastics, which was originally founded in 1979. Thrace NG exports all over the world, to more than 80 countries. The company consists of six departments, which makes it possible to use it in our study as it has large technological variations. Analytically, Thrace NG strives for excellence, which shapes every aspect of procedures, processes, and people. Thrace NG's strategy is to sustain growth through long-term client relations by implementing the latest manufacturing technologies and innovations [55].

4.2 *Current, under consideration production system*

Our case study focused on Plant No. 6, the layout of which is depicted in Figure 4 and consists of two machine types (FARE - green, Asselin - beige, and DILO - blue) that synergise together in the production process. Specifically, this plan shows the current positioning of the three machines that are installed inside Plant No. 6. The purpose of this arrangement is very important as it follows the process flow. More specifically, the direction of FARE (blue-colored machine) has its output at the feeding areas of Asselin and DILO (as FARE produces fiber - the semi-product). These two machines, Asselin (beige machine) and DILO (green machine) have their output in the same area, which is declared as the plant's logistics area. Lastly, this figure showcases the successful implementation of a product transfer between two different production stages.

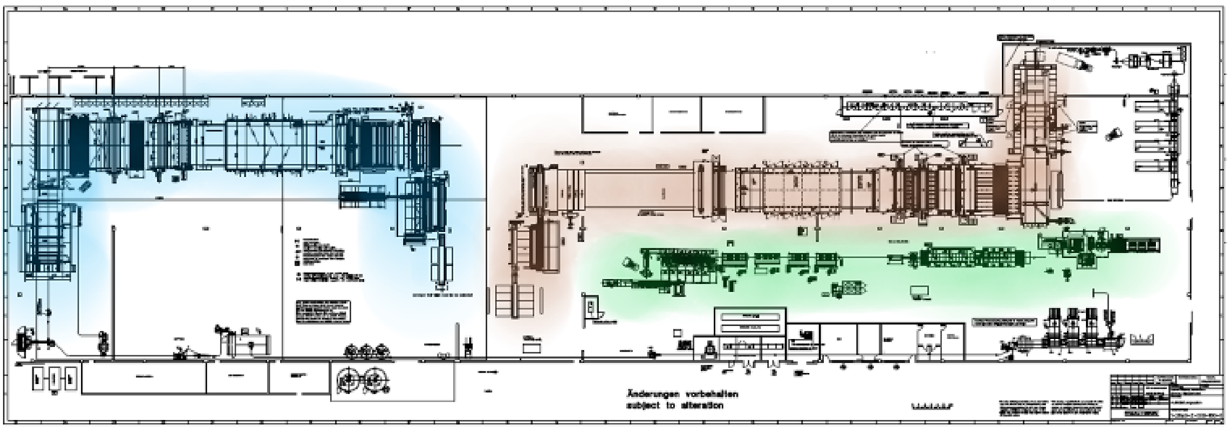

Figure 4. Plant No. 6.'s layout

In the following sections, we will present a detailed analysis of the three engineering areas of Plant No. 6.

4.2.1 *Area of machinery*

4.2.1.1 *FARE (year of construction: 2007)*

The FARE machine of FARE SpA, presented in Figure 5 [56], uses polypropylene (PP) and less polyester (PET) as raw materials along with various additives, in order to produce, by extrusion, bundles of synthetic and staple fibers that are not carded, combed, or otherwise processed.

Figure 5. FARE's machinery layout

Operational Description: The process presented in Figure 6 starts with FARE's dosing units being supplied with raw material from silos through vacuum pumps. Any other materials (sunscreen, colour, etc.) are also occasionally suction pumped from special containers. Then, depending on the recipe given by the operator, the dosimeters feed the extruder with the final mixture, consisting of granules. By means of lateral resistance and mechanical friction, the screw increases the temperature of the material, and thus the grains melt and the polymer mixture passes through a pump into the 9 spinnerets (spin heads) as fluid. This is where the production of fluid and continuous fiber takes place. Afterwards, the flowing material is cooled by air (quenching) in order to solidify. Thereafter, the fiber goes through finishing rolls and is attributed to mechanical stress caused by the heating rollers in order to obtain the desired strength and elasticity. At this point, the fiber is transferred to the crimping section and then to a furnace for thermofixation. All the procedures above are absolutely critical for the physical properties of the fiber as well as for the flow rate of the line. Finally, fibers are cut into lengths and packed into a fiber ball (bales). The maximum machine productivity is estimated at 2.00 tn/h.

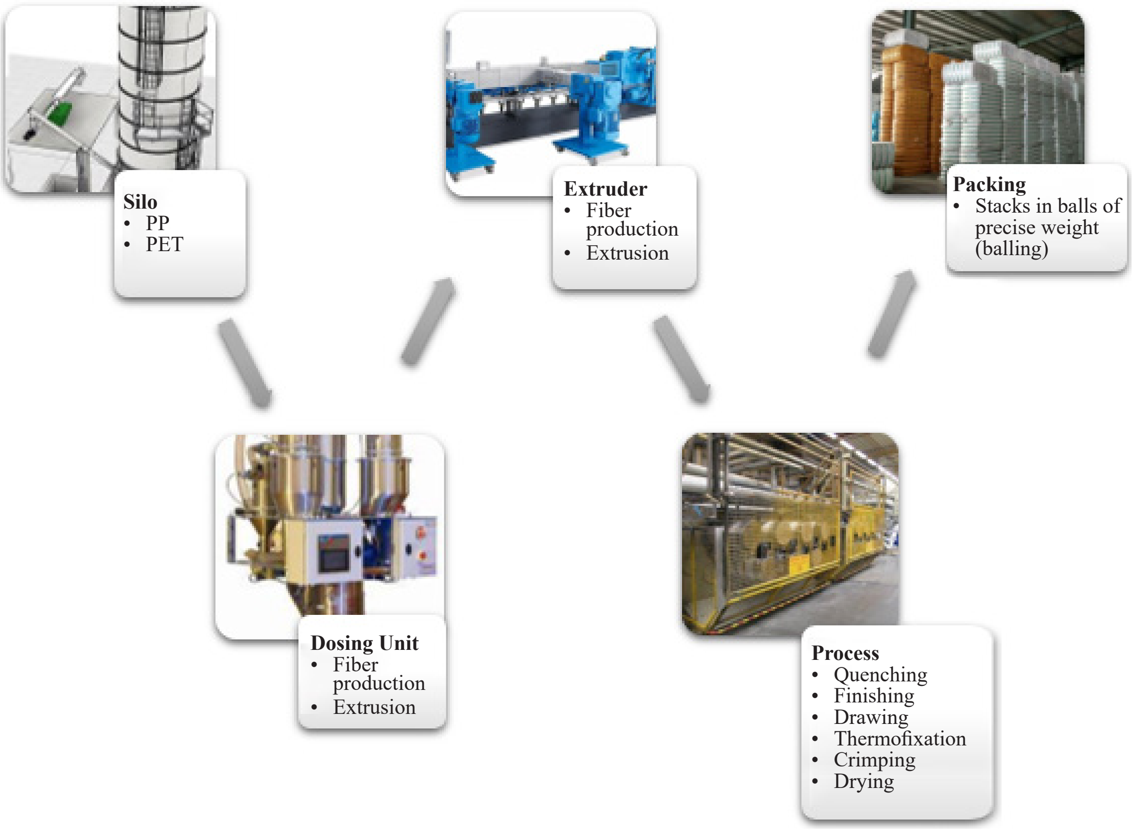

Figure 6. FARE's flow chart

4.2.1.2 *Asselin (year of construction: 2007)*

Asselin of ANDRITZ Asselin - Thibeau S.A.S., presented in Figure 7 [57], is a nonwoven geotextile with a needle-punching production line. The nonwoven geotextile is made of staple polypropylene fibers. Its applications include project foundations (railways, roads, reservoirs, and tunnels) and building construction as part of the installation of permanent drainage, separation, stabilisation, and reinforcement systems.

Figure 7. Nonwoven geotextile's machinery layout

Operational Description: The manufacturing steps toward nonwoven fabric production, include the fabrication of fabric layers by welding staple fibers. In the first stage, bales consisting of randomly oriented fibers, are opened through a process called carding. In this process, fibers gain a uniform distribution as well as the same alignment among them. In the vast majority of nonwoven geotextiles, the fibers are made of polypropylene. These oriented fibers assemble a web in which there is no binding (laid webs - layers). Thereafter, fabrics are produced by mechanical welding of fibers (needle punching) when barded needles are pushed through the fibrous cross-laid web, which forces some fibers through the web where they remain when the needles are withdrawn (looms). The bonding between fibers is achieved either mechanically, thermally, or chemically. Asselin uses a thermosetting oven along with a calender (heated roller) and needle-punching looms. The density and thickness of the final product depend on the density of the needles and on the speed of the line. The fibers are then heated at their melting points as the web passes through an oven and then between two heated rollers rotating opposite each other (calenders). In the last stage, the cloth is wrapped in rolls. Note that at the end of the process the fabric is checked by a radioactive laser to verify the fabric's thickness. This information is used as quality control feedback for self-optimising. The maximum machine productivity is 1.30 tn/h [58].

4.2.1.3 *DILO (year of construction: 2015)*

The DILO machine of DILO System S.A. is a nonwoven geotextile production line, just like Asselin [59]. Its operational capabilities, illustrated in Figure 8, are similar to Asselin's with some improvements. The maximum machine productivity is 1.50 tn/h.

4.2.2 *Process area*

The process contains three consecutive phases:

4.2.2.1 *First phase*

Initially, the fiber is produced in the FARE machine. The FARE machine is supplied by polypropylene from the silos, which are filled in two ways:

- either by silo trucks which fill in silos with raw material by exploiting vacuum pumps, 50% of the time,
- or manually by emptying sacks of raw material by the operator, 50% of the time.

The raw material is then passed to the dosing units, where the extrusion process takes place. In the manner described already, the fiber is put up in bales of about 200 kg. The bales are wrapped up with stretch film, then tagged after they are weighed (side labelling), and are deposited via a bridge crane in a 6-bay capacity field. From there, the forklift operator takes care of transporting them to the warehouse, where they are stored either for sale or domestic use.

In parallel, quality control is performed at regular intervals. The operators analyse some samples of fiber for some of the characteristics such as elasticity, strength, linear density, and crimping. According to the results of the measurements, the operator has to choose whether to modify some parameters of the machine or not.

4.2.2.2 *Second phase*

In order to produce geotextile, DILO and Asselin machines should be fed with fiber bales. They must meet conditions such as:

- High consistency, as it ensures that the grid provides high levels of strength that are necessary for higher take-off rates (throughput). It is also essential to have uniformity in the grid, not breakpoints.
- Good separation helps with the uniformity of the mesh.
- Good crimping maintains better carding.

The fiber bales are thus initially transferred from the warehouse to the openers where the separation begins. Next, the production process of the nonwoven fabric follows. The product is characterised by its weight and width. The packaging is made of rolls whose length is at the disposal of the customer. These rolls are automatically wrapped with stretch film, tagged with Side Labelling, and deposited at a point where a forklift will pick them up from the warehouse, from where it will be sent to the customer. The certification obtained by the geotextile is in accordance with the European Union directives on technical design (CE marking). Weights range from 100 g/m^2 to 2,000 g/m^2 while the roll length can be 1 m up to 5.40 m. The final product is tested to determine its quality. In order to control the thickness of the fabric, Asselin and DILO machines have an automatic thickness control unit that controls uniformity throughout the entire surface of the fabric. After the machine collects data about the thickness of the fabric, according to the results, then modifies itself in order to normalise the deviation (error) according to the desired final product.

Lastly, apart from increased productivity, Asselin differs from DILO in its innovative technology in the way of transitioning from lightweight productions to heavyweight while delivering better quality features. Additionally, production costs are expected to be very low. Using less material for equivalent resistance results in heavier products. The excellent uniformity of fabrics is among the most important features.

4.2.2.3 *Third phase*

Finally, the phase of storing the rolls in the warehouse is followed in order to ease truck loading. The rolls are taken over by the forklift operator.

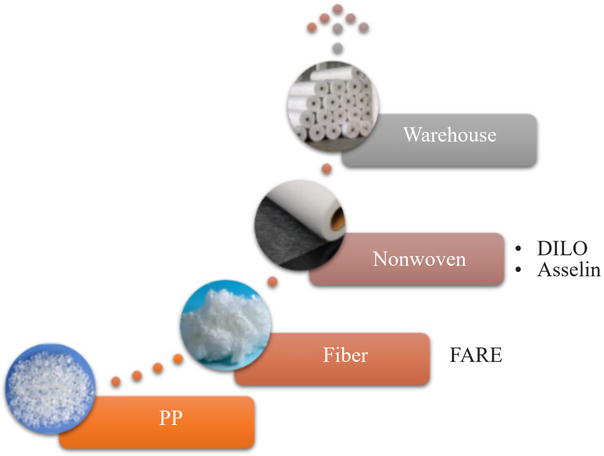

Figure 8. Process flow chart

4.2.3 *Area of factory*

The plant is based on an enterprise resource planning (ERP) system that provides the most essential infrastructure for business functionality, e-commerce, relationships, and communication with its customers.

The ERP system is managed by the department managers. Specifically,

- the production manager
- the financial manager
- the person responsible for the procurement
- the sales manager

To start with, the sales manager is responsible for promoting the products, but also choosing the market to be addressed. The final choice will be made after the product has been examined and its requirements can be met and its economic worth can be assessed. They will then forward the orders received via email to the production manager. The production manager undertakes to be informed by the system about the stock, in order to update the production programme and calculate the estimated delivery time. Unless a matter of urgency comes up, the production programme is promoted to the machine operators on paper. At the same time, the production manager contacts the procurement department to inform them about the plant's stock of raw materials.

Beyond the ERP system, the plant also uses a system that is a subsystem of ERP and is called the warehouse management system (WMS). This system consists of some software applications that support the daily tasks that take place in the warehouse. These applications allow the central management of work in a warehouse, from tracking the amount of inventory to placing it in appropriate locations within the storage area. They were developed to speed up loading/unloading time, improve the validity of the stock list, optimise the management of warehouse space, and enhance its productivity.

When a piece of an order is completed, a sticker with a barcode is placed on the package. WMS also calculates all the necessary means related to the forthcoming production updates in the ERP system.

The installed ERP system allows the integration of all business processes. The distribution of information supports the reorganisation of business processes in financial services, accounting, human resources management, supply chain management, management restructuring, and other strategic manipulations that meet the needs of the customer. Eventually, the sales department is duly informed of the warehouse stock, the availability of the machine, the estimated time of delivery of the orders, and the machine's flexibility for any new products.

4.3 *Gap between current system and Industry 4.0*

The analysis above, through the framework described, is represented in Figures 9, 10, 11, 12, and 13. A considered characteristic is covered when it is fully or partially fulfilled according to the maturity level.

4.3.1 *At machinery level*

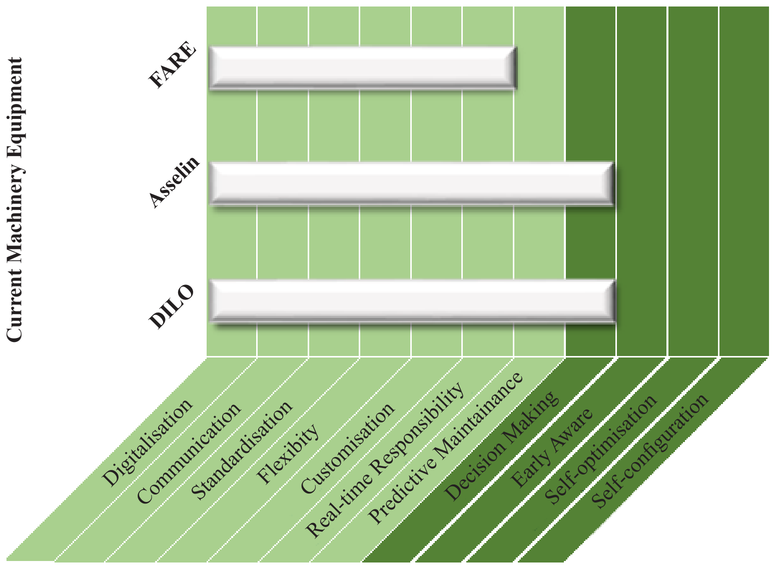

Figure 9. Characteristics fulfilled on the machinery level

4.3.2 *At production process level*

The maturity is set out in Figure 10. The data are derived from all the observations on maturity by the executives, as well as by the scholar. The same method is used for the production process and factory level.

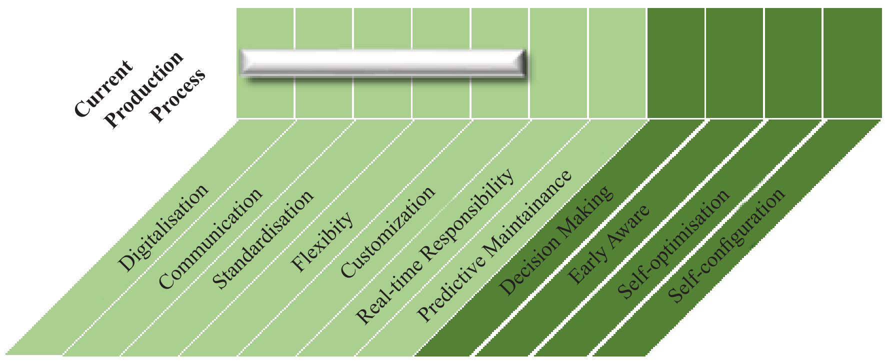

Figure 10. Characteristics fulfilled on production process level

4.3.3 *At factory level*

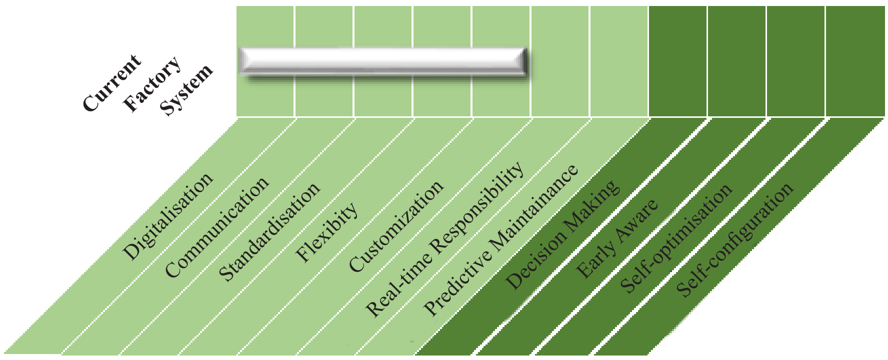

Figure 11. Characteristics fulfilled on factory level

4.3.4 *At all levels (comparison)*

Overall, taking into account all of the above, we observe that the two machines (Asselin & DILO) are approaching the early stages of Industry 4.0 to a good extent, and the other one lags behind Industry 3.0.

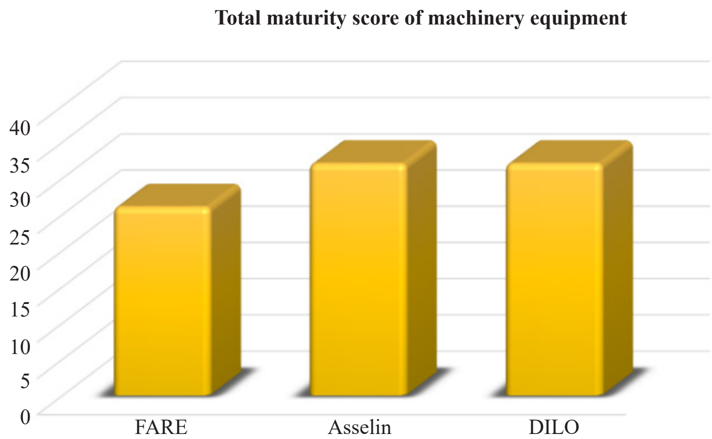

Figure 12. Maturity score of machineries

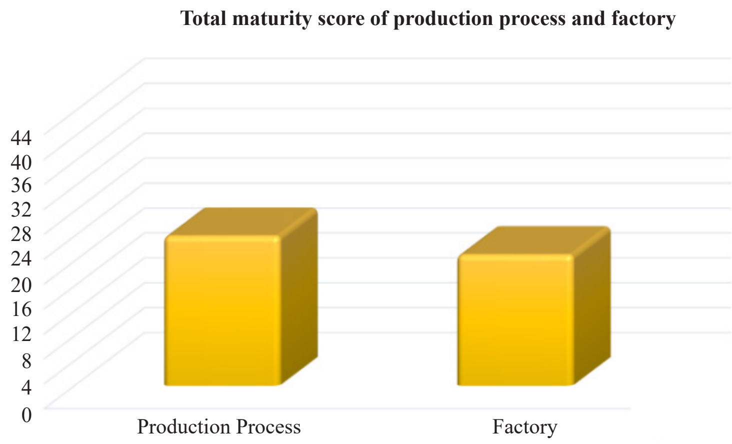

Figure 13. Maturity scores of production process and factory

Lastly, we notice that current production processes have many limitations. Specifically, many of the above-mentioned areas do not provide adequate capabilities in monitoring and error-finding techniques as they severely lack the full automation and artificial intelligence systems that Industry 4.0 targets. As a result, due to the lack of "smart" automation processes, current production is usually characterised as Industry 3.0. Finally, the factory or production system inevitably follows the individual. Although some automation is distinguished, the lack of intelligence at all levels is obvious. Overall, it is at a level that is theoretically not far from full automation, but from a practical point of view, the "gap" between the current situation and Industry 4.0 is blatant. In Figure 14, we illustrate the area of the gap between Industry 4.0 and other industrial revolutions.

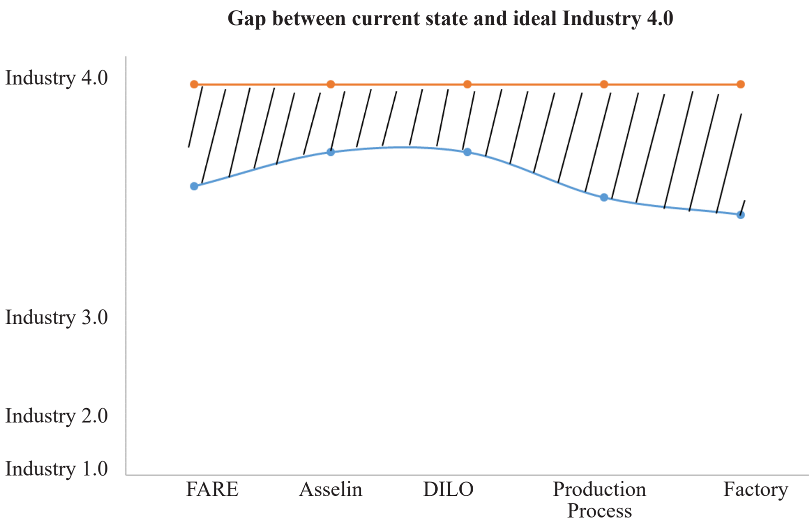

Figure 14. Graph which depicts the "gap"

5. Bridging the gap

In the following sections, we will present our suggestions to improve the current state of the industry so as to increase the current use of Industry 4.0 technology in the plant. As in the previous sections, we will distinguish the plant at three distinct mechanical levels.

5.1 *At machinery level*

As previously discussed, the machinery level is separated into these key sections: FARE, Asselin and DILO machines.

5.1.1 *FARE machine*

The machine, technologically, belongs to Industry 3.0 and satisfies the level of digitisation (it has computers that allow it to digitise information), communication (it is equipped with devices that allow it to interact with other entities for the exchange of information), personalisation (adapts to any potential production resulting from demand), standardisation (its function is governed by rules), flexibility (it has the ability to configure its working conditions according to the requirements of the customer of the final product), and the response in real-time (the camera is able to provide information about the operating conditions and to utilise and provide instruction in minimum time).

The FARE machine should have a mechanism in the case of the start and the cases where the fiber failed (automatically broke) to find itself in the way through the rollers and the furnace it needs in order for it to be processed. In order to implement this requirement, a provision is proposed that will operate temporarily, and with the help of the suction nozzles, the fiber will be transferred to all the points needed to continue its operation without human assistance.

Additionally, provisions for quality control should be added to each process to enable the machine to self-optimise. However, it is lagging in defining preventative maintenance, decision-making on any changes, early critical situations, self-improvement at all levels, and self-conformation in different modes of operation.

According to our study and based on industry experience [60], if a proclamation is made by a plant and offers are requested to fill the gap and make the transition to Industry 4.0, the average cost (for consulting, manufacturing, and materials) would be approximately 2,900,000 euros.

5.1.2 *Asselin & DILO machines*

In textiles, Industry 4.0's terms are still not widespread. The cost structure of the nonwoven fabric is of high importance due to the competitive market it is targeting. Developments in Industry 4.0 in the nonwoven fabric industry, therefore, tend to focus on reducing the labour force, increasing productivity (by introducing additional quality controls), and reducing downtime with preventative maintenance. In fact, there are three areas of particular importance: self-optimisation of nonwoven fabrics, data analysis, and assistive systems. These fields are presented in the "EasyNonwoven" standard, which aims to self-optimise machine settings using routines.

The first step for self-optimisation was carried out by the Institute of Technology Assessment (ITA) with the "EasyNonwoven" model [61], presented in Figure 15, which focuses on the machine part called Card as the machine is mainly to determine the quality of the product. In order to develop a self-optimised card, electronic quality control must be made directly to the non-integrated web. Quality data based on the remaining data can be used by a self-optimised algorithm that enables the camera to adjust the rotations of the roller card.

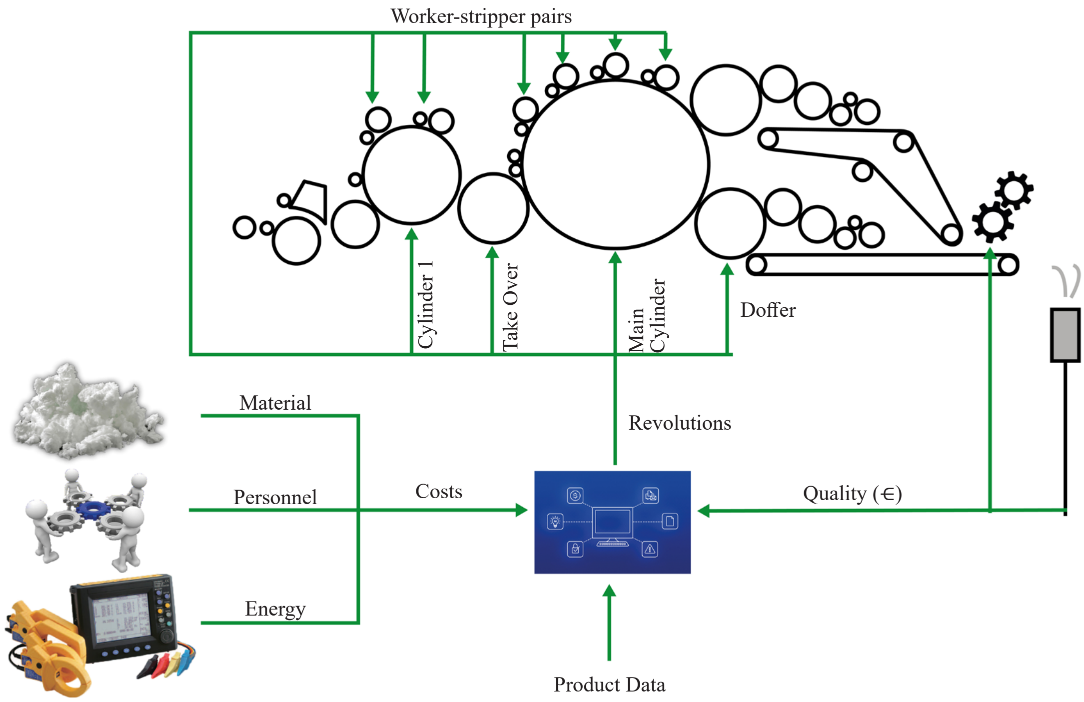

Figure 15. ITA's EasyNonwoven model

The development of the DigiTextil model is also important in the textile industry. Big data (large data) is characterised by volume, variety, speed, and accuracy. Big data analyses lead to technologies, concepts, data structures, and tools that can be used in a variety of forms [62]. This provides the opportunity for consistent optimisation of production and maintenance. In addition, it is possible to detect an error in the quality of the finished product. In the latter case, the data storage capability has prompted companies to develop the DigiTextil model, which allows secure data transfer and storage in a secure third-party cloud. According to these data, if a product error occurs, the company is able to resort to other companies to find a solution. Data stored in the cloud can therefore advise on how to avoid the error in the future. Finally, the development of robotic devices will make the engine autonomous at all levels.

DILO and Asselin as machines meet some of the requirements of Industry 4.0. They are equipped with automation that makes their operation intelligent since there are mechanisms that allow quality control to be in operation at the same time as the operator's warning parameterisation in order to achieve the standard product. Related Industry 4.0 technologies that will improve the nonwoven fabric production are smart machines, optimisation of electronic machines, smart power consumption, predictable maintenance, ancillary systems for maintenance, repair, and machine operation, automating work through the knowledge that will be acquired, advanced process control, and the use of large data.

Lastly, according to our study and based on industry experience, if a proclamation is made by a plant and offers are requested to fill the gap and make the transition to Industry 4.0, the average cost would be approximately 2,230,000 euros per machine.

5.2 *At production process level*

At this level, the spatial flexibility that characterises the department is of crucial importance. It is important, when talking about the cooperation of independent processes, that implementation is done effortlessly. Initially, the areas involved will be examined and some suggestions will be made to bring the current production process into Industry 4.0.

Analytically, the process should be improved at the feed level with either FARE raw material or Asselin or DILO fiber bales. It is obvious that there is a problem with storing units (ready-made and semi-finished). The human factor plays the leading role in the process of producing something that excludes the required automation and artificial intelligence.

The feed process could be automated by placing a Depalletiser - Bag Emptying Machine (Figure 16) for the automatic tearing of the 25 kg bags and air conveyance of the plastic granules contained in them to a silo. By installing the machine, automatic feed safety, precision, cost-savings, and cleanliness are achieved.

Figure 16. Equipment for the automated conveyance of raw material

In the production line of the nonwoven fabric, an Automatic Palletiser & Strapping could be placed. The palletiser is a device by which palletising rolls (packaging, tagging, and strapping) are fully automated. For proper mapping in the warehouse and beyond, it is possible to place RFID devices on fiber bales and rolls to identify each product [62]. A mechanism should also be installed to automatically store the fiber bales and simultaneously feed the stitching machine with them, similar to the one depicted in Figure 17.

Figure 17. Palletiser and strapping for packing rolls

Finally, conveyor belts and crane bridges (Figure 18) should be installed in order to transfer them from the machine to the semi-finished warehouse and vice versa. In addition, referring to the movement of raw materials and products within the factory, it is crucial to add an automated guided vehicle (AGV) robot (Figure 19), which makes the internal logistics process automated. AGV warehouse systems (portable robots that follow indexes or cables on the floor for navigation) are growing increasingly, which contributes to further automation of production processes.

Figure 18. Machine for carriage of rolls to the warehouse

Figure 19. AGV for the automated conveyance of products and raw materials

The current production process belongs to Industry 3.0 as it satisfies the level of personalisation, flexibility, communication, and digitisation, but lacks the level of defining preventive maintenance, real-time response, decision-making changes, early detection of critical situations, self-improvement at all levels, and self-configuration in different modes of operation.

According to our study and based on industry experience, if a proclamation is made by a plant and offers are requested to fill the gap and make the transition to Industry 4.0, the average cost (for consulting, manufacturing, and materials) would be approximately 1,650,000 euros.

5.3 *At factory level*

Overall, there appear to be mechanisms that provide facility facilitation at several levels of the plant's functionality; however, artificial intelligence through full automation is not far enough. In order to achieve this automation, programmes that will collaborate with the lower mechanical levels in real-time should be introduced. Information will be available on all levels. Customers will be able to place online orders and receive real-time updates on availability, delivery time, and costs (taking into account any maintenance, damage, and other unhealthy factors). These processes require intelligence and automation at the field level.

It is obvious that the entire plant belongs to Industry 3.0 since it satisfies the level of personalisation, the definition of preventive maintenance, standardisation, flexibility, communication, and digitisation, but lags behind in real-time response, decision-making on any changes, timely critical situations, self-improvement at all levels, and self-configuration in different modes of operation.

According to our study and based on industry experience, if a proclamation is made by a plant and offers are requested to fill the gap and make the transition to Industry 4.0, the average cost (for consulting, manufacturing, and materials) would be approximately 800,000 euros.

6. Conclusion

The introduction of a categorical framework helps companies discover the "gap" that they should cover to approach the idea of modernising activities via Industry 4.0. Specifically, our proposed framework points out the main directions that the industry should focus on, emphasising the IoT and Machine to Machine (M2M) design principles that must be followed.

Furthermore, as presented in our case study regarding plants dominated by machine equipment, it is evident that in their present state they are mostly handled by human operators. Unfortunately, automation processes and machine systems are non-existent and by extension, the industry severely lacks in terms of the typical and necessary Industry 4.0's standards. Analytically, actions must be taken in almost every aspect of their operating principles, from the automation level to the decision-making equipment and the regulation of diagnostic mechanisms. Moreover, since the production systems in question perform their functions in more than one distinct phase, we must focus on transitioning between phases in the smoothest way. This means that to achieve this transition, a plant factory should carefully understand its operating architecture and activities, and gradually expand/augment and implement our techno-economic solution to transit into Industry 4.0.

Moreover, a crucial factor that must be taken into consideration is the agile nature of the proposed framework, i.e., its reusability in other manufacturing sectors aside from textile and plastics. Analytically, this framework categorises the operation flow of a textile and plastic manufacturing factory threefold, i.e., machinery, processes, and factory field; however, one can argue that this separation is valid for other plants as well, specialising in fabrication, processing, finishing, refinishing, and assembly lines. More specifically, all these industries have similar-sized industrial sites and similar building structures; thus, regarding the process area and the factory area, the separation of concerns and the proposed methods are valid, whereas, regarding the machinery area, many limitations exist as it is highly dependent on unit production.

Lastly, as for future works, based on this study, besides explaining the machines and plant activities, this article has focused on providing in detail the average cost for upgrading machinery and operations. This means that future research should focus on expanding our suggestions to further increase their profit margins, decrease their operating costs, and increase the overall business return on investment. More specifically, they should focus on new operations and automation procedures to decrease operation/execution timeframes, labour costs, energy costs, waste costs, and especially maintenance costs.

Conflict of interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this research.

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