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Conceptualizing Industry 4.0 for Greek Manufacturing Sector

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Abstract

The so-called "fourth industrial revolution" or Industry 4.0 aims to transform the current EU industries into synchronous global market leaders, by incorporating into their production and functional framework the contemporary digital opportunities. Several EU countries have already launched the initiatives to adopt the next generation technologies into their industries. Recently, Greece recognized the necessity to upgrade its industrial environment with features such as "flexible production lines", "smart IoT solutions", "collaborative robotics", "inter-operable services", "adaptable industrial processes" etc., by identifying them as the key technological instruments that will bring its industry into the forefront of EU production sector. This will allow to state to overcome the so far major socio-economic and financial barriers that dragged the country back from its extrovert market potential. To this end, the paper at hand aims to propose a comprehensive transition to Industry 4.0 strategy by introducing a conceptual implementation approach that will pose the steps to be followed for the Greek stakeholders in order to pass from the era of computational automation, through the digital transformation, into the era of the ubiquitous cyber-physical systems (CPS), necessitated from the next generation industrial environments.

Keywords: Industry 4.0; Greek industrial domain; design principals; lean production; predictive maintenance; supply chain management; cyber-physical systems

1. Introduction

During the last decade, the manufacturing technology witnessed substantial growth mainly due to contemporary advances in the industrial domain as well as the information and communication technology (ICT) systems (Alexopoulos et al., [1]). It is evident that the tremendous progress in these sectors along with the lately introduced research technological accomplishments, led the industry into the so-called *fourth industrial revolution* as described by Xu et al. [2], which has been initially announced at the Hannover Fair in 2011 and, since then, has been established as the *Industry 4.0* (I4.0). This includes the edge of the technological advancements of automation technologies in the manufacturing domain and it mainly involves key enabling technologies such as the cyber-physical systems (CPS), Internet of Things (IoT), cloud computing and collaborative robotics (Hermann et al., [3]). Moreover, in I4.0, smart embedded systems, trends for ubiquitous robots, cross- platform communication, IoT and CPS technologies are integrated into a virtual space with the physical world. Factories of the future, which comprise the next generation of industrial systems, enclose all the aforementioned technologies that aim to tackle the complex production emerged in the cyber- physical environment as stated by MacDougall, [4].

Despite the fact that the incorporation of such technologies into the current industrial environments can bring great technological and productivity advancement, there are barriers which drag this evolution back and prevent most of the countries to shift in such undertakings. Specifically, in accordance to the report presented by Klitou et al. [5], I4.0 has low adoption rate; for example, over 41% of EU companies have not adopted any of the new advanced digital technologies. This relied mainly on the absence of common and flexible adoption policies, funding approaches and implementation strategies and, as a result, only a fraction of the European countries have actively adopted I4.0, including Spain, UK, France, Italy, Germany, the Czech Republic, Sweden and the Netherlands, while the rest of them struggle to incorporate into their modern industrial environments only some of the key enabling technologies.

When it comes to countries with inherited and enduring socio-economic issues, such as Greece, the modernization pace is even slower, since the evolution from the current technological state to the new aspects of I4.0 necessitates specific strategies and titanic efforts [6],[7]. There are emerging reasons that necessitate the Greek industrial transition to the digital way of production and operation [8]. Specifically, in accordance to the Readiness for the Future of Production report, of the World Economic Forum, [8], there is an immense need of Greek companies to change their growth strategy and invest towards the I4.0 transition. The readiness of Greek has been ranked in the bottom among 100 states in the world, rendering the manufacturing domain of the country the only Western European economy that is categorized as "critical" in terms of readiness to take part in Industry 4.0. Two main reasons are responsible for this situation. The first one is related to the economic crisis of the past decade, that forced the enterprises to remain attached to old-fashioned production models, struggling to

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face the upcoming needs of the ubiquitous productivity and, the second one, is related to the lack of labor skills linked to the digitization requirements of the new industrial revolution. The successful paradigm of German industrial domain, which seamlessly integrated the new technologies into the production lines of their companies and remained at the forefront of the global economy, can benefit Greek industry to scramble in the manufacturing domain. This can create a viable and competitive industrial eco-system relied in the flexibility of the small and medium-sized enterprises(SMEs), which constitute more than the 95% of the production domain in Greece.

Based on these considerations, the paper at hand aims to respond to the question on *how the Greek industry can progressively get transformed and meet the I4.0 requirement*. To this end, this work documents the considerations, analyze the already adopted solutions and opportunities and proposes a conceptual strategy for the incorporation of I4.0 technologies into the Greek industry. In a nutshell, the required effort can be outlined as an intensive cooperation between industrial, public and academic sectors with the aim to assess the current technological and production state, research essential to facilitate the knowledge transfer between the different parts.

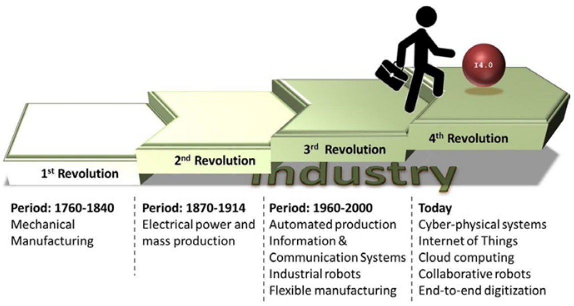

Fig. 1. Graphic representation of the Industrial evolution along the four known revolutions.

2. Background knowledge

A deeper understanding of the industrial evolution during the last decades can be obtained by studying the progression from Industry 1.0 to Industry 4.0 [8],[11]. The industrial advancement roadmap is graphically illustrated in Fig. 1 and outlined as follows:

- The 1^{st} industrial revolution made use of water and steam power to industrialize the production as stated by Horn et al. [12].
- The 2^{nd} industrial revolution made use of electricity to move to mass production, as stated by [13].
- The 3^{rd} industrial revolution made use of electronics components and information technology to automate production, as stated by [13] and [15].
- The 4^{th} industrial revolution makes use of digital transformation of the structures of the 3rd one and is therefore characterized by the seamless merge of subsistent technologies so as to write off the boarders between natural, digital and biological entities, as stated by Xu et al. [2].

Realization of I4.0 is mainly based on various technologies among which the IoT, CPS, cloud computing, collaborative robots, cyber-security and technologies that enable smart production [16], [17], [18]. CPS are usually referred to as the next generation of the ICT systems and comprise the cornerstone of the I4.0 They include computational components seamlessly integrated with the information systems installed in the industrial environments and allow intercommunication among hardware (machinery) and software components in multiple ways [19],[20]. Cloud computing is related to the cloud- manufacturing, which aims to exploit a wide network of computational and storage resources to establish ubiquitous factories in the entire manufacturing chain [21]. All these factors lead to the need for trusted transactions in all levels of modern industrial manufacturing processes, which can be provided by the cyber-security models e.g. block chain [12],[2]. The above mentioned technologies act complementary to the already installed manufacturing systems in industry and can further assist the realization of collaborative robots, which will work in close distance with the humans to increase manufacturing flexibility in the contemporary production lines [23], [24].

Albeit technologies that characterize I4.0 are already clearly established in the scientific and technological community, the adoption rate of such technologies from different countries is not the expected one. For instance in Europe, only a fraction of countries have incorporated the new technological features in their industry, while their adoption policy exhibits a great variation. For example, the French cross-cutting *Industrie du Future* programme is linked to New Industrial France programme, whilst the Italian national technological intelligent factories cluster *Fabbrica Intelligente* was drawn up against the Italian Innovation Roadmap. On the other hand, Netherlands was boosted from the low share of employment associated to the manufacturing sector to create the *Smart Industry* as stated by Roblek et al. [25]. All these facts reveal that although I4.0 is a mainstream policy, yet there is not a solid approach towards its implementation. Thus, for some countries still remains in conceptual state and, thus, the adaptation diverge from one member state to the other and even from region to region within the same country. Towards overcoming these barriers, European Union encourages research into the field of smart technologies that favor I4.0. Specifically, the Horizon 2020 work-program initiated funding programs for research and development projects such as factories of future, smart cities, leading technologies for energy, mobility, autonomous personal/professional collaborative robots and other [23. Outside Europe, there are also emerging countries, such as Brazil, that aim to transform their industrial perception under the wider framework in I4.0. Dalenogare et al. [26] in their work proved that some of technologies incorporated under I4.0 are positively associated to the expected industrial benefits of Brazil, while others are still at a very early stage of adoption and, thus, without clear expected benefits, exhibiting that Brazilian industry has not yet taken advantage from specific technologies such as big data analysis, cloud services etc.

3. Methodology

The main methodology on which our work has been relied is tightly related to the system architecture design strategy, initially introduced from Mitchell [27], concerning the development of complex systems and is further adjusted to the most recent theory introduced by Rozanski and Woods [27]. Thus, we tackle herein the transition of Greek industry into the I4.0 as a new system to be developed, with the existing technologies treated as the subordinate components that need to be integrated and seamlessly cooperate with each other. Initially, an overall conceptual architecture has been defined, layered to the "key enabling technologies" that mostly characterize I4.0. Then, the existing "transportation means" along with the required "design principals" are presented exhibiting how the "key enabling technologies" can be applied in a systematic manner. Next, the implementation view presents three "application domains", critical to the Greek industry, on which the above mentioned technologies and principals can be applied. Last, the potential risks and mitigation strategies for the ambient transition to the I4.0 are identified and discussed. It should be stressed here that the paper at hand presents a conceptual realization of Greek industry into I4.0 and the outlined sections are relied most on bibliographic findings and statements, offering to the stakeholders an initial guide on how to incorporate new technologies into the Greek industrial domain. Moreover, it should be noted that the proposed adaptation strategy is not tailored solely to the Greek industrial sector, yet similar adaptation strategies, to those proposed herein, can be applied to any other country with socio-economic and manufacturing profile close to Greek one.

3.1 Realization strategy

Figure 2 graphically illustrates a conceptual architecture for the transition of the current technological state to I4.0. It incorporates specific key enabling technologies, the transformation means required for their systematic realization and the design principals that should be followed along with preliminary identified application domains on which such technological advancements should be applied.

3.1.1 Key Enabling Technologies

It is evident that the transition of Greek industry into I4.0 will be accomplished by fusing the existing with the upcoming key enabling technologies that involve:

- robotics
- cyber-physical systems
- cloud computing
- cyber-security systems
- smart sensors
- smart devices
- augmented reality

Those technologies will intensify the current automation through the rapid and constant data exchange on the production lines. The transformation means that should be applied on these technologies to contribute in the transition to I4.0 are summarized as follows:

- artificial intelligence
- data and systems security
- simulation
- big data analytics
- information systems
- internet of things

Fusion of these technologies constitutes the so called "smart" or digital factory. In this, the key enabling technologies monitor the processes and when exploited by such technological means can set the basis to satisfy the designed principals necessary for the transition in I4.0. In more detail, smart sensors and ubiquitous connectivity constitute basic principals in the digitalization domain enabling rapid information exchange, intra-shopfloor connectivity and thus increased situation awareness in workstation level, that leads to decentralized decision making, an aspect that boosts the flexibility within an enterprise. Another component of the factories of future that realize the I4.0 vision is the industrial augmented reality (AR) as introduced by Masood and Egger [29], a connective tissue among the physical and the digital world. AR can augment workers to promote human-centric industrial environment, since it has a broad range of applications with the most representative of which to be the safety enhancement in human-robot and human-machine interaction in the contemporary collaborative factory floor plans.

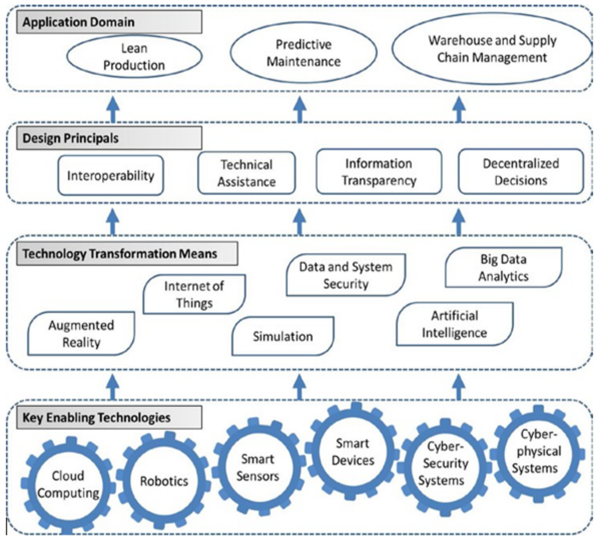

Fig. 2. Conceptual realization architecture for the transition to Industry 4.0.

In order to achieve this, existing basic IT solutions need to be evolved and adapted to the specific requirements of digital factories as well as on SMEs needs and continue to be developed with particular applications. Following this strategy, I4.0 can significantly contribute at SME's business, by integrating them into digital value chains, by fostering the adoption of specialised digital services and by increasing the data collection in order to efficiently monitor the production. This digitalisation should allow partners along the supply chains to improve the quality of products and/or services, to manage operations in a more efficient way thanks to real time production monitoring offered by the inter-operable CPS, to reduce costs and to improve their competitive position.

3.1.2 Design Principals

There are four pillars that should be followed by the Greek industrial stakeholders on which the I4.0 can be designed, described as follows:

- **Interoperability**, which is the ability of the machinery, devices, sensors and humans to be connected and communicate with each other while operating for a common task.

- **Information transparency**, which is the ability of the information systems to create virtual copies of the natural world, enriching the digital models of the industrial facilities with data of the installed sensors.
- **Technical assistance**, which is the ability of the supporting systems to back humans by concentrating and visualizing information in an apprehensible manner, allowing the decision making systems to timely address emergency situations. Moreover, the technical assistance comprises the ability of the CPS to support in a physical manner humans by undertaking a series of tasks unpleasant, exhausting or insecure for their coworkers.
- **Decentralized decisions**, which is the ability of the CPS to draw decisions on their own while completing their assignments autonomously. In this way, only in exceptional situations, interference from external factors or contradictory inputs, the scheduled tasks are assigned to a higher decision making level.

These four pillars are applicable both in factory environment as well as in SMEs, offering services related to the analysis of data. For instance, “information transparency” is crucial in the smart product services systems leading to more dependable solutions. In addition, considering that the business of the majority of the SMEs in Greece are related to services provision, “decentralized decisions” and “interoperability” of their systems constitute a basic principal for their competitive operation under a technologically advanced framework.

3.1.3 Implementation View-point

The physical developments and implementations that should be considered by Greek industrial sector are essential to be grounded on the aforementioned designed principals. Taking into consideration that the studied industrial sector is not characterized by heavy manufacturing units, yet it mainly involves SMEs oriented towards medium scale processing and services provision, the evolution to I4.0 should be targeted to the main existing infrastructures allowing smooth transition to the new era, rather than applying holistic changes on the entire production infrastructures. Considering this, implementation of the I4.0 designed principals have been chosen to be applied on three distinctive initiatives, namely *Lean production, Predictive Maintenance and Supply Chain Management*, thus applying a substantial reinforcement to the backbone of the Greek SMEs [30].

Lean Production: The lean philosophy is concentrated on the diminishing of waste, the strengthen of the human workers, in the reduction of the stock in the warehouses and the improvement of the productivity as stated by Bicheno [31]. Reduction of stock can be achieved in close cooperation with the raw materials providers. In this way, it is possible to achieve highly personalized and on-demand products [32]. The lean production is also relied on the maximization of the flow in the production lines, while the production is oriented towards the customers needs. Moreover, it necessitates adaptive design of the product and flexibility in the production lines [33]. To achieve this, technologies such as smart collaborative robots should be installed in the shop- floor environments that will be capable of combining in a modular manner the existing skills required for the construction of the products [34]. In addition, modelling and simulation tools are essential for the rapid transformation of the current production line to the modified one that would be capable of addressing the requirements necessitated from the new personalized product queried in the shop-floor information system. Additionally, the lean production necessitates the rapid training and adaptation of the workers which can be performed with augmented reality tools.

Predictive Maintenance: Predictive maintenance targets to increase of productivity through the continuous operation of the production workstations which is ensured by applying prediction and avoidance of failures [35]. Up to now, the design of productions lines has been characterized by safety engineering methods to avoid potential hazards and risks identified at the system level, while the safety analysis had been performed using qualitative and quantitative methods with the goal of identifying dependencies between the potential hazards and failures of the individual system components, exploiting techniques such as Failure Mode and Effects Analysis (FMEA) or Failure Mode and Effects and Criticality analysis (FMECA) and Fault tree analysis (FTA) [36]. These methods have been proved to be adequate in static production lines however, the necessity of I4.0 to maintain flexible productivity that emerges the continuous shop-floor transformations, does not allow traditional safety analysis to perform well since they are typically demand a large amount of performance data for an adequate operation. The necessity of on-the-fly predictive maintenance emerges the adoption of more flexible and holistic methods for hazard analysis defined from the design phase of complex systems in shop-floor environments such as STPA [37], RiskSOAP [23], Decision Making Grids and Jack Knife Diagrams [38] tools that endorse synchronous automated systems with the necessitated dependability [39], [40]; that will eventually allow predictive maintenance. Such methods integrated with artificial intelligence, big data and visual analytics constitute powerful tools that strengthen the prediction of hazard situations in production lines, preventing excessive down time, decreasing thus the excessive maintenance costs. Consequently, the unobstructed information flow of sensors installed in multiple machinery and the utilization of the machine learning methods for the timely fault detection is essential. This is directly associated with the *Technical assistance* design pillar of the I4.0 since it provides in real time essential informations required for the timely decision making for the production line and can predict a failure before its occurrence.

Warehouse and Supply Chain Management: The warehouse 4.0 comprises a component of the I4.0 considering that smart technologies bring transparency and interoperability of the global supply chain [41]. The operation of synchronous warehouse necessitates the automated completion of the raw materials in stock, the incorporation of the autonomous smart vehicles endorsed with capabilities of object- material recognition, order collection, decision making and routing of the intra-transportation systems. Moreover, integration of IoT with the above mentioned technologies into supply chains will bring major advances in the next generation warehouses [42] The current trend in I4.0 is the installation of cellular transport systems (CTS) that consist of groups of autonomous guided vehicles having advanced perception and cognition capabilities allowing them to operate as a whole in the shop-floor in order to complete ordered tasks. Moreover, it is typical for the contemporary autonomous guided vehicles to be equipped with advanced manipulation mechanisms that allow their in-between as well as their collaboration with humans in the shop-floor environment. Their inter-connectivity to central information system allows CTS to have increased situation awareness and enables them to draw decisions regarding their plan, the route selection, the priorities in the ongoing industrial processes by shared data with other CTS regarding the current environment state.

The above mentioned initiatives are crucial for the industrial transformation towards I4.0 of a country (such as Greece) with low industrialization profile and the majority of the production capacity to be held by SMEs. In more technologically advanced countries with greatest industrialization maturity and readiness to adopt the new technologies [43], there are several other tools and practises, their incorporation of which can significant expedite this transition process. Of such, can be considered the horizontal integration of models, designs and implementations through value networks sustainable supported using CPS, through the end-to-end digital engineering across the entire value chain and the vertical integration of networked manufacturing systems, [44]. Additional enabling technologies and application domains in I4.0 are considered to be the product and production monitoring, the quality control, the workplace safety and the assets utilization.

3.2 Indicative Use Cases Definition

It is evident that the application of the above mentioned technological advances to the identified application domains imply fundamental changes to the traditional Greek industrial character. To this end, stepping towards should occur smoothly and provide an undisrupted transition of Greek enterprises into I4.0. This, can be achieved by preliminary identifying use cases to be applied firstly in a pilot manner. The realization of these features should be performed systematically on each distinguished initiative. Firstly, the majority of all the industries should be contacted from all the provinces of the country, aiming at the interaction and reassurance of their understanding of the new models of structure in the manufacturing domain and to assess the technology readiness of each individual one. Specific questionnaires will be tailored for this purpose. In the next stage, implementation of customized prototype projects will be designed in the lab and should be applied to specific and representative industrial stake-holders aiming to cover all the above described technological advancements. The final step concerns the application of those technological advancements in larger scale aiming at the stabilization of the new trend, while at the same time the continuous familiarization to then needs of I4.0 will be applied aiming to spread it widely in the Greek Industry and the greater audience.

In particular, for the *Lean Production* advancement the systemic confrontation with problems in production scheduling is foreseen. The existing issues would be tackled through the development of advanced methods for the big data analysis including, among others, reactive and predictive time-scheduling methods, update policy techniques considering event driven, periodic, schedule repair and on-demand situations. Development and installation of decision support systems for the continuous monitoring of the on-going processes in the production lines as well as optimization of processes flaw, are also part of the lean production balancing.

Considering the *Predictive Maintenance*, the installation of total productive maintenance methods should be performed. This would be achieved, on the one hand, through the autonomous and scheduled maintenance tactics that introduce in the industry the new role of the human workers. On the other hand, predictive maintenance would be further reinforced by applying intelligent systems on the fault detection exploiting machine learning, data and visual analytics and predictive methods. Moreover, the incorporation of integrated information systems of maintenance management that concerns the administration of all the faults restoration, the administration of the functional information of the shop-floor maintenance department and the introduction of IoT technologies for the faster communication between the machinery and the maintenance devices are all key technological factors that should be applied during the implementation stage of the I4.0 at the selected industries.

For the *Warehouse and Supply Chain Management*, the holistic and systematic confrontation of the existing problems in the supply chain is foreseen through a series of technological improvements. The latter concern the installation of smart sensors in all stages of the supply chain -from the supplier to the consumer- for the decentralized monitoring of the processes, in-between the different stages. This will have as a result the arousal of the need for security protection, where cyber-security systems should be installed to face potential attacks and threats. The great number of sensors will produce data that will emerge the installation of software components responsible for the big data analytics, while the adoption of methods of just-in-time delivery should be relied in a great amount to the CPS.

4. Potential Risks and Mitigation Strategies

The industrialization roadmap could be proven of high risk, especially in the situations where the strategic decision for the transition to I4.0 is not aligned with the technology readiness of the dominant organizations' systems e.g. the existing IT infrastructure, the level of automation in manufacturing processes, the business' digitalization, the overall network etc. In particular, for many SMEs, which are the central productivity and business body in Greece, it is still not a standard practice to use model-based simulations in order to configure and optimise manufacturing processes. One major challenge for I4.0 will be to raise awareness of models' potential among the wider engineering community and equip engineers with the means to use appropriate models to depict real-world systems in the virtual world. Another important risk is the safety and security breaches that may arouse cyber-security attacks. Such breaches may occur due to the immature existing IT infrastructure at SMEs and the integration on them with technologically advanced CPS. In such occasions, backwards and forwards compatibility, as well as block-chain protection is imperative to cope with such issues, diminishing thus the cyber-security threats. Moreover, the protection of data and services in (digital) systems against misuse, e.g. unauthorised access, modification etc, is of great importance. The security measures should increase confidentiality, integrity and availability of the system. I4.0 technologies require vast amount of investments, with an unknown duration for amortization together with uncertain success. It would be possible to automate, digitize, and network many processes of operational value creation, an attempt that requires large expenditures for the infrastructure, implementation, and maintenance. Thus, the detailed scheduling, the existence of advanced and synchronous ICT solutions and the selection of mature I4.0 key enabling technologies is critical for the smooth transition of SMEs and industries to the era of I4.0. Another strategy, to deteriorate the risks for an enterprise towards the insertion to I4.0, is to utilize specific Maturity-Models, introduced in [45],[**Error! Reference source not found.**] and used to assess the current technological situation of the enterprise, taking into consideration aspects like the readiness of the working environment, the existing skills and resources etc. and suggest the safest starting point for a smooth transition.

5. Discussion

In this work, a conceptual realization approach of Industry 4.0 for the Greek industry has been presented. Considering the theoretical contributions, initially, a high level architecture that outlines the realization strategy along with the key-enabling technologies and the design principals, which constitute the pillars for the entrance of Greek industries into I4.0, have been exhibited. In this work, an implementation view point has been provided in order to discuss the physical developments and implementation, in a multidimensional fashion tailored to the SMEs character which hold a great share of the Greek business models. The findings of this work are also applied on three use cases which constitute major manufacturing domains in the examined industrial environment.

Concerning the managerial contribution of the proposed conceptual paper, the main objective is to provide at the production and shop-floor managers a useful guide with the main toolkits and alterations required for the transition of their industrial environments into the I4.0. Moreover, in order to achieve this, indicative use cases and requirements have been posed, while attributes for the future designed pilots have been provided.

As for the future work which could act complementary to the present study, pilot manufacturing hubs and production lines should be designed and developed on which each industrial stakeholder could apply and test the envisioned improvements before the installation to the real environment. This will offer the opportunity to tackle potential limitations and resolve any unidentified problems during incorporation of I4.0 key enabling technologies in the real industrial plants. Finally, it should be mentioned that the proposed realization approach of I4.0 could be applied in all countries with inherited socio-economic problems similar to Greece, where industrial modernization occurs with slowpace.

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