Assessing the synergies between lean manufacturing and Industry 4.0

Jordi Fortuny-Santos, Patxi Ruiz-de-Arbulo López, Itziar Luján-Blanco, Pin-Kuo Chen

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Abstract

Lean Manufacturing has been for years a successful paradigm that leads companies to operational excellence. However, changes in the market that require cheap mass customization seem beyond the scope of lean manufacturing, which relies on more stable schedules. Meanwhile, Industry 4.0 appears as one of the most promising approaches for dealing with future challenges in manufacturing environments through automation and data exchange thanks to cyber-physical systems and the Internet of Things. The relationship between lean manufacturing and Industry 4.0 attracts management scholars and the number of contributions that can be found in the literature is increasing quickly. However, the lack of real implementations leads to conceptual papers based on hypothetical outcomes on a number of aspects.

The aim of this research paper is to explore and evaluate, through a systematic review of the literature up to September 2019, previous work focusing on the relationship and links between lean manufacturing and Industry 4.0, in order to understand whether lean manufacturing and Industry 4.0 can be integrated to achieve synergies between the two approaches. Besides, a bibliometric study is performed.

Although different scenarios are considered possible, most relate to lean tools being enhanced by real-time information. The majority present an evolution, not a revolution. Lean manufacturing offers stable processes where automatization and digitalization can be successfully implemented. Otherwise, new technologies will fail to make the most of poorly managed processes. The role of employees has not been addressed in the reviewed literature.

Keywords

Value stream map, kanban, jidoka, cyber-physical systems, Internet of things

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✉ Jordi Fortuny-Santos *
jordi.fortuny@upc.edu
ORCID iD: 0000-0001-8106-3385

Patxi Ruiz-de-Arbulo López **
patxi.ruizdearbulo@ehu.eus
ORCID iD: 0000-0003-4881-0304

Itziar Luján-Blanco ***
itziar.lujan@upc.edu
ORCID iD: 0000-0002-2869-4708

Pin-Kuo Chen ****
a1104100@ms23.hinet.net
ORCID iD: 0000-0003-1373-396X

* Department of Business Management, Universitat Politecnica de Catalunya, Manresa, Spain. Grupo OPE-PROTHIUS 2017 SGR 314

** Department of Business Management, University of the Basque Country (UPV/EHU), Bilbao, Spain

*** Department of Business Management, Universitat Politecnica de Catalunya, Manresa

**** Department of Business Administration, Shantou University, Shantou, China

1. Introduction

For the last thirty years, lean manufacturing has been a buzzword. This manufacturing paradigm has its roots in the “Toyota Production System” (TPS), which was gradually developed after World War II. In the 1970s, TPS was known in English as “Just in Time” manufacturing because one of its facets is to produce the necessary products, in the right quantities, just as they are required (Sugimori et al., 1977). In the 1980s, a comparison of car manufacturers at the Massachusetts Institute of Technology (where the term “lean” was conceived) revealed the operational superiority of Japanese automakers while ringing all the alarms among European and American manufacturers (Krafcik, 1988). The term lean became popular and fashionable after the book “The machine that changed the world” (Womack et al., 1990), which offered a new approach based on value and flow and quite free from Japanese reminiscence. Since then, many companies have embraced lean manufacturing (or, at least, some lean practices) in order to increase productivity, financial performance and market performance following Toyota's success path (Shah and Ward, 2003; Yang et al., 2011).

However, in 2011, Germany, another lead player in the world of manufacturing -31 percent of industrial value added in the European Union (Heng, 2014), came to the fore. The concept Industrie 4.0 in German (or Industry 4.0 in English), where number four refers to the so-called "Fourth Industrial Revolution", was presented at the Hannover Fair (Drath and Horch, 2014). The term was coined by Siegfried Dais, from Robert Bosch GmbH and Henning Kagermann, from the German Academy of Science and Engineering (Cattaneo et al., 2017).

The German government announced a research funding program termed Industrie 4.0 (I4.0, from now on) with the intention to promote the computerization of manufacturing industries to move from automated manufacturing to smart manufacturing in order to meet the growing challenges faced by industry, such as the flexibility needed to handle mass customization (Sanders et al., 2016) and to maintain the technological edge for the German industry. I4.0 is expected to bring about a digital transformation; a revolution; a big change in the way products are manufactured such as steam power changed industry in the 18th century.

There is not a specific list of the essential elements of the so-called "smart manufacturing" (Thoben et al., 2017; Kusiak, 2018) but the most frequently mentioned technological ingredients of I4.0 are collaborative robots, cloud computing, big data analytics, artificial intelligence, internet of things, real-time sense-and-response technologies, cyber-physical systems and 3D printing or additive manufacturing (Brusa, 2017). The novelty in such a scenario is not in a new technology –which already exists- but in that it combines existing technologies (Drath and Horch, 2014; Buer et al., 2018). In the smart factory, machines, and even parts, can carry computation (sensors, software, memory chips and microprocessors) and communication systems (protocols and antennae) becoming cyber-physical systems that can interact with other objects. The Internet of Things is the network that allows the communication between those "smart" objects. However, this requires the deployment of Internet Protocol version 6 (IPv6), which allows theoretically up to 2128 addresses in order to identify each connected device. Unluckily, IPv6 and the current IPv4 are not interoperable and this delays the transition. Besides, cybersecurity needs to be improved in order to protect devices from remote attacks that could alter business processes.

Many other countries have also established national programs on smart manufacturing (Mrugalska and Wyrwicka, 2017; Thoben et al., 2017; Alfonso-Ruiz et al., 2018) and currently I4.0 is becoming a new manufacturing paradigm (Doh et al., 2016) and a new buzzword that seems to take over from LM. Beyond the marketing pitch, I4.0 has attracted many scholars and, not surprisingly, the role of LM in the I4.0 era and the relationship between the two approaches are becoming important research streams (Sanders et al., 2016).

There are many questions that need to be answered: If a company is thinking about implementing either lean manufacturing or I4.0, what should it do? (Alfonso-Ruiz et al., 2018); where does I4.0 leave lean manufacturing? Are we going to witness two production systems clash? (Rüttimann and Stöckli, 2016); will the automatization and computerization of manufacturing make the principles of LM irrelevant in few years (Netland, 2015; Martinez et al., 2016)? Since each paper addresses a specific aspect of the relationship between LM and I4.0, insights into the relationship between LM and I4.0 are only fragmented.

Reviews of the literature can help to classify extant literature. In this respect, Buer et al. (2018), in the first systematic review published in a relevant journal, found that papers could be classified into four research mottos: I4.0 supports LM; LM supports I4.0; performance implications of integration between I4.0 and LM; and the effect of environmental factors on the integration of I4.0 and LM. After they review, Buer et al. set forth the need to further explore the relationship between I4.0 and LM in order to understand how these domains interact.

The goal of this paper is to explore the current state of research on the relationship between the I4.0 and LM, to characterize how and to what extent the relationship between LM and I4.0 has been previously studied; whether the role played by I4.0 tools on LM practices (an vice versa) are well identified and supported, in order to figure out whether companies can expect some synergies between LM and I4.0. Because of that, a systematic review of the literature on the topic of LM and I4.0 has been conducted.

An earlier version of this work was presented at the 13th International Conference on Industrial Engineering and Industrial Management (Fortuny–Santos et al., 2018).

This paper is organized as follows. The second section details the methodology. The third section lists the results of the literature review (including bibliometric analysis and content analysis) and discusses the findings. The fourth section is devoted to the role of people. Finally, the paper ends with a Conclusions section, which includes a synthesis of key findings and directions for further research

2. Research method

A systematic review of the literature is carried out to explore the current state of research on the relationship between the I4.0 and LM in order to assess whether companies can expect some synergies between LM and I4.0.

In order to minimize bias in the selection of the papers included in this study, a systematic methodology was undertaken. Unlike the sort of bibliographical review that any research involves, a systematic review can be defined as the review of a matter using systematic methods to identify, select and critically assess relevant research (Martin et al., 2006). The methodology proposed by Tranfield et al. (2003) was considered to be the most appropriate because it has been used many times in the domain of Social Sciences.

Papers were extracted from Web of Science and the Scopus database. These resources guarantee a selection of papers in high impact factor journals and refereed manuscripts in renowned conference proceedings. Web search engines were not used in order to avoid noise information. In consequence, grey literature and non-academic material have not been included in the review.

All searches were limited to the following conditions:

1. Document type: papers in journals (most are academic journals but some are journals for practitioners), conference proceedings (since I4.0 is a very new area, some relevant papers exist only as conference proceedings) and book chapters.

2. Language: It was not fixed a priori but the words that were searched for limit the papers to English.

3. Year: From 2011 (the year that the term Industry 4.0 was created) to extraction date (September 12, 2019).

In order to define the search terms, the researchers had a brainstorming session and finally reached a practical consensus. The search string used to retrieve papers form databases was: ("lean") AND ("I4.0" or "Industrie 4.0" or "Industry 4.0" or "digital transformation" or "digital factory" or "digital manufacturing" or "fourth industrial revolution" or "smart factory" or "smart factories" or "smart manufacturing" or "Internet of Things"). This combination must be present in either the title or the keywords or the abstract of a document. 176 files in WOS and 368 files in Scopus matched these search criteria. The final number of eligible papers was 433 because some documents were present in both databases 433.

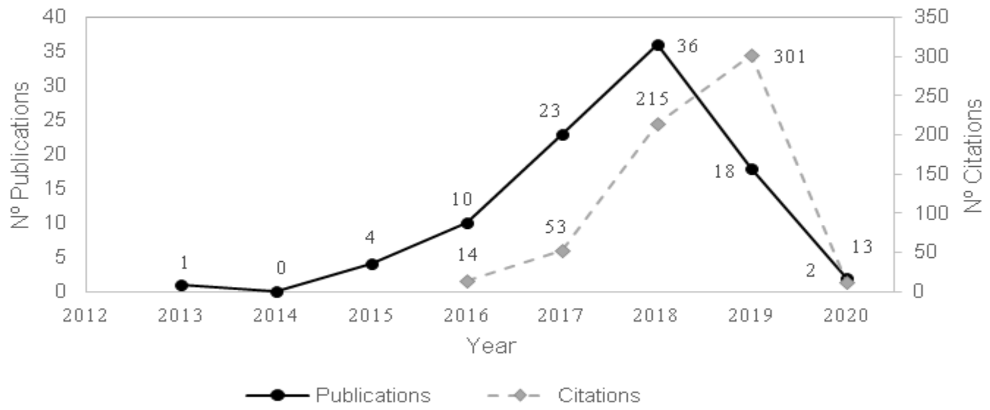
The next step was to read the abstract of each one of the 433 documents and decide whether they corresponded to the topic of our research. One researcher and one assistant reviewed the abstracts for the first time and later a second researcher repeated the review. In addition, some papers were excluded for different reasons and 108 files remained in the short list. Eventually, because of software limitations, 94 documents retrieved from Scopus were selected for the bibliometric analysis (35 articles in journals, 51 conference papers, 6 book chapters and 2 reviews). As stated before, an important number papers come from conference proceedings (IFAC, Procedia), and some of them are among the most cited in the field

3. Review findings and discussion

Bibliometric analysis

Although it can be considered a young research field, the number of publications has skyrocketed. The first paper was published in 2013 and few papers were published until 2016, but in 2018, 36 papers appeared (Figure 1). The number of citations has increased accordingly, but 67% of the papers have been cited less than five times, including 34 papers that have never been cited so far. The most cited papers are Thoben et al. (2017) with 144 cites; Kolberg and Zühlke (2015) with 129 cites; Sanders et al. (2016) with 97 cites; Mrugalska and Wyrwicka (2017), cited 60 times; Wagner et al. (2017), with 49 cites; Luz Tortorella and Fettermann (2018), cited 44 times; and Buer et al. (2018) with 39 cites. Following papers in this ranking would have around 20 cites (e.g. Meudt et al. (2017) with 22 cites). In consequence, some papers are starting to stand out as the works with the greatest impact on this field

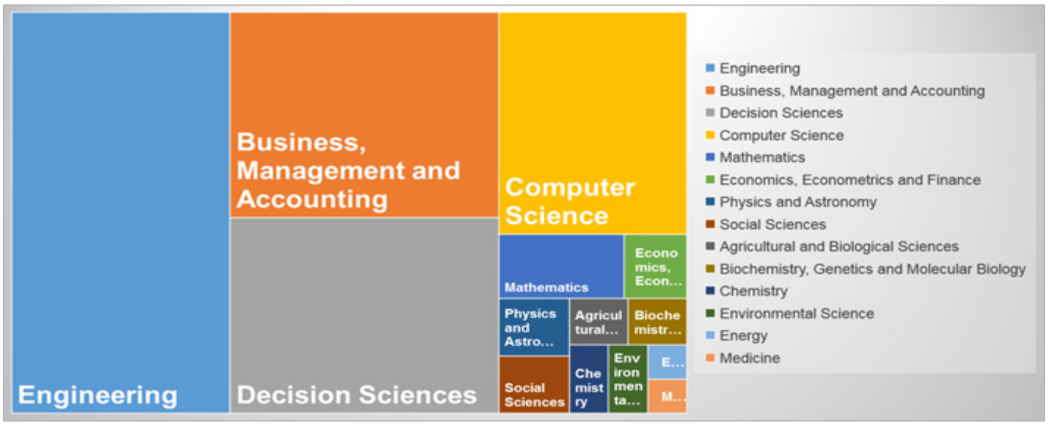
Figure 1 Papers and citations per year..



The most prolific authors are Metternich (5 papers), Dombrowski (4 papers), Meudt (4 papers) and Matt, Powell, Rauch, Richter, Schneider, and Luz Tortorella with three papers each. There is not a clear relationship between the most cited papers and the most fecund authors because this is a recent research fields.

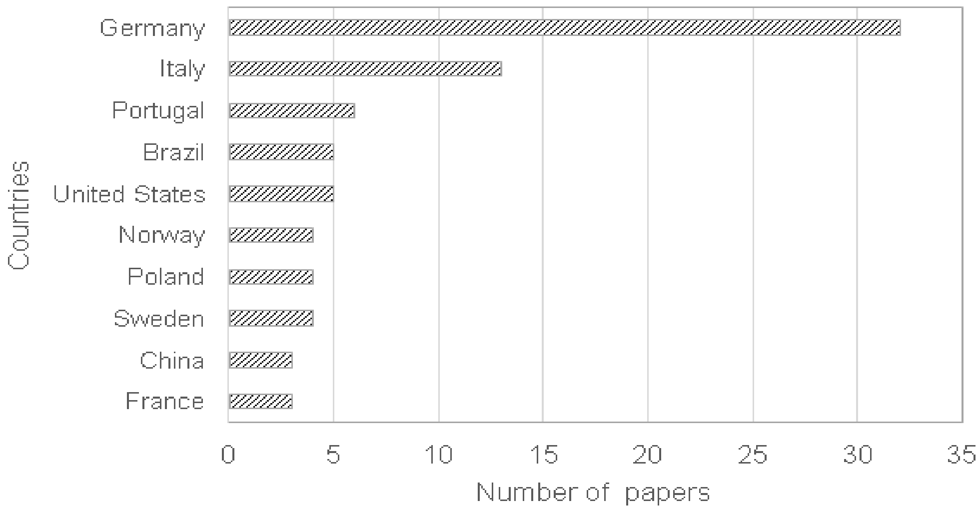
The journals that publish works on LM and I4.0 belong to a number of disciplines. The three more relevant ones are Engineering, followed by Management (Business, Management and Accounting) and Decision Sciences. The fourth place is for Computer Science (Figure 2). Most papers are conceptual and qualitative.

Figure 2 Disciplines of the journals or proceedings.



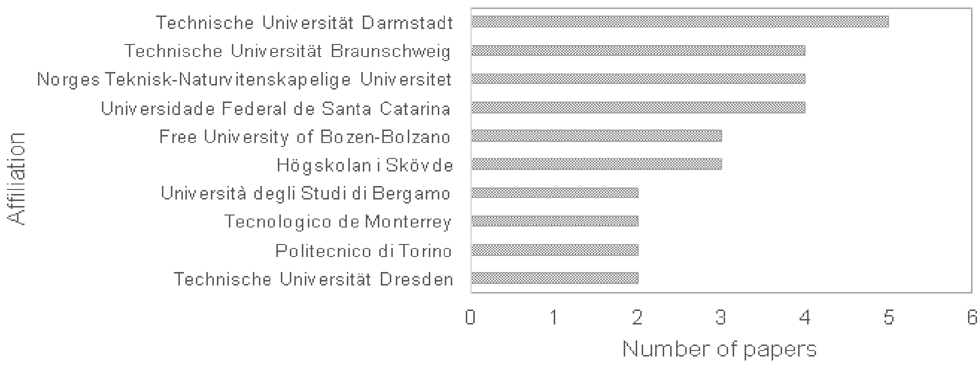
The majority of the most fruitful authors are from Germany, the country where the I4.0 concept was born. A country-wise analysis (Figure 3 shows the top ten countries) reveals that the 94 papers come from all over the world but especially from European countries. Germany is the country with more papers (32) and this can be attributed to the fact that the I4.0 concept appeared in Germany and is sponsored by the German government.

Figure 3 Country-wise analysis



If we look at the affiliatio (Figure 4) of authors of papers about the relationship between LM and I4.0, the institution with a higher number of papers is the university of Darmstadt (Germany). The second place shows a tie between the University of Brunswick (also from Germany), the Norwegian University of Science and Technology and the Brazilian University of Santa Catarina. All the Norwegian papers in the sample (4) and most of the Brazilian papers (4 out of 5) come from the same institutions. Three of the ten institutions with a higher number of papers are from Germany, a country with a leading role in developing I4.0 -that also shows interest in LM-.

Figure 4 Institution-wise analysis

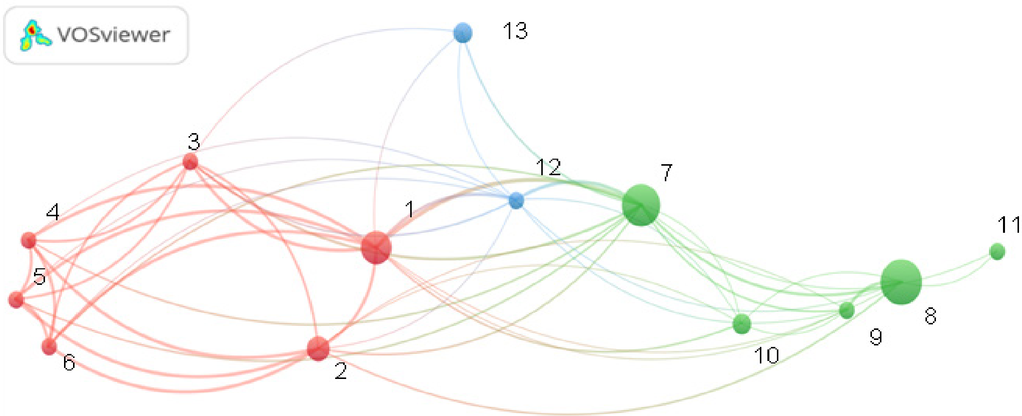


Next, references were analyzed in order to identify whether two or more documents were cited together by a third one. The more co-citations two documents receive, the more likely they are related. Three clusters of papers can be identified (Figure 5) when a minimum of four common cites are required. The co-citation map (Figure 5) shows some of the most cited papers on the relationship between LM and I4.0, such as Kolberg and Zühlke (2015), Sanders et al.(2016), Mrugalska and Wyrwicka (2017) or Wagner et al. (2017). These papers start to shape the research on the relationship between LM and I4.0

Eventually, a co-word analysis was performed in order to map the interactions between the topics, the strength of such associations and even research trends. Figure 6 displays seventeen words in four different clusters

- Cluster 1 describes the operations management approach (production system, engineering, lean)
- Cluster 2 describes the technical facet of I4.0 ("automation", "embedded systems", "cyber physical system" and "internet of things"). There are many links between the words in this cluster but not many between cluster 1 and cluster 2, despite the fact that each word in cluster 2 is related to the word "lean". This means that these technical elements of I4.0 are associated to LM in the literature.
- Cluster 3 is made up of "industrie 4.0" and "supply chain management". The strength of the links within the cluster is small. There are a lot of links between "I4.0" and words in other clusters and a strong link between "I4.0" and "lean".
- Cluster 4 includes differen elements related to I4.0 or smart manufacturing (e.g. "big data").

Figure 5 Reference co-citation analysis



Legend

1. Sanders, A., Elangeswaran, C., and Wulfsberg, J. (2016). op. cit.

2. Schumacher, A., Erol, S., and Sihn, W. (2016). "A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises". Procedia CIRP, 52, pp. 161-166.

3. Qin, J., Liu, Y., and Grosvenor, R. (2016). "A categorical framework of manufacturing for industry 4.0 and beyond". Procedia CIRP, 52, pp. 173-178.

4. Gjeldum, N., Mladineo, M., and Veza, I. (2016). "Transfer of model of innovative smart factory to Croatian economy using lean learning factory". Procedia CIRP, 54, pp. 158-163.

5. Kull, T., Yan, T., Liu, Z., and Wacker, J. (2014). "The moderation of lean manufacturing effectiveness by dimensions of national culture: testing practice-cu - ture congruence hypotheses", International Journal of Production Economics, 153, pp. 1-12.

6. Shah, R., and Ward, P. (2007). op. cit.

7. Kolberg, D., and Zühlke, D. (2015). op. cit.

8. Wagner, T., Herrmann, C., and Thiede, S. (2017). op. cit

9. Mrugalska, B., and Wyrwicka, M.K. (2017) , op. cit.

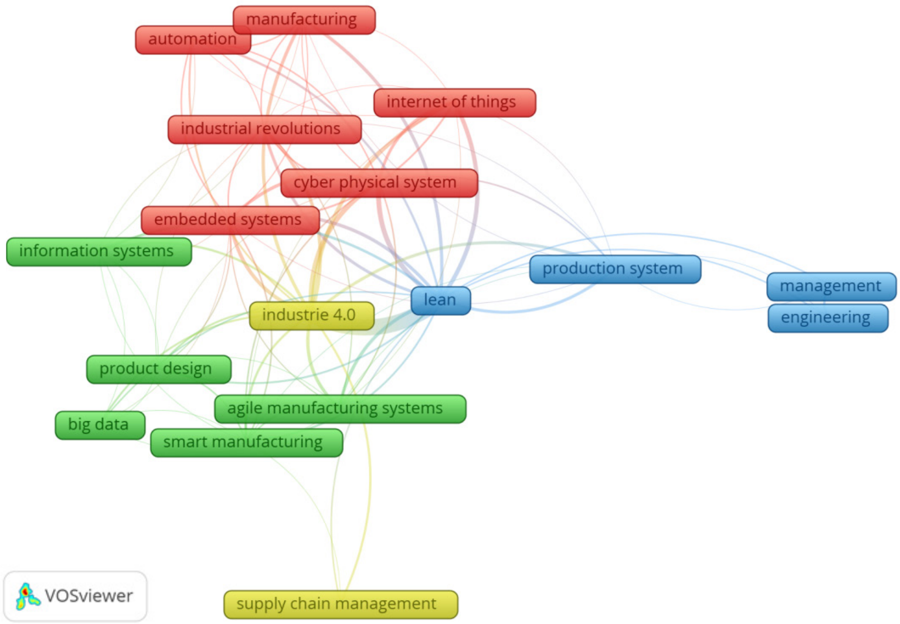
10. Monostori, L. (2014). "Cyber-physical Production Systems: Roots, Expectations and R&D Challenges". Procedia CIRP, 17, pp. 9-13.

11. Liker, J.K. (2004). The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer, New York: McGraw-Hill.

12. Kolberg, D., Knobloch, J., and Züehlke, D. (2016). "Towards a lean automation interface for workstations". International Journal of Production Research, 55 (10), pp. 2845-2856.

13. Stock, T., and Seliger, G. (2016). "Opportunities of sustainable manufacturing in industry 4.0". Procedia CIRP, 40, pp. 536-541.

Figure 6 Co-word analysis



Both Figure 5 and Figure 6 where generated by VOSviewer software (Van Eck and Waltman, 2010), following the procedure described by Calzado-Barbero et al. (2019).

Content analysis

With the constant changes in global markets and high competitiveness, companies need to supply customized products to satisfy increasingly demanding customers. This business model is beyond the scope of lean manufacturing (Santos et al., 2018). Organizations have sought to find new management and production methodologies, such as I4.0, in order to achieve the necessary flexibilit . It does not mean that I4.0 is going to replace lean manufacturing. The new flexible and collaborative systems may help reach the high levels of productivity and quality desired by lean manufacturing. Santos et al. show some possible interactions between I4.0 solutions and LM tools.

For Netland (2015), the lean principles are not left behind by the I4.0. Quite the opposite, they become even more relevant in the light of the new I4.0 factories. This is because "Doing more with less" is a lean principle that is fully valid for the future (Cattaneo et al., 2017). Thus, reducing complexity and avoiding anything that does not add value will continue to be features of the I4.0. In consequence, I4.0 companies will have to be lean if they are to meet future challenges. Besides, we could add that a solid strategy cannot be based on I4.0 alone because technology can be copied by any competitor. I4.0 can only be an enabler of the true strategy. Lean manufacturing practices can be copied too (any company can do 5 S and kanban) but the lean mindset can be just imitated because it lies inside every person.

Dombrowsky et al. (2017) study the relationship between advanced communication technologies and lean manufacturing. They conclude that information and communication technologies (ICT) can improve the performance of lean factories. They classify extant literature into four clusters:

i) LM as a basis for I4.0

ii) I4.0 completes LM

iii) I4.0 increases the efficiency of

iv) Changes the principles of LM

According to Dombrowsky et al. (2018), the first option is supported by two thirds of the papers they compiled. It may not stand to reason that to implement I4.0, a company has to be lean first. However, success of I4.0 may depend on the previous level of organization of the company. As Kaspar and Schneider (2015) pose it, while poorly coordinated and inefficien processes can be automated or digitally supported, the process itself will remain inefficient Digitization of unstable processes, with no standards or performance indicators (Enke et al., 2018) will not improve the operational performance. LM would assure that I 4.0 is implemented on free of waste well-defined processes

This hypothesis agrees with the results of a survey among the members of the White Goods Suppliers Association (Turkey): Turkyilmaz and Cebeci (2018) found that the first place where advanced lean companies would apply I4.0 is the already automated assembly line.

Rossini et al. (2019), by means of a survey on 108 European companies that were implementing LM and adopting I4.0 solutions, find that LM is a facilitating condition for I4.0 adoption, but LM is independent of I4.0 –this must not be understood as if lean companies could ignore I4.0-. Besides, Rossini et al. find that LM has a stronger positive impact on performance improvement than I4.0 implementation.

This debate is not as new as it may seem. Hoque (2000) shows that, in the 1980s, several papers already studied the relationship between LM ("JIT" at that time) and automation to conclude that "the implementation of JIT production systems makes it easier for an organization to automate".

Finally, Sanders et al. (2018) identify standardization, value stream mapping and SMED as the basic lean elements that serve as a foundation and support successful implementation of I4.0

Remaining possibilities in Dombrowsky et al.'s (2017) list are not so differ nt one from another: they mean that technological advances transform the tools of LM and provide lean with new tools. Probably the principles of lean do not need to change, but the way how they are applied will change.

Other options not mentioned by Dombrowsky et al. could be the (future) scenarios suggested by Roser (2018):

v) LM and I4.0 are unrelated and they are even antagonists

vi) LM is embedded in I4.0

vii) I4.0 is embedded in LM

viii) Lean 4.0 (conjunction of both paradigms) –The term is also mentioned in Enke et al. (2018) and Mayr et al. (2018)-.

There are not many articles supporting the fifth option. However, two papers have to be cited. Martinez et al. (2016) found, in a quantitative review of the words in the literature, that the body of knowledge on I4.0 had low or non-relation with LM (e.g. one is about "CPS" and the other is about "waste"). In our view, the differences between both strategies are:

- While LM is based on simple principles, I4.0 depends on complex systems.
- LM tries not to depend on software and computers, but computers are a fundamental element of I4.0.
- While LM relies on people, I4.0 relies on technology.
- In LM, improvements require operators (kaizen), while in I4.0, they require technicians and programmers.
- While LM aims to reduce variability in production, I4.0 focuses on flexibility (mass customization)
- While LM is an old strategy based on the means available in 1950, I4.0 is a new strategy based on current and future technologies.
- LM is based on continuous improvement and I4.0 on frequent changes.
- While LM tools such as VSM have limitations to handle variation, complex systems have a stochastic behavior.

LM attempts to reduce waste and simplify industrial processes, according to Lugert et al. (2018), this includes the minimization of the complexity that could be generated by the use of information technologies, and therefore, the goals of LM clash with the ambitions of Industry 4.0. In spite of these differences, other sources accept that LM and I4.0 have common goals -to increase productivity and flexibility (Buer et al., 2018)- and therefore, they can interact.

The result of Roser's (2018) small survey among lean practitioners revealed that most people believed that a scenario where LM and I4.0 overlapped was the most likely one. Scenario v was voted for few people and scenarios vi to viii were the preference for different groups of the audience. Lugert et al.'s survey (2018) showed that experts appreciated a combination of lean manufacturing and Industry 4.0.

Although it was not mentioned in their work, according to Dombrowski et al.'s (2017) study of the Interdependencies of LM principles and the characteristics of I4.0 shows that option viii (the integration of LM and I4.0), later studied by Dombrowski et al. (2019), is feasible because both approaches share some common elements. In practice, Rossini et al.'s (2019) survey shows that adoption of I4.0 is linked to LM implementation and conclude that manufacturers that aim to adopt higher levels of I4.0 must concurrently implement LM as a way to support process improvements.

Enke et al. (2018) discuss practical applications that resemble Dombrowsky et al.'s (2017) options and finally they support the integration of LM and I4.0 into "Lean 4.0". Küpper et al. (2017) anticipate (although it is difficul to make such predictions) that manufacturers who successfully implement this integrated approach will reduce conversion costs by as much as 40% in five to ten years. This is much more that the reductions captured by LM or I4.0 alone.

Ghobakhloo & Fathi (2019) also support this integration "lean-digitized manufacturing" through a case study. They contend that, as stated by Moyano-Fuentes et al. (2012), ITC tools are crucial for achieving LM effectiveness in the era of I4.0 and they enable LM practices and allow LM and I4.0 integrate and mutually support each other.

We have seen in the past how, in order to reduce costs, to improve quality and eventually to become competitive, companies rely on two pillars: the first one is automation and the second one is management. Flooding industries with new technologies does not improve their performance. People may feel disappointed. We have witnessed the lack of success of ERP programs or Computer Integrated Manufacturing (CIM). They were not able to solve the problems of a company –maybe they solved some, or made them easier, but they also created other types of problems-. Besides, the failure of such tools cannot be attributed to the lack of available technology. In consequence, the best strategy must be a combination of management (LM) and technology (I4.0). According to Doh et al. (2016), companies have the chance to implement automation technologies that make extensive use of intelligent information processing techniques -at the core of I4.0- and to adopt the lean manufacturing philosophy and Ma et al. (2017) affir that simply implementing lean production-based human-centered production or high automation to improve system flexibility are not enough to meet the challenges of mass customization. Finally, Rüttimann and Stöckli (2016) recommend implementing LM today, instead of waiting till the technologies in I4.0 are ready. Contrary to that view, Sanders et al. (2016) suggest that I4.0 solutions will support companies become lean without "striving-for-lean" efforts, but this is hard to believe because lean is much more than a set of practices and tools. Technology may enhance these tools, but the company culture must adopt the lean thinking.

Kolberg & Zühlke (2015) asseverate that I4.0 can be integrated in LM and even improve LM by increased integration of ICT. If we remember that lean manufacturing is based on the elimination of muda and in continuous improvement, we can detect that information is the first thing that one needs to succeed in that tasks. Data coming from the sensors placed on machines, materials and people and tools like cloud computing and big data analysis will serve well that purpose.

Luz Tortorella and Fettermann (2018) find evidences of the integration of lean practices and I4.0 in 110 Brazilian manufacturing companies. Authors state that lean practices are positively associated with I4.0 technologies and that, if they are adopted concurrently, they will lead to improved firm performance. They provide evidence that, even though lean manufacturing is a non-technological approach, its benefits can be increased if technologies are incorporated correctly. Their survey shows that most firms with a high I4.0 level also have a high level of adoption of lean manufacturing. Besides, there is evidence that size may not be a barrier for the successful adoption of lean manufacturing and I4.0.

Wagner et al. (2017) present many examples of how I4.0 tools affect several LM tools and they study a case process improvement. It is a cyber-physical just-in-time delivery solution in an automotive company. It allows work in small batches, enabling the reduction of lead time. It avoids safety stock, work in process and overproduction.

Netland (2015) states that although the changes that come with the I4.0 surely will impact lean production -at least in its physical aspects with fewer Kanban cards, fewer boards, etc.-, the lean method will continue to be valid and will be supported by new ways of sharing information to meet the need for flexibility and adaptability in new industry and logistics.

In a similar way, Powell et al. (2018), after a review of the literature and the study of an Italian company in the automotive industry, contend that lean manufacturing can benefit from I4.0 tools such as digital technologies and cyber-physical systems. This is because LM is based on standardized practices and worker involvement (kaizen), which can take advantage of the environment presented by cyber-physical systems and the Internet of Things. This view does not coincide with that of Meissner et al. (2018) who see LM as system of continuous learning and improvement based on standards, focused on people, while I4.0 focuses on technical improvements. Therefore I4.0 cannot replace lean manufacturing. Meissner et al. agree that lean can be improved through new technologies: information is helpful to manage the shop floor (e.g. detect abnormalities, decision based on facts, teamwork). However, they present some drawbacks: Digital shop floor management tools can be seen as a management monitoring tool by the employees; Managers tend to solve problems themselves instead of leading their employees.

Romero et al. (2018) carry out an exploratory study on the integration of lean philosophy and the I4.0. They offer a review of lean philosophy in the light of the technologies emerging from the I4.0 and reflect on the potential of such technologies to eliminate waste in existing lean manufacturing programs (the traditional physical waste types can be better identified and eliminated through I 4.0 technologies) and for facilitating leaner production. Their main contributions come in the form of two concepts: "Digital waste" (new sources of muda such as the creation, collection, management, transmission or storage of unnecessary data) and "Digital lean manufacturing" (integration between LM and I4.0).

Different studies agree that I4.0 will bring changes to common lean practices and tools (see, for example, Davies et al., 2017). Currently, papers concentrate on the first step, which may be to present an updated version of the tool (e.g. from the paper kanban to the e-kanban) but the final step may be something that we are not able to currently envisage (For example, Wagner et al. (2017) mention machine to machine communication). In fact, some of the tools of I4.0 are already contributing to the adoption of lean manufacturing (Andriulo et al., 2013). We can mention Radio Frequency Identification (RFID) and Near Field Communication (NFC), which are simple forms of the Internet of Things used to track items and deliver them in a just-in-time fashion. And elements of

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the "previous" generation, such as Computer Aided Design (CAD), are currently perfectly integrated into lean environments (Cattaneo et al., 2017). An issue that hinders the smooth integration of Industry 4.0 into lean manufacturing is the highly cost-intensive implementation process of I4.0 and some risks associated to cyber security (Beifert et al., 2018).

One of the two most described tools is Jidoka or autonomation. Ma et al. (2017) present "Lean automation" (a new name for jidoka) that utilizes cyber-physical systems (CPS). This type of automation implements some supervisory functions rather than production functions. According to Ma et al., I4.0 technologies have widened the application of jidoka as a way to improve production system flexibilit . Although not discussed in their paper, we believe that this capability of self-diagnosis based on data collection of sensor data may lead to a new level of predictive maintenance (part of Japanese Total Production Maintenance or TPM), reduce maintenance cost and increase equipment availability.

The other most studied tool is value stream map (Meudt et al., 2017; Hartmann et al, 2018; Lugert et al., 2018). Lugert et al. used a survey instrument to collect the views of lean experts (mainly from Germany) and most of them were in favor of a development of VSM by means of digitalization.

The digital enhancement of other LM tools have been studied too. Kolberg & Zühlke (2015) prepare a list of several lean tools that can be implemented in an I4.0 environment:

- Digitalization of kanbans (e.g. empty bins are recognized automatically via sensors and replenishment orders are transmitted to suppliers). This way, traditional Kanban systems with fixed amount, fixed cycle times and fixed round trips for transporting goods become dynamic in nature.
- Status displays (andon) are not necessary because Machines send directly errors to operators and employees receive error messages in their smartwatches.
- In the context of continuous improvement (kaizen), sensorized "Smart" products will collect process data.
- Technical installations help employees to avoid mistakes (poka yoke).
- I4.0 could support Single-Minute-exchange-of-Die (SMED) to allow flexible, modular production

Sanders et al. (2017) present a comprehensive table that shows to what extent each one of the principles of Industry 4.0 (namely: real-time capability, decentralization, modularity, interoperability, service orientation and virtualization) support each LM tool according to a scale that ranges from -10 to +10. The average beneficiary coefficien is only negative for takt time because Sanders et al. believe that the application of takt time is too rigid to benefit from principles based on flexibilit . TPM gets the highest score with 9.5 marks on average.

Other lean tools and practices that may be enhanced are the 5S (only 2.5 marks according to Sanders et al., 2017), standardized work (only 2.8 marks in Sanders et al., 2017), and cellular manufacturing (seru in Japanese, to avoid confusion with group technology cells) –ignored in Sanders et al. (2017)-. Since Six Sigma needs data to optimize processes and improve quality, it can benefit from the huge amount of data captured by sensors, and methods like big data analysis (Dogan & Gurcan, 2018). Maybe the most difficul element to integrate is the collaborative robot (cobot). It is not the conventional robot that performs repetitive and ergonomically unfriendly tasks. Cobots must decide what task to do and how to do it (Suárez and Rosell, 2019). This will contribute to achieve lean's one piece flow instead of batch manufacturing. However, the question then is: can the robot assess the quality of the product, improve its method and make improvement suggestions as a thinking worked would do? These aspects have not been well addressed in literature. Probably this technology is not yet mature, but cobots are going to have an impact on flexibility strategies and on people working alongside them.

Sanders et al. (2016) suggest solutions from the I4.0 that can update and improve each one of the 10 dimensions of lean manufacturing described by Shah and Ward (2007). Sanders et al. conclude that I4.0 can help companies (their paper specially focuses on SMEs in Germany) that want to implement lean manufacturing. Their view is later shared by Alfonso-Ruiz et al. (2018).

If I4.0 may improve lean tools, maybe lean thinking itself should evolve in line with the technological trends of the I4.0 (Caldwell, 2018) to become "lean enterprise 4.0". Caldwell's research, based on interviews with lean practitioners from large companies in Costa Rica, concludes that changes should take place especially in the conceptualization of value, the flow of value and muda, and the need to integrate techniques for collaboration between people and robots. This may lead to a real integration that he names "lean-cyber-physical systems".

While many of the previous mentioned papers seem to suggest the same type of integration, Sony (2018) assumes a triple integration based, where the principles of LM (Womack et al., 1990) act as drivers and the tools of I4.0 act as enablers:

- Horizontal integration: collaboration between companies in the same value chain (or supply chain).
- Vertical integration: the creation of flexible and reconfigurable manufacturing system through digitization
- End to end engineering integration: that enables the creation of customized products across the value chain.

4. The role of people

Since companies are socio-technical systems, one must consider the role of people in a smart factory because the digital technologies that support the I4.0 also bring important opportunities, as well as difficul challenges, for people. At least, this has been true for the previous "industrial revolutions". The (first) Industrial Revolution created the "industrial manufacturing system", moving from craftsmen to proletarians; In the second one, mass production brought the division of labor and the assembly line and led to the concept of Scientific Management and the disciplines of Industrial Engineering and Operations Management; the automation revolution transferred responsibilities from manual workers to a control worker and promoted the discipline of "control engineering" (Davies et al., 2017). Also lean manufacturing created a way of working, with cross-trained employees, working in teams, and used to problem solving. The way in which the I4.0 will impact people's working methods and their interaction with technologies and the disciplines that will arise are still unknown.

Few papers have considered the role of people. And the consequences of I4.0 for managers and operators seem beyond the scope of those who study the relationship between LM and I4.0 (and those who simply study I4.0). Bonekamp and Suri (2015), in their review of the literature, find that experts think that I4.0 will lead to an important decrease in low-skill tasks (humans will be replaced by machines) and to an increase in high-skill activities (such as planning, process control and IT-related tasks). It is difficul to predict how this will affect our societ .

Anyway, far from the rather generalized Sci-Fi view that the digital factory will need no people, human workers are not expendable in I4.0 because only humans can accomplish complex operations (Ma et al., 2017). Mrugalska and Wyrwicka (2017) point out that lean manufacturing depends on the "strict integration of humans in the manufacturing process"; it relies on team-work by engaged and empowered multi-skilled operators, making continuous improvement possible. Companies such as Toyota realize that continuous improvement is not possible without people, who can understand processes, solve shop floor problems and discover opportunities for improvement (Bauer et al., 2018). "Thinking workers" cannot be replaced. This is a clear message for companies that want to be lean in the I4.0 era.

Different competences (professional and methodological skills, social competence and self-competence) will be required by the workers of the digital era (Dombrowski et al., 2019). Díaz and Flores (2017) identify the necessary capacities for high-skilled workers (such as information technologies, data-based quality control, robot-assisted production, simulation, predictive maintenance, additive manufacturing) and for managers (goal oriented, teamwork, involvement with employees). Ayneto (2019) supports that floor shop employees will be the most affected by the technological changes related to I4.0. He contends that new knowledges and skills will be necessary and, in consequence, higher education must play a leading role. In spite of everything, many people do not need to understand the technology that makes I4.0 possible (Enke et al., 2018).

With respect to the human-machine interaction (ways in which they share information and collaborate), most papers concentrate on technological aspects (Wagner et al., 2017) of the communication between men and machines. Issues such as safety (people working next to robots) and security still need to be addressed (Thoben et al., 2017). Virtual reality and augmented reality -by means of wearable devices such as smartwatches, smartglasses, smartphones and tablets (Gorecky et al., 2014)- are possible ways in which operators can receive information. With these tools, work may become a game, and this fact will contribute to people engagement (Meissner et al., 2018). Kolberg and Zühlke (2015) contend that, in this environment, operators become Smart Operators or Augmented Operators (Mrugalska and Wyrwicka, 2017) who are capable of supervising and controlling ongoing activities. Mayr et al. (2018) identify lean practices that can be enhanced by the human-machine interaction: kanban, value stream map, total productive maintenance, visual management (5S, andon) and poka-yoke (smart machines will prevent mistakes). In this respect, technology, instead of replacing workers, can contribute to empower human operators. The consequence is that workers can assume more responsibility and even a larger operating area (Gorecky et al., 2014), taking advantage of the information from cyber-physical systems.

It is well known that it is not enough to copy Toyota's tools to achieve success. Leadership is required. If we had a man with brain sensors and computers could analyze data from his brain, a cerebral interface between man and machine would be possible, allowing faster communication in I4.0 environment. Currently, we can only analyze the brain patters of his behavior (Villalba-Diez et al., 2019). While this still seems fiction, the possibility to monitor workers (through devices such as smartwatches and other sensors) to enhance their productivity and their safety is perfectly real. However, this has not been addressed in the compiled papers (only hinted by Rother and Baboli, 2019). Since the necessary technology is already available, this lack of interest relegates people to the role of bystanders as if these decisions did not have any impact on the strategy. Technology is ready. But, are people ready for the changes in their jobs? This issue should be addressed in future research.

5. Conclusions

This work contributes to the development of research on the relationship between I4.0 and LM and, from a managerial perspective, it could support entrepreneurs in better understanding the implications of adopting I4.0 in relation with

LM. This study has its limitations. While most researchers claim that LM and I4.0 interact in a positive way, thus leading to synergies, most of the papers that have been reviewed in previous sections are conceptual ones and there is still a lack of empirical evidence. In consequence, many conclusions of the review of the literature can be seen as predictions.

A bibliometric study has unveiled who is working on the link between LM and I4.0 and where. The number of papers on this topic has quickly increased in the last years, showing that there is a real interest on this issue. Since this is a young research field, it is still difficul to identify the main authors in the research stream. As I4.0 emerged in Germany, most papers are from German authors from German institutions. However, we have reviewed papers from many countries, especially Europe, showing the great expectation caused by LM and I4.0.

The so-called fourth industrial revolution is not linked to break-through scientific discoveries (such as it was the steam machine in the 18th century) but to a different usage of already existing technologies –such as the Internet of Things- that may manage and control processes in the so called I4.0. Besides, this revolution is not studied a-posteriori like all historical events, but announced by governments, consultancy firms and big companies. This justifies a lot of expectation but also skeptical reactions and the conviction that I4.0 is just marketing hype or a passing fad. Experts in lean manufacturing see I4.0 either as an evolution of LM or as a way to support lean practices. Anyhow, they see it as an evolution not a revolution.

Whether it is a true revolution or not, companies in diffe - ent industries are adopting elements of the I4.0 since they are becoming standard components just as a company would buy a computer with a high-definition color monitor instead of one with a green phosphor display. However, I4.0 cannot solve a company's problems. Surely it will make some things easier, but it will create other problems and non-value added activities -and whoever ignores this will feel disappointed-.

LM has shown its capability to improve a company's performance over the last decades. However, a huge percentage of companies have failed to implement it properly. Surprisingly, after all these years, it is still a buzzword. This outstanding position indicates that lean manufacturing is not going to disappear overnight.

Both LM and I4.0 aim at improving the competitively of firms, but they try to do it with different practices and tools. While LM relies on continuous improvement, led by operators, I4.0 relies on advanced technology. Now these two approaches coexist, and we have identified up to eight possible combinations on the type of relationship between LM and I4.0. Most papers support different types of beneficial relationships between them. However, it seems as if authors interested in the relationship between LM and I4.0 were keen on LM. Some authors consider that, before implementing I4.0, in order to make the most of it, the company must have, at least, some lean tools in place to ensure stable and efficien processes. Once the firm has reviewed its processes in line with a lean philosophy, the I4.0 can become an important new ally in the search for value and excellence. Not only are lean principles not left behind by the I4.0 but they become more relevant in the new I4.0 factories which have to be lean in order to meet new challenges. This is the educated opinion of lean experts but one can question whether a non-lean company, interested in implementing I4.0, will consider implementing lean.

Others contend that the great changes that come with the I4.0 can be expected to have an impact on lean production as we see it today as regards its physical facets, with fewer Kanban cards, fewer boards, etc. The lean methodology will continue to be supported and enhanced by I4.0 (in the form of improved tools such as Value Stream Map, 5S, etc.) yielding new ways of sharing information and meeting the need for flexibility and adaptability in manufacturing and logistics.

Finally, others mention an integration of both approaches. Beyond a set of tools and practices, LM is based on a philosophy that may be called lean thinking. The digitalization of a company offers new opportunities to apply the lean philosophy. Although this may currently seem marketing hype, some use terms like "lean 4.0" to describe how lean manufacturing is applied in the new context. This could be compared to "lean six sigma": the emphasis of lean manufacturing on quality and continuous improvement has made many lean companies embrace the six sigma methodology. The global conclusions are that, from the bibliographical review, it seems clear that the I4.0 will become an important ally of LM and that companies need LM and I4.0 in whatever combination may fit their strateg .

In the extant literature many tools of I4.0 have been mentioned: Sensors, Cloud computing, Big data and Data analysis, vertical and horizontal Integration, simulation, Virtual reality and augmented reality, 3D printing, ITC (software), etc. The lead characters are cyber-physical systems and Internet of Things because they support data collection and data exchange. Otherwise, I4.0 would be simple automatization. They can help in tools and practices such as Value Stream Map, jidoka, 5 S, poka-yoke, kanban, TPM, andon, kaizen, jit deliveries, heijunka, cellular manufacturing, standardization, inventories, waste reduction, six sigma or SMED. Only the takt time concept seems to be against the flexibility pursued by I4.0. LM will evolve towards more digital methods because technology may enhance traditional lean tools for the reason that I4.0 collects real-time data that can be used to take decisions based on facts. The role of cobots has not been well addressed from the point of view of management and requires further research.

The least studied aspects in literature are those related to people. For LM, engaged employees are crucial to solving shop floor problems but I4.0 focuses on technology. In the short run, workers are not going to disappear from the shop floor but their future role is not clea .

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