08, 09, 10 e 11 de novembro de 2022
ISSN 2177-3866

Lean concept and industry 4.0: new frontiers of research and trends

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1. Introduction

Since its origins in the 90s, grounded in the pioneering studies at MIT developed by Womack and Jones (1996), the Lean Management Model has been demonstrating its advantages and benefits in guiding the adoption of new technologies, preparing the ground for the implementation of new operations in such a way that works, and information flows are positively impacted and continue in continuous improvement.

It was not a coincidence that, from the 2000s, Silicon Valley innovators, pioneers of the digital world, made contact with the then novelty of lean management principles, studied by companies and universities in the automobile industry, whose applications also expanded in innovations in business models (Gobble, 2018).

Eric Ries, one of the entrepreneurs of that innovation ecosystem in California, coined the expression 'lean startup' in 2011 in his eponymous book, designating a management model for innovative ventures intensive in digital technology, guiding the creation, growth, and scalability phases amid an environment of significant uncertainties (Ries, 2011). The agile practices that emerged from this new technological scenario, such as Kanban, Scrum, DevOps, User Experience, and Customer Development, to name a few, were also developments based on lean management principles, systematized and expanded from the Toyota Production System developed throughout the twentieth century (Belling, 2020; Sutherland, 2014; Sutherland, Viktorov, Blount, & Puntikov, 2007).

This is not an atypical or unexpected move, considering that companies had to develop the ability to produce customized products and services and be dynamic in a competitive business environment. In this sense, Lean Management principles are the 'best fit', since its cornerstone is to reduce waste in the value chain and, by doing so, reduce total lead time in delivering solutions (Ejsmont, Gladysz, Donatella, Castaño, & Mohammed, 2020).

Moreover, a brief and general view of Lean's development throughout the years suggests that the infamous Lean Model had been responsible for spreading and adapting the Toyota Production System to several industries and businesses worldwide (Belling, 2020; Gobble, 2018). Since the creation of the Lean Model, three decades have passed, and the concept has evolved: Lean Management, Lean Design, Lean Process and Product Development (LPPD), Lean Digital, and Lean Startup are derivations and adaptations of the original concept.

Although research on the topics mentioned above reached saturation, a new wave of practices and research in academia has started associating Lean concepts with Industry 4.0 (Ejsmont et al., 2020). Thus, this research explores the opportunities of combining the renowned Lean concept with the emerging Industry 4.0 practices. Through a Systematic Literature Review (SLR), the study brings the origins of Lean and Industry 4.0 concepts suggesting that the Lean Model plays a double role in its adoption: on the one hand, as a guide in the choice of the implementation trajectory and, on the other hand, as qualifying and enabling prerequisite for the absorption of integrated technological packages.

Based on the above, the research question of this exploratory study will be: *how can Lean Model and the Industry 4.0 concepts' can be combined?*. Replying to this question will start a discussion on how the Lean concept can positively contribute to the Industry 4.0 trend, following the past successful cases of Lean Startup, LPPD, Lean Digital, and other derivations (or combinations) of Lean and management trends.

2. Theoretical background

2.1 Lean and lean startup

The evolution of production systems is linked to the history of the Toyota Motor Company (TMC), which has its roots in 1918 when Sakichi Toyoda revolutionized the weaving industry. The successful case in the waving industry was replicated in Toyota's automotive industry. As a result, the company reinvented itself by establishing the Toyota Production System (TPS) later by 1960 (Holweg, 2007).

Though academia and adopters of the Lean concept credit the term to Womack et al. (1990), in the best-selling book entitled *The Machine That Changed The World*, the term was coined by Krafick (1988) to describe the Toyota Production System. Anyhow, the most straightforward definition of *Lean* can be extracted from Womack et al. (1990, p.13) in terms of its outcomes:

> *(...) compared to mass production, it uses less of everything – half the human effort in the factory, half the manufacturing space, half the investment in tools, and half the engineering hours to develop a new product in half the time.*

Since then, Lean has evolved to be one of the best-known methodologies, which still attracts much attention from researchers and practitioners. Additionally, the Lean concept has been constantly adopted by various industries and adapted by several fields of knowledge (Belling, 2020; Gobble, 2018). As a derivation of the Lean concept, Lean startup is defined by its pioneering practitioner and disseminator Eric Ries as *a new approach to creating continuous innovation*. (Ries, 2012, p.4), and he adds further in his pioneering text that the lean startup is *the application of lean thinking to the innovation process* (Ries, 2012, p.5)

Edison et al. (2017) propose a simplified step-by-step framework for applying the lean startup approach. According to the author, the process' first step involves establishing the entrepreneur's vision and the definition of the hypotheses to be tested. Subsequently, experiments are created to test the hypotheses raised with real consumers and measure the results obtained. The next step is to learn, that is, to verify if the hypotheses were validated or rejected. Suppose the hypotheses are all validated and gradual development proceeds. If the hypotheses have been rejected, the startup must pivot or abandon adjusting its strategy or give up on that initial idea (Edison et al., 2017). The Lean concept has been permeating various knowledge fields, including Industry 4.0 (Ejsmont et al., 2020).

2.2 Industry 4.0

From a technological evolution perspective, it is considered that there are four stages commonly identified (Kagermann, Wahlster, & Helbig, 2013). The first, by the end of the 18th century, was marked by the introduction of water, steam-powered machinery, and facilities; the second, dating back to the early 19th century, contextualized by the introduction of an electrically-powered mass production process; and the third, during the 1960s and 1970s, marked by the introduction of IT to support the automation of the processes (Drath & Horch, 2014). Finally, the fourth stage, Industry 4.0, was first referenced in 2011 (Kagermann et al., 2013).

The fourth industrial revolution is characterized by technological transformations, artificial intelligence, and the digital revolution, which gives long-term efficiency and production (Wang, Luo, Sari, & Shao, 2020). Moreover, it is a real business transformation aiming to meet customers' requirements, optimize decision-making and create new value opportunities by combining performance management systems with business performance (Raffoni, Visani, Bartolini, & Silvi, 2018). Almada-Lobo (2015, p.17), in turn, describes Industry 4.0 as a striking and fascinating combination of the virtual and physical worlds (CPS - Cyber-Physical Sytems), the Internet of Things (IoT), and the Internet of Services (IoS) which allows companies to anticipate trends and, therefore, take specific actions before it happens.

The recent hype surrounding Industry 4.0 can be explained by its disruptive force and capability for: i) designing, adapting, and marketing product-service systems (Coreynen, Matthyssens, De Rijck, & Dewit, 2018; Matthyssens, 2019); ii) blending digital strategy and processes with value offerings (Hasselblatt, Huikkola, Kohtamäki, & Nickell, 2018; Matthyssens, 2019); iii) combining and integrating technological and value innovation approaches (Ringberg, Reihlen, & Rydén, 2019; Matthyssens, 2019); iv) linking value creation to value capturing (Perks, Kowalkowsky, Witell, & Gustafsson, 2017; Matthyssens, 2019). Furthermore, these forces motivated the increasing academic publications since 2015, as disclosed in the following sections (Matthyssens, 2019).

2.3 Lean and Industry 4.0

In Industry 4.0, the convergence of technologies such as autonomous robots, big data, augmented reality, cloud computing, IoT, and many others that may be incorporated shortly, aim to achieve a high degree of integration with full and broad physical and virtual connection, without departmental boundaries and organizational barriers (Porter & Heppelmann, 2014; Porter & Heppelmann, 2015).

Factories are connected with logistics, markets, and people, several agents in a network, allowing a value chain in which the processed information generates knowledge and coordinates, almost instantly, the productive resources, directing their capacity to the demand, creating value through a structure of intelligent machines and processes. (Porter & Heppelmann, 2014; Porter & Heppelmann, 2015).

Machines and facilities digitally integrated into the cloud allow for high synchrony throughout the chain, given the articulation of the production flow with the fulfillment of demand and making us see the bullwhip effect as a phenomenon to be forgotten. An accurate fulfillment in the entire supply chain becomes an objective made possible by Industry 4.0, thus realizing the vision of the Lean Model of horizontal management throughout its entire value stream, from marketing, sales, and supply to production and delivery, not talk about all the stages and associated services throughout the after-sales and post-consumer life, without borders between companies and departments. (Almada-Lobo, 2015; Porter & Heppelmann, 2014; Porter & Heppelmann, 2015).

This perspective of total integration of the new technological base of Industry 4.0 is present in the concept of building Physical-Cybernetic Systems (CPS), defined as the tool for joining the physical and digital domains through computer networks that monitor and control physical processes and involve control loops where physical systems change digital systems and vice versa. A constant supply and feedback in short cycles and for all flows (Almada-Lobo, 2015).

On the other hand, although the strength of such concepts has allowed the direction of technological development towards several integrative tools (Raffoni et al., 2018), in organizational reality, what Lean designates as *Gemba* (from the Japanese concept = real place where real things happen), the concepts and the different alternatives end up being covered with a high degree of uncertainties and ambiguities (Prinz, Kreggenfeld, & Kuhlenkotter, 2018).

It causes ambiguity because it generates a profusion of imagination in the management body and provokes crucial and procrastinating doubts about where to start the transformation and the direction of change. However, at this point, if we understand that Industry 4.0 leads to the materialization of the lean ideal, with a value stream fully articulated and synchronized with demand, consequently the lean management model also starts to work as a guide and orientation for the introduction and transformation of the Industry 4.0 in every organizational reality and its supply chain (Prinz et al., 2018).

These propositions demand research concerning the relationship of both approaches: if Lean Management and Industry 4.0 can be combined and to which extent the combination can raise a company's results or if one approach is a prerequisite for the other (Prinz et al., 2018).

3. Methodology

Literature review works represent 'critical evaluations of already published research and seek to identify and synthesize relevant scientific production on a topic to evaluate a specific research question, a domain of knowledge, theoretical approach, or methodology and, in this way, provide to the academic community an understanding of state of the art concerning a topic (Palmatier, Houston, & Hulland, 2018; Torraco, 2005).

Furthermore, the contributions involve clarifying ambiguities about theoretical definitions, providing an integrated and synthetic view of state of the art in a field of knowledge. Also, identifying inconsistencies in the results of previous works and their causes, evaluating existing methodological approaches, developing conceptual frameworks to reconcile and/or extend past research and describe insights, and identifying gaps and opportunities for future work on predecessor research (Palmatier et al., 2018, p.2). The development of the present research is based on the proposals of Snyder (2019), Tranfield et al. (2003), and Wong et al. (2013), which organize the key questions for each of the stages of conducting the systematic literature review, as shown in Table 1 below:

Table 1 - stages to conduct a systematic literature review. Source: adapted from Snyder (2019), Tranfield et al. (2003), and Wong et al. (2013)

Step	Key questions
Step 1: Define the objective and scope of the systematic literature review (SLR)	• What are the objectives and scope of the study? • Is the scope of the study broad enough to justify the use of SLR analysis?
Step 2: Choice of techniques for SLR	• Which techniques should be selected to meet the objectives and scope of the study?

Step 3: Collect data for analysis	• Do the search arguments adequately represent the scope of the study? • Is the database coverage adequate? • Does the dataset meet the requirements of the chosen techniques?
Step 4: Operationalize the SLR analysis and report the results	• Can the SLR abstract be easily understood by readers? • Is the writing in line with the SLR abstract presented? • Does the writing explain the peculiarities and implications of the SLR summary?

3.1 Defining the objective and scope of the bibliometric study

As described in the introduction session, the research regarding Lean Management reached saturation; however, a new trend regarding combining the concepts of Lean Management and Industry 4.0 is a new world to be explored. Conclusions and contributions are still unexplored, raising the question if both concepts can be combined, if Lean Model can guide the adoption of Industry 4.0 or if it is a prerequisite for the absorption of integrated technological packages (Belling, 2020; Gobble, 2018). The objectives and scope of the research comprise shedding some light on these questions. Therefore, considering the subject's novelty and broadness, the use of SLR can be justified (Donthu et al., 2021; Snyder, 2019; Tranfield et al., 2003; and Wong et al., 2013).

3.2 Choice of techniques for SLR

A systematic review of the hybrid literature will be adopted, which in the classification of Paul and Criado (2020, p.2) occurs when there is the integration of different approaches, as in the present case, the combination of bibliometric analysis (bibliometric analysis) and the review that aims to develop a theory. While the first seeks to understand the pattern, history, frequency, and concentration of publications in the main databases (Donthu et al., 2021; Paul & Criado, 2020), the second will provide subsidies for the proposal of constructs and the framework (Paul & Criado, 2020).

Furthermore, the bibliometric analysis aims to review an extensive amount of published research using statistical tools and, in this way, suggest trends, citations, and co-citations on a particular topic, year of publication, research location, method, theory, domains, and research problems (Paul & Criado, 2020). Literature reviews that include bibliometric analysis have gained popularity in research in the area of applied social sciences, mainly due to the increasing availability of technological tools such as VOSviewer® and the ease provided by databases such as Scopus and Web Science (Donthu et al., 2021). Two techniques represent bibliometric analysis, namely, i) performance analysis and ii) scientific mapping (science mapping). Both categories are composed of techniques, as systematized in Figure 1.

This study will use performance analysis, scientific mapping techniques, and clustering and visualization improvement techniques through the VOSviewer® software.

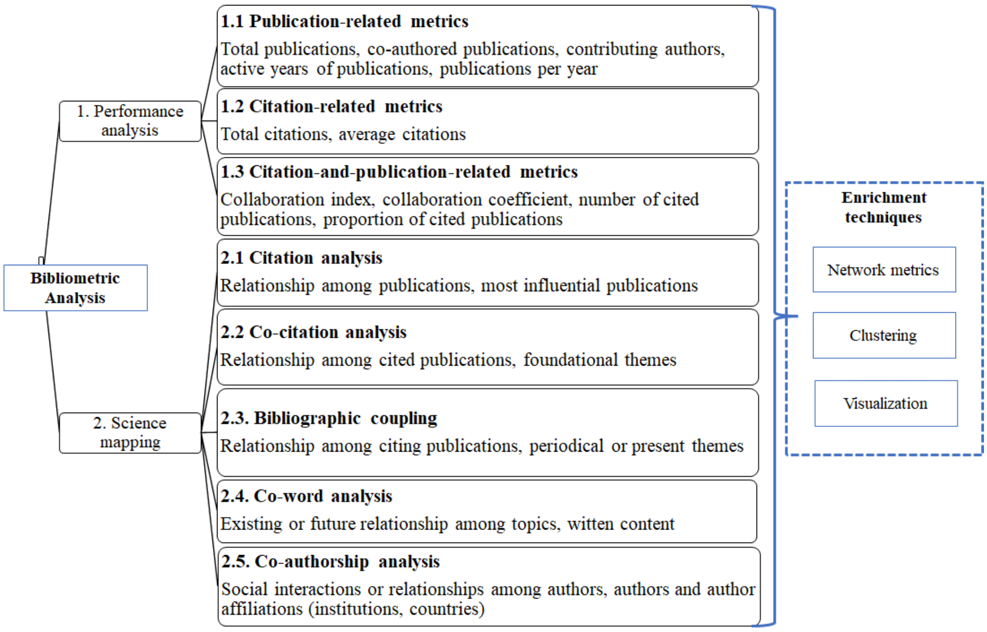


Figure 1 - categories and techniques of bibliometric analysis. Adapted from Donthu et al. (2021)

3.3 Collect data for analysis

For this exploratory research, the data was gathered from the Web of Science (WoS) database, the most commonly used scholarly citation (Strozzi, Colicchia, Creazza, & Noè, 2017), along with Scopus. While the first brings more explicit data results, the latter, despite the larger dataset, brings papers that are not uniquely identified, which may lead to a wrong analysis of the citation network (Strozzi et al. 2017, p.6573).

The selection of keywords in the searching query considered the terms' Lean' and 'Industry 4.0' and their variations: *("Lean" OR "Toyota") AND ("industry 4.0" OR "industrie 4.0" OR "I4.0" OR "I 4.0" OR "I4" OR "fourth revolution" OR "4th revolution")*. From 'Lean' concept 'side', the selection comprises just two terms ('Lean' or 'Toyota'), aiming to make the result as broad as possible. On the other hand, the 'Industry 4.0' side considered the semantic and orthographic variation because, during the conduction of the theoretical background, it was realized that there is still no standardization of the term in academia. Therefore, the original term 'industry 4.0' and its variants were extracted from the full description of the concept in Kagermann et al. (2013). Moreover, only conference papers published articles, and early access papers were considered to refine the search.

3.4 Operationalize the SLR analysis and report the results

From the search query above, 476 documents matched the criteria of relevance and language (published in English). Therefore, the following step comprised a screening process based on abstract and keyword checking to suppress irrelevant articles, resulting on 239 documents. Next, those documents were submitted to a new round of content analysis, floating reading, and full-text content analysis, resulting in a selection of 167 documents. In this sense, the content analysis was conducted individually for each of the works identified after step 2 in a sample of papers not exceeding the so-called low hundreds (100-300) defined by Donthu et al. (2021) and Snyder (2019). Finally, the selected documents had their content analyzed through floating reading and staged review, supported by detailed content analysis. The formation of the *corpus* is schematized in Figure 2 below.

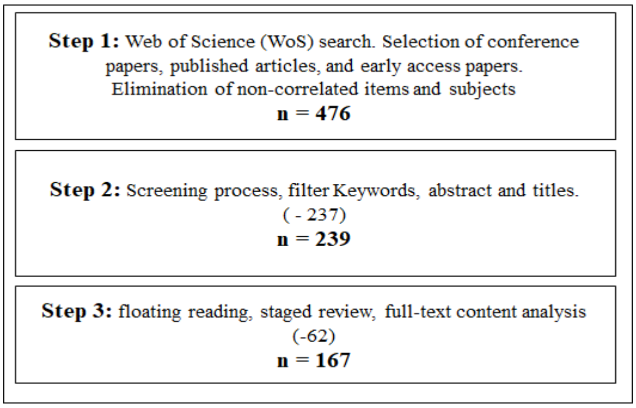


Figure 2 - formation of corpus for the research

As mentioned elsewhere, the study will adopt the techniques of performance analysis and scientific mapping, improved by clustering and visualization techniques through the VOSviewer® application, and its conduction will be guided by the four steps suggested by Donthu et al. (2021), as shown in Table 1. Initially, the results regarding the performance analysis will be presented, focusing on i) publication metrics (total publications per year) and ii) citation metrics (total citations and average citations per year).

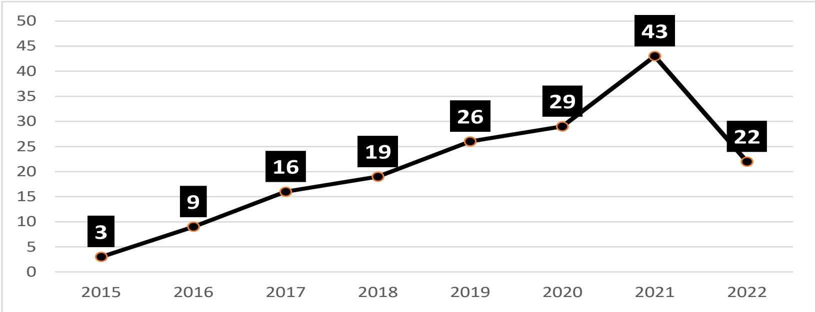
It will be followed by the presentation of the results of the scientific mapping, explicitly addressing: i) citation analysis (correlation between publications, influential publications); ii) co-citation analysis (relationship between cited publications, foundational themes); iii) bibliographic coupling (existing or potential relationships between topics, periodic, recurrent and present themes); and iv) analysis of correlated terms (existing or potential relationships between terms, words, and expressions). Finally, results will be enhanced by network analysis, clustering, and visualization supported by VOSviewer® software, version 1.6.17. This approach is in line with the categories and techniques of bibliometric analysis by Donthu et al. (2021) and presented in the diagram in Figure 1 of this methodological section.

4. Results

The presentation of the results will follow the structure (Figure 1) adapted from Donthu et al. (2021). Therefore, after the presentation of the performance analysis metrics, the science mapping comprising citation analysis, co-citation analysis, bibliographic coupling, and co-word analysis will be presented based on clustering visualization. The presentation of the results will follow the structure (Figure 1) adapted from Donthu et al. (2021). Therefore, after the presentation of the performance analysis metrics, the science mapping comprising citation analysis/co-citation analysis, bibliographic coupling, and co-word analysis will be presented based on clustering visualization.

4.1 Bibliometric analysis: performance analysis

The 167 articles in the sample are distributed in 99 publications from 2015 to 2022. Graph 1 shows the distribution of publications from 2015 to 2022 (2022, as of July).



Graph 1 - publications per year

The distribution of the publications corroborates the trend stated by Kagermann et al. (2013) and Matthyssens (2019): sparse research was published after 2011 when the term 'Industry 4.0' was first mentioned, and increasing academic publications since 2015. Thus, considering that the search string combined the terms' Lean' and 'Industry 4.0' (and their variations) above distribution suggests that publications studying the combination of these terms are still a novelty, as suggested by Ejsmont et al. (2020).

Concerning the publications per source and year, Table 2 shows that publications are pulverized among sources. The *International Journal of Production Research* concentrates the highest number of publications (eight in total), representing 4.79% of the total. On the other hand, conference papers and other journals with just one publication represent 47.90% (respectively 23.25% and 24.55%) of total publications in the period. Tables 3 and 4 respectively show the most cited and most cited papers per year. Those publications will be further detailed in the *Bibliometric analysis: science mapping* section when the cluster formation will be explored.

Table 2 - publications per source and year

Source Title	2015	2016	2017	2018	2019	2020	2021	2022	Total Geral	%
INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH			1	3		3	1		8	4,79%
PRODUCTION PLANNING & CONTROL						2	4	1	7	4,19%
IFAC PAPERSONLINE	1				4		1		6	3,59%
SUSTAINABILITY					1	1	4		6	3,59%
3RD INTERNATIONAL CONFERENCE ON INDUSTRY 4.0 AND SMART MANUFACTURING								5	5	2,99%
JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT						1	3	1	5	2,99%
8TH CIRP SPONSORED CONFERENCE ON LEARNING FACTORIES (CLF 2018) - ADVANCED ENGINEERING EDUCATION & TRAINING FOR MANUFACTURING INNOVATION				4					4	2,40%
ADVANCES IN PRODUCTION MANAGEMENT SYSTEMS: ARTIFICIAL INTELLIGENCE FOR SUSTAINABLE AND RESILIENT PRODUCTION SYSTEMS, APMS 2021, PT IV							3		3	1,80%
ADVANCES IN PRODUCTION MANAGEMENT SYSTEMS: TOWARDS SMART AND DIGITAL MANUFACTURING, PT II						3			3	1,80%
APPLIED SCIENCES-BASEL							2	1	3	1,80%
INTERNATIONAL JOURNAL OF INTERACTIVE DESIGN AND MANUFACTURING - IJIDEM								3	3	1,80%
Conference papers	2	7	12	8	11	8	5	2	55	32,93%
Other Journals	0	2	3	4	10	11	20	9	59	35,33%
Total Geral	3	9	16	19	26	29	43	22	167	100,00%

Table 3 - Most cited publications (top 10)

Author Full Names	Year	Source Title	Times Cited, All Databases
Kolberg, Dennis; Zuehlke, Detlef	2015	IFAC PAPERSONLINE	254

Buer, Sven-Vegard; Strandhagen, Jan Ola; Chan, Felix T. S.	2018	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	253
Tortorella, Guilherme Luz; Fettermann, Diego	2018	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	249
Yin, Yong; Stecke, Kathryn E.; Li, Dongni	2018	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	245
Mrugalska, Beata; Wyrwicka, Magdalena K.	2017	7TH INTERNATIONAL CONFERENCE ON ENGINEERING, PROJECT, AND PRODUCTION MANAGEMENT	179
Wagner, Tobias; Herrmann, Christoph; Thiede, Sebastian	2017	MANUFACTURING SYSTEMS 4.0	136
Kolberg, Dennis; Knobloch, Joshua; Zuehlke, Detlef	2017	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	107
Ghobakhloo, Morteza; Fathi, Masood	2020	JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	103
Sony, Michael	2018	PRODUCTION AND MANUFACTURING RESEARCH-AN OPEN ACCESS JOURNAL	102
Tortorella, Guilherme Luz; Giglio, Ricardo; van Dun, Desiree H.	2019	INTERNATIONAL JOURNAL OF OPERATIONS & PRODUCTION MANAGEMENT	85

Table 4 - Most cited publications, average per year (top 10)

Author Full Names	Year	Source Title	Avg. Citation per year
Buer, Sven-Vegard; Strandhagen, Jan Ola; Chan, Felix T. S.	2018	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	63,25
Tortorella, Guilherme Luz; Fettermann, Diego	2018	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	62,25
Yin, Yong; Stecke, Kathryn E.; Li, Dongni	2018	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	61,25
Ghobakhloo, Morteza; Fathi, Masood	2020	JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	51,50
Kolberg, Dennis; Zuehlke, Detlef	2015	IFAC PAPERSONLINE	36,29
Mrugalska, Beata; Wyrwicka, Magdalena K.	2017	7TH INTERNATIONAL CONFERENCE ON ENGINEERING, PROJECT, AND PRODUCTION MANAGEMENT	35,80
Kamble, Sachin; Gunasekaran, Angappa; Dhone, Ncelkanth C.	2020	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	33,00
Chiarini, Andrea; Belvedere, Valeria; Grando, Alberto	2020	PRODUCTION PLANNING & CONTROL	32,50
Ciano, Maria Pia; Dallasega, Patrick; Orzes, Guido; Rossi, Tommaso	2021	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	29,00
Tortorella, Guilherme Luz; Giglio, Ricardo; van Dun, Desiree H.	2019	INTERNATIONAL JOURNAL OF OPERATIONS & PRODUCTION MANAGEMENT	28,33

4.2 Bibliometric analysis: science mapping

Science mapping will examine the relationships between research constituents, disclosing their intellectual interactions and structural connections. Thus, the following subsections explore the citation and co-citation analysis, bibliographic coupling, and co-wording analysis, as defined by Donthu et al. (2021).

4.2.1 Citation and co-citation analysis

The analysis of citation and co-citations suggests the thematic similarity of cited publications that are cited together, often revealing the intellectual structure of a field of knowledge (Hjørland, 2013; Rossetto, Bernardes, Borini, & Gattaz, 2018). In this approach, publications are connected when there is a co-occurrence of these in another publication, suitable for identifying seminal works or foundations of a field of knowledge (Donthu, et al., 2021; Hjørland, 2013). First, the corpus was loaded into the VOSviewer® application. Then the options *Create a map based on bibliographic data -> Read data from bibliographic database files -> [Co-Citation + Cited referents] -> Minumum no of citations = 10* were selected, resulting in three clusters, as shown in Figure 3.

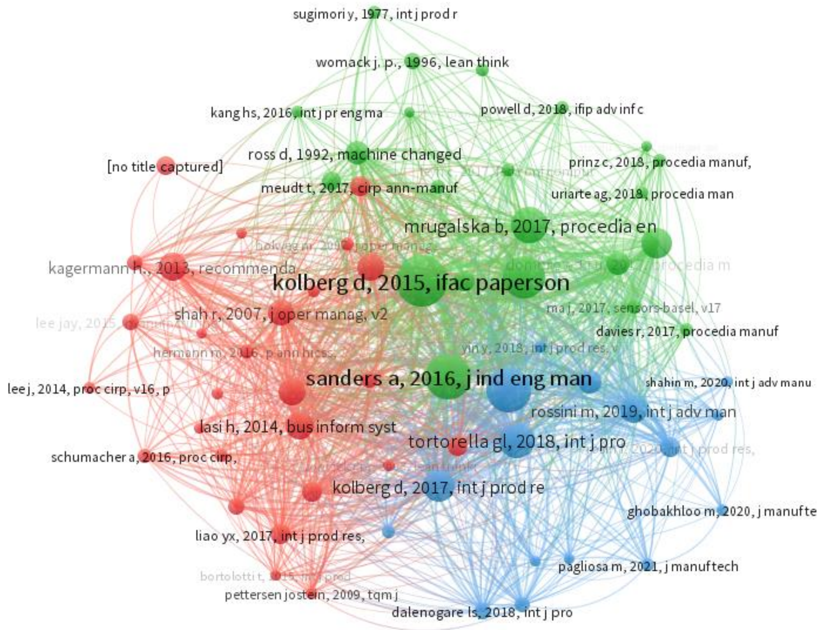


Figure 3 – citation and co-citation analysis clustering

From the resulted clustering in co-citation analysis, it is possible to note the importance of Kolberg and Zuehlke (2015) research entitled 'Lean Automation enabled by Industry 4.0 Technologies' serving as a link for the seminal (and fundamental) works of Ohno (1988), Sugimori et al. (1977), and Womack et al. (1990). Furthermore, the position paper from Kolber and Zuehlke (2015) gives an overview of existing combinations of Lean Production and automation technology, linking Industry 4.0 to the well-proven Lean approach. Finally, inspired by those authors, further studies from Buer et al. (2018) and Tortorella and Fettermann (2018), which are central in one of the clusters identified, attempted to present a positive association between Industry 4.0 technologies and lean concepts, suggesting their concurrent implementation leads to more significant performance improvements in organizations.

4.2.2 Bibliographic coupling

Bibliographic coupling supports the idea that two publications sharing references are also similar in content (Weinberg, 1974). It is nothing more than a similarity matrix between articles that measures how much each text shares with other bibliographic references. Therefore, the greater the degree of sharing, the greater the weight of the relationships between texts (and vice versa) (Botelho et al., 2019, p. 728; Donthu, et al., 2021). To analyze the bibliographic coupling, the database was loaded into the VOSviewer® application, and the option *ii) Create a map based on bibliographic data -> Read data from bibliographic* *database files -> [Bibliographic Coupling + Documents] -> Minumum no of citations = 10*, resulting in five clusters as shown in Figure 4.

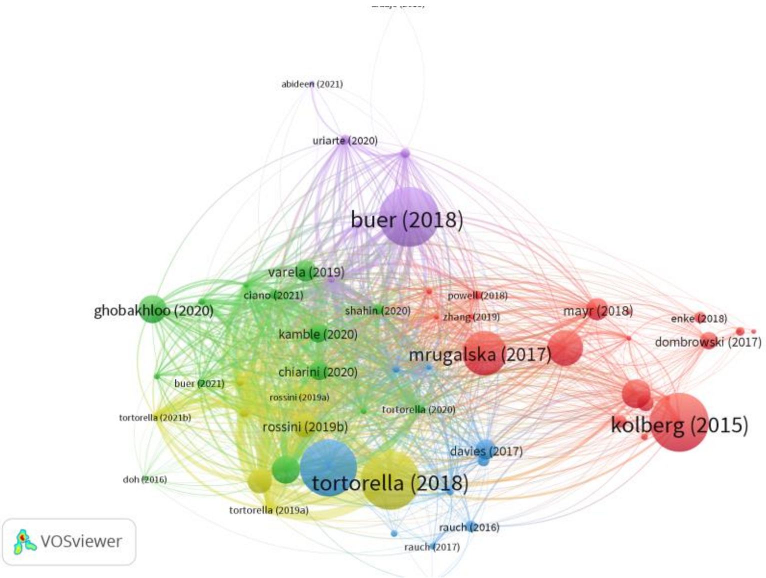


Figure 4 - bibliographic coupling clustering

Results of the bibliographic coupling showed a cluster centered on the work of Buer et al. (2018), which advocates that Industry 4.0 and lean manufacturing similarities lie in decentralized control and flexibility to pursue productivity improvements. On the other hand, authors like Kolberg and Zuhlke (2018) and Mrugalska and Wyrwicka (2017) base the discussion on the importance of lean principles to avoid waste during the implementation of Industry 4.0 through the entire value chain appraisal. Finally, the cluster centered on the works of Ghobakhloo and Fathi (2020) and Yin, Stecke, & Li (2018), brings the benefits of combining Lean and Industry 4.0 concepts from a practical and applied perspective lied on case studies. On the other hand, Tortorella and Fettermann (2019) lead a more conservative stance, stressing that the positive correlation between Lean and Industry 4.0 can be obtained when the first is properly incorporated by the latter.

4.2.3 Co-word analysis

The analysis of correlated terms (co-word analysis) was used to explore existing or potential relationships between topics in a field of knowledge, focusing on the relationships in the content of the analyzed publications (Emich et al., 2020). Unlike the analysis discussed in the previous subsections that focus on the 'publications' cited, this analysis has the 'terms' as its unit, examining the actual content of the publication itself (Donthu et al., 2021). To analyze the bibliographic coupling with a focus on titles and abstracts, the database was loaded into the VOSviewer® application, and the option *Create a map based on text data -> Read data from bibliographic database files ->Title and abstract fields -> binary counting -> choose threshold = 10,* resulting in 4 clusters, as shown in Figure 5.

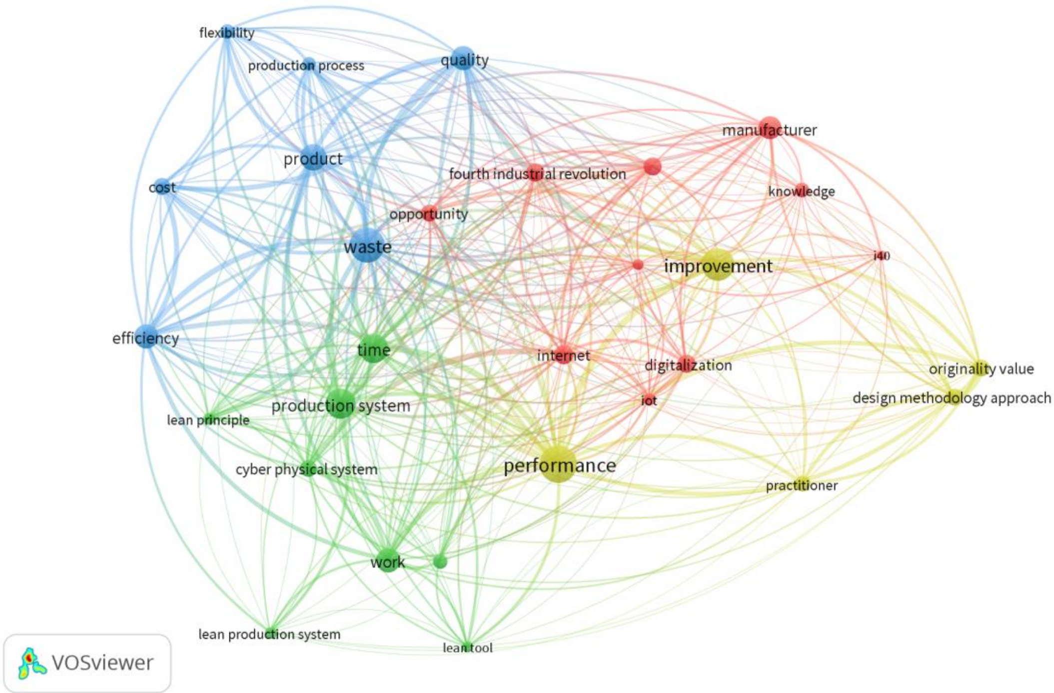


Figure 5 - co-word analysis clustering

Results show possible segregation between the conceptual and practical aspects of Lean and Industry 4.0 combination. While the cluster formed by terms like 'waste', 'product', 'productions process', 'quality' and 'flexibility', lie on the principles of the Lean concept, 'digitalization', 'internet', 'manufacturing' and 'iot' are application-centered. The cluster formed by 'lean principle', 'lean production system', and 'production system' appears to be a tentative integration between the practical and theoretical perspectives of the theme. Finally, the 'design methodology approach', 'practitioner', 'improvement', and 'performance' cluster tends to focus on the contributions of Lean and Industry 4.0 combination from a macro, organizational perspective.

5. Discussions and final considerations

This exploratory study investigated if the Lean Model and the Industry 4.0 concepts could be combined. By doing so, start a discussion on how the Lean concept can positively contribute to the Industry 4.0 trend, following the past successful cases of Lean Startup, LPPD, Lean Digital, and other derivations (or combinations) of Lean and management trends.

Although authors like Dombrowski, Richter, and Krenkel (2017) and Prinz et al. (2018) propose two main perspectives of the Lean concept and Industry 4.0, Lean as a prerequisite for Industry 4.0 or vice-versa, results of the SLR suggest that a third trend should be considered. Instead of considering Lean and Industry 4.0 as sequential introduction processes, practitioners should consider an iterative relationship. This conclusion can also be found in the works of Meudt, Metternich, and Abele (2017), Mrugalska and Wyrwicka (2017), Sanders et al. (2017), and Satoglu et al. (2018).

From a theoretical perspective, the present study contributes to shedding light on an underexplored theme that has gained more prominence since 2015. Emerging topics and trends like the 'iterative interactions of Lean and Industry 4.0 concepts must be addressed further. Also, from the systematic literature review perspective, this research adds knowledge to existing SLR like the works of Bittencourt, Alves, & Leao (2019), Buer et al. (2018), Ejsmont et al. (2020) and Pereira, Dinis-Carvalho, & Alves (2019), bringing new publications and insights to the emerging and promising *corpus* of the subject.

Limitations of the research consist of: i) the adopted database – despite the reliability of Web of Science, it represents a fraction of the scientific publications; ii) the correlation based on terms, keywords, titles, and abstracts could not represent the full content of the publication, may resulting in biases in the conclusions. Finally, suggestions for further studies involve the refinement of SLR procedures, the addition of publication *corpus* from distinct sources, as well as opening the path to qualitative and/or qualitative-quantitative studies to develop and correlate constructs regarding Lean concepts and Industry 4.0.

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