Toward the integration of Lean Six Sigma and Industry 4.0: Current trends and future perspectives-Descriptive Bibliometric Analysis

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Abstract

This paper aims to identify and analyze the existing literature regarding the combination of Lean six sigma 'LSS' and Industry 4.0 'I4.0'. Based on a descriptive bibliometric analysis, the literature on the Scopus database was scanned from 2011 to September 2021. The authors identified and analyzed the most relevant articles to explore trends in the research field and to identify potential gaps, concerns, and perspectives for future research. The fourth industrial revolution, known as Industry 4.0, represents a new phase for manufacturing industries. The technological advances offered by industry 4.0 provide a real-time data connection, which leads to greater availability and accessibility of data. LSS is one of the most widely used operation management concept for optimizing production processes in manufacturing. The connection between the two concepts LSS and I4.0 marks the beginning of a new era for digital Lean Six Sigma and process optimization. The analysis shows that few research studies have been conducted on LSS and I4.0 integration; no studies have examined readiness assessments and framework for the integration of LSS and I4.0. The result confirms that I4 is growing fast as a research field, which covers a variety of disciplines and research areas. The study is useful for both academics and professionals because it outlines the major lines of research in the field.

Keywords
Industry 4.0, Lean manufacturing, Lean Six Sigma, Literature review.

1. Introduction

Since the industrial revolution, manufacturing organizations have been developing better business models and strategies to enhance what it has traditionally been considered their primary objectives of increasing economic profit and resources throughput(Garza-Reyes et al. 2019). Thus, the avenue of Industry 4.0 advanced technologies has changed the operations management in manufacturing industries around the world. Industry 4.0 technologies have generated a major impact on manufacturing and subsequently increased competitive pressure. For this reason, continuous improvement methodologies such as Lean, Six Sigma and Lean Six Sigma have become useful and must be improved by following the new I4 technologies.

Over the past five years, Industry 4.0 has been classified in several studies as a successful new strategic paradigm for improving metrics such as cost, productivity, quality, customer satisfaction, energy and lead time (Buer et al.2021; Chiarini and Kumar 2020; Deuse et al. 2020; Kolberg and Zuehlke 2015; Lu 2017; Luz Tortorella et al.2021; Santos and Martins 2020).

Over the past three decades, Lean and Six Sigma have helped manufacturing industries to achieve operational excellence, efficiency and improved customer satisfaction. LSS is a popular and widely applied methodology adopted by many organizations for process improvement (Shah et al. 2008). Cherrafi et al. (2017) defines Lean Six Sigma as an integrated strategy, which reflects a combination and synergy between two powerful continuous improvement approaches, viz. Lean and Six Sigma In recent years the Lean and Six Sigma methodologies are applied and studied as one (Shah et al. 2008).Several authors classified LSS as one of the best models leading to the Operational Excellence (Chiarini 2011; Salah et al. 2010; Jaeger et al. 2014). Contrary to lean production, digital technologies and their growing role within operations practices are a nascent phenomenon (Schniederjans et al. 2020).

The main goal of both LSS and I4.0 is to improve the compitiveness of the manufacturing but in different ways and using different tools and principals. The potential integration of Lean Six Sigma and Industry 4.0 has received much attention for both academics and practitioners over the past few years. Few authors(Anass et al. 2021; Cifone et al. 2021; Deuse et al. 2020; Ejsmont et al. 2020; Ejsmont and Gładysz 2020; Gallo et al. 2021; Tortorella et al. 2020, n.d.; Yadav et al. 2021) have contributed to the research and development of this field.The motivation for addressing this topic is that relatively little research has been conducted around the relationship between LSS and Industry 4.0.

The purpose of this article is to review what has already been discussed in the literature on the concept of "Lean Six Sigma Industry 4.0". To address the objective of this research, we conducted a literature review of LSS and I4 paradigms published over the past ten years (2011-2021).The research objectives are classified as follows (1) to present the state of the art in the field of I4 and LSS and (2) to indicate the future research directions in this field.
A number of studies indicate that research investigating the impact of I4.0 technologies on LSS implementation is currently limited, and empirical evidence on the combination between them is still scarce (e.g., Tortorella and Fettermann, 2018; Ciano et al. 2021; Pagliosa et al. 2021). Considering this gap, the following research question arises: What are the present trends in the association of lean six sigma and industry 4.0 paradigms?

To address this question, we performed a bibliometric analysis. The paper is structured as follows. Section 2 establishes the background on the main concepts related to our study, i.e. the Industry 4.0 and Lean Six Sigma as well as the relationship between the two concepts. Section 3 describes the proposed research method and results are shown in Section 4. Then, we present our analysis and discussion in Section 5. The paper ends with the conclusions which highlight the implications of the study, limitations and future research directions.

2. Theoretical background

In this section, we briefly review the established concepts and practices of Lean Six Sigma, and Industry 4.0. Then, we summarize the relationship between these two concepts according to the literature.

2.1 Lean Six Sigma

The concept of LSS was used for the first time by (George 2002) in the book "Lean Six Sigma: Combining Six Sigma with Lean Speed». It's an initiative to integrate the "Lean" manufacturing approach, whose origin refers to the Toyota Production System (TPS) and was later adopted by North American companies (Womack et al. 1990), with the "Six Sigma" methodology, which included several quality management techniques.

The Lean Six Sigma (LSS) approach can be defined as a strategy or methodology capable increasing the performance of a process, resulting in increased customer satisfaction and financial results for an organization (Snee 2010).When the VSM identifies a quality issue in a process step, Six Sigma provides a methodology for data driven analysis to define and quantify the types of errors. Statistical analysis is used to identify root causes and implement process improvements that reduce the errors.(Sodhi 2020).

Lean Six Sigma has been widely applied with great success in manufacturing industries to improve operational performance. Its application was focused in manufacturing environments for many years. However, LSS is being increasingly discussed and implemented in different sectors like healthcare (Chiarini and Cherrafi n.d , Laureani et al.2013), construction (Van den Bos et al. 2014) and, education (Thomas et al. 2015b). Furthermore, Lean Six Sigma was also discussed and combined with many concepts such as sustainability, green, and even agility and

resilience. (Belhadi et al.2020; Cherrafi et al.2016; Duarte et al.2020; Leong et al. 2020; Titmarsh et al.2020; Touriki et al.2021).

2.2 Industry 4.0 : Definition, Technologies

Industry 4.0 was recognized as the 'Fourth Industrial Revolution (4IR)' by the World Economic Forum (Schwab 2016). Industry 4.0 is a continuation of the previous industrial revolutions as shown in Fig2 An Industrial Revolution may be defined as a turning point in which there was a significant transition to new manufacturing processes supported by advances in science and technology, shifting their methods, organization and resources (Belvedere et al.2013).Industry 1.0 refers to the mechanization of manufacturing systems using water and stream power. The First Industrial revolution is defined as one of the most important advancements in humanity, starting in 1760 (Liao et al. 2018), then came Industry 2.0. The second industrial revolution began in late 19th century and was characterized by mass production through the utilization of electric energy (Rojko 2017). While the introduction of automation and information technology has launched Industry 3.0. The Third Industrial Revolution began.in the late 1960s and was characterized by the automation of production processes and utilization of computers to support manufacturing management (Yin et al.2018).

Industry 4.0 is one of the most discussed topics by experts and academics in recent years; however no definition of the term I4.0 has been clearly stated. It is recognized as the convergence of several different technologies (Raj et al.2020). In view of its novelty, there is neither a world-wide accepted definition of it nor a proper classification of technologies under its umbrella (Culot et al.2020).

From a business perspective, I4.has been claimed as an approach for significantly improving performance through automation and digitalization(Luz Tortorella et al. 2021). This performance improvement is enabled by higher levels of interconnectivity among people, products, processes, services and equipment, big data analytics, as well as both horizontal and vertical integration of value chains (Ghobakhloo 2018; Fatorachian and Kazemi 2018).

The concept of Industry 4.0 is gaining interest among researchers, focusing on the increase in operational capabilities (Bai et al. 2020). The goal of the initiative is transformation of industrial manufacturing through digitalization and exploitation of potentials of new technologies (Sodhi 2020).

3. Research method

The present review aims to assess the ongoing research on the integration of LSS and I4.0 and analyze the most relevant papers to establish potential gaps, concerns, and prospects for future research using descriptive bibliometric analysis.The most appropriate research method to explore a field regarding scientific production and impact is the bibliometric analysis.

Bibliometric analysis promises a systematic, transparent and reproducible review process and therefore helps improve the quality of reviews by following five steps (Zupic and Cater 2015). The figure 1 illustrates the bibliometric method workflow inspired from (Santos and Martins 2020: Zupic and Cater 2015).

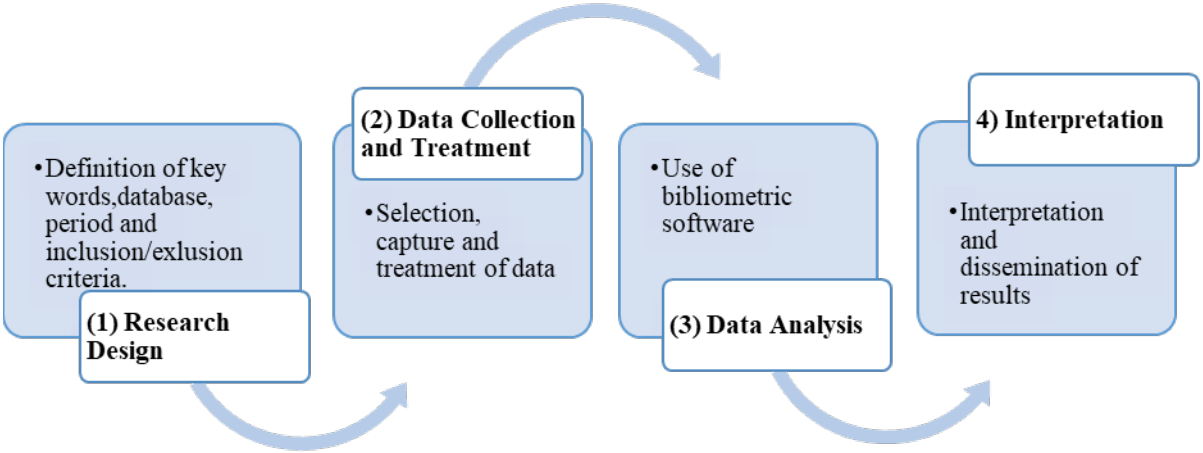

Figure 1. Research method

(1) To define the research key words, the authors conducted a brainstorming workshop. The keywords used in the search query was carried out as follows: various terms, synonyms and abbreviations related to the words “Lean”, "six sigma", "lean six sigma" and ‘Industry 4.0′ have been identified in the literatureThe search query used to extract papers from the Scopus database was as follows: ("lean" or "lean manufacturing" or "LM" or " lean six sigma" or "LSS" or "DMAIC" or "continious improvement") 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 manufacturing" or "Internet of Things"). The authors search this combination in the title, keywords and abstract. The period of the researched articles is 2011 up to September 2021. The reasons for this time period are explained by the fact that the term "Industry 4.0′ was first used in 2011 at the Hanover fair. We conducted the search according to the inclusion/exclusion criterion showed in Table 1.

(2) The second step was to read the summary of each of the documents found in databases and decides if they fit the research topic. The selected articles were deeply analyzed to ensure that their content was relevant to our study. The result of this process was that 60 articles were finally selected to be analyzed.

(3) For the analysis, we use the software applications, i.e. VOSviewer (https:// www.vosviewer.com).

(4) We describe and interpete the findings.

Table 1. Inclusion and exclusion criteria.

Inclusion criteria	Document type: Journal article, conference article or book chapter *English language*
Exclusion criteria	Non-English language publication Text–books, unpublished working papers, and conference presentations Not peer-reviewed academic literature Not related to Industry 4.0 and lean or six sigma or lean six sigma No full text

4. Results and Analysis

4.1 Annual scientific production

Figure 2 1illustrates the number of publications per year. Referring to this graph we note that the first article was published in 2013 and few papers were published until 2017. The majority of relevant publications in the research area started in 2018. This could be explained by the fact that I4.0 is a relatively new topic. The annual scientific production has been rapidly increasing since 2018.

Further, 70% of the papers were published over the last three years, with a peak of 22 papers in 2020.
Thorough a depth analysis of the statistics related to the number of publications in 2020 which is graphically highest, we notice that only 35% of the publications are related to the main keywords "lean" "six sigma" and "industry 4.0" while the majority of the publications are related to the integration of lean and industry 4.

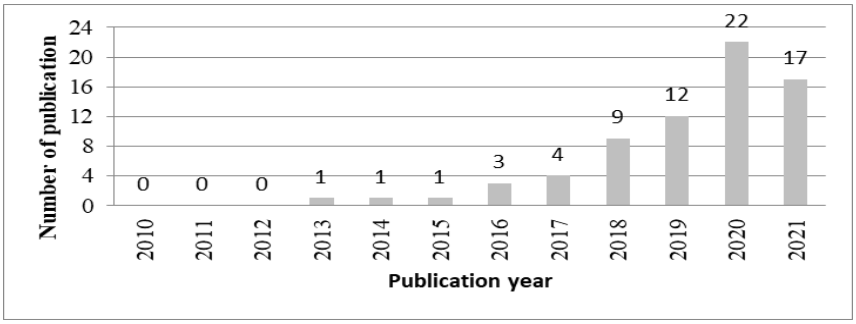

Figure 2. Publication year

4.2 Geography distribution

Figure 3 presents a country wise analysis of the top countries interested in our research area and Figure 4 shows percentage of publications per Continent. The 60 articles reviewed come from all over the world, 12 different countries were involved, with 84% of the research performed in developed countries (i.e. Europe and North America) and 15% in developing countries (i.e. Asia, Africa and South America).

According to the affiliation of the authors. Figure 3 shows that Brazil is the country with the highest incidence of Publications (22%), followed by Germany (18%) and Italy (16%). We noted that the author with the most publications in the fiels "Guilherme Tortorella "is Brazilian.

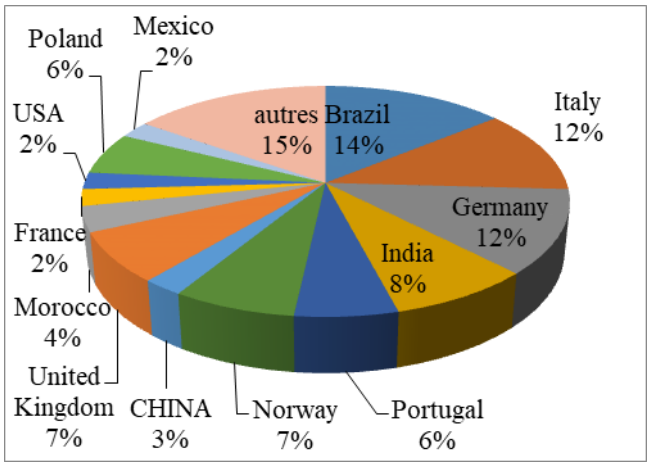

Figure 3 Geographical distribution as per first author affiliation

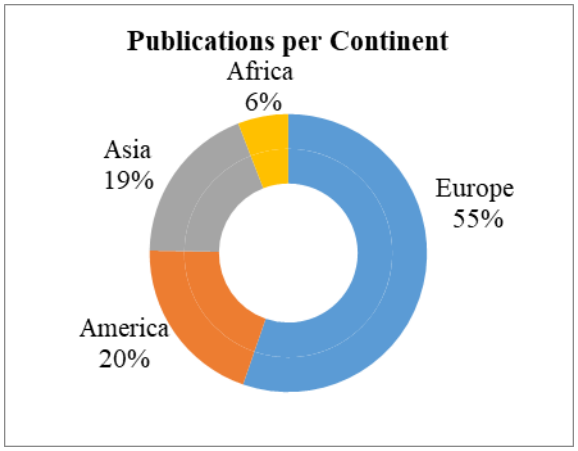

Figure 4. Geographical-based classification.

4.3 Top field journals

The most relevant journals publishing studies on LSS and I4 belong to three disciplines which are respectively Engineering, followed by Business, Management and Accounting and the third represented by Computer Science. Regarding Figure 5, 50% of the research articles were published in four journals: International Journal of Production Research (IJPR), Procedia Manufacturing, International Journal of Production Economics (IJPE) and Journal of Manufacturing Technology Management. IJPR has the highest number of articles in 2019 and 2020.

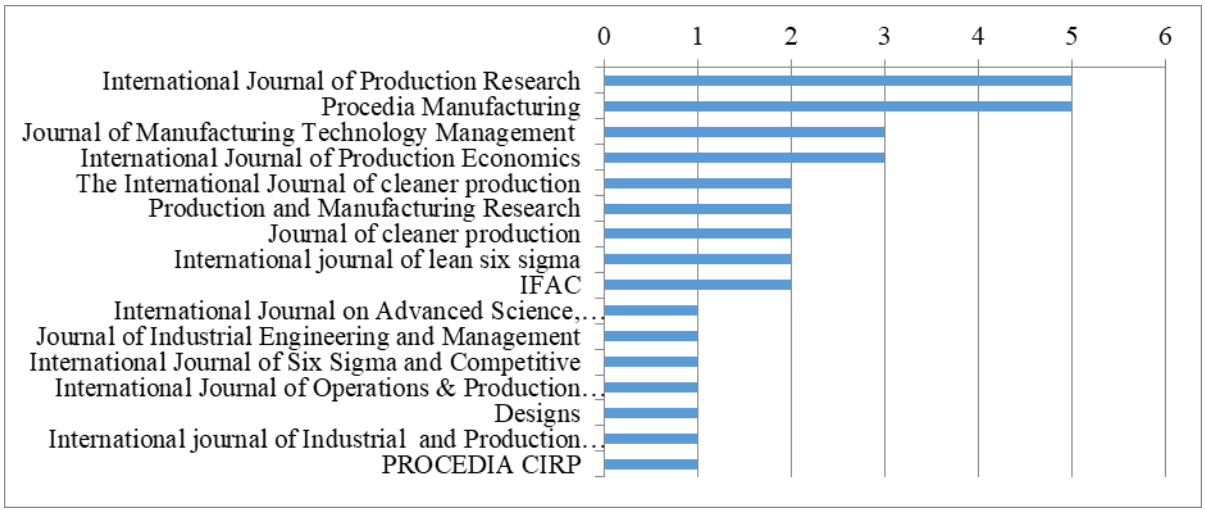

Figure 5 Top field journals

4.4 Most relevant authors' production

Table 2 presents the most productive authors funded in the literature review which are Luz Tortorella with 15 papers, Pagliosa (5 papers) Angappa Gunasekaran (4 papers) Martin Molina (4 papers) Joseph C. Chen (4 papers).

Table 2 Most relevant authors' production

Author	First Publication Year	Last Publication Year	Number of publcation
Guilherme L. Tortorella	2018	2021	11
Pagliosa	2018	2021	5
Kamble	2018	2021	4
Martin Molina	2018	2021	4
Joseph C. Chen	2014	2021	4
Belhadi amine	2019	2021	4
Angappa Gunasekaran	2018	2021	4
Dombrowski	2017	2020	3

4.5 Most cited articles

According to the table 3, we summarize the most cited papers in litterature .As we see, (Thoben et al. 2017) came at the first range with 759 cites, succeded by (Sanders et al. 2016) with 479 cites, (Kolberg and Zühlke 2015) with 408 cites, (Buer et al. 2018) with 387 cites. (Luz Tortorella and Fettermann 2018) was cited 364 times, (Wagner et al. 2017), with 298 cites; and (Mrugalska and Wyrwicka 2017) cited 237 times.

Table 3. Most cited articles

Reference	**Nbr citation**	**Publication year**	**Source**
Thoben et al. (2017)	759	2017	International journal of automation technology
Sanders et al. (2016)	479	2016	IFIP Advances in Information and Communication Technology
Kolberg and Zühlke (2015)	408	2015	IFAC-PapersOnLine
Buer et al. (2018)	387	2018	International Journal of Production Research
Luz Tortorella and Fettermann (2018)	364	2018	International Journal of Production Research
Wagner et al. (2017)	298	2017	Procedia CIRP
Mrugalska and Wyrwicka (2017)	237	2017	Procedia Engineering

4.6 Discussed keywords in the literature

4.6.1 Lean six sigma

The continuous improvement strategies reported by the studied articles among lean, six sigma or lean six sigma and I4 are presented in the figure 6. As seen, the majority of the literature focuses on Lean rather than Six Sigma or Lean Six Sigma when associated with I4 advanced technologies.

Lean six sigma combined with I4 has been of increasing interest to researchers since 2020. Value stream mapping (VSM) is the lean tool with more practical applications. There have been significant efforts towards I4.0 in companies from diverse sectors, such as manufacturing (Dalenogare et al. 2018), supply chain (Zekhnini et al. 2020; Núñez-Merino et al. 2020), healthcare (Tortorella et al. 2019a), public services (Gerrikagoitia et al. 2019), among others.

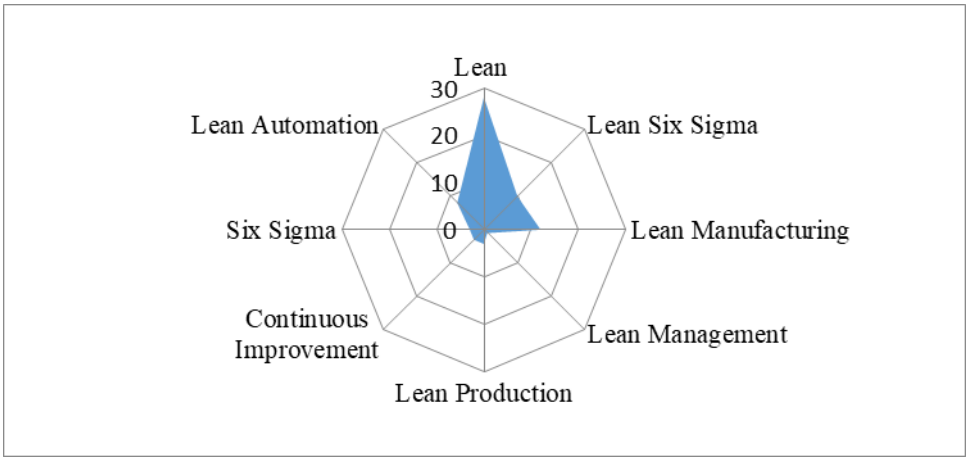

Figure 6. LSS most used keywords in the literature

4.6.2 Industry 4.0

Table 4 dresses the I4 technologies that were linked with different Lean and LSS principles and tools in the literature review. Among the papers studied, the authors that reported I4 tools and LSS in their papers are referenced below (Table 4).The results highlight that very few authors addressed all I4 tools in their studies; other researchers presented a few tools, and the majority discussed the LSS concepts embedded in I4.0.

Table 4 shows the tools of Industry 4.0 that have been mentioned in literature review and the authors discussing I4 tools in their papers. Iot, Big Data, Cloud computing, CPS, Robotic, Technology and processare the most mentioned tools by the authors.

Table 4. Most cited I4 Tools in litterature

References	I4 Tools
(Pereira et al., 2019)	Iot, Big Data
(Buer et al., 2018)	Iot, Big Data, Cloud computing, CPS, Robotic, Technology and process
(Sony, 2020)	IoT, Cloud computing, CPS
(Tortorella and Fettermann, 2018) (Pereira et al., 2019; Rossini et al., 2019; Tortorella et al., 2020, 2019, 2021)	Iot, Big Data, Cloud computing, CPS, Robotic, Technology and process
(Belhadi et al., 2021, 2020)	Big data
(Kolberg et al., 2017)	CPS
(Kolberg and Zuehlke, 2015)	Robotic, Technology and process

4.7 Keywords occurrence

Referring to the visualization analysis in figure 7, we note that the keywords are classified into three clusters. It can be seen that the term Industry 4.0 is in the middle of the scale (green) due to the repetition of this keyword across the period analyzed. On the other hand,

- Red Cluster describes the operations management (quality management, lean six sigma) there are light links between the words in this cluster and Industry4.0
- Green cluster describes the I4.0 technologies combined with lean in literature. The Main I4.0 technologies associated with LSS as identified in the literature are: internet of things, big data, and machine learning. There is a strong link between “Industry 4.0” and “lean”.
- And the blue Cluster consists of lean manufacturing and framework with a strong link with industry 4.0.

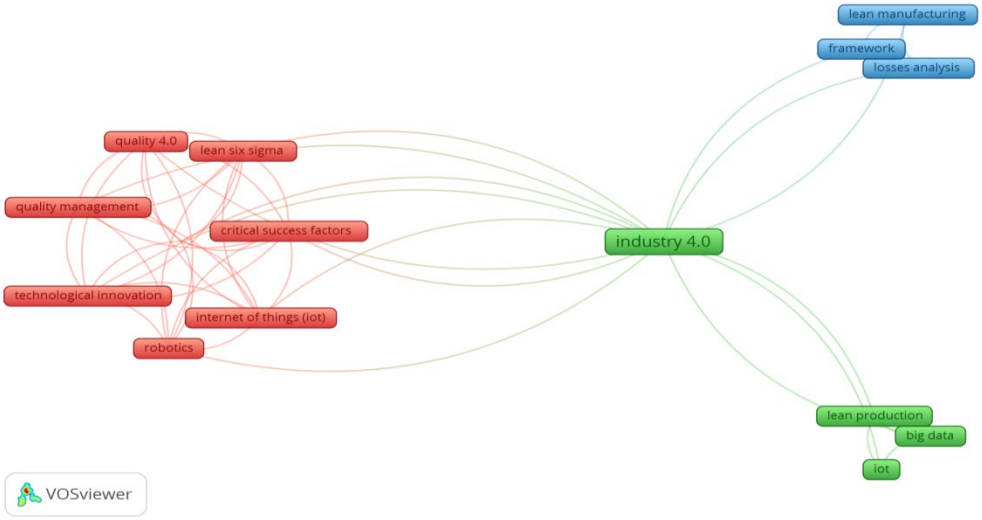

Figure 7. Keywords Occurrence

4.8 Distribution across the document type

One part of this descriptive review are the journals that have published the most research works related to LSS and I4, which are presented in Figure 8. Out of 60 papers evaluated, journals papers have a predominant aspect when looking at the types of the publications by 49%. While conference papers represent 45% Over the 29 conference articles studied. Further, 34% of conference papers are published on the international conference of industrial engineering and operational management IEOM. Figure 8T illustrate the breakdown of the bibliography based on the publication types. Regarding journals, the IJPR played an important role in this field because it published 10.6% of the papers considered for this review. It can be deduced that research on the integration of lean, Six Sigma and industry 4.0 is likely to be published in a range of highly specialized journals.

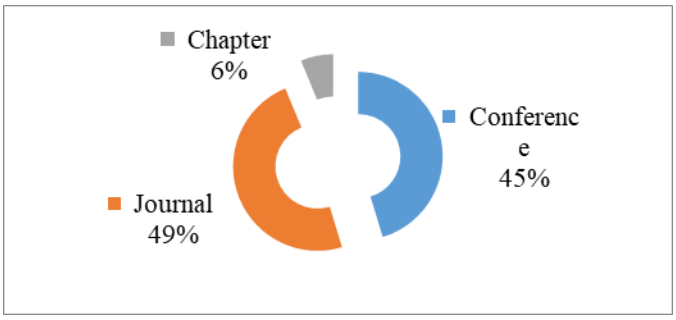

Figure 8. Document type distribution

5. Research streams and Discussion

Our paper examines the state of the art, trends, and the perspectives of LSS and I4 integration in the context of manufacturing. From the literature review, we conclude that the lean-SS-I4 topic has gained special interest and popularity within the research community since 2018 as 80% of the publications are released in the period from 2018 to 2021. The findings indicate that the lean-SS-I4 is an emergent research field. The limited literature review on LSS and I4 motivated our search.

The findings indicate that there is a rising interest in the field of integration LSS and I4 in manufacturing environment. We note from the literature that research on LSS and l4 (LSS4.0) is conducted worldwide. Studies are done in developing, emerging and developed countries. The highest number of research articles emerged from the combination of Lean manufacturing and I4.

It was also observed that Big Data and IoT are the most used I4 technologies in the LSS and I4 integration discussions; however, we found that technologies such as cloud computing, robotics, and AI do not receive enough attention. However, the contribution of these technologies has to be investigated. The growing interest among practitioners and academics in the integration of LSS and I4 has prompted the researchers to examine whether there is a correlation between these two approaches.

Our literature review described the relationship and identified the three different possible combinations of Lean/LSS and I4 in the context of manufacturing as follow: (1) Lean/LSS as a basis for industry 4.0, (2) Industry 4.0 and lean/LSS interact with each other and (3) Industry 4.0 supports lean/LSS and increases efficiency.

(Arcidiacono and Pieroni 2018) states that "Industry 4.0 enables real-time planning of production plans, along with dynamic self-optimization. The authors report that advanced analytics improve the performance of Lean Six Sigma projects through faster data collection and analysis. Sodhi (2020) states that by implementing IoT techniques with LSS methodology organization can better perform in effective decision making and providing products with better quality. Future work can be done on integrating more techniques of Industry 4.0 to maximize benefits. Dogan and Gurcan (2018) found that traditional data collection, monitoring and traditional analysis techniques, takes more time and cost. But with the use of big data techniques, both cost and time could be saved in effective decision making. Jayaram (2016) stated that Industry 4.0 and Lean Six Sigma are complement to each other, and proposed a model for managing global supply chain management.

6. Conclusion

This research paper contributes to the literature review on the relationship between LSS and I4 technologies in a manufacturing context. We conducted a bibliometric analysis of the literature review, the findings provided many insights to the research. The main conclusion is that the research area is attracting growing interest from researchers.

In conclusion and regarding the literature review The authors have identified many research gaps listed as follow:

(1) Lack of defined frameworks which describe a clear and suitable guidelines and roadmaps for the adoption of Lean Six Sigma integrated with industry 4.0 technologies wich will help managers and practionners to adopt and deploy the LSS4.0 even more, development frameworks would provide support in changing the management practices within the lean six sigma.
(2) There are barriers that will play a critical and challenging role in the implementation of Lean Six Sigma 4.0. and in the other hand there are the "drivers keys" derived from existant literature that provide guidance for LSS4.0 adoption for a successful integration of the two continuous improvement strategies lean and Six sigma in the Industry 4.0 era. There are not enough studies on how to effectively treat these.
(3) Few studies discuss a clear Definition of the CSFs (critical success factors) that will help managers and practionners in the implementation of Lean Six Sigma 4.0.

This study aimed at investigating the concept of LSS in the I4 which led to the formulation of future research propositions. We suggest that future researchers further explore the correlations between LSS4.0 and other management strategies such as Green, Resilience and Agility.

This paper presents some limitations that should be addressed. The using of specific keywords and databases, may contribute to leaving out some high-quality articles. Moreover, the study findings reflect only the selected papers.

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