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Implementation of Industry 4.0 Techniques in Lean Production Technology: A Literature Review

Laura LUCANTONI, Sara ANTOMARIONI, Filippo Emanuele CIARAPICA, Maurizio BEVILACQUA

Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica Delle Marche, Italy

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Abstract

Lean thinking and Industry 4.0 have been broadly investigated in recent years in intelligent manufacturing. Lean Production is still one of the most efficient industrial solutions in business and research, despite being implemented for a long time. On the other hand, Industry 4.0 has been introduced referring to the fourth industrial revolution. This study aims to analyze the combination of both Industry 4.0 and Lean production practices through a systematic literature review from a Lean Automation perspective. In this field, 189 articles are examined using VOSviewer for cluster analysis. Then, a more detailed analysis is provided to explore how Industry 4.0 and Lean techniques are integrated from a practical perspective. Results highlighted Big Data Analysis and Value Stream Mapping as the most common techniques, also emphasizing a growing trend toward new publications. Nevertheless, few practical applications are identified in the literature highlighting six gaps in the correlation of LA practices.

Keywords

Industry 4.0, Lean management, Total productive maintenance, Big data analytics, VOSviewer.

Introduction

Due to the dynamic nature of the organization's environment, business development is highly growing as new methods, policies, and techniques are implemented. Indeed, during the fourth industrial revolution, companies have always searched for new business opportunities and strategies to improve their profits, adapt to market needs, and maintain processes sustainability (Antomarioni et al., 2021).

Lean Production (LP) and then Industry 4.0 (I4.0) practices are widely used to achieve these goals. LP provides continuous improvement and cost reduction through wastes elimination OR nonvalue-added activity and efficiency increase (Bevilacqua et al., 2017; Bevilacqua et al., 2019).

I4.0, first introduced in Germany, is instead identified as an intelligent industry, able to digitize the production processes using the third industrial revolution (Gallo et al., 2021). In several studies, I4.0 has often been presented as the solution that will, by itself, ensure productive sector success in the digital era, leaving a gap in lean manufacturing efforts (Marcucci et al., 2021). However, in recent years LP and I4.0 have been studied in literature focusing on their relationship.

The LP and I4.0 tools relationship provides a continuous, transparent, automated, and customer-driven product and information flow by addressing supply chain flexibility (Valamede & Akkari, 2020) and resilience often marginally analyzed (Bevilacqua et al., 2018).

Incorporating I4.0 technologies into LP has been named Lean Automation (LA) (Tortorella et al., 2021). In this context, the present work aims to develop a systematic literature review regarding LA.

The proposed analysis aims to explore the topic status, evaluate its trend, and show practical implications.

Several papers in the literature focus on the interaction between LP and I4.0 since 2015 (Taghavi et al., 2020), and it appears to be an emerging research area with most of the studies published in recent years (Bittencourt et al., 2021; Cagnetti et al., 2021). Hence, the existing literature reviews are valuable to identify the benefits of the LP and I4.0 interaction. However,

***Corresponding author**: L. Lucantoni – Dipartimento di Ingegneria Industriale e Scienze Matematiche, Università Politecnica Delle Marche, Italy, phone: +4877 423 40 31, e-mail: mper@univtech.eu*

to the best of the authors' knowledge, an analysis of the explicit correlation between the application of I4.0 practices within LP principles is not yet present in the literature.

For this reason, the literature review proposed in this work aims to address this gap and answer the question "how have I4.0 and LP techniques been integrated in the current literature?", focusing mainly on case studies, real applications, and projects. Hence, the final objective is the identification of gaps and possible future research direction in this field.

The rest of the paper is as follows. In Section 2, the state of the art in literature review papers about I4.0 and LP correlation is analyzed. In Section 3, the research approach is described highlighting key findings. Finally, in Section 4, paper contributions and possible future research directions are discussed.

State of the art

Preliminary research of the scientific literature is developed to conduct exploratory research analyzing the extant literature review papers in LA.

It is studied how the concepts I4.0 and LP have already been investigated together in literature from various research databases, i.e., Google Scholar, Research Gate, Scopus, Science Direct, and Web of Science. It should be noted that due to the multitude of databases, the lists are exported to an excel file in order to avoid the duplication problem.

Several papers are identified, but only 14% of these are literature reviews papers. Overall, twenty-seven literature review documents are identified, and 10 are considered relevant to properly define different authors' perspectives.

To this end, the key findings on the interaction between LP and I4.0, as retrieved in selected scientific literature review papers, are shown in Table 1.

LM and I4.0 share the same goals of increasing flexibility and productivity (Agostinho & Baldo, 2021) and several perspectives on their correlation can be analyzed.

As the LP may not meet the new needs imposed by applied digital technology in the industry (Valamede & Akkari, 2020) most of the research in the literature focuses only on how it can be used as a guideline for investments in advanced technologies and how I4.0 can be used to benefit from the LP methodology (Kassem, 2019). For instance, in (Kassem, 2019)., the literature review comes from only two databases and

Table 1
Key findings about the main LA literature reviews' papers

Keywords	LA literature review papers			
	# of papers	# of relevant papers	Reference	Topic
TITLE-ABS-KEY "Industry 4.0" AND "Lean" AND "literature review"	40	9	Kassem, 2019	Map of existing literature addressing the interaction between LP and I4.0.
			Gallo et al., 2021	What Industry 4.0 tools are used by the companies, reasons and advantages.
			Cagnetti et al., 2021	How Lean and Industry 4.0 concepts can be implemented in a company in two different clusters: strategic/managerial and techniques/implementation.
			Tissir et al., 2020	Lean tools and principles will not disappear; they will just be improved by the emerging technologies to reach high performance.
			Bittencourt et al., 2021	Deep analysis to indicate how management, processes and people are the most cited words, reinforcing their role of Lean as a trigger for Industry 4.0.
			Taghavi et al., 2020	Quantitative and qualitative analysis of the relationship between lean and industry 4.0.
			Pagliosa & Tortorella, 2021	Knowledge on I4.0 technologies and LPs applications in different levels of the value stream identifying their synergies (theoretical contribution).
			Bittencourt et al., 2019	Identification of the effect of Lean Thinking as a facilitator within the scope of Industry 4.0.
			Santos et al., 2021	Identify six examples of real cases that address LM-Industry 4.0 integration in the extant literature.
			Mayr et al., 2018	How LM and I4.0 can complement each other, and I4.0 can support lean methods, exemplified by production use case.

it is subject to a qualitative analysis, as in (Taghavi et al., 2020; Mayr et al., 2018; Bittencourt et al., 2019). In these papers the synergies between them are identified through a theoretical contribution, as follow:

- LP acts as a basis for I4.0.
- Positive interaction between I4.0 and LP.
- I4.0 advances LP efficiency.

Key aspects and implications of the relationships between I4.0 techniques and LP principles have been widely studied in the literature. However, several aspects should be studied to be useful not just from a theoretical point of view but also in terms of application, e.g., including recommendations for industrial managers and policymakers as the case of (Merino et al., 2020).

Reference (Pagliosa & Tortorella, 2021) is limited to conceptual/theoretical contributes considering the citation frequency of I4.0 technologies and LPs, their application at different levels of value stream, and relevance of the literature. It can be helpful as initial guidelines to strengthening the body of knowledge on I4.0 and LP technologies based on their level of synergy.

Regarding practical implications, reference (Pagliosa & Tortorella, 2021) affirmed that in lean implementation efforts should be preferably invested in Internet Of Things (IoT) and Cyber-Physic Systems (CPS) to benefit from I4.0.

Previous studies considered I4.0 as the integration between intelligent technologies and data exchange, focusing mainly on CPS (Gallo et al., 2021; Mayr et al., 2018).

Other technologies are analyzed in the literature, e.g., reference (Mayr et al., 2018) illustrated a matrix combining all I4.0 tools and lean methods. Despite this being based only on reasonable assessments of the authors, their exemplification of two use-cases and (Gallo et al., 2021), (Santos et al., 2021) also appears to be helpful to improve the quality of the results of the present research.

This paper aims to study how different authors have related I4.0 techniques in practice to lean principles. For instance, reference (Santos et al., 2021) is focused on expliciting the best practices implemented by six specific industrial sectors: automotive, paper, furniture, healthcare, apparel, and machine manufacturing; while, the most significant number of scientific papers highlight that companies have applied the concepts of I4.0 and LP as managerial strategies (Cagnetti et al., 2021).

For this reason, the current paper also aims to fill this gap by focusing on new features. How LP principles and I4.0 technologies have been related from a technique/implementation perspective is identified.

Research approach

The research adopts a multi-level approach based on a database definition and cluster analysis. The latter section consists of (a) countries bibliographic coupling, (b) co-occurrence network analysis, and (c) keywords evolution trend. Finally, the correlation between I4.0 and LP best practices is identified. Those phases are subsequently detailed.

Database definition

The literature search includes several papers about the correlation between Industry 4.0 techniques and Lean principles, implying Scopus and Web of Science as databases. The keyword research parameters are summarized by the Boolean expression "Industry 4.0" AND "Lean", searched within articles title, abstract, or keywords to discover the most reliable, relevant, and up-to-date English-written documents. The review is conducted from the 2014 to 2021 timeframe, and only peer-reviewed academic journal articles, conference articles, or book sections available up to and including June 2021 were considered. After obtaining the initial set, several papers were excluded. The search was limited to those papers dealing with engineering topics, thus excluding economics, medicine, and so on. Overall, database creation results in 285 relevant papers with an increasing trend, as shown by an average annual rate of more than 12 documents, respectively, with a peak of more than 22 and 28 in 2018 and 2019, remaining constant in 2020. Articles and conference papers dominate the document type, with a significant 84% of the total amount. It has been possible to develop bibliometric analysis and extrapolate relevant information from the created database, as detailed below.

Cluster analysis

The cluster analysis in this paper is developed using VOSviewer software to create and visualize bibliometric maps. Unlike most of the other computer programs used for bibliometric mapping, VOSviewer pays particular attention to the graphical representation of these maps (Gallo et al., 2021). In this research, three different VOS viewer functionalities are utilized, i.e., (a) Countries bibliographic coupling, (b) Co-occurrence network analysis, and (c) Keywords evolution trend.

Countries bibliographic coupling

As shown in Table 2, Italy and Germany are the most significant countries contributors to studying correlations between I4.0 in Lean practices. The results highlight that Itay and Germany are part of the first cluster (red cluster). They have 40 and 35 documents published and 269 and 755 citation numbers, respectively.

Based on that, Italy appears to have the highest *total link strength* with Scotland, witha score of 14550 compared to the 4569 of Germany.

Co-occurrence network analysis

This section uses the cluster method to develop the keywords co-occurrence network analysis in LA papers. The keywords relatedness is determined based on the publications number in which two terms occur together, i.e., the strength of all the links.

Keywords with more than five occurrences are classified into five clusters as shown in Fig. 2 and summarized in Table 2. A total of 134 keywords in 285 relevant papers from 2015 to 2021 are identified.

Fifty-eight keywords have more than five occurrences; 28 are relevant, and 14 are without synonyms. The most recurring keywords are *lean* used 253-time, *industry 4.0 (industry 4)* used 221-time, *digitalization* used 120-times, *smartly* used 52-time, and *cyber-physical systems* used 47-time.

Among all keywords, several practices of both Industry 4.0 and Lean techniques are identified.

As the main topics in LA papers, the results highlight *Big Data* analytics (BDA) and *Internet Of*

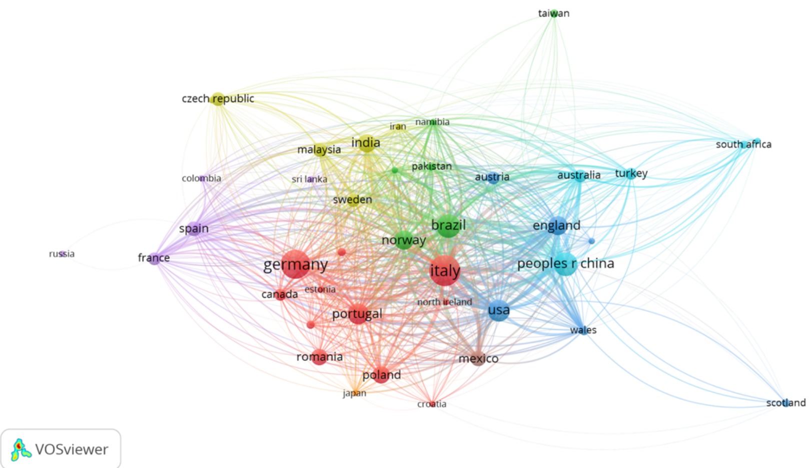


Fig. 1. LA countries Bibliographic Coupling

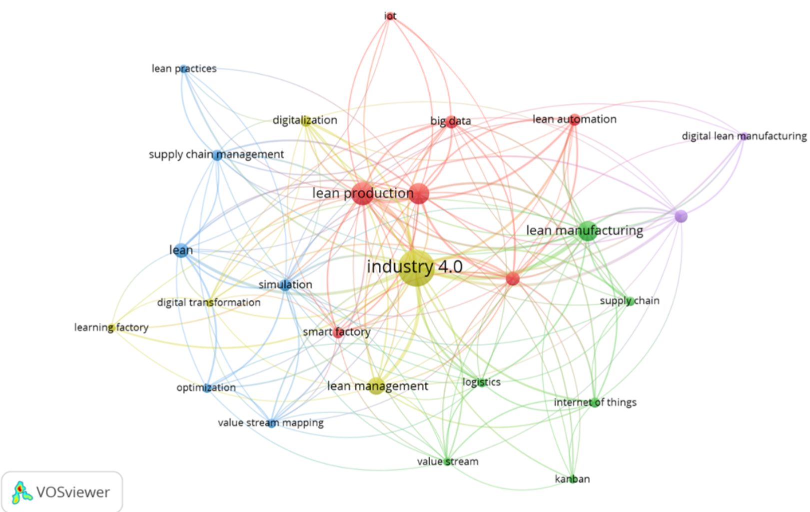


Fig. 2. Co-occurrence analysis

Table 2
Results of the co-occurrence analysis

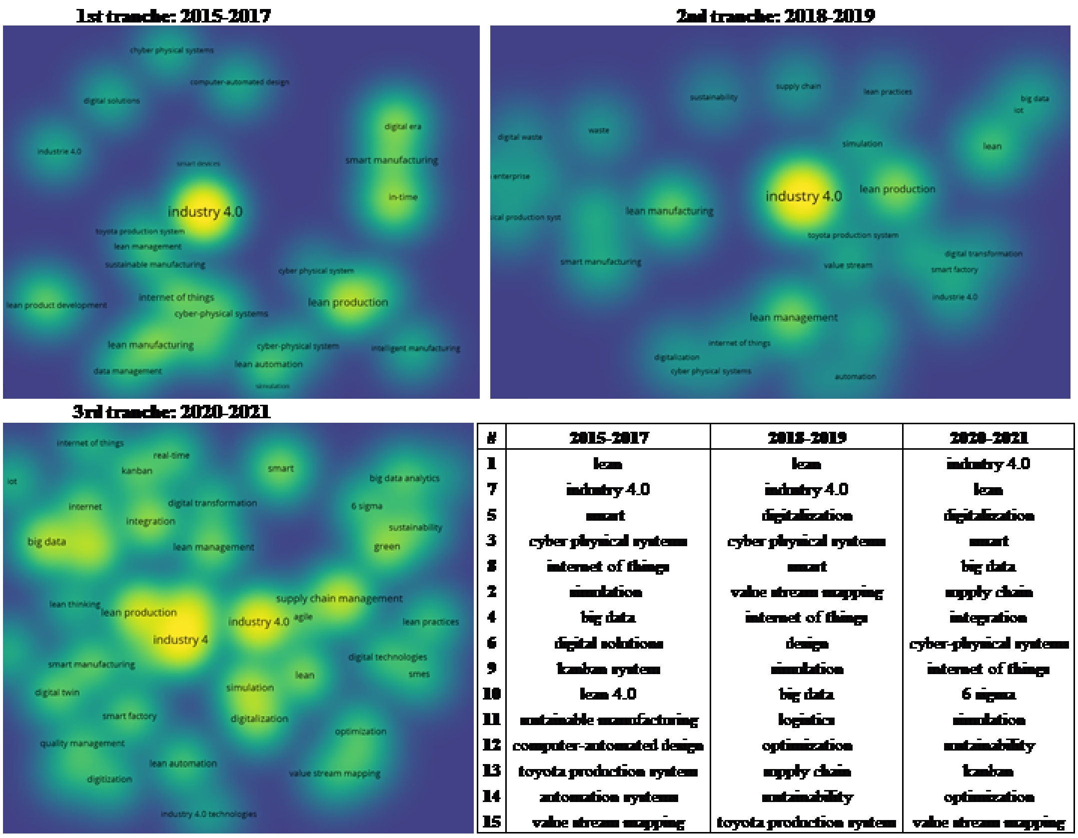
Cluster	# Keywords por cluster	Primary keyword por cluster	Total link strenght
Cluster 1	7	Industry 4.0	155
Cluster 2	6	Lean production	81
Cluster 3	6	Lean manufacturing	65
Cluster 4	5	Big Data	31
Cluster 5	2	Internet Of Things	22

Things (IoT) followed by *simulation* as I4.0 technologies, and *Value Stream Mapping* (VSM) followed by *Kanban* as LP principles.

Keywords evolution trend

In this section, different maps are created in order to show the trend evolution of keywords in the last six years, based on four timelines as shown in Fig. 3: the first tranche from 2015 to 2017, the second tranche from 2018 to 2019, the third tranche from 2020 to 2021. In each map, all the main keywords were selected independently of the minimum number of occurrences in order to consider the currency of the research topic and the comprehensiveness of the map. In Fig. 3, the table contains the most important keywords of the specific tranche in order of highest occurrence weight. The VOSViewer density visualization option shows the density of each item through a different color. The color is closer to yellow the larger the number and weight of neighboring elements. While the color is closer to blue, the smaller the number and weight of neighboring elements. Next, the theme evolution is analyzed based on the keyword position within the table in Fig. 3. According to Fig. 3, the following observations occurred:

A. From 2015 to the present, the most important topics are LP and I4.0. The last one, increasingly evolving, has become the most in the last two years with an occurrence weight of 61.
B. From 2015 to 2017, the subsequent core topics are smart production, CPS, IoT, and simulation. However, the themes above have low occurrence weights than the I4.0 and LP, ranging from 8 to 3.
C. From 2018 to 2019, the subsequent core topics are digitalization, CPS, smart, VSM, and IoT. In particular, the second-to-last reaches here its maxi-



#	2015-2017	2018-2019	2020-2021
1	lean	lean	industry 4.0
7	industry 4.0	industry 4.0	lean
5	smart	digitalization	digitalization
3	cyber physical systems	cyber physical systems	smart
8	internet of things	smart	big data
2	simulation	value stream mapping	supply chain
4	big data	internet of things	integration
6	digital solutions	design	cyber-physical systems
9	kanban system	simulation	internet of things
10	lean 4.0	big data	6 sigma
11	sustainable manufacturing	logistics	simulation
12	computer-automated design	optimization	sustainability
13	toyota production system	supply chain	kanban
14	automation systems	sustainability	optimization
15	value stream mapping	toyota production system	value stream mapping

Fig. 3. Keywords evolution trend

mum peak, while the latter one is still a growing theme today with a weight of 9 compared to 3 in the first tranche.

D. From 2019 to 2021, the subsequent core topics are digitalization (as in the second tranche), smart, and big data as one of the most important I4.0 techniques.

The highly developed and isolated themes show that big data, sustainability, and green have developed rapidly in recent years, highlighting data management focus and green attention. CPS, instead, has always maintained a constant weight over the years between eight and nine. In comparison, the relevance of simulation has grown together with I4.0. Finally, in recent years, research has aimed to provide more digital and automated scenarios for I4.0 and Lean practices. Based on this, the keywords *digital twin* and *LA* are included, respectively, in digitization and LP.

LA best practices correlation

In this section, several practices of both I4.0 and LP are analyzed among all keywords. Practical applications between I4.0 and LP technologies in literature are discussed and presented in Table 3. As emerged in Section 2, several research approaches on I4.0 and Lean integration are presented in the literature. For instance, a new holistic approach for the integration is proposed by (Valamede & Akkari, 2020), to show how Lean Management tools mainly interact with BDA, Cloud, Virtual Simulation (VS), and Augmented and Virtual Reality (AR-VR). However, studies regarding functional interactions are not present in the literature. Firstly, more attention is paid to BDA and TPM techniques since BDA resulted as the main topic of LA within I4.0 from the co-occurrence analysis addressed in this paper. However, the success of I4.0 and BDA depends mainly on knowledge regarding the application of TPM (Oliveira & Fernandes, 2017). Specifically, TPM has a facilitating effect towards the transition into I4.0, and BDA provides support to lean increasing productivity. In this sense, reference (Pozzi et al., 2021) identified a set of data science techniques and tools that can support LP practices and develop a model to guide their implementation. However, companies need to implement new solutions for managing the more significant volumes, velocity, and variety of data (Lisowski & Bednarek, 2019), through an essential system for BDA. In previous research, many systematic literature reviews are presented in the field of

Table 3
Results of the co-occurrence analysis

Industry 4.0	Lean							
	JIT	5S	Cellular Manufacturing	TPM	Kanban	Value Stream Mapping	Poka-Yoke	Jidoka
Augmented and virtual reality		Bun et al., 2018			Husar et al., 2021	Wang et al., 2020b	Yin et al., 2017	Kolberg & Zuhlke, 2015
Big Data Analysis		Ilangakoon et al., 2021	Kumar et al., 2018	Oliveira et al., 2017	AlShebli et al., 2017	Phuong & Guidat, 2018	Muharam & Latif, 2019	Abed, 2016
Autonomous robots	Todoran & Bader, 2018			Bekar et al., 2018		Loan et al., 2020		
Additive manufacturing			Wang et al., 2020a	Bekar et al., 2018		Kurdve et al., 2020		
Internet of Things	Xing et al., 2021	Ramadan & Salah, 2019	Wang et al., 2018		Matsuo & Barolli, 2020	Ramadan, 2012	Ramadan & Salah, 2019	Ma et al., 2017
Cloud	Siu, 2021	Ilangakoon et al., 2021	Kang et al., 2016	Mayr et al., 2018	Cerna et al., 2020	Ilangakoon et al., 2021		Ma et al., 2017
Virtual Simulation		Nallusamy & Adil Ahamed, 2017	Hongfei et al., 2021		Pekarcikowa et al., 2021	Bait et al., 2020		Villalba-Diez et al., 2021
Cyber Physical System	Kolberg & Zuhlke, 2015		Kataoka, 2020	Venancio et al., 2021	Kolberg & Zuhlke, 2015	Chen, 2017	Danut-Sorin et al., 2021	Ma et al., 2017

BDA and 5S integration with only a few practical applications. Likewise, few researchers have developed robust and sustainable Cellular Manufacturing (CM) by using BDA as the key towards I4.0.

Multidisciplinary analyses for operations management are often described, but most industries still rely on the Computer-Integrated Manufacturing (CIM) model with a static and rigid program implementation (Pologe et al., 2020). However, case studies are developed moving away from the rigid automation of CIM towards machine learning-based automation by using BDA, without discussing their integration.

An example of combining both I4.0 and LP is provided by Bun et al., 2018 via Augmented Reality (AR) to familiarize students with the rules and stages of the 5S tool; reference (Kang et al., 2016) instead provided examples for supporting AR application in Jidoka principle or CPS for a flexible Kanban production scheduling.

In previous literature, Jidoka utilizes CPS as a cost-efficient and effective approach for improving system flexibility (Ma et al., 2017). In contrast, Poka Yoke, which utilizes CPS, can offer a solution for manufacturing polymeric products (Danut-Sorin et al., 2021). In order to assess how the IoT-enabled CPS concept can enhance the efficiency of the food traceability system, an intelligent VSM method is proposed (Chen, 2017). VSM has been selected as a complementary method for both data collection (Barring et al., 2017) and waste reduction (Bait et al., 2020) using simulation. On the other hand, according with the keywords evolution trend, Digital Twin is one of the new techniques for modelling and optimization from a future simulation point of view (Weyer et al., 2016), linking real-time to a digital systems. For instance, most studies related to virtual simulation in CM are addressed employing the Digital Twin. Due to its high computational performance, Digital Twin permits applying Jidoka (automation with a human touch) in real-time within manufacturing processes (Villalba-Diez et al., 2021).

Recently, several studies developed an integrated organizational system for Just In Time (JIT) material delivery, also proposing the inclusion of the IoT for process automation in future research, such as Wang et al. (2020). In this regard, the case study revealed how the implementation of lean practices in their project, including IoT, JIT, and Kanban, all contributed to project performance improvement. Since a Radio frequency identification system (RFID) is an automatic technology often seen as a prerequisite for the IoT (Jia et al., 2012), a framework to digitalize 5s and Poka-Yoke through RFID is introduced by (Ramadan & Salah, 2019). In order to enhance smart lean-based manufacturing environments, RFID is also applied for dynamic VSM (Ramadan, 2012). Instead, an IoT sensors management system is proposed by (Matsuo & Barolli, 2020), considering Agile–Kanban for electric wheelchair management. In this sense, several studies applied IoT in smart manufacturing. Specifically, a new warehousing paradigm named cellular warehousing is proposed. This concept is adapted from CM, taking advantage of the similarities between online-offline orders within the IoT-based warehouse (Wang et al., 2018). Several authors proposed practical techniques for designing cellular structures with spatially varying unit cell structures for Additive Manufacturing (AM) (Wang et al., 2020a). Optimization and simulation models are presented in the literature related to CM and Kanban, respectively. In this sense, extensive sensitivity analysis and optimization experiments indicate that using a Kanban system dramatically impacts the performance measures identified in the field of Simulation methods for automated guided vehicles (Bhosekar et al., 2018). On the other hand, a case study is presented regarding the implication of automated guided vehicles contributing to value stream mapping (VSM) in warehouse operations (Loan et al., 2020). While few case studies about the relationship between AR and LP have been implemented, focusing mainly on JIT, TPM, and VSM. Reference (Bekar et al., 2018) predicted I4.0 impact on TPM just focusing on AR and AM in a real case study. Reference (Mayr et al., 2018) instead exemplified how condition monitoring and Cloud computing contribute to enhancing TPM in electric drives production. Finally, automated psychological assessments with Cloud computing based on the Kanban method have been proposed (Cerna et al., 2020) since the inclusion of Kanban in project management software often seems to be good in the literature.

Discussion and results

In order to answer the initial question "how have I4.0 and LP techniques been integrated in the current literature?", the practical application of LA techniques in the literature through case studies, projects, and real applications has been analyzed. In order to be more effective than a systematic literature review, this paper also provides a comprehensive overview of the current LA literature by using VOSviewer software for cluster analysis finding that: Italy and Germany are the most contributors in studying I4.0 and LP practices correlations, in particular focusing on BDA within I4.0 techniques and VSM within LP practices, although the keywords evolution trend emphasizes the focus on BDA, IoT, and CPS practices. Then, the practical correlation between I4.0 and LP is explored in real case studies and projects. Results are summarized by the identification of the following gaps:

- All integrations have a limited number of scientific references and should be expanded.
- AM with VSM, IoT with Poka Yoke, and BDA with Jidoka mainly focus on ergonomic aspects.
- IoT and Cloud systems with Jidoka, and AR-VR with Poka-Yoke mainly focus on product design and development.
- There are no practical applications of BDA with JIT, and only a few in the TPM area.
- Kaizen and CIM lack practical applications.
- No case studies were found in the integration of AR and Kanban practices.

The results allow the authors to identify the research gaps as possible future research directions for real applications. For instance, the future direction of the authors' work will focus on the development of a framework for the integration of BDA and TPM practices in a real case study. In conclusion, due to the growing importance of I4.0, it might be interesting to study LA within emerging topics and perspectives such as green manufacturing (Vrchota et al., 2020) and Smart factory (Pech et al., 2021).

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