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Review

Stories Told by Publications about the Relationship between Industry 4.0 and Lean: Systematic Literature Review and Future Research Agenda

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Abstract: Industry 4.0 and its application in the business has been the focus of attention by the academy, for its ability to establish principles of flexibility and connectivity along the shop floor. Meantime, because of a lean wave in the 1990's, most of the western industry adopted principles, techniques and tools of lean production, whose results were quickly captured, guaranteed its adoption worldwide. Thus, with a view to turning traditional manufacturing companies into smart companies, it is essential to preserve the existing system and find ways for the two concepts (Lean and I4.0) to come together. This study was conducted based on a systematic literature review, using the Scopus database. The PRISMA process was the method used to select the articles. Finally, to analyze and discuss the results, the bibliometric analysis of the articles and content analysis were adopted. The results point to a greater impact of I4.0 technologies on lean, since it was perceived that I4.0 technologies give to lean tools a more dynamic way of working, accelerating information sharing processes and improving production manager's and operator's decision making. In the perspective of lean's contribution to I4.0; however, there is little practical and theoretical application, thus the actual contribution is still somewhat blurred.

Keywords: systematic literature review; PRISMA method; lean production; Industry 4.0; content analysis

Citation: Salvadorinho, J.; Teixeira, L. Stories Told by Publications about the Relationship between Industry 4.0 and Lean: Systematic Literature Review and Future Research Agenda. *Publications* **2021**, *9*, 29. https://doi.org/10.3390/publications9030029

Academic Editor: Rosa Scoble

Received: 26 April 2021
Accepted: 29 June 2021
Published: 5 July 2021

1. Introduction

Industry 4.0, also known as the Fourth Industrial Revolution (4IR), is the wave of the moment and has surfaced due to disruptive advancements in manufacturing processes and technology [1]. These technologies allow production systems to be flexible and modular, enabling the mass customization [2].

Lean is the current companies shop floor's philosophy [3] that drives for stability and low variability in products type [2]. This philosophy aims to reduce the waste on the shop floor and improve productivity, not forgetting customers' requirements [1].

Even though I4.0 has gotten significant attention from academia in the past few years, the actual effects, obstacles and key success factors for its broad embracement across different industrial sectors and contexts still require additional investigation [4]. Empirical studies have shown that the implementation of I4.0 technologies can benefit greatly from Lean practices, since these guarantee standardized and robust processes. [5]. On the other hand, most of the companies that have implemented lean practices have faced a common problem related to the sustainability of the implemented practices throughout the system and over time [6]. Since we face a digital transformation in the way we work, it is essential to make this change as short as possible, considering the existing manufacturing systems. For this reason, the first research question arises: "How can Industry 4.0 and lean benefit each other?" This article intends to carry out a systematic literature review to answer this question and, consequently, to support the future of this topics in academic literature. The database used to collect the articles was Scopus and, in order to have a universe of articles sufficiently capable of responding to the purpose, the PRISMA method was applied. After executing this method, bibliometric and content analyses were carried out. This last step was essential in the sense that it allowed to understand which lean techniques/tools are the most cited and that, due to this fact, they are considered the most applied in the industrial environment. Thus, the focus of this work was to understand, in light of what is most talked about/applied with regard to lean, how technologies associated with industry 4.0 can help improve the performance of existing manufacturing systems. With this analysis it was possible to establish a matrix capable of summarizing the current contributions, practices, and theorists of the technologies I4.0 to lean techniques/tools, taking into to account stories told by publications. In addition to the influence of I4.0 technologies on lean techniques/tools, the opposite was also analyzed, with the perspective that lean methodologies could ensure some degree of standardization in the introduction of digitization. This review, then, intends to make known the current state of the art, in order to provide gaps in the knowledge that need to be evaluated, for further future investigation.

The present paper is structured as follows: In Section 2, there is a theoretical background, where Industry 4.0 and lean concepts are specified. Then, in Section 3, the planning of the systematic literature review is presented, emphasizing the need for a systematic review on this topic, as well as the formalities considered for the selection of articles (research formula and inclusion and exclusion criteria). Section 4 exhibits the bibliometric and content analysis to the universe of selected papers and, finally, the summary and outlook, in Section 5, intends to review the results obtained. Section 6 stipulates the future research according to this paper authors.

2. Theoretical Background

2.1. Industry 4.0

Today, great technological changes are happening, also bringing great challenges to organizations. Supply chain's globalization, unpredictable markets, customer demands, individualization, and shorter product life cycles are some of the changes identified by Lugert et al. [7].

Industry 4.0 (I4.0) brings together a series of initiatives to improve processes, products and services favoring the interconnection between people, objects and systems through the exchange of data in real-time [8–11]. This phenomenon contributed to the paradigm shift of production from a centralized to a decentralized system [12]. If production data are related to consumer behavior, enterprises can dynamically answer to changing market demand [13,14], increasing capability to adapt quickly to products with shorter cycles [2,14]. Communication, flexibility, real-time, and decentralized decision-making represent the most popular key terms related to I4.0 [8,15].

The I4.0 paradigm is strongly techno-centric with cyber-physical systems (CPSs) [16], incorporating intelligent machines, storage systems, and production mechanisms with power to swap information autonomously, whilst promoting actions to adapt to mutable contexts [8,17,18]. Although material requirements planning (MRP) or enterprise resource planning (ERP) are almost a standard, to make companies more agile and flexible, more advanced solutions must be implemented [19]. Smart factories use CPS to link the physical world with the virtual one, creating a working network [20–22]. The internet of things (IoT) included in CPS contributes to monitor and, consequently, improve the production process [23]. During IoT implementation it is important to understand how a company is structured and how different sectors should be put together. Thus, three types of integration arise: (i) horizontal—allowing inter-corporation collaboration through value networks; (ii) vertical—allowing integration of hierarchical systems inside a manufacturing system; and (iii) end-to-end, allowing connectivity throughout value chain [24]. Manual ways of production will not be able to deal with the challenges of mass customization and globalization in such a way that the solution passes by extending levels of industrial automation in manual work in the form of human-machine collaboration [25]. In what concerns to decision-making, the most relevant technologies are cloud computing, IoT, big data, and RFID (radio frequency identification) connections [16].

Although this new environment creates, for the manufacturing industry, challenges in relation to automation and digitalization of production processes [8,26], it represents an important technology-based opportunity to shift how companies generate value for their customers [17]. For many manufacturers, the existing infrastructure may not be capable of supporting the transformation into Industry 4.0, since this makeover might impact human resources development and customer relationship management [27]. Dutta et al. [28] established that large enterprises tend to be better equipped and prepared than small enterprises to receive the introduction of disruptive technologies. This happens because companies from emerging economies mostly need to import a technological solution that adds a substantial financial barrier, when compared to companies from developed economies [4].

It is important to understand; however, that applying high automation technologies to enhance production system flexibility may cause troubles; examples of them are a high-level of investment cost, low returns, and, consequently, investment transformation failure [29].

Generally speaking, a I4.0 project must be carried out as a gradual process, and the current manufacturing systems must be preserved and considered in a socio-technical view [20,26,30]. Western industrial production was typified by the wave of lean production and lean management in the recent decades, creating now the idea that the I4.0 context may have to be integrated into existing lean production systems in order to succeed [30].

Furthermore, the lean philosophy has been identified as a beneficial tool to change and improve the cultural value of a company, improving at the same time the work that is done. In this line of thought, lean could support the development of industry 4.0 in a company [31].

2.2. Lean Manufacturing and Its Key Concepts

Lean manufacturing can be deemed as one of the most meaningful contributions in the history of operations management [32,33]. This philosophy has turned into a widespread approach because of its high efficiency gain in enterprise production and logistics [27,34,35].

Lean aims to have a streamlined process flow where a systematic and visual approach is used to reduce waste [3] and increase flow via extensive employee involvement and continuous improvement, always identifying value from the customer's perspective [10,34,36]. Therefore, the basis of this philosophy places the human being as an import issue in all its decisions [27,29,37], although, nowadays, companies tend to forget this facet, focusing just on waste reduction [1,37].

Lean emphasizes that everyone can definitely recognize problems and anomalies, triggering the problem-solving process, which is considered to be an essential capability, providing both development of organizational processes and individuals who execute it [5]. It incorporates several tools, such as key performance indicators (such as overall equipment effectiveness —OEE—that is a metric that aims to monitor productivity), and single-minute exchange of dies—SMED—a lean technique that supports the changeover and startup processes); 5S (focuses on organization and discipline in the workplace); value stream mapping (visual tool that shows the flow of both materials and information as they progress through the process); jidoka (technique described as intelligent automation that makes it possible to stop production whenever there are abnormalities); kanban (signage cards that control production or transport flows in a shop floor); and others which collect various types of data. In the same line of this thought, data analytics is considered to affect enormously the success rate of lean implementation. However, these data were just used to monitor and not to improve existing operations. That way, Abd Rahman et al. [38] referred that the usage of data analytics in process improvement is one of the most challenging aspects in lean manufacturing. If managers do not have all the surrounding information they require in terms of decision-making parameters and/or effects, subsequently they do not perceive the positive impact of good practices on their company's performance [39]. Practices associated with just-in-time (JIT) production systems are more extensively implemented and appreciated by manufacturers in emerging companies compared to productive/preventive maintenance tasks, which use more advanced statistical process control [40].

3. Methods

3.1. Motivation and Research Question

Globalization has been intensifying competition among manufacturers and lean has been a valuable approach in improving productivity and it is already recognized that I4.0 technologies have the potential to further increase that [41]. Nonetheless, Ma et al. [29] emphasizes the idea that lean production eradicates much of the creativity required for innovations, making enterprises miss advanced technology-push chances. Although some authors alert to the possible conflict between I4.0 and lean, since the second is considered to be a low-tech approach [2,32] that protrudes for simplicity, which may possibly conflict with technology-driven approach of I4.0. On the other side, Kolberg et al. [42] and Kolberg et al. [43] identify potential in the integration of I4.0 and lean, reactivating the idea of lean automation that has been around for some time (since 1990′s). However, authors suggest that existing approaches are proprietary solutions, not supporting modularization and changeability, thus they need to be tailored to individual needs. In the last three decades an extensive adoption of lean practices was occurred, primarily in the occidental industry [3]. Yin et al. [44] stated that lean is considered to be a production concept which is nowadays still explored by researchers and imitated by many companies. At a time when a new paradigm is emerging—industry 4.0—most companies in a position to adopt it are embedded in a lean philosophy with various practices on the factory floor. This has attracted the attention of some researchers, leading them to question whether these practices—lean and I4.0—could have an impact on each other. Lean has its focus on financial and operational performance via a systematic and continuous search for waste decrease and improvements, so in line of this thought a few researches support that the implementation of lean and I4.0 could mitigate existing management complications and direct manufacturers to even higher performance standards [4]. Industry 4.0 is capable of improvement, but in a mostly technical approach, which does not replace the value-based mind set of lean [45]. For this reason, the integration of both concepts is better received by the academy, hoping that the opportunities that I4.0 can bring will take lean to another level of excellence. Thus, this paper intends, in a systematic way, to address the confluence of the two concepts and understand the impact on each other, in order to update the state of the art in this area and to understand what is critical to be done. Given this contextualization, this study aims to answer the general research question "how lean and I4.0 can help each other towards achieving a more decentralized, efficient, and cohesive business?". This question was broken down into other eight specific questions—four with answers through bibliometric analysis and the remaining four through a content analysis (see Figure 1).

Bibliometric analysis

RQ1- How articles are distributed over time?

RQ2- What type of scientific documents publish the most in this area?

RQ3- What is the impact and quality of the most relevant Journals in this area?

RQ4- How are the papers distributed in the geographical context?

Content Analysis

RQ5- Which I4.0 technologies are considered most relevant?

RQ6- Which lean techniques and/or principles are considered most relevant?

RQ7- What is the contribution of Industry 4.0 to Lean?

RQ8- What is the contribution of Lean to Industry 4.0?

Figure 1. Specific research questions.

3.2. Research Formalities—Articles' Selection

3.2.1. Research Formula

The database used for the research was Scopus that is now the major database for multidisciplinary scientific literature. Overhead, it is a database which allows connections among different disciplines, attaining high levels of accuracy when corresponding references to summaries [46]. To collect all relevant articles to answer the question of investigation, the following research formula was developed (Table 1). Lean manufacturing has several practices with this research formula and, in May 2020, 159 articles were collected.

Table 1. Research formula.

Scope	String
Industry 4.0	("Industry 4.0" OR "fourth industrial revolution" OR digitization* OR "Digital Twin")
Lean	(lean OR Kaizen OR "Value Stream mapping" OR "Just-in-time" OR "Total productive maintenance" OR "Kanban" OR "Total Quality Management")
Impact between the two concepts	(Effect* OR influence* OR impact* OR response* OR reaction*)

The research formula was created after 11 iterations and the Lean tools associated with the second part were based on [8,30,47,48].

3.2.2. Exclusion and Inclusion Criteria—PRISMA Method

In order to select the articles, exclusion and exclusion criteria had to be carried out. Figure 2 exhibits the PRISMA method scheme, illustrating all the steps carried out until reach the final articles.

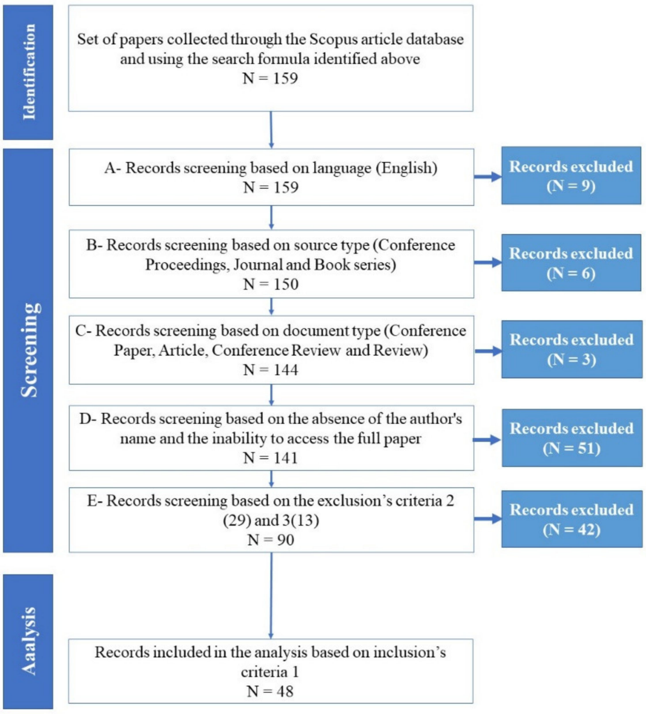

Figure 2. PRISMA scheme of articles' selection.

As can be seen in Figure 2, firstly, only articles in English were considered, hereby excluded 9 articles. Next screening was the source type, considering conference proceedings, journals and book series, and consequently the type of document which included conference paper, article, conference review and review was also the target of choice. Thus, the set more 9 articles are excluded. Finally, the articles that did not present an author and/or it was not possible to access the full paper are filtered, excluding, with this criteria, 51 articles. The remaining 90 articles were manually screened based on title and abstract to verify if each paper was relevant to be included in this research, considering the inclusion and exclusion criteria present in Table 2. When the title and the abstract were not conclusive, the full article was analyzed.

Table 2. Exclusion and inclusion criteria specification.

Criteria Number	Criteria Specification
1	The paper investigates I4.0 and Lean, showing contributions of both concepts to each other, carrying out systematic reviews, case studies, practical applications or surveys design and distribution.
2	The paper investigates in an exploratory way about I4.0 and Lean, evidencing contributions of both concepts to each other, creating frameworks that initiate ideas for more practical studies.
3	The paper refers to I4.0 and Lean concepts in a broad way just for contextualize, with no interconnection of the terms.
4	The paper uses the notions of lean and I4.0, however it applies them in another area than manufacturing sector.

By applying criteria 2 and 3, 42 articles were excluded. A great number of documents only mention the topics of Industry 4.0 and lean in a superficial way, without an analysis of the impact of each in the other. Consequently, only 48 papers were selected, based on inclusion criteria, integrating the research procedure.

This reduced number of papers clearly shows that this topic has been almost neglected in the literature, despite the great increase that studies on Industry 4.0 has registered in the past few years as well as lean practices.

4. Results of Systematic Literature Review Study

This section presents the results divided into two parts. In the first part, a bibliometric analysis is carried out to answer the questions, Q1, Q2, Q3, and Q4. In the second part, a content analysis was conducted in order to answer the questions Q5, Q6, Q7, and Q8.

4.1. Bibliometric Analysis

RQ1: How Articles Are Distributed over Time?

Until 2019 it is possible to observe an almost exponential growth in the number of articles published with topics that relate the concepts of lean and I4.0's, and it is in that year that the largest number is registered (19). Since the date of completion of the paper, the year 2020 has not yet ended, growth is also expected this year, in the sense of following an exponential curve. It is possible to conclude that we are facing with a recent topic with the first paper to appear in 2014.

It should be added that the value of conference articles is also significant, so it can be extrapolated that this is a relatively new subject, as already observed by the distribution of papers over time presented in Figure 3.

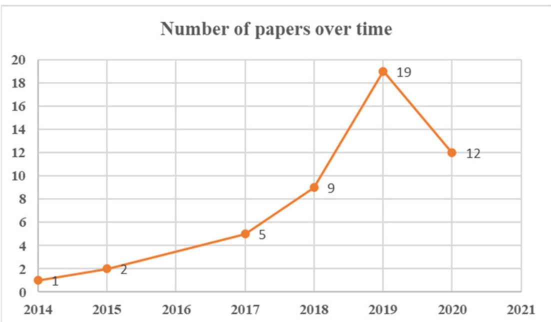

Figure 3. Distribution of papers over time.

RQ2: What Type of Scientific Documents Publish the Most in This Area?

By analyzing the Figure 4, it can now be argued that the journals are already quite interested in this area (76%), being able to see it as a subject on which to invest in future investigations.

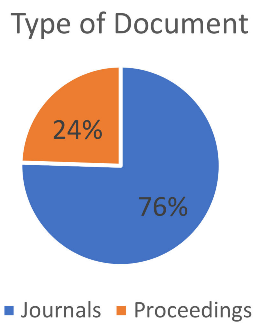

Figure 4. Frequency of type of documents (Journals and Proceedings).

RQ3: What is the Impact and Quality of the Most Relevant Journals in this Area?

Figure 5 presents the world of journals inherent in the group of articles analyzed, journals of quartile 1 (Q1—46%) stand out, whose quality is considered the highest, followed by quartiles 3 (Q3—35%) and 2 (Q2—19%). Pondering the previous question that referred to those who published the most in this area, the International Journal of Production Research which is a Q1 stands out. Regarding the highest number of citations (Table 3), it is highlighted the article published in 2015 in the IFAC-OnlinePapers Journal. Two papers of 2018 published in International Journal of Production Research appear again, in second and third places.

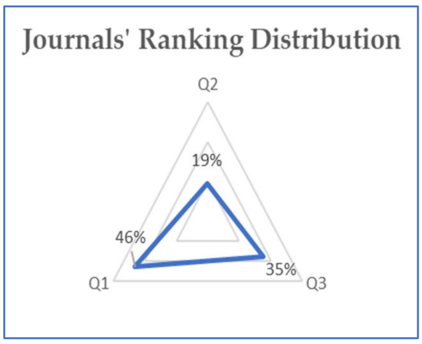

Figure 5. Journals' Ranking distribution.

Table 3. Articles' Top 5 with the most citations.

Article	Journal/Proceedings	Citations	Year
Kolberg et al.	IFAC-PapersOnline	164	2015
Yin et al.	International Journal of Production Research	83	2018
Tortorella et al.	International Journal of Production Research	79	2018
Wagner et al.	Procedia CIRP	74	2017
Kolberg et al.	International Journal of Production Research	60	2017

Finally, with 5 articles published, Tortorella is the author with the most publications in this area.

RQ4: How Are the Papers Distributed in the Geographical Context?

The bibliometric analysis with respect to the geographic region focused on the affiliation of the authors. By analyzing Figure 6, Italy is the country with the highest incidence of publications (22%), followed by Germany (18%) and Brazil (16%). It should be noted that the author with the most publications, Guilherme Tortorella, has a Brazilian origin.

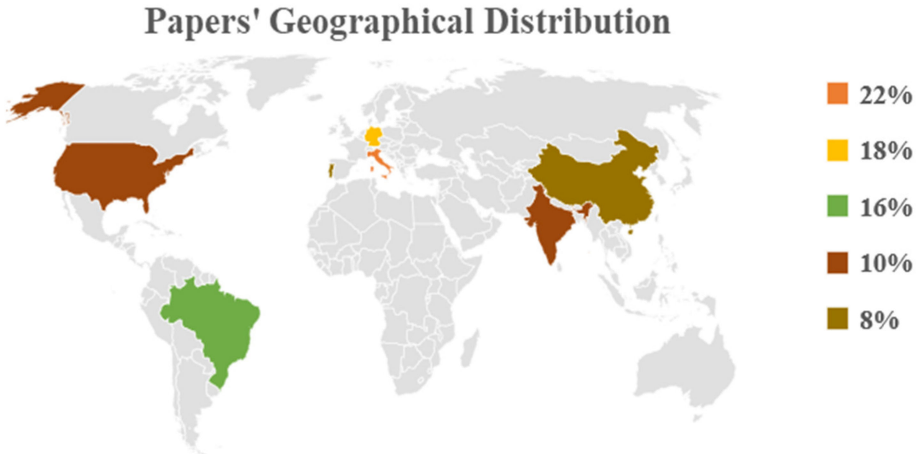

Figure 6. Papers' geographical distribution.

4.2. Content Analysis

RQ5: Which I4.0 Technologies Are Considered Most Relevant?

The number of articles where it was possible to see each reference to I4.0 technologies was considered, so that the most relevant I4.0 technologies could be established. It should be noted that only I4.0 technologies with a frequency equal to or greater than 10% were considered, which corresponds to a minimum of 5 articles where the technology was referred. Table 4 summarizes these same technologies. The top 3 most referred technologies were Internet of Things (with 47%), Big Data Analytics (with 43%) and Cloud Computing (with 35%). These three technologies are indicated as the most applied by lean, which allows for the elevation of fragility more than conscious of lean. According to the literature, it is said that lean demonstrates a weakness with data processing, since it brings together several tools for its extraction; however, they are only used to monitor and not improve processes. Thus, the application of IoT in lean tools improves the capture of this data, Big Data Analytics comes to treat and give meaning to these data that are in their most primitive state, and cloud computing offers a place to store this created information.

Table 4. Most relevant I4.0 technologies.

I4.0 Technologies	Frequency
Internet of Things	47%
Big Data Analytics	43%
Cloud Computing	35%
Cyber-Physical Systems	31%
Virtual Reality and Augmented Reality	25%
Robotics	22%
3D Printing	22%

RQ6: Which Lean Techniques and/or Principles Are Considered Most Relevant?

As in RQ5, the number of articles that referred in their content to each of the technologies belonging to the I4.0 paradigm was analyzed; here, the same was carried out; however, the scope of the scrutiny was based on lean tools. The ones that demonstrated just one article where the tool was referred were not considered (corresponding this to about 2%). Table 5 summarizes these tools. Here, the top 3 most referred technologies were just-in-time (with 18%), value stream mapping (with 18%) and heijunka (with 16%). The existence of more references in these tools may constitute the conclusion that they are seen in the academia as being more viable and easier to integrate with the I4.0 paradigm. The 5S (Sort, Set in Order, Shine, Standardize, Sustain), for example, which appear at the end of the table, can nevertheless be considered a very mechanical tool, where the application of technology does not bring added direct benefits.

Table 5. Most relevant Lean techniques and/or principles.

Lean Principles and Tools	Frequency
Just-In-Time	18%
Value Stream Mapping	18%
Heijunka	16%
Jidoka	14%
Kaizen/Continuous Improvement	14%
Andon	12%
Kanban	12%
Key Performance Indicators	10%
Total Productive Maintenance	10%
Single Minute Exchange of Die	8%
Poka yoke	6%
Visual Management	4%
5S	4%

RQ7: What is the Contribution of Industry 4.0 to Lean?

Based on content analysis, this section will highlight the impact of 4.0 technologies on lean tools. Every lean tool was evaluated by studying the combination with I4.0 technologies.

In visual management 4.0, the automated acquisition of data (using IoT) saves time for managers and employees since boards can be automatically updated with information (with pre-processed data) [45]. Smart visualization abilities emerge from this combination, and entire processes and activities can be visualized across the supply chain, allowing a better risk management, predicting future incidents [36]. This is possible to use for not just IoT, but also the cloud which makes information available to all the right people. Big Data Analytics can be used to extract and process the data collected, convert it in information and the augmented reality (AR) provides and presents the visual information to managers and/or employees [8].

In Wagner et al. [30], just-in-time is integrated in an IT-system to support a lean Just-in-time materials flow process (cyber-physical just-in-time delivery). In this project, Kanban cards were switched by a vertical integrated solution, creating a gapless information flow between manufacturing order, material supply, material stock, and material consumption, not forgetting the computerized purchase order to the supplier. Sensors detect every material movement (IoT tracks products in real-time) [8], displaying the information into a basic big data architecture, that in connection with the material consumption of the manufacturing machines, can send an automatic order to the supplier, each time the minimum inventory level is hit. An analytics service on statistical data was aggregated here in order to have a prognostic of material requirement, comparing the available information with a digital model of the complete process [30]. Robotics, more specifically collaborative or even autonomous robots, are able to adjust the productive flow and act promptly, ensuring that production runs smoothly [8]. With 3D Printing, since it can be mounted near the customer's location, it is possible to reduce distance and delivery cost, which enhances the JIT principle, decreasing lead times and augmenting logistics performance [1]. CPS-based devices will be able to provide information about cycle times to operators using it for that augmented reality (AR), which will support the performance of JIT tasks [1]. Therefore, JIT can be of benefit alongside I4.0 in a way that provides visualization of the entire supply chain, improved demand forecast and accuracy, responsiveness to changes, and superior inventory management and control [36].

Several studies have been already investigated the digitization of conventional Kanban cards, thus emergence of the e-Kanban system. With this system, missing or empty bins can be exposed, and replenishment can be triggered automatically [42]. In Bittencourt et al. [20], a case study is cited, carried out by the Wurth Company, which introduced an order replenishment system based on Kanban baskets. The new program can send orders automatically to suppliers, decreasing, in that way, stock and consequently space clearance on the shop floors occurs. Above that, orders are concise with demand. Another study in the Wittenstein Company uses automated guided vehicles (AGVs—included in the Robotics group) which provide and establish the milk-run system-based interval via real-time demand [20], possibly changing the e-Kanban system. Additionally, Cloud Computing can be of superior interest when it is necessary to have an exchange platform to facilitate JIT supply between the producer and the supplier [8]. With the implementation of a system like the ones mentioned, lost Kanban will not cause problems anymore, and modifications in kanbans due to shifts in batch sizes, work plans, or cycle times will be easier [42,43].

A CPS-based jidoka system was already planned and implemented by Ma et al. [29]. It is considered a distributed system self-possessed of analogue and digital parts, actuators, controllers, ICT, software, and jidoka rules. Pereira et al. [1] also cited an integrated and standardized approach to implement and design a CPS-based smart jidoka system, which was a system mainly based on CPS technology, including other technologies such as Cloud Computing and IoT, capable of allowing data collection of resources and flexible configuration of the system itself. Rosin et al. [8] also cited the use of autonomous robots capable of detecting and correcting production errors, which makes part of the jidoka principle. Thus, the defect detecting process is carried out with more accuracy, the identification of any errors is supported in real-time, preventing them from moving to the next process, and it is easier to manage the identification of the causes of any errors occurring [36]. Together and closely linked to the principle of jidoka, there is the poka yoke lean tool, which is improved and more effective, using the technologies mentioned for jidoka. Haddud et al. [36] analyses this tool together with jidoka, and the benefits encountered were the same as the mentioned above. Although, some authors show some reluctance with the relation between simulation and poka yoke, since the first one can foresee potential difficulties and mitigate failures in the production process; however, it does not avoid errors (which is poka yoke's goal) [2]. A particular complementarity between these two methods can be achieved, even though practical application is needed [2].

In the Andon principle, IoT provides products to connect with equipment and send a warning once the incorrect product is being produced, offering the capability of the equipment to react to errors, discontinuing the work or changing products [8]. In Pereira et al. [1] and Kolberg et al. [43] it is mentioned that the use of CPS-based smart devices (smart watches, SMS or even email, for example) by operators provides the reception of error messages in real time, alerting the operator in case of failure, prompting repair actions, and reducing delay times due to failure incidences. With this approach, recognizing failures will not depend on location of employees. In a more standardized environment, CPS will be capable of automatically trigger fault-repair actions on another CPS [43]. Alert notifications becoming more frequent can occur, notifying a possible failure for the system. In that way, it will be important for PLC's to be programmed to generate an alarm whenever any sensor value captured is outside of the tolerance or even when the rate of the recurrence of the number of alerts goes beyond a certain limit [24]. For this to happen, the combination with artificial intelligence would be important, in a way that it could be confirmed, based on historical data, if the problem would be on the product or machine.

For the heijunka principle, Ante et al. [49] reveal some projects in the I4.0 context. One of them is related with the construction of a digital heijunka board. It is intended that the system automatically creates the production Kanban cards and places them in the build to order slot of the Digital heijunka board, which has been developed following the standard leveling rules for assembly. The logistics department sends the assembly program automatically to the system board and leveling performance is calculated automatically. In Kolberg et al. [42], another project is revealed by the Wittenstein Company which digitized their heijunka board. Graphical user interfaces connected to the production line and MES are displayed, which contribute to diminish information flows and efforts for updating the board. Pekarčíková et al. [35] exposes some relations between heijunka and I4.0 technologies, such as augmented reality (AR), virtual reality (VR), horizontal and vertical integration, Cloud Computing, Big Data, data analytics and IoT. The last five can be assumed by the examples listed above, although the first two still need practical application. However, it is appropriate to extrapolate the use of AR and VR to display the heijunka board, eliminating the one that is physical. Pereira et al. [1] sums up all the seven I4.0 technologies as artificial intelligence, arguing that this technology is indicated to provide analytical support in the decision-making process and apply intelligence environment approaches that allows complex analysis and learning.

Value stream mapping (VSM) is the lean tool with more practical applications, and because of that has more evidence of the capabilities gathered through the connection with I4.0 technologies. Phuong et al. [50] developed sustainable value stream mapping, which involves three dimensions above the traditional one; they are economy, societal factors, and environment. I4.0 technologies were integrated in this tool, such as RFID, providing real-time tracking, allowing, at the same time, employees to be more quickly reactive to potential incidences. Additionally, Big Data collected by the real-time tracking of SVSM can be used for forecasting reasons, possibly preventing waste in resources consumption and any damage to workers. Molenda et al. [15], inspired from value stream mapping 4.0, suggested a new methodology for the visualization, analysis, and assessment of information processes in manufacturing companies—The VAAIP mapping. For the visualization, quantitative measurements and a qualitative analysis were carried out. Ramadan et al. [32] presented a real-time scheduling and dispatching module (RT-DSM) that traces the flow of products and detects the incompatibilities and inconsistencies between the physical and virtual world that are caused by lean waste. This module runs on dynamic value stream mapping (DVSM) to prevent a frozen production schedule, producing appropriate reactions and directives to be executed both by machines or a human to relieve the impact of incidents and try to match up the virtual value stream mapping with the actual value stream mapping. Huang et al. [33] also designs a DVSM version that is included in a cyber-physical multi-agent system that real-time and virtual attributes make visible the conditions of material, workforce, and machine. The DVSM is considered by authors capable of providing valuable information for the decision-making process. Therefore, DVSM or VSM 4.0 provides real-time data which allows appropriate action in the right time, overcoming the static behavior of VSM and, above that, the current value stream can be constantly displayed and bottlenecks as well as improvements continuously ascertained, which facilitates the implementation and concretization of Kaizen activities [7,23]. Balaji et al. [23] also refers the enhancement of the team's morale as an advantage, since they are able to see the results of their kaizen activity very quickly and suggest the standardization of measurement methods across the organization.

Gambhire et al. [24], Pagliosa et al. [2], Pekarčíková et al. [35], and Wagner et al. [30] considered that the 5S lean tool can usufruct the I4.0 technologies' integration, believing that Virtual Reality and Augmented Reality are the ones capable of having a greater impact. This can be explained by the fact that this lean tool is still some kind of mechanical, which just can be solved by I4.0 tools capable of representing it in a virtual world, in order to facilitate the shop floor disposition.

Kaizen strategies relay profoundly on well-timed detection of errors and abnormalities all over the processes and supply chain operations [36]. Because of this, some tools mentioned above, such as jidoka, VSM, heijunka, kanban, and andon, properly integrated with I4.0 technologies can be a source to provide insights to adopt kaizen strategies or even can be the kaizen strategies themselves. In that way, a totally integrated production system will actually increase the value chain's performance and the responsiveness of the whole system [12]; make it easy to catch, process, and distribute information to the right people, permit suppliers, and customers participation; and make timely improvements, since identification of errors is easier and promptly [36].

Key performance indicators (KPIs) are metrics often used by lean. Pereira et al. [1] makes reference to a case in automotive electronics production where the main problem was the missing traceability for the shop floor KPI reporting process. To apply a solution, data analytics and a cloud solution were essential to process the live data collected from all lines in the production network. Abd Rahman et al. [38] also applied simulation in their work, but the integration was more specific, since the overall equipment effectiveness was the KPI metric chosen. This metric is the most used in companies to measure their efficiency.

Ayabakan et al. [13], as already mentioned, analyzed a digitalization of a Kanban system, but above that, an automatic change over system was the focus of attention too (based on single-minute exchange-of-die—SMED—lean principle). The system uses RFID (radio frequency identification) to recognize each die and know their storage address. It was concluded that, with this system, an increase of the line's productivity was felt, as well as its capacity, reducing, at the same time, the number of production people. Pagliosa et al. [2] supports the idea that IoT can have a crucial impact in the execution of adjustments and setup of workstations, but states too that the integration of robotics with SMED can cause conflicting efforts for operational improvement. This can happen because elevated levels of robotization and automation can create less flexible production lines, limiting the customization of products and weakening changeover time. However, on the other hand, the authors assume the capacity of carry complex activities with the utilization of advanced robotization. Therefore, more study and practical applications are needed in this aspect, to converge results.

The total productive maintenance (TPM) is another lean tool that has been recently attracting attention for integration with I4.0 technologies. Big data analytics, cloud-based systems, and IoT enable real-time information and data that can support productive and preventive maintenance [36]. Sensors produce data which are then contrasted to the information from the machine and the specific workpiece being processed, allowing to continuously keep in check and predict the incidence of failures, as there are multiple signs and tendencies that the component demonstrates "symptoms" of forthcoming failure or degradation in performance [24,30]. The timely information sharing, and real-time data provides better inventory management and shorter downtimes [24,36]. Smarter maintenance is capable of guarantee better processing equipment performance and fewer defects, which aids an increase in the product's quality [41]. With prompt information about the equipment's state and properly triggered repair actions, a smart planner can be easily updated on reconfiguring production lines and updating kanbans in real-time, based on changes [1]. Pagliosa et al. [2] refers to the connection between TPM and AR as being explained by the support in performing maintenance remotely through knowledge sharing and technical guidance. Marcello et al. [51] carried out a construction of an ensemble-learning model that combines prediction results from multiple algorithms, using big data analytics, to estimate failure rates of equipment subject to distinct operating conditions (reached an accuracy value of 96.15%). On the other side, Passath et al. [52] created a standard criticality analysis as a foundation of an agile, smart, and value-oriented asset management system to dynamically adjust the maintenance strategy. It was concluded that the more complex and disparate the assets are, the more essential it was to have a guideline to dynamically adapt the maintenance approach due to the environmental variations as well as production circumstances.

After analyzing each of the lean principles and their correlation with I4.0 technologies, it can be concluded that lean and digital technologies support organizations in becoming faster, more efficient, and more economically sustainable [11,53].

Since waste reduction is the lean's main goal, an overall analysis about the impact between the seven wastes and the I4.0 introduction should be done. Overproduction can be reduced in the I4.0 context, since a better order management is provided and information is communicated through the shop floor directly and constantly [41]. The waiting time is able to be decreased too as smarter decisions are made on site and feedback from related stakeholders can be received by vertical or horizontal levels [41]. Here, the horizontal and vertical integrations will have a huge impact in identifying waste, as well as big data which can be used to detect, in real time, unusual situations in the production system and identify the root causes of these conditions [8]. IoT is already assumed as an important tool to reduce transportation, since it takes advantage of real-time product tracking to see unnecessary transportation [8], and robotics and infrastructures brought by I4.0 support the transport by itself and even the calculation of best routes [41]. Simulation allied with augmented reality or virtual reality is a possible resolution to over-processing, because it allows the replication of scenarios for testing ideas, providing managers space to choose the most promising ones. Additionally, the defects and unnecessary processes can be minimized with this tool, as a copy of the production system can be constructed, and several scenarios can be provided to solve production problems [8]. Additionally, the digitalization of value streams provides real-time feedback, allowing the control of processes' efficiency [41]. A better control of production and raw materials is given by the connectivity between customer, supply chain, and individual processing equipment, which offers the ability to decrease the inventory [41].

Besides, since lean puts people at the center of almost every strategy, the I4.0 impact in the way collaborators do their work is essential to be understood. Augmented reality, for example, is considered by Rosin et al. [8] and Dutta et al. [28] as a useful tool to learn new processes, perform material audits, and, further down, to execute on-site maintenance tasks, allowing the sharing of knowledge with other employees. Simulation is another tool considered to be able to validate human operations and train new employees (in conjunction with AR and VR) [2,8,10,28]. I4.0 pretends to change the workers' role from machine operator to augmented operator, whereby the main position is supervising the work (while it is being performed by the machine) [12].

Although, before introducing I4.0 technologies, companies should appropriately weigh the maturity of their organization [21], paying special attention to structure, jobs, and competences. Experimentation is essential to recognizing the interventions at both technological and organizational levels and companies must never misjudge the time required [17].

The matrix presented in Table 6 arose from a unification of the content of articles subject to the systematic review. In this way, and with a view to a consistent follow-up, the vertical axis refers to I4.0 technologies identified as being the most relevant and most referred in the articles. The vertical axis refers to lean practices, which were also presented as being the most significant. Every lean tool was evaluated by considering the combination with I4.0 technologies, which resulted in the introduction of an "x" in case of existing some kind of impact between the two (I4.0 technology and lean practices).

The two lean practices that can most benefit from the contribution of I4.0 technologies are just-in-time and standardization, as can be seen from the Table 6.

RQ8: What is the Contribution of Lean to Industry 4.0?

In the previous chapter, I4.0's contribution to lean was analyzed. Therefore, it is time to analyze the reverse.

Architectures for establishing dynamical and self-controlled Industry 4.0 productions centered on CPSs exist, but they are predominantly high-level methodologies focus barely on technology approaches. It has been said in academia that smart factories must consider the technology perspective, as well as the organizational and human point of view [42].

Table 6. I4.0 vs. lean matrix: The contributions of I4.0 technologies on the lean practices.

	Just-in-Time	**Standardization**	**Heijunka**	**Kaizen**	**Pull Flow**	**VSM**	**5S's**	**SMED**	**Andon**	**Jidoka**	**Kanban**	**Poka Yoke**	**TPM**	**KPI's**	**Visual Management**
Augmented Reality	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Big Data Analytics	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cloud Computing	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cyber-Physical Systems	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-
Internet of Things	x	x	x	x	x	x	x	x	x	x	x	x	x	-	x
Robotics	x	x	-	x	x	x	x	x	-	x	x	x	x	-	-
Virtual Reality	x	x	x	x	-	x	x	-	-	-	-	-	-	-	-
Artificial Intelligence	-	x	x	-	-	-	-	-	x	-	-	-	-	-	-
3D Printing	x	-	-	-	x	-	-	x	-	-	-	-	-	-	-

According to Tortorella et al. [4], Rauch et al. [54], Tortorella et al. [5], Erro-Garcés et al. [31], Rossini et al. [3], Bittencourt et al. [20], and Rossini et al. [27], lean practices implementation shows a great potential of a higher adoption of I4.0 technologies. This is assumed because of the solid behavioral and processes foundation that lean can provide. However, Tortorella et al. [4] considered that, to implement I4.0 technologies, it is necessary to have a minimum maturity level of lean practices. If this lean maturity level is not adequate, results of the implementation of industry 4.0 practices will be below expectations, producing management frustration and financial waste. Tortorella et al. [5] discuss the association regardless the companies' size and the conclusion is that size is not a barrier for implementation of I4.0 technologies. Nonetheless, Rossini et al. [3] establish the independence of lean practices adoption from the presence of I4.0 technologies. Lean practices adoption effects still prevail over the impact of I4.0, and this happens since companies' perception and implementation maturity with respect to lean are considerably larger than I4.0.

There are already some more concrete contributions from lean to I4.0. It is the case for Rosienkiewicz et al. [19], whose contribution settles in the conception of a lean production control system that uses the Glenday Sieve lean tool ("states that a small percentage of procedures, processes, units or activities account for a large portion of sales, and includes a color-coding system for labelling processes by output volume" [19]) and I4.0 technologies, such as artificial neural networks (ANNs). The lean tool was used to establish which type of products were able to be predicted by ANNs.

Bittencourt et al. [20] recommend having a framework for the implementation of I4.0 technologies in a production system and that it must adopt tools such as process standardization and production flow, intrinsic to lean, which will ensure transparency of the process and gain of productivity. Qu et al. [55] creates a framework to overpass gaps between requirements for traditional manufacturing systems and smart manufacturing systems. Some of the design requirements settle in lean principles, such as standardization, in which it pretends to establish a data dictionary, uniform document format and sheet design, and standardizes the database.

Constantinescu et al. [56] suggest another approach, which the authors called just-in-time information retrieval (JITIR), founded on using, as an input, the users' environment and activity, and delivering, as an output to the user, information reclaimed, proposing documents which potentially match the users' concern. Furthermore, JITIR agents are capable of being performed automatically and; therefore, decrease considerably the cost of search, behaving as a time-saver search. Other authors carried out the analysis of the importance of using the JIT principle to display information, since they agree about the power of having information displayable, reusable, and provided to the right person, in the right format, at the right moment [14,57]. Lean information management (LIM) is a management practice enhanced by Teixeira et al. [57] as a benefit for systems such as enterprise resource planning (ERP) and manufacturing execution system (MES), because of its capacity to eliminate all waste in terms of avoidable data and processes.

Bittencourt el al. [20] also conclude that, on one side, lean thinking focuses on waste reduction, while, on the other side, I4.0 concentrates on the use of new technologies driven by IoT. However, with different tactics, the concepts can and ought to be complementary, since the implementation of lean will inspire a company to stimulate thinkers who will be necessary in implementing the changes needed by I4.0.

5. Discussion

There are several examples of lean tools capable of integrating I4.0 technologies. Some, though, need to be subject to practical application. However, the ones that have already seen their integration in the virtual world and its consequent application in the real world following should be highlighted: kanban, jidoka, VSM, SMED, TPM, and KPIs.

It should be noted that one of the problems highlighted in the theoretical background in relation to lean was its excessive difficulty in using and managing data analytics in the improvement process, with difficulty, consequently, in understanding the positive impact or not of the practices introduced in the organization's performance. All tools considered as those with more application have a huge influence of data, which, with the introduction of technologies, made the instruments become more dynamic, with sufficient capacity to support decision making and the ability to allow action in almost real time in the face of abnormalities. Control and action in real time in the face of problems occurring, on the shop floor, allows to severely reduce waste, which is the focus of lean. Since the focus on the human being was also evidenced with the lean purpose, additionally it is to be expected that connectivity provided by I4.0 affords knowledge sharing, on-site training with greater application (even if virtual), and even greater involvement of more operational staff in the management and decision-making process directed to the manufacturing processes. Here, the need to acquire more technological and out-of-the-box skills is highlighted. Broadly speaking, I4.0 can severely bring lean to a new level of excellence, fomenting the innovation, considered to be a kind of a difficulty denoted for this philosophy.

Therefore, lean practices have an enormous space to grow and be more impactful, since I4.0 allows a better insight of customers' demands and accelerates information sharing processes, empowering employees, which is the core key in lean production [40].

In the perspective of lean's contribution to I4.0; however, there is little practical and theoretical application, the actual contribution is still somewhat blurred. In any case, the knowledge management systems are highlighted, which, with lean techniques (specifically the JIT), will promote the effective and efficient distribution of existing and stored knowledge, as well as its creation.

The architectural structures of information systems can also take advantage of principles such as standardization.

Either way, there is already a considerable amount of work carried out by the academia that suggests the need for the lean environment to be on an I4.0 implementation basis [3,8,27]. In this way, companies can rely on the implementation of their technologies into standardized and tough processes. However, it is important to consider that if the company does not present a good lean maintenance management (which sometimes requires financial costs), then the impact and the assumed support of the digital paradigm may be compromised. The implementation of lean requires cultural change, presenting itself as such a change. The maintenance and its implementation require consistency and determination on the part of the organization.

Lean establishes practices, behaviors, and habits, stimulating the problem-solving process among their collaborators. Besides, it groups several simple tools, capable of having a successful outcome. I4.0 can possibly, in order to respect the already stated shop floor (because of the lean wave among western industry), usufruct the existing tools, updating them, and the thinkers' promotion, with origin in the lean philosophy.

Because of its high-tech solutions, I4.0 needs to be capable of being simple. Lean is a low-tech approach, but their results were above what was expected, so there is a huge necessity to preserve what there is already and, if it is possible, to try to make it better. This work may help companies to understand what bases they should already have for the introduction of the I4.0 environment, so that it is not a target of disappointment and high investment with no return.

6. Conclusions

Considering the bibliometric analysis carried out, it can be concluded that the integration between I4.0 and lean is a recent topic and with a growing trend. Most of the papers are articles, belonging to journals of high quality (Q1), which allows the claim that the subject in question is in force in the academia with a tendency for more investigations in this area.

This work may help companies to understand what bases they should already have for the introduction of the I4.0 environment, so that it is not a target of disappointment and high investment with no return.

This work differs from those already done, since it focuses on the bilateral effects, not restricting the focus only to the influence of Industry 4.0 on lean or lean on Industry 4.0 (the influence of technologies on lean being the most existing). Most articles that assess bilaterally only conclude that there is a significant influence between the existence of a lean shop floor and a favorable integration of the digital paradigm, not trying to understand to what extent this is effective in operational terms. In addition, the analysis was based on the most cited lean techniques in the universe of articles considered, with a view to envisioning the impact of I4.0 technologies in a very operational perspective that aims to prepare companies whose shop floor is lean, for the digital paradigm.

It is worth highlighting the disproportion of work regarding lean's contribution to I4.0 (Figure 7), which allows us to conclude that the focus of attention is on how I4.0 can improve lean (with 77% of academic works). Several authors have already taken the entrance of I4.0 into manufacturing as being beneficial, capable of creating a flexible and interconnected shop floor. However, integration with lean is said to be essential for successful implementation. This portion of study and investigation found reveals that studies are more focused on implementing technologies than methodologies that are aligned or even align with the digital purpose. In any case, it may be questioned whether lean will effectively support the implementation of the digital paradigm. As studied by the authors in [58], it is understood that this does not support the readiness of I4.0.

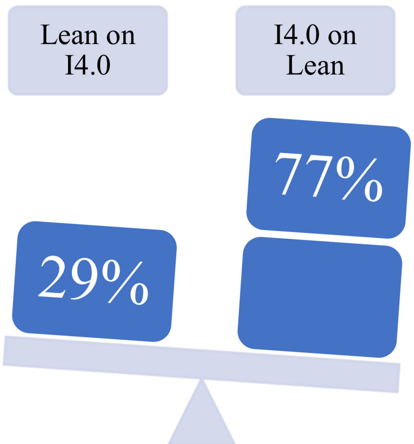

Figure 7. Proportion of influence of the lean concept on I4.0 (**left**) and I4.0 on lean (**right**).

As study limitations, the influences of I4.0 technologies are highlighted only in the most cited lean techniques in the universe of articles considered and, in addition, the findings were raised from the perceptions of a small number of experts with different backgrounds (academia, industry or both). Hence, a confirmatory analysis with some more experts would also be recommended as future working opportunities. Furthermore, it is important to point out that there are other conditions that can influence the bilateral effect of these two worlds (Lean and Industry 4.0) and that were not considered, as is the case of the skills that both require. These are different and must come together. Regarding the perspective taken by the authors of the paper, this one focused on a more positive approach and, above all, it intends to help under the implementation of what is already working well in current manufacturing systems. Anyway, a more pessimistic approach, and against the possible failures that could happen, could be something to take in the next investigation.

As future work, the following guidelines are highlighted:

1. Empirical validation of the synergies evidenced is necessary, either between I4.0 and lean or between lean and I4.0;
2. A research more oriented to the impact of Lean in I4.0 is essential, with a view to the consolidation of results;

3. For each implementation of technology belonging to the digital paradigm in support of a particular Lean principle, performance indicators should be measured to validate the impact.

Author Contributions: Conceptualization, methodology, formal analysis, writing—original draft preparation, writing—review and editing have been conducted by both authors, J.S. and L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Portuguese funds through the Institute of Electronics and Informatics Engineering of Aveiro (IEETA) and Foundation for Science and Technology, in the context of the project UIDB/00127/2020.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

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