Quality Management Journal

Taylor & Francis
Taylor & Francis Group

Industry 4.0 and Lean Six Sigma Integration in Manufacturing: A Literature Review, an Integrated Framework and Proposed Research Perspectives

Journal:	*Quality Management Journal*
Manuscript ID	UQMJ-2022-0072.R1
Manuscript Type:	Review Article
Keywords:	Six Sigma, Lean Six Sigma, Lean Manufacturing, Digitalization, Industry 4.0

Abstract:	This paper explores the literature on lean management (LM), Six Sigma (SS), Industry 4.0 (I4.0) and their relationship. A systematic literature review (SLR) combined with bibliometric analysis was conducted to identify, select and evaluate articles and was supported by content analysis to classify papers into group discussed clusters. A total of 134 articles were retrieved from relevant databases and publisher engines between 2011 and June 2022. The analysis of these articles enabled us to identify the impact of Industry 4.0 technologies on Lean Six Sigma; the relationship between LM, SS and Industry 4.0 and the implications of their combination on operational excellence. The results show that while a majority of researchers consider Industry 4.0 to be a driver of LSS and a prerequisite for helping companies access the data and analytics needed, others find them to be complementary and synergistic. Similarly, various authors support the idea that LSS could be a facilitator of Industry 4.0. This study provides an overview of the main research streams in this field and its shortcomings and presents an LSS4.0 framework integrating lean six sigma and Industry 4 which will be of great value to academics and practitioners working in this area.

Industry 4.0 and Lean Six Sigma Integration in manufacturing: A literature review, an integrated Framework and a proposed research perspectives

Abstract

This paper explores the literature on lean management (LM), Six Sigma (SS), Industry 4.0 (I4.0) and their relationship. A systematic literature review (SLR) combined with bibliometric analysis was conducted to identify, select and evaluate articles and was supported by content analysis to classify papers into group discussed clusters. A total of 134 articles were retrieved from relevant databases and publisher engines between 2011 and June 2022. The analysis of these articles enabled us to identify the impact of Industry 4.0 technologies on Lean Six Sigma; the relationship between LM, SS and Industry 4.0 and the implications of their combination on operational excellence. The results show that while a majority of researchers consider Industry 4.0 to be a driver of LSS and a prerequisite for helping companies access the data and analytics needed, others find them to be complementary and synergistic. Similarly, various authors support the idea that LSS could be a facilitator of Industry 4.0. This study provides an overview of the main research streams in this field and its shortcomings and presents an LSS4.0 framework integrating lean six sigma and Industry 4 which will be of great value to academics and practitioners working in this area.

Keywords: Six Sigma, Lean Six Sigma, Lean manufacturing, Digitalization, Industry 4.0, literature review.

1. Introduction

Manufacturing companies are facing and continue to undergo various challenges such as the evolution of customer requirements, e.g. shorter lead times, higher product quality and customized products and services, among others, increased competition, market share, financial crisis and economic decline (Antony et al., 2022; Lameijer et al., 2021; Psomas and Antony, 2019; Cherrafi et al., 2016). Competitiveness is the main concern of organizations, which are continually looking for ways to reduce complexity and waste and increase value and revenues.Since the rise of Industry 4.0(I4.0) and related technologies, additional pressure and challenges have been added to manufacturing companies on how to digitally transform operations management structure to compete in a highly digitized business environment(Morteza Ghobakhloo, 2020).I4.0 is expected to have a positive impact on manufacturing processes and operational performance(Ali and Xie, 2021; Calış Duman and Akdemir, 2021)wich have led companies to rethink their operational processes and manufacturing approaches to accommodate advanced I4.0 technologies and meet customer expectations seeking for smart products and services.Given a series of enabling technologies offered by the new I4.0 paradigm(Culot et al., 2020; Schwab, n.d.), operations management is currently exposed to a significant "shift" of many traditional approaches, namely Lean Six Sigma (LSS) (Arcidiacono and Pieroni, 2018).Manufacturing companies need to redesign the way they manage processes and adapt them to integrate information and physical data into an intelligent workflow. Today, continuous improvement and digitization are not merely good practices or buzzwords, but rather business necessities. The combination of LSS and I4.0 is an effective way to address the stated challenges. The philosophy of LSS is to design an efficient production system that generates less waste and delivers high quality products with optimal use of resources(Chiarini, 2020; Pepper and Spedding, 2010). Similarly, I4.0 enables the transformation of manufacturing tools into smart and efficient ones, to boost operational performance and customer satisfaction. Both LSS and I4.0 paradigms share a common goal, which is improving business performance(Antony et al., 2022; Lameijer et al., 2021).As stand-alone approaches, LSS and I4.0 are good and effective drivers for business performance and process improvement. When combined, they have the potential to be an exceptionally powerful tool.Aligning I4.0 technologies with Lean and Six Sigma tools will provide enormous potential for improvement and help companies achieve better performance(Anass et al., 2021; Sodhi, 2020; Tissir et al., 2022).The integration of LSS and I4.0 is gathering the interest of both researchers and practitioners. Many authors have been involved in the investigation and advancement of this field(Antony et al., 2022; Narula et al., 2022; Tissir et al., 2022; Anass et al., 2021; Bittencourt et al., 2021; Alexander et al., 2021; Anvari et al., 2021; Sony, 2020; Belhadi et al., 2020; Yadav et al., 2020; G.L. Tortorella et al., 2019; Arcidiacono and Pieroni, 2018a).While there is a great scientific interest in the current research topic, as evidenced by scientific conferences and a large number of publications to date, there are a limited number of articles that focus on LSS and I4.0. A limited number of articles have attempted to assess the state of research on the integration of LSS and I 4.0(Antony et al., 2022; Anvari et al., 2021; Arcidiacono and Pieroni, 2018a; Bittencourt et al., 2021; Duarte et al., 2020; Tissir et al., 2022).The majority of studies have addressed lean and I4.0 integration(A. Al-Futaih and Demirkol, 2020; Buer et al., 2020; Duarte et al., 2020; Mahdavisharif et al., 2022; Narula et al., 2022; Prinz et al., 2018; Rossini et al., 2019; Sanders et al., 2016).(Antony et al., 2022)studied the benefits, drivers, CSFs, and challenges of LSS and I 4.0 integration, theoretically using the literature review. Authors found that most studies focus on Lean and I4.0 integration and that there is a lack of literature addressing the challenges and CSFs related to the integration of LSS and I4.0. These results need to be proven empirically. Yet, there is no comprehensive study in which drivers, barriers, and CSFs for a potential integrated model are explored empirically. Existing knowledge about the potential synergies between the two concepts is still in its infancy.The literature debates the role of Industry 4.0, on whether it is an enabler/driver in the implementation of LSS or the reverse.The results of this review show that researchers agree on three views regarding the relationship between LSS and I4.0: some authors argue that I4.0 can drive continuous improvement and is, therefore, a prerequisite for LSS, others argue that they are complementary, and a few believe that LSS can facilitate the implementation of I4.0. Industry 4.0 is presented as a driver and enabler of LSS implementation. The authors can emphasize that technologies such as cloud computing, Industrial Internet of Things, BDA, CPS, and machine-to-machine communication will enable organizations to have the ability to better manage LSS projects in time and data accessibility. An organization that has Industry 4.0 technologies as dynamic capabilities will be able to smoothly move its processes and operations towards lean six sigma and operational excellence.

To fill this gap, the main purpose of this paper is to provide a state of the art of literature regarding the integration of the two concepts LSS and I4.0 (LSS4.0) using a Systematic Literature Review. Accordingly, the research questions that arise are as follows:

RQ1: What is the current state of research on the linkage between I4.0 and LSS?

RQ2 : How can I4.0 and LSS be integrated to achieve better operational performance?

This paper is structured as follows: Section 2 presents conceptual terminology that guided the research. Section 3 describes the research methodology. Descriptive analysis is presented in Section 4 while Section 5 describes the bibliometric analysis. A qualitative content analysis to illustrate the research streams is presented in Section 6, whereas in Section 7, the conceptual framework is developed and a discussion of theoretical elements of our integrated model is provided. Also, the research gaps and future research directions are proposed in section 8. Finally, the conclusion and the research limitations are presented.

2. Theoretical background

Given the extensive literature on I4.0 and LSS and the various definitions, this section aims to present the conceptual terminology used in the remaining work.

2.1. Lean management (LM)

Lean is an organizational philosophy and approach to business efficiency developed by the Japanese company Toyota, designed to reduce waste and non-value added activities in manufacturing. Lean manufacturing uses a set of tools and philosophies that impacts positively quality and productivity and reduces manufacturing costs (Sanders et al., 2016) including value stream mapping (VSM), Just in time(JIT), Kanban, Jiduka, among others. Lean management was widely applied by both larger companies and small and medium-sized businesses and has led to improved business performance such as reducing waste and costs (Leong et al., 2019; Cherrafi et al., 2016; Garza-Reyes, 2015), improving customer satisfaction and increasing process efficiency(Bhattacharya et al., 2019; Garza-Reyes, 2015). Although lean has proven its ability and support for process optimization and operational performance by eliminating waste and engaging people in daily process improvement, it does not take into account the analysis of process variability and the causes of defects covered by the Six Sigma methodology (Alami 2019; Lai et al. 2020 and Elkhairi, Fedouaki).Defects require additional work to be addressed, which results in lost time and losses.Lean is a state of mind rather than a methodology that requires the involvement of people, changes in attitude and process improvement wich the need to be integrated with six sigma for better process efficiency and business performance. Six-Sigma therefore aims to identify defects, determine their cause and eliminate them.

2.2. Six Sigma (SS)

Six Sigma (SS) is a powerful concept used to achieve continuous improvement, and identify and eliminate the causes of error in processes. Using statistical and non-statistical tools and techniques, the method addresses process variability and deviations. With SS, manufacturers can achieve greater customer satisfaction while simultaneously maximizing economic gains. After its success in manufacturing companies where it was first introduced, SS has been extended to several sectors, e.g. healthcare, public service, construction, and education(Jiménez et al., 2020; Antony and Sony, 2019; Pardamean Gultom and Wibisono, 2019; Hseng-Long Yeh, 2011).SS is well known as a problem-solving approach using qualitative and analytical tools to develop core processes based on the DMAIC or DMADV methodologies. DMAIC stands for Define, Measure, Analyze, Improve and Control while DMADV is the acronym of Define, Measure, Analyze, Design and Verify and is used when companies need to develop a new product or process. While lean thinking brings innovation and business change, Six Sigma does not drive innovation within companies. SS can generate higher results when combined with lean management.

2.3. Lean Six Sigma (LSS)

The union of the two very powerful approaches to continuous improvement namely Lean and SS gave birth to an integrated approach called LSS(Cherrafi et al., 2016). As an integrated methodology, LSS includes the speedy capability of Lean through process flow and the robustness of SS through a disciplined and systematic approach to problem-solving (Antony et al., 2018). Lean and Six Sigma methodologies are being used and examined as a whole (Shah et al., 2008).

The LSS approach can solve complex industrial problems that generate financial and operational improvements. Manufacturers are applying the LSS methodology to achieve better performance and reduce losses and non-value added activities.

2.4. Industry 4.0 (I4.0)

The term I4.0 refers to the fourth industrial revolution, which represents a technological alongside an economic, sociological and strategic revolution(Arcidiacono and Pieroni, 2018a). The advanced technologies of I4.0, enable the collection, storage, analysis and exchange of massive data between man and machine in a fast and efficient way(Angreani et al., 2020, p. 0; Radziwill, 2018).I4.0 enables the design of smart products and services with features such as more insight into customer requirements, better connectivity with customers, and real-time monitoring for better performance(Koh et al., 2019; Tay et al., 2018). The term "I4.0" was first coined in 2011 at the Hannover Fair, with the digitalization of the manufacturing industry as the main goal. Since that time, I4.0 has become a sought-after topic among experts and academics around the world due to its novelty and has given rise to numerous conferences on the topic. Several recent studies have been involved in the promotion and advancement of knowledge on the subject, resulting in interesting papers(Bermúdez and Juárez, 2017; Bittencourt et al., 2019; Dogan and Gurcan, 2018a; Karadayi-Usta, 2020; Kolberg and Zuehlke, 2015; Powell et al., 2018; Raji and Rossi, 2019; Rossini et al., 2019; A. Sanders et al., 2017; Shrouf et al., 2014; Sven-Vegard Buer et al., 2018).I4.0 has been explored in the literature from different perspectives: definitions, technologies, a roadmap for implementation, performance impacts, potential barriers, drivers and key success factors for practical implementation, and success stories(Angreani et al., 2020; Chettri and Bera, 2020; Culot et al., 2020; Gallab et al., 2021; Karadayi-Usta, 2020; Sony and Naik, 2020; Raj et al., 2020; Sony and Naik, 2020, p. 0; Machado et al., 2019; Tay et al., 2018; Kamble et al., 2018; Haddud et al., 2017; Schumacher et al., 2016; Lee et al., 2015). (Haddud et al., 2017) presented an assessment of the benefits and challenges of adopting IoT.(Machado et al., 2019) defined a model to measure manufacturing companies' readiness for digitalization.(Sony and Naik, 2020) have focused on the study of CSFs of I4.0 using a critical literature review and found 10 factors impacting the successful implementation of I4.0. The authors highlighted the need for specialized talent and a workforce to manage I4.0 projects. Studies conducted by (Antony et al., 2022)confirmed that I4.0 technologies can help improve the performance of companies that are already working with the LSS methodology. This manifests the motivation and benefits of this integration.

In the recent literature, the terms "digitization", "digitalization" and "digital transformation" are closely related to I 4.0 and are often used by authors to talk about the fourth industrial revolution. In our study, we build on this interpretation of I4.0, which means the integration of I4.0 enabling technologies into manufacturing processes.

3. Research Methodology

The purpose of this study is to assess current research on the relationship between Lean, SS, and I4.0 and to analyze the most relevant articles to identify gaps, concerns, and potential insights for future research. A systematic review of the literature (SLR) was performed following the guidelines developed by Tranfield et al., (2003) as described in Figure 1. The main reason for adopting the Tranfield model and an SLR is to adopt a comprehensive, scientific, methodical and reproducible design process that allows for a rigorous and efficient synthesis of existing information(Denyer and Tranfield, 2009; Tranfield et al., 2003). A SLR serves as an approach to conducting a comprehensive review of previous and current studies on a research topic (Vinodh et al., 2020).

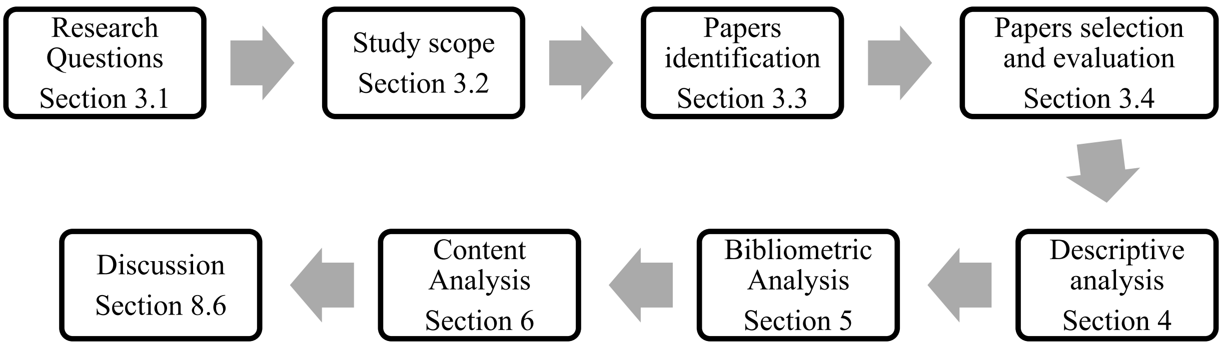

Figure 1. Research protocol

3.1. Research questions

Given the objectives of the study, the two research questions as depicted in the introduction are as follow :

RQ1: What is the current state of research on the linkage between I4.0 and LSS?

RQ2: How can I4.0 and LSS be integrated to achieve better operational performance?

3.2. Scope of the study

At this stage, we define the keywords, research time, the inclusion and exclusion criteria, and the research databases. The definition of keywords and terms was carried out following an iterative process. Terms and synonyms associated with "Lean," "SS," and "I4.0′ were inventoried in literature and based on a discussion with senior researchers in the field. Due to the complexity of finding a precise definition and synonyms of the term I4.0, we have made a considerable effort to search and filter publications related to our research topic by examining their titles, abstracts and full text. In most cases, this task can be accomplished by focusing on the most relevant and influential peer-reviewed journals and conferences in the research area. Since the advent of the term I4.0 in 2011, there has been interest from governments, industries, and researchers around the world(Yin et al., 2018). Such strategies have been developed by the governments of the world's leading industrial countries, mainly Future Factories by the European Union, Internet+ launched by China, Industrial Internet Consortium created by the United States, Industrie 2025 developed by Switzerland and e-Factory designed by Japan (Uriarte et al., 2020; Mrugalska and Wyrwicka, 2017).

To define a set of synonyms for "I4.0", we studied the highest ranked literature reviews on Scopus and the Web of Sciences addressing I4.0 and we included the above names of strategies related to I4.0. To enrich the keyword list, a panel of academics and practitioner sexperts in the field was approached to support us in refining and validating the inventory of keywords. The keywords considered are summarized in Table 1. Searching online databases is now the leading practice to identify the most relevant articles. To cover a wide range of academic publications, the literature was identified using the following electronic databases and publication engines: Scopus, Elsevier, Emerald, Taylor & Francis, Springer, IEEE and Google Scholar. Table 2 describes the inclusion and exclusion selected criteria.

3.3. Papers identification

The research of the keywords in titles, abstracts and full article text was carried out from 2011 to May 2022 using Boolean operators (AND and OR) in database queries. The period was determined owing to the introduction of I4.0 in 2011 at the Hannover Fair.Papers were identified according to defined inclusion criteria (Table 2). In an effort to verify that all articles on lean manufacturing, SS, and I4.0 have been identified, the authors decided to create a list of journals that regularly publish articles in this area. All electronic editions of the International Journal of Lean Six Sigma(IJLSS), the International Journal of Quality & Reliability Management (IJQR), International Journal of Production Economics (IJPE), Journal of Production Planning & Control (IJPPC), International Journal of Production Research (IJPR), Production and Operations Management (POM), were systematically searched. In addition, the references of the selected studies were manually reviewed to check that no relevant studies were missed.

Table 1:Main keywords searched

Keywords	
Lean Six Sigma	Industry 4.0

or	Lean manufacturing	Fourth Industrial revolution	or
or	Lean	I4.0	or
or	LM	4th Industrial revolution	or
or	Lean production	Digitization	or
or	LSS	Digitalization	or
or	Continuousimprovement	Smart factory	or
	Six Sigma	Future Factories	or
	Quality management	Industrial Internet Consortium	or
		Internet+	or
		e-Factory	

3.4 Papers selection and evaluation

The selection and evaluation process was carried out in three phases: (1) elimination of duplicates, (2) evaluation of the relevance, and finally (3) evaluation of the availability of the articles in full text. A number of 786 papers were extracted from databases. By eliminating 352 duplicated papers, the remaining papers were assessed for eligibility. The first eligibility filter is about the relevance of papers. To ensure that the selected articles were relevant to our study, an abstract review was performed by the authors. The assessment of the relevance of the articles to the subject matter resulted in the elimination of 292 articles that were considered off-topic. The second eligibility filter was to assess the accessibility of the articles. Only articles that were accessible in full text were retained. This process resulted in 142 articles being selected for further reading and evaluation. Nine articles were excluded because of the unavailability of the full text. Finally, 133 articles were selected for analysis. A databank was generated in Excel to codify and classify the selected materials and group them by theory, method, objective, outcomes and the main discussion areas. The detailed research methodology is shown in Figure 2.

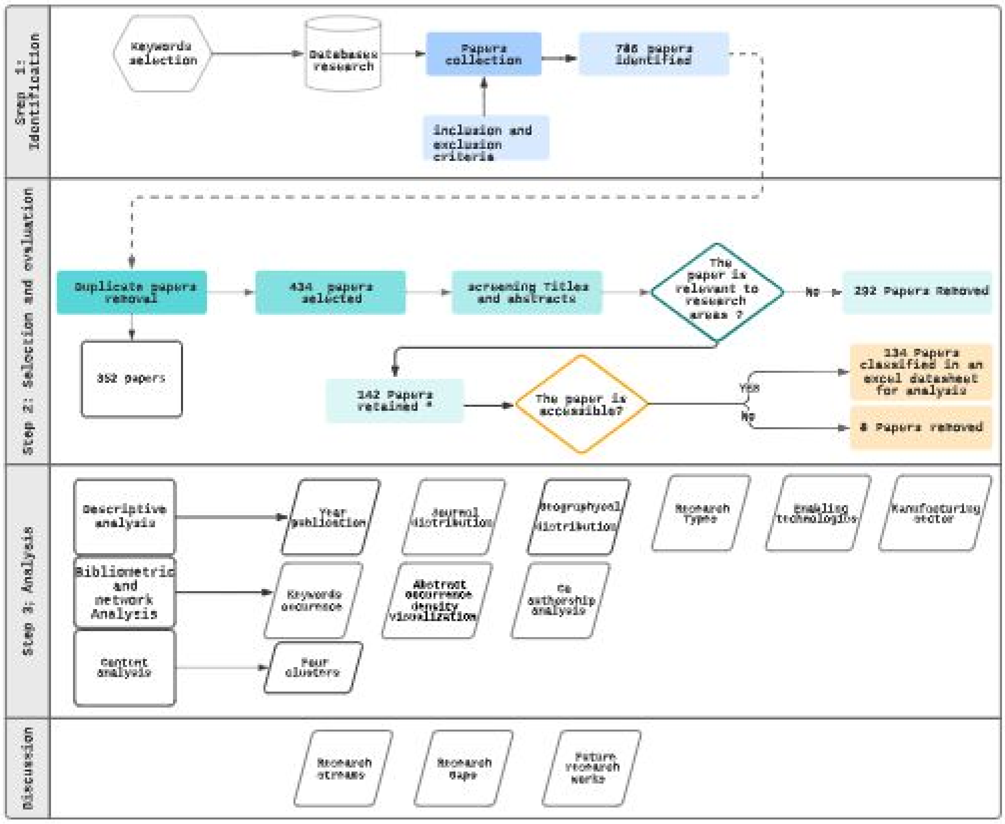

Figure 2:Literaturereview process

Table 2: Research criteria

Inclusion criteria	Peer-reviewed journal publication, conference paper, book chapter English language Paper published between 2011 and June 2022 Articles related to the manufacturing area Peer-reviewed literature
Exclusion criteria	Publication in other languages than English Unpublished papers Not relevant to the subject. No full text available

4. Descriptive analysis

The descriptive analysis focuses on the following five parameters:

Publication Year (Fig3): The distribution of publications by year, to identify the trend in the number of studies on the research theme.

Geography Distribution (Fig 4): Considering the affiliation of the first author, we aim to identify the countries most active on the research theme.

Publications breakdown (Fig 5) and Distributionacross journals (Table 3): Publications breakdown informs on the proportion of publications by journal, conference and chapter while the distribution of publications by journal aims to identify the journals most involved in the research theme.

Research Types (Fig6): The purpose is to gain insight into the research type used in the reviewed articles that discuss the combination of LSS and I4.0.

Enabling I4.0 technologies for Lean and SS (Fig7): We aim to identify the different technologies discussed in the field of I4.0 and LSS.

Distribution of empirical studies across industry sectors (Fig8): We seek to identify and define the industrial sectors most affected by this integration.

4.1 Year of publication

The articles published in the last five years follow a progressive tendency, with 75% of publications appearing between 2020 and 2022 indicating that the topic of lean, SS, and I4.0 has gained interest and popularity within the research community since 2020 (figure 3). Through a depth analysis of the statistics related to the number of publications in 2020 (57 papers) which is graphically highest, we notice that only 28% of the publications this year are related to the main keywords "LSS" and "I 4.0" while the majority of publications focus on the combination of lean manufacturing and I4.0.

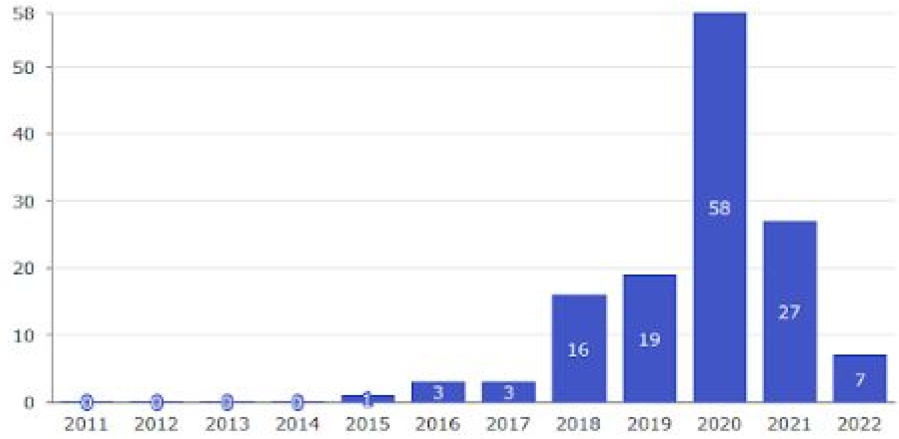

Figure 3: Distribution of publications by years

4.2 Geographical distribution

Figure 4 presents graphical information on the geographical distribution of papers based on the affiliation of the first author. Europe is by far the leading continent in scientific discussion and studies on the integration of I4.0 and LSSheadedby Germany (12 articles) and Italy (12 articles). It is explained by the number of conferences organized since 2016 in relation to the topic. In the second range came the South America continent represented by Brazil, which gained the top number of papers published in the field with 12 publications. Developing countries are less involved. Fig 4 shows the most active countries in the research field.

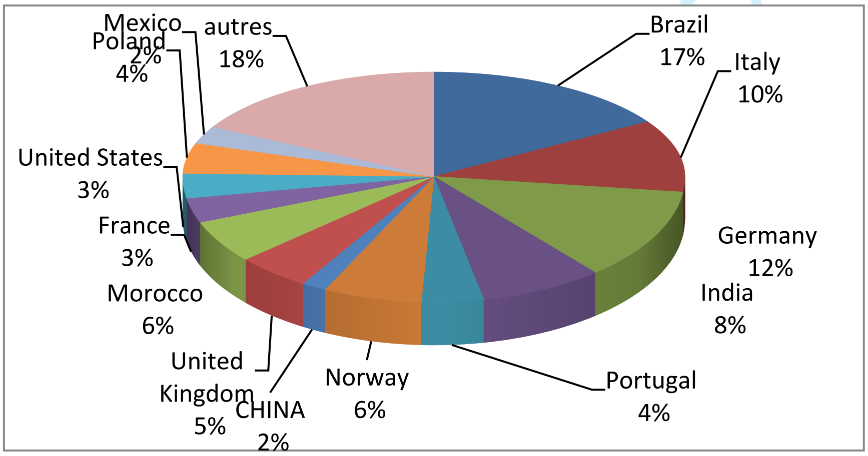

Figure 4: Geography distribution

4.3 Distribution by sources

Figure 5 illustrates the breakdown of publications based on the sources. Journal papers have a predominant aspect when looking at the types of publications (87 papers). 55% of the journal articles reviewed were published in four major journals (Table 3): International Journal of Production Research (IJPR), International Journal of Lean Six Sigma (IJLSS), Production Planning and Control(PPC) and Journal of Manufacturing Technology Management (JMTM). The IJLSS held an active position in this area as it published 7% of the papers included in this study.

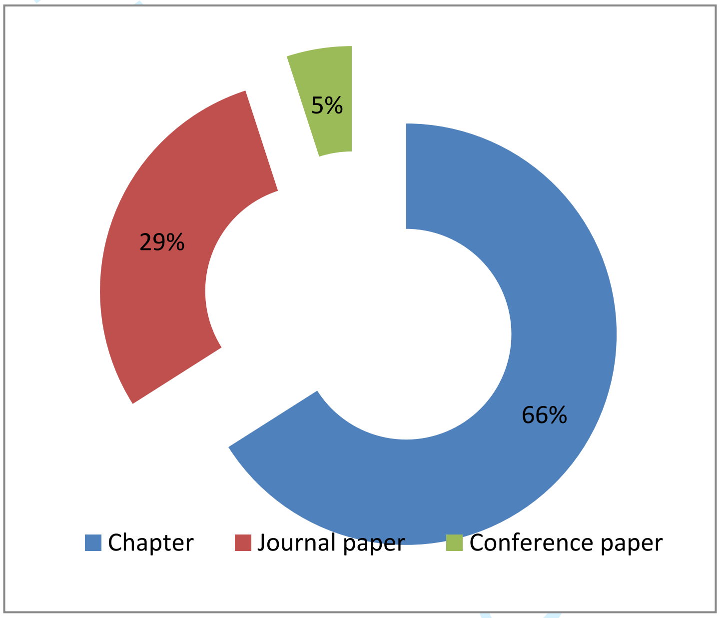

Figure 5: Breakdown of publications by sources

Moreover, Taylor and Francis is the leading publisher in this field (30%), represented by two journals IJPR and PPC. Presumably, research on the integration of LSS and I4.0 has appeared in a range of highly ranked journals.

4.4 Classification by research type

The articles are categorized into five areas: Research Article, Literature Review, Case Study, Survey, and Miscellaneous. Figure 6 shows that 43% of the articles addressed the topic in a conceptual way (24% of the literature review articles and 19% of the publications were research articles). The remaining 57% used more empirical research techniques, including case studies (14%), simulations (8%), surveys (25%), and 10% fall into the "miscellaneous".

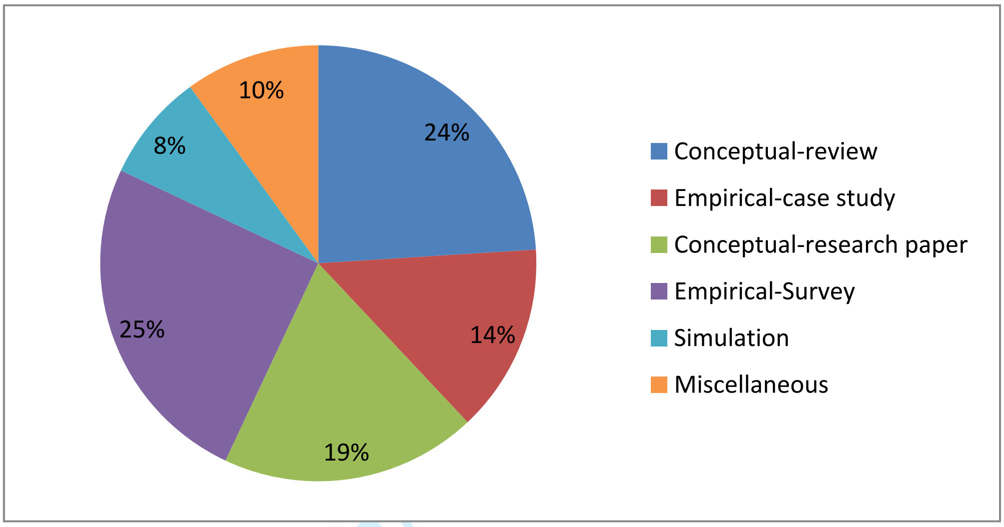

Figure 6: Distribution by search method

Table 3: Distribution by source

Journals	Nbr of paper
International Journal of Production Research	14
Production Planning & Control	10
Journal of Manufacturing Technology Management	6
International journal of Lean six sigma	6
Procedia CIRP	4
Procedia Computer sciences	4
ProcediaManufacturing	4
International Journal of Production Economics	4
Total Quality Management & Business Excellence	4
TQM	4
The International Journal of Advanced Manufacturing Technology	3
Advances in intelligent systems and computing	3
Production and ManufacturingResearch	2
The International Journal of cleaner production	2
Sensors	2
Production and ManufacturingResearch	2
Others (13journalswith 1 paper)	13

4.5 Enabling I4.0 technologies for Lean and SS

Regarding enabling technologies, the selected articles are classified into three categories. First, some articles deal with several technologies, which means that several digital technologies can be used simultaneously in LSS projects second, articles that deal with only one technology and finally articles that do not address any technology. Figure 7 presents the most discussed I4.0 technologies with either LSS, SS, or Lean. 36% of articles mentioned Big Data Analytics (BDA)'s ability to support lean manufacturing and smart LSS while the Internet of Things (IoT) came in second, accounting for 23% of articles that discussed LSS 4.0 and Lean 4.0. Cyber-Physical Systems (CPSs)and simulation follow in third place with 15% and 12% of the papers on smart lean and smart LSS. Finally, Artificial Intelligence (AI)accounts for 8% of the articles. The IoT, BDA, AM, AI and CPS are identified as the significant I4.0 that affect the LSS4.0 integration This result indicates that there is significant interest in using different new technologies, but especially BDA. This can be due to the fact that multinational companies have a high preference for the application of this technology (Makris et al., 2019).BDA offers the possibility to save, exploit and integrate practical solutions to current business problems in a timely manner. Big data techniques, that is, video mining, machine learning, and text mining support the identification of problem causes for better decision-making by providing in-depth information about the process(Dogan and Gurcan, 2018).

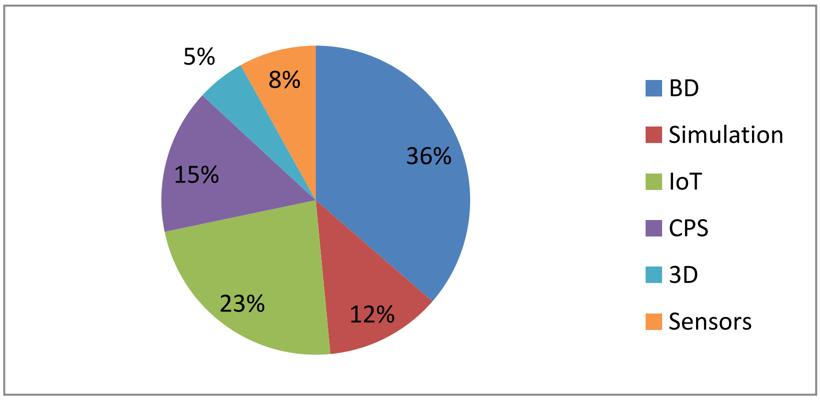

Figure7: I4.0 Enabling technologies

4.6 Distribution of studies across manufacturing Industry sectors

Figure8 shows the distribution of papers by manufacturing sector. This distribution suggests that the evaluated papers cover several different sectors. There is a predominance of automotive manufacturing industries for both LSS and I4.0 studies. The majority of empirical studies have examined manufacturing companies in automotive(38%), followed by metal industries(25%), food (15%) and textile (12%)while the chemical, heavy and electronics industries have attracted less attention from researchers(10%) and classed under others. The results reveal that 40 % of papers were conducted in the manufacturing environment with no specification of the sector are placed in multi sectors.

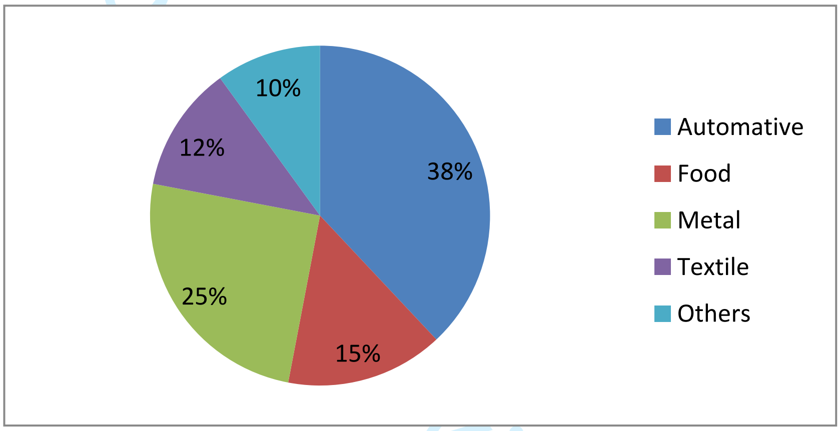

Figure8:Distribution of studies across manufacturing Industry sectors

5. Bibliometricsanalysis

The bibliometric analysis serves as a tool to create, visualize and analyze maps based on network data (Laengle et al. 2018). We conducted a bibliometric analysis using VOS software. Three co-occurrence networks have been evolved to identify the relationship between the concepts discussed: the co-author network, abstract co-occurrence terms, and keyword clusters.

5.1 Co-authorship analysis

In terms of co-authorship analysis, we have set 3 as the minimum of papers published by authors, 27 have been found to meet the criteria, but they are not connected to each other. The largest connected group has 5 authors, as shown in Figure 9. We conclude that there is a poor connection and collaboration between author clusters, which explains the novelty and scarcity of the topic. This may result in a lack of productivity and research intensity in this area and can be explained by the avoidance or inability of authors working in combined disciplines due to the scarcity of the topic. Hence a collaboration between authors is greatly recommended.

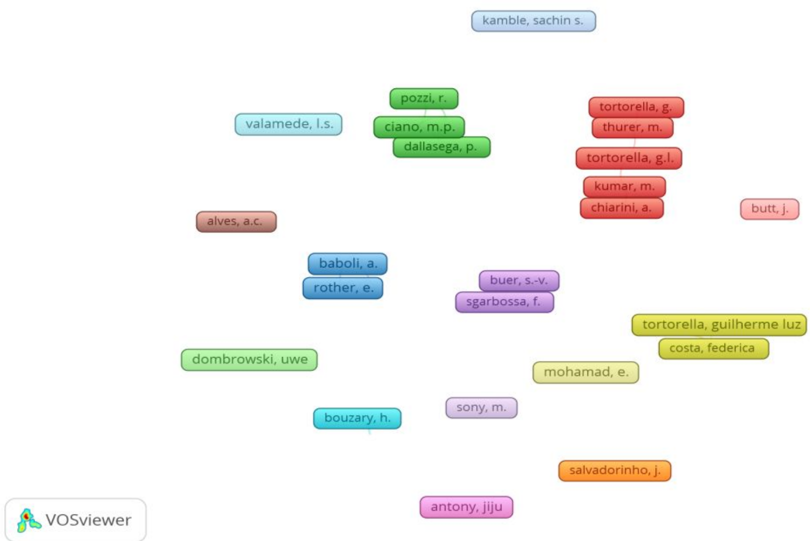

Figure 9: Co-authorship cluster network

5.2 Abstract occurrence density visualization

Figure 10 shows the abstract occurrence density visualization represented by three clusters. Ten was set as the minimum number of occurrences of a word, hence 15 of the 1287 terms match this criterion and eleven most relevant words were selected. The red cluster is the most prominent and represents the integration between lean and I4.0 while the green cluster related to LSS and the blue cluster representing I4.0 are discussed separately.

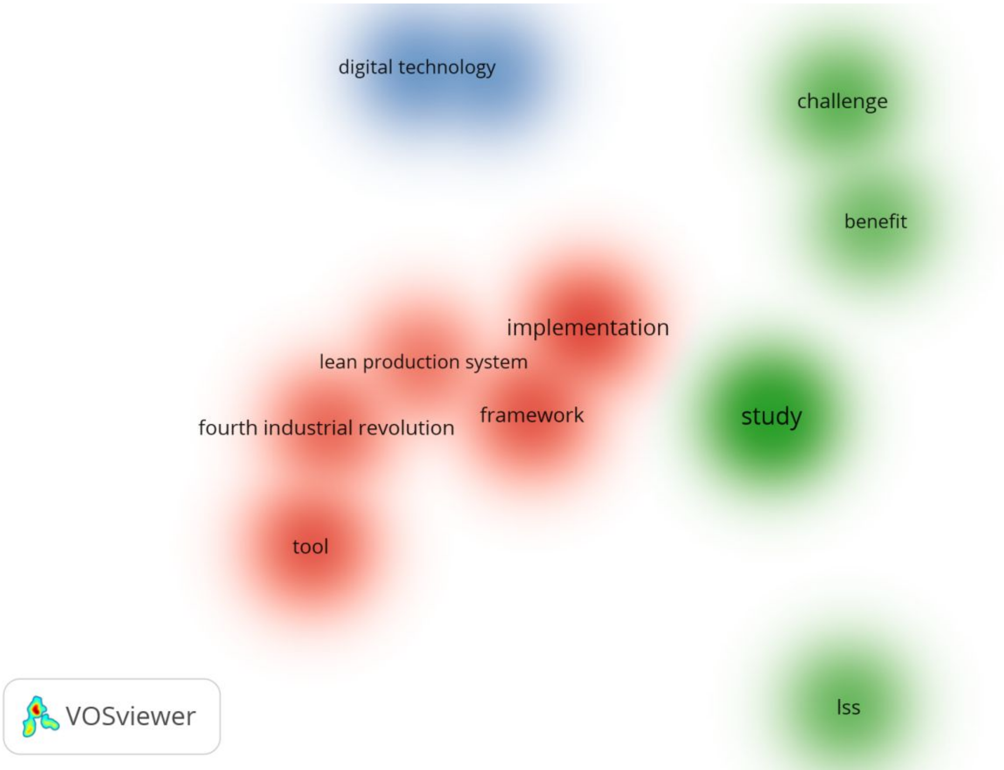

Figure 10: The abstract cluster network.

5.3 Keywords' occurrence

The main purpose of the keyword occurrence analysis is to assess the most used terms and their interactions. By setting the minimum number of occurrences for the keywords to three, we noticed that out of 100 keywords, 18 reached the criteria. However, 11 of the most relevant keywords were selected (Figure 11). The most frequently used word was "I4.0", followed by "lean manufacturing" and "LSS". I4.0 was linked to almost all other keywords, especially "lean". Indeed, the I4.0 tools par excellence are IoT and Big data. That is to say, numerous articles have addressed the link between lean, SS and I4.0, indicating the relevance of this integration.

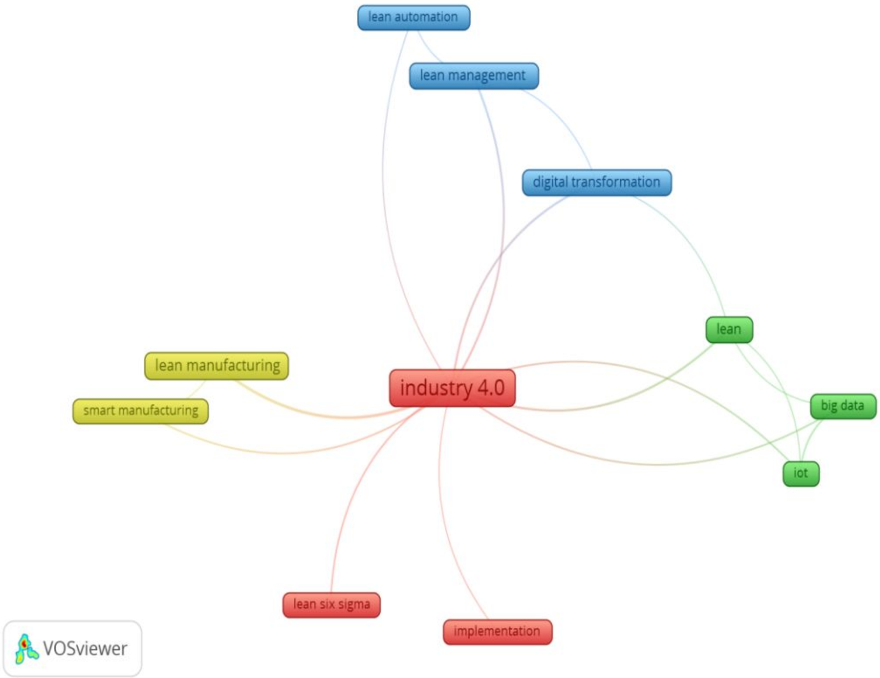

Figure 11: Keywords cluster network

6. Content analysis

A content analysis's main purpose is to identify, organize, and categorize ideas about a particular topic (Breslin&Gatrell, 2020). As such, an inductive content analysis was conducted, where data was extracted and coded into an Excel spreadsheet, including the title, research objective, concepts discussed, and I4.0 technologies discussed, among others. Next, we clustered the articles according to common themes. As a result, three main research foci emerged: (1) the relationship between Lean Six Sigma and I4.0; (2) the effects of combining I4.0 and LSS; and (3) performance (outcomes). The researchers have been focused on analyzing the relationship between LSS and I4.0 and the performance gathered through descriptive analysis and empirical studies, while integration model and implementation issues were neglected.

6.1 Industry 4.0 and LSS correlation

The majority of publications have discussed the correlation and synergies between LSS and I4.0. An analysis of the relationship between LSS and I4.0 is necessary before an implementation framework can be proposed (Antony et al., 2022). The detailed correlations that emerged from the literature are explained in section 7.3 and summarised in fig 13.

6.2 I4.0 impacts on LSS concept

One of the objectives of our study is to investigate how Industry 4.0 (I4.0) technologies can enhance Lean Six Sigma implementation. This section illustrates the impact of I4.0 technologies on the LSS subfields using the DMAIC methodology. Based on the authors' insights, we evaluate and report in Table 4 whether the technology has a moderate (+), strong (++), or no (0) impact on each DMAIC step and the corresponding activities. Some technologies have a cross-cutting impact on the DMAIC process, others affect only one step. The authors can highlight the evolving nature of literature on this topic. Most of the potential effects studied have been found to improve specific phases or sub-phases of LSS, which will ultimately lead to improved design and performance of LM/SS. For example, in their literature review study(Ahmed et al., 2020), the authors indicated that simulation techniques impact positively and directly all DMAIC stages, mainly the analysis, improvement and control phases, due to their ability to investigate and capture potential problems and improvement.

6.3 Performance (Outcomes)

Another cluster we identified was the LM, SS and I4.0 combination outcomes. We can highlight that researchers have studied the impact of this combination on firm performance in general and on the value chain and operational excellence in particular. Previous studies

(Acosta-Vargas et al., 2021; Buer et al., 2021; Kolberg and Zühlke, 2015; Prinz et al., 2018; Yadav et al., 2020) have suggested that the combination of Lean and I4.0 positively supported organizational performance and lead to improvements.

Table 4: Conceptual combination between DMAIC and I4.0 technologies

		BD /AI	IoT	CPS	Sensors	3D printing	Simulation	Cloud	AR/VR	Robotics
Define	• Define problem	++	++		++		++		++	
	• Define the goal						++		++	
	• Processmap	++	++		++		++	++	++	
	• Defineprocesscustomer	++	++		++		++	++	++	
	• Customer expectations.	++	++		++		++		++	
Measure	• Mappingcurrentprocess	++						+	++	
	• Defineprocess performance	++ ++			 ++		 ++			
	• Find the source of the problem	++			++			++		
	• Collect data									
Analyze	• Processanalysis	++					++	++		
	• Data analysis	++						++		
	• Potential causes analysis	++ ++					++ ++	++ ++		
	• Value streammapping						++			
Improve	• Brainstormproblems solutions	++					++			
	• Mapping of problems solutions	 ++	 ++				++			
	• Select and implement solutions						++			
	• Measureimprovement						++			
Control	• Value	++					++	++		
	• Flow	++					++	++		++
	• Pull	++			++		++	++		++
	• Perfection	++			++		++	++		++

(Sodhi, 2020) stated that by using IoT techniques with LSS methodology, the company can achieve higher performance by taking effective decisions and producing high-quality products. (Prinz et al., 2018) have predicted that productivity can be increased by Lean and I 4.0 implementations. This means that the integration of LSS and I4.0 promises a smarter, more efficient future for manufacturing processes. Due to the paucity of research and empirical studies on the LSS and I4.0 integration benefits, the increase in productivity and process efficiency can only be roughly estimated. McKinsey estimates that switching to automated production 4.0. can boost productivity by 45%-55%. Referring to these authors (Buer et al., 2020; Kolberg and Zühlke, 2015) I4.0 is expected to drive companies' operational performance by improving productivity and process efficiency, increasing profits, flexibility and competitiveness. The literature shows that the combination has a positive effect on improving performance indicators which should be confirmed empirically.

Based on the content analysis and the results of the previous section, we developed an integrated model Section 7.

7. An emergent framework to integrate LSS and I4.0

In light of the lack of a structured and comprehensive model for lean, SS, and I4.0 integration, we propose a framework for the implementation of these three concepts, based on the combination of theoretical elements resulting from the literature review. The framework is illustrated in Fig. 12 and follows a classic and iterative development process approach, from initial inputs and requirements to the final outcomes and benefits, where the traditional LSS-DMAIC process is translated into smart LSS called in this study LSS4.0 model. The framework outlines the drivers, barriers, synergies, challenges and critical success factors that are the primary component of the integrated model LSS4.0. A good understanding of these factors helps to define a managerial response on how best to implement LSS4.0. The proposed framework is part of a reflection and conception of the digital transformation of the LSS concept as a quality improvement tool, which tends to go beyond a technological perception in favour of a strategic vision of an intelligent and digital LSS. The objective of the framework is to support companies in their journey of development and transformation into digital LSS. The proposed model (Fig. 12) is structured by coupling the three building blocks: lean and SS concepts, I4.0 enabling technologies and digitalization. I4.0 means the digitalization of industry. Hence, in our model, I4.0 is represented by digital technologies 4.0 and digitalization detailed in Digital strategy, Digital maturity, and Digital transformation and resumed in 3D.

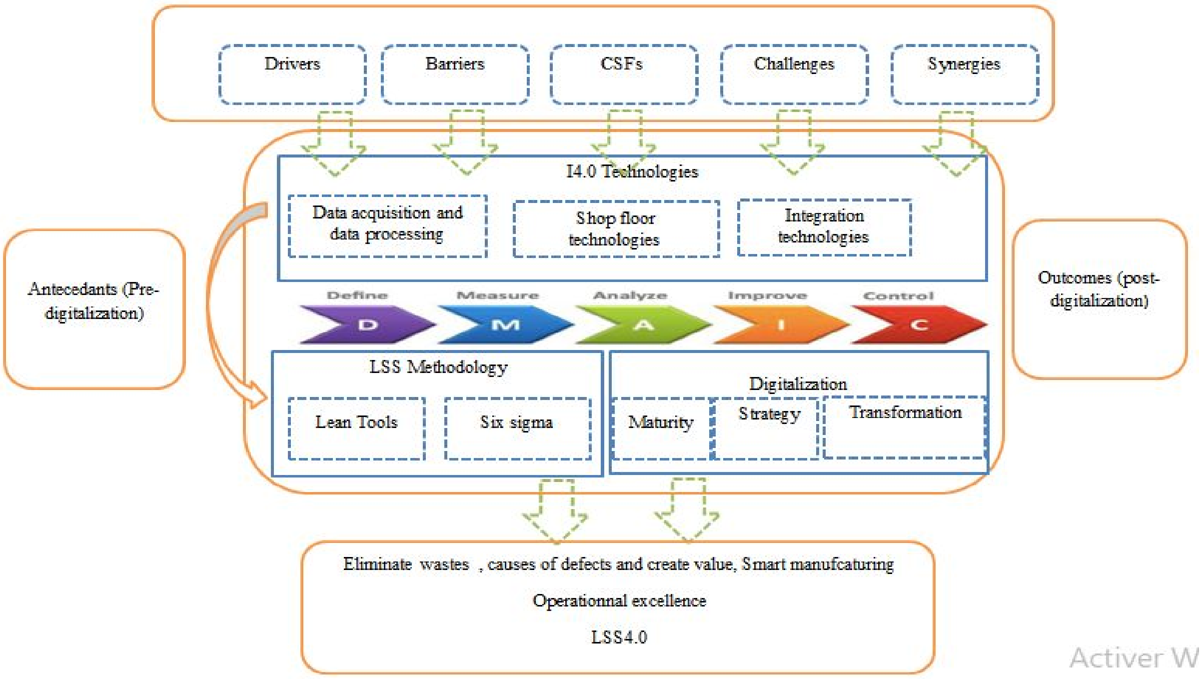

Figure 12: The proposed smart LSS framework

Our model starts with antecedents representing the enablers, i.e. the factors that make this integration possible. An analysis of the organization's antecedents is necessary. The questions that arise at this stage are: How are organizations prepared for the digitalization of LSS and what is the vision and strategy for moving towards digitalization? In other words, the company should identify its weaknesses and strengths related to the four dimensions of organization, people, process and technology by assessing their maturity level and clearly defining its objectives and expected results. It is necessary to assess the skills and competencies of the existing workforce. As stated by (Machado et al., 2019), digital awareness, skills and organization are the first steps for any digitalisation initiative. The successful deployment of every continuous improvement initiative depends heavily on the people which represent the most strategic asset of any company(Sven-Vegard Buer et al., 2018; Ciano et al., 2019).

On the other hand, we find drivers, barriers, CSFs and the relationship between LSS and I4.0 and their synergies on the top of our model representing the theoretical basis for such integration. Having knowledge of these factors and how the LM, SS ad I4.0 may impact or complement each other is crucial. Then, we found that the core of this model includes LM, SS, I4.0 technologies, and the digitization process to explain how this integration will address the trade-offs between these components to improve operational performance, The use of digital technologies and the resulting innovation can address many of the traditional challenges of LSS and provide benefits. Companies must choose the right technology investments based on their specific value-added potential and the most suitable I4.0 technologies that support LSS projects' achievement and improve operations. For example, augmented reality (AR) can have a direct impact on business performance by reducing time and avoiding human error, increasing productivity and quality, improving safety and facilitating maintenance and training. I4.0 stands for the digitalization of the production and value chain(Weking et al., 2020).In the context of I4.0, before its practical deployment, a strategic digitalization plan must be defined (Haddud and Khare, 2020; Machado et al., 2019; Schumacher et al., 2016). This involves assessing the company's digital maturity and defining the future action plan by clearly integrating the objectives to achieve (Kane et al., n.d.). Determining the level of **digital maturity** is critical to defining the appropriate **digital strategy** and the most appropriate and prioritized digital technologies. Being a smart manufacturer or having smart operations management does not imply deploying all I4.0 technologies. Referring to the literature, every digitalization project starts by defining an **I4.0 strategy** and objectives to which the smart and digital transformation will lead. Companies need to adapt their strategies in the current digital revolution to remain competitive (Helfat and Raubtischek 2018; Tallon et al. 2019). Since each manufacturing company has its own process and operations management, it will have a **digital strategy** and goals specific to each scenario. Hence, organizations must define their digital strategy according to their business model and need to place digital at the heart of their business strategy. To overcome the human resources resistance, **a change management strategy** must be defined, in order to allow a seamless shift to a digital management system (Fernández-Caramés, 2019). The objective of I4.0 is to digitalize the industry which concerns suppliers, corporate, operations, products and customers. **Digital transformation** means the integration of emerging digital technologies to solve complex problems and increase performance. (Butt, 2020). Digital transformation is a complex time and cost challenge. It is seen as a more general term that encompasses changes to business models, operations, processes and skills to take full advantage of the deployment of new technologies(Machado et al., 2019). Finally, we find the performance at the edge of the model, representing the result of the integration of the three concepts (lean, six sigma and industry 4.0). The outcomes involve performance and capabilities improvement to achieve represented by KPIs. Considering the following drivers, barriers, CSFs, synergies and benefits discussed below, a detailed comprehensive theoretical element of the LSS4.0 model is proposed in fig13.

7.1 Drivers and barriers

Drivers are the factors and reasons that motivate companies to embark on a project, while barriers are the factors that can impede successful implementation. Given that our research topic is an emerging research area, there is a lack of literature addressing motivations for the integration of LSS and I4.0, also empirical evidence is missing. The most quoted drivers behind LSS adoption are improving efficiency and performance of the manufacturing process (Cherrafi et al., 2016), cost reduction and profitability(M. Ghobakhloo, 2020), and market image (Stentoft et al., 2020). The discussed drivers are summarized in Table 14. On the other hand, the barriers that may hinder the LSS4.0 implementation are financial constraints, poor management support, low awareness, resistant behaviours, and lack of skills, which are also the main barriers to I4.0 implementation (Sony et al., 2021). (Butt, 2020) presents some I4.0 adoption barriers that include lack of expertise, lack of quantified financial benefits, and lack of skilled labour. The factors that emerged from the literature were regrouped into five family factors: managerial, environmental, people, financial, and technological and listed in Table 14.

7.2 CSFs

It is worth noting that the barriers to the LSS concept have been widely discussed in the literature. However, Industry 4.0, which was only mainstreamed in 2011 following an initiative launched by a group of business and industry, academia and government leaders in Germany, is still recent. The main objective of the I4.0 initiative was to promote German manufacturing companies and improve their competitiveness and business performance. Nevertheless, I4.0 faces many obstacles, including cybersecurity management, appropriate skills and high investment costs. Thus, studies on its barriers remain limited, especially those where I4.0 is combined with LSS. (Sony et al., 2021) have empirically investigated the CSFs of implementing I4.0 in both manufacturing and services.(Narula et al., 2020) studied the critical factors and sub-factors for I4.0 adoption in manufacturing industries and observed that non-technical factors including " organization, people, culture, skills" and " strategy, leadership" are the most prioritized, whereas technical aspects of technology, digital factory, operations, processes, applications are less prominent among the authors.

7.3 Benefits

As evidenced in the literature, both LSS and I4.0 have a positive impact on business performance and, when combined, they should lead to greater operational excellence.(Mrugalska and Wyrwicka, 2017)stated that lean manufacturing integrated with I4.0 can help achieve great flexibility of production systems and processes, realizing complex products and supply chains. (Kiel et al., 2017) have identified various benefits of I4.0 mainly, productivity and efficiency increase, expanded knowledge sharing and collaborative labour, agile and flexible process, better regulations conformity, better customer satisfaction, cost savings and increased business profits.

7.4 Synergies between LSS and I4.0

In terms of the link between LSS and I4.0, the authors point out in this section the synergies discussed by researchers. Several studies state that the two concepts are synergic and influence each other. Table 5 summarizes the main findings in the literature on the correlation between LM, SS and I4.0.The findings are categorized into three relationship perspectives :

(1) Lean-SS is a prerequisite for Industry 4.0. (Buer et al., 2018)explain that companies with a relatively advanced Lean maturity level are more likely to implement I4.0 in emerging economies.(Rossini et al., 2019) carried out a survey of108 European manufacturers that have already adopted lean philosophy. Their conclusions align strongly with (Buer et al., 2018) and imply that manufacturers aiming to integrate Industry 4.0 need to simultaneously implement lean manufacturing to drive process improvements. The same findings were stated by Tortorella and Fettermann (2018) as a result of a survey of 110 Brazilian manufacturing companies. **(2) Industry 4.0 and Lean-SS are mutually interactive.** According to some studies, lean/SS and I4.0 interact with each other and their combination positively affects performance(Anass et al., 2021; Anvari et al., 2021; Buer et al., 2020). (Anass et al., 2021) conducted a survey in a Moroccan context to study the connection between LSS and I4.0. The findings show that LSS and I4.0 are synergic and compatible. Similarly, a survey of manufacturing companies(Anvari et al., 2021)studied the relationship between Lean, plant digitization and operational performance. The results show that Lean and I4.0 are synergic and their combination leads to better operational performance. The authors confirmed empirically the complementarity effect of Lean and I4.0 on company performance. **(3) I4.0 supports and increases the efficiency of Lean-Six sigma.** In an empirical study (Kamble et al., 2020) investigated the impact of I4.0 on lean management based on a survey of 115 Indian manufacturing firms and found that I4.0 positively and directly impacts lean management. (Guilherme Luz Tortorella et al., 2019) Investigate the moderating effect of I4.0 technologies on lean supply chain practices and performance improvement through a survey of 147 Brazilian manufacturing companies. The results confirm that I4.0 has a positive impact on lean and improves performance. Industry 4.0 technologies have changed how organisations operate and react face to operational gaps. Sensors used in the IoT, which collect data at all levels of the manufacturing chain, are an important driver of innovation. This data helps to improve the analysis level in DMAIC approach (G. Arcidiacono, A. Pieroni 2018).

We synthesized drivers, barriers, CSFs and benefits found in the literature in Table 6.

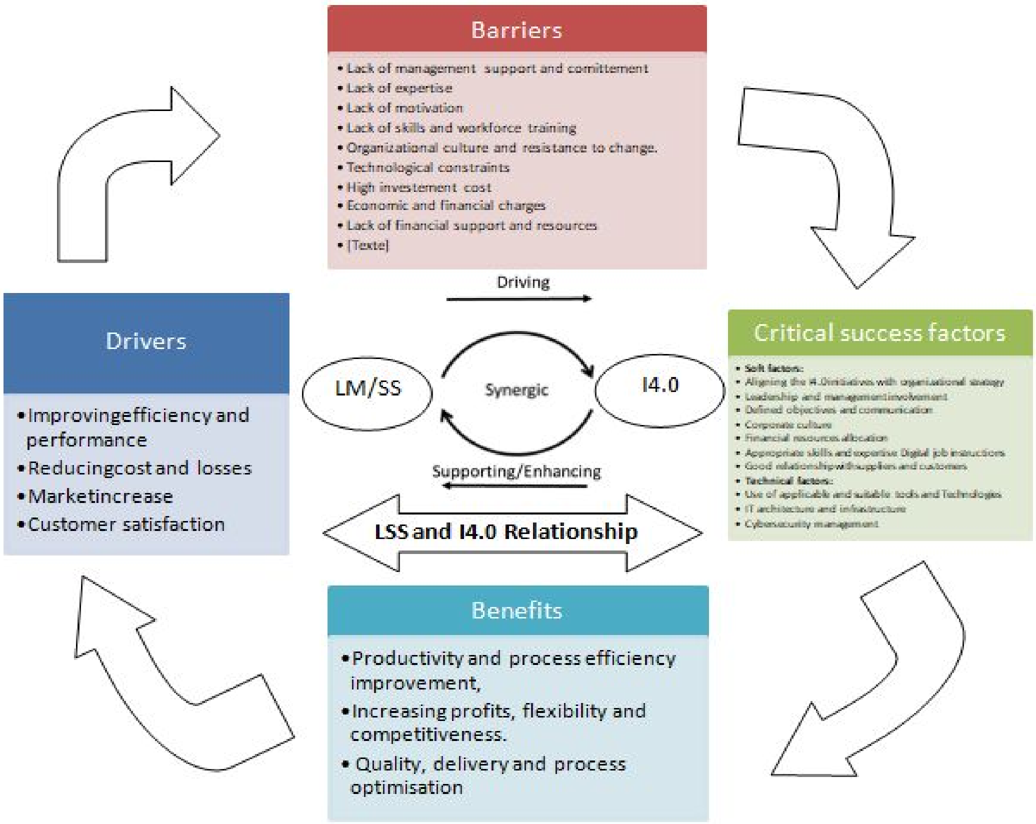

Figure 13: Comprehensive theoretical elements of the LSS4.0 model

8. Research gaps, implications for practitioners and future research directions

8.1 Research gaps and future research directions

The literature review provided us with in-depth knowledge about the research work related to the LSS4.0 concept. Few studies introduced LSS with I4.0, the research work is more focused on the lean combined with I4.0 rather than the potential integration of LSS and I4.0. The academic community's interest in the Lean 4.0 topic, revealed by the results of this study, is in line with the results of the SLR study conducted by (Tissir et al., 2022). We recommend more studies to empirically validate the existing findings.The reasons for the industry's delay in its digital journey include the lack of a roadmap that provides guidance for this transformation, the lack of awareness of digital capabilities, and the lack of required skills among employees and stakeholders.Based on the results, we identify gaps (fig 14) in the literature.

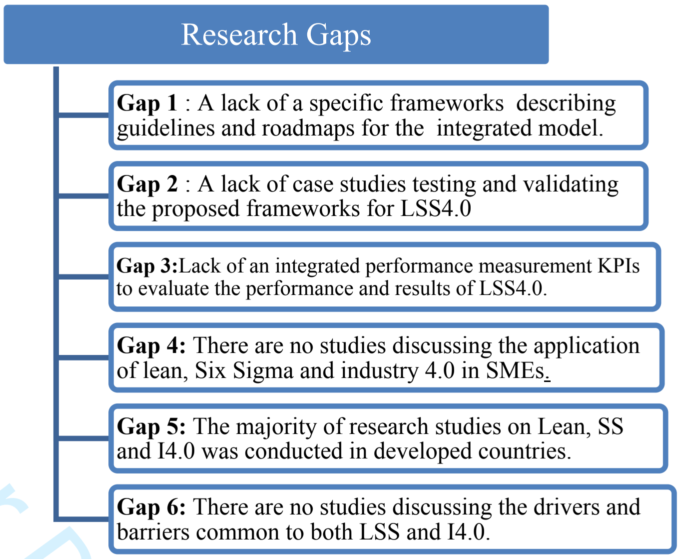

Figure 14: Research gaps

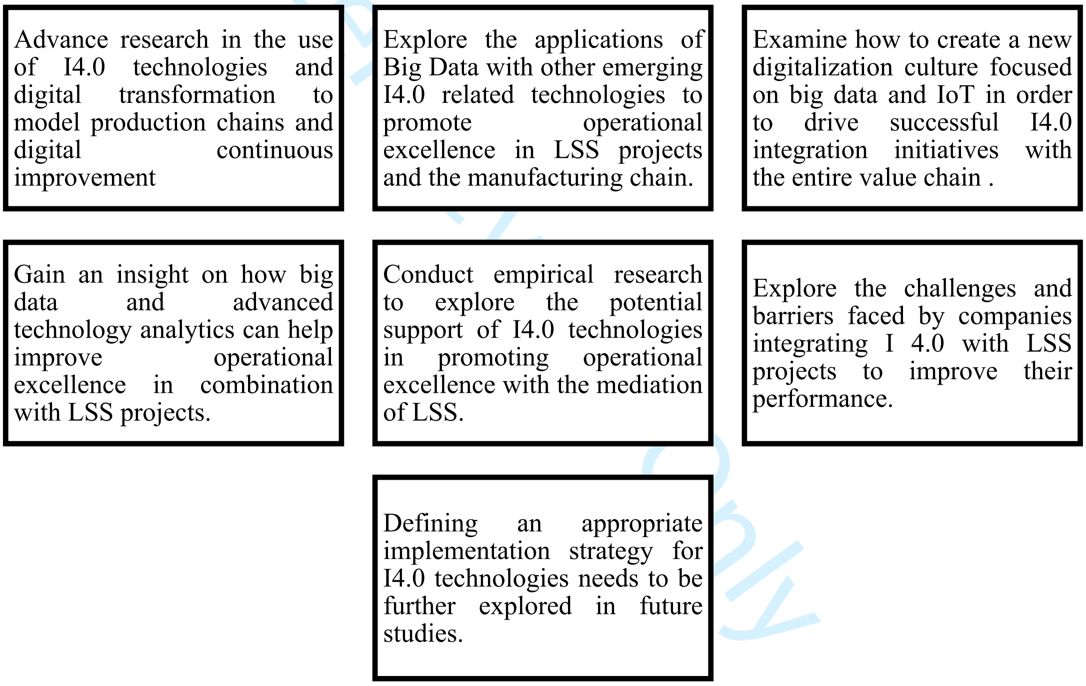

Figure15: Future research perspectives

We listed the future research paths for LSS4.0 (fig 15). We suggest that future studies explore empirically the drivers and the challenges of LSS4.0. We highly recommend the study of this integration model for SMEs. The proposed framework can be used in subsequent studies to conduct empirical studies to develop and validate the integration model of LSS and I4.0.

Structural equation modelling can be performed to analyze the effect of I4.0 on LSS and Operational excellence.

8.2 Implications for practitioners and researchers

The findings of the SLR study presented in the proposed framework will guide manufacturing companies in their journey towards operational excellence. The study identifies the relationships between I4.0 technologies and LSS and the key I4.0 technologies discussed in the literature to achieve integration leading to improved operational performance. Understanding the potential of digital technologies such as the IoT, cloud, big data, 3D printing and simulation, among others, will assist managers in driving smart and digital continuous improvement trends in their production systems.

This paper provides five main implications for both theory and practice.

- It is a good background about LSS4.0
- The literature review provides a comprehensive overview of the topic
- It describes the drivers, motivations, barriers, CSFs and impact of the novel technologies on LSS
- It can be used as a baseline for future research studies.
- A conceptual framework for LSS4.0 implementation is proposed that can serve as a roadmap for future work.

The insights gained from this study will inform future research programs on the integration of LSS4.0 with other management strategies such as Green manufacturing, Resilience, and Agility. We identified five emerging LSS4.0 trends (fig 16):

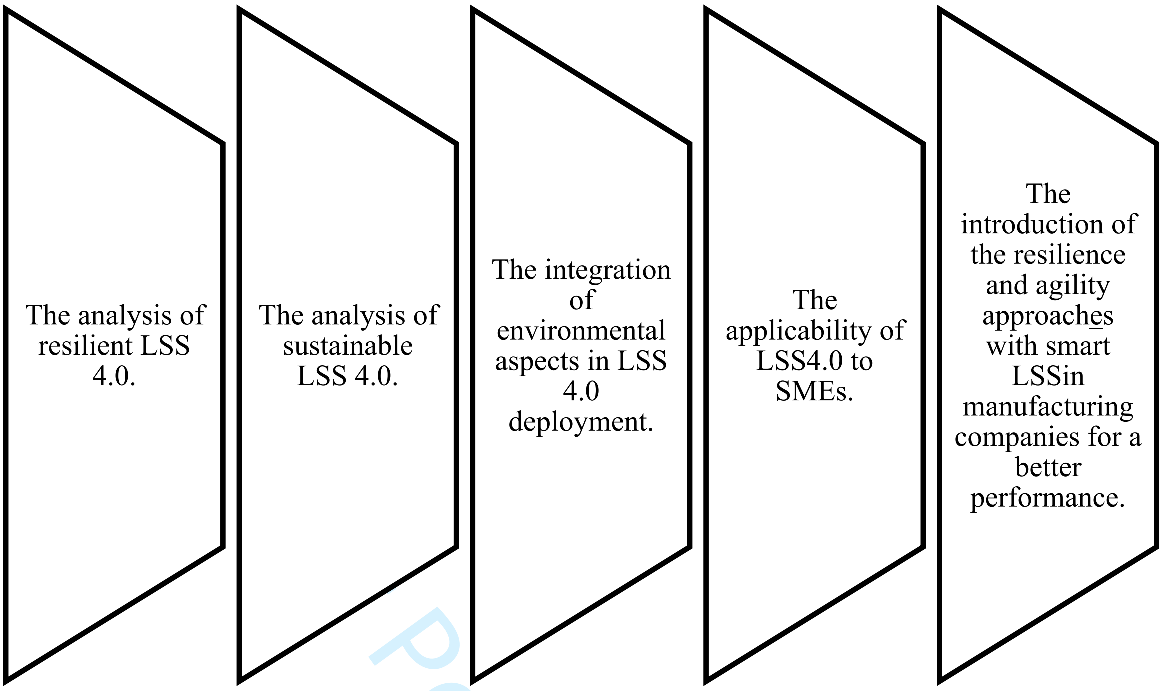

Fig 16: The emerging LSS4.0 trends

9. Conclusions

The purpose of this study was to explore the relationship between Lean Manufacturing, SS and I4.0 and investigate the current state of research by conducting a SLR. We identified 139 articles published between 2011 and May 2022 that were related to our research field. Several researchers in this area have examined quality management with emerging I4.0 technologies from a holistic perspective. However, literature focused on combining LSS with I4.0 technology components is scarce. Therefore, this study explores this area with a focus on LSS at the source. To the best of our knowledge, there is one systematic review article presenting a comprehensive review and classification of the literature, focusing specifically on the topic of LSS4.0. Rigorous bibliometric approaches revealed new insights that have not been fully evaluated elsewhere. Results show that LSS and I4.0 are mutually synergistic and compatible. The literature has mapped the links between LSS and I4.0 from 3 different perspectives: “LSS as the basis for I4.0”, “I4.0 as an enabler of LSS”, and “ I4.0 and lean complement each other”. Further empirical studies that include case studies and surveys must be conducted to confirm and validate the findings. This review identified the literature trends and gaps to define the theoretical elements of an integration model. We proposed a structured and integrated conceptual model for the combination of the two paradigms LSS and I4.0 in the context of manufacturing companies. The model will be applicable, independently of the industry, the area or the size of the business. We proposed a clear and coherent conceptual framework, which provides a structural synthesis of the literature findings and describes the relationships among the key concepts explored in this study and is supported by the results of the review. The framework will help managers to align I4.0's advanced technologies with the existing LSS data-driven methodology and guide future researchers to know emerging themes and existing collaborative opportunities in this research area. The limitation of this article is the subjectivity of the article selection. Also, we have limited our review to the manufacturing area. Publications on LSS and I4.0 are scarce and limited, as the research topic is an emerging area and still in its infancy. Furthermore, as Industry 4.0 was launched in Germany, there may have been relevant publications in the German language that we missed since we only consider articles published in English.

References

A. Al-Futaih, A., Demirkol, İ., 2020. The Relationship Between Industry 4.0 and Lean Production: An Empirical Study on Bursa Manufacturing Industry. J. Bus. Res. - Turk 12, 1083–1097. https://doi.org/10.20491/isarder.2020.897

Acosta-Vargas, P., Chicaiza-Salgado, E., Acosta-Vargas, I., Salvador-Ullauri, L., Gonzalez, M., 2021. Towards Industry Improvement in Manufacturing with DMAIC. Adv. Intell. Syst. Comput.

Ahmed, A., Page, J., Olsen, J., 2020. Enhancing Six Sigma methodology using simulation techniques: Literature review and implications for future research. Int. J. Lean Six Sigma 11, 211–232. https://doi.org/10.1108/IJLSS-03-2018-0033

Alexander, P., Antony, J., Cudney, E., 2021. A novel and practical conceptual framework to support Lean Six Sigma deployment in manufacturing SMEs. Total Qual. Manag. Bus. Excell. 1–31. https://doi.org/10.1080/14783363.2021.1945434

Ali, S., Xie, Y., 2021. The impact of Industry 4.0 on organizational performance: the case of Pakistan's retail industry. Eur. J. Manag. Stud. 26, 63–86. https://doi.org/10.1108/EJMS-01-2021-0009

Amjad, M.S., Rafique, M.Z., Khan, M.A., 2021a. Leveraging Optimized and Cleaner Production through Industry 4.0. Sustain. Prod. Consum. 26, 859–871. https://doi.org/10.1016/j.spc.2021.01.001

Amjad, M.S., Rafique, M.Z., Khan, M.A., 2021b. Leveraging Optimized and Cleaner Production through Industry 4.0. Sustain. Prod. Consum.

Anass, C., Amine, B., Ibtissam, E.H., Bouhaddou, I., Elfezazi, S., 2021. Industry 4.0 and Lean Six Sigma: Results from a Pilot Study. Lect. Notes Mech. Eng. 613–619. https://doi.org/10.1007/978-3-030-62199-5_54

Angreani, L.S., Vijaya, A., Wicaksono, H., 2020. Systematic Literature Review of Industry 4.0 Maturity Model for Manufacturing and Logistics Sectors. Procedia Manuf., System-Integrated Intelligence – Intelligent, Flexible and Connected Systems in Products and ProductionProceedings of the 5th International Conference on System-Integrated Intelligence (SysInt 2020), Bremen, Germany 52, 337–343. https://doi.org/10.1016/j.promfg.2020.11.056

Antony, J., Gupta, S., Sunder M., V., Gijo, E.V., 2018. Ten commandments of Lean Six Sigma: a practitioners' perspective. Int. J. Product. Perform. Manag. 67, 1033–1044. https://doi.org/10.1108/IJPPM-07-2017-0170

Antony, J., McDermott, O., Powell, D., Sony, M., 2022. The evolution and future of lean Six Sigma 4.0. TQM J. https://doi.org/10.1108/TQM-04-2022-0135

Antony, J., Sony, M., 2019. An empirical study into the limitations and emerging trends of Six Sigma in manufacturing and service organisations. Int. J. Qual. Reliab. Manag. 37, 470–493. https://doi.org/10.1108/IJQRM-07-2019-0230

Antosz, K., Stadnicka, D., 2018. Possibilities of maintenance service process analyses and improvement through six sigma, lean and industry 4.0 implementation. IFIP Adv. Inf. Commun. Technol. 540, 465–475. https://doi.org/10.1007/978-3-030-01614-2_43

Anvari, F., Edwards, R., Yuniarto, H.A., 2021. Lean Six Sigma in Smart Factories based on Industry 4.0 1, 26.

Arcidiacono, G., Pieroni, A., 2018a. The revolution Lean Six Sigma 4.0. Int. J. Adv. Sci. Eng. Inf. Technol. 8, 141–149. https://doi.org/10.18517/ijaseit.8.1.4593

Arcidiacono, G., Pieroni, A., 2018b. The Revolution Lean Six Sigma 4.0. Int. J. Adv. Sci. Eng. Inf. Technol. 8, 141. https://doi.org/10.18517/ijaseit.8.1.4593

Belhadi, A., Kamble, S.S., Zkik, K., Cherrafi, A., Touriki, F.E., 2020. The integrated effect of Big Data Analytics, Lean Six Sigma and Green Manufacturing on the environmental performance of manufacturing companies: The case of North Africa. J. Clean. Prod. 252, 119903. https://doi.org/10.1016/j.jclepro.2019.119903

Belhadi, A., Touriki, F.E., Elfezazi, S., 2019. Evaluation of critical success factors (CSFs) to lean implementation in SMEs using AHP: A case study. Int. J. Lean Six Sigma 10, 803–829. https://doi.org/10.1108/IJLSS-12-2016-0078

Bermúdez, M.D., Juárez, B.F., 2017. Competencies to adopt Industry 4.0 for operations management personnel at automotive parts suppliers in Nuevo Leon, in: Proceedings of the International Conference on Industrial Engineering and Operations Management.

Bhattacharya, A., Nand, A., Castka, P., 2019. Lean-green integration and its impact on sustainability performance: A critical review. J. Clean. Prod. 236. https://doi.org/10.1016/j.jclepro.2019.117697

Bittencourt, V.L., Alves, A.C., Leão, C.P., 2021. Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review. Int. J. Prod. Res. 59, 1496–1510. https://doi.org/10.1080/00207543.2020.1832274

Bittencourt, V.L., Alves, A.C., Leão, C.P., 2019. Lean Thinking contributions for Industry 4.0: A systematic literature review. IFAC-Pap. 52, 904–909. https://doi.org/10.1016/j.ifacol.2019.11.310

Buer, Sven-Vegard, Fragapane, G.I., Strandhagen, J.O., 2018. The Data-Driven Process Improvement Cycle: Using Digitalization for Continuous Improvement. IFAC-Pap. 51, 1035–1040. https://doi.org/10.1016/j.ifacol.2018.08.471

Buer, S.-V., Semini, M., Strandhagen, J.O., Sgarbossa, F., 2021. The complementary effect of lean manufacturing and digitalisation on operational performance. Int. J. Prod. Res.

Buer, S.-V., Semini, M., Strandhagen, J.O., Sgarbossa, F., 2020. The complementary effect of lean manufacturing and digitalisation on operational performance. Int. J. Prod. Res. https://doi.org/10.1080/00207543.2020.1790684

Buer, S.-V., Strandhagen, J.O., Chan, F.T.S., 2018. The link between industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda. Int. J. Prod. Res. 56, 2924–2940. https://doi.org/10.1080/00207543.2018.1442945

Burggräf, P., Lorber, C., Pyka, A., Wagner, J., Weißer, T., 2020. Kaizen 4.0 Towards an Integrated Framework for the Lean-Industry 4.0 Transformation. Adv. Intell. Syst. Comput.

Butt, J., 2020. A strategic roadmap for the manufacturing industry to implement industry 4.0. Designs 4, 1–31. https://doi.org/10.3390/designs4020011

Calış Duman, M., Akdemir, B., 2021. A study to determine the effects of industry 4.0 technology components on organizational performance. Technol. Forecast. Soc. Change 167, 120615. https://doi.org/10.1016/j.techfore.2021.120615

Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., Benhida, K., 2017. Exploring Critical Success Factors for Implementing Green Lean Six Sigma, in: Brennan, L., Vecchi, A. (Eds.), International Manufacturing Strategy in a Time of Great Flux, Measuring Operations Performance. Springer International Publishing, Cham, pp. 183–195. https://doi.org/10.1007/978-3-319-25351-0_9

Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., Benhida, K., 2016. The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model. J. Clean. Prod. 139, 828–846. https://doi.org/10.1016/j.jclepro.2016.08.101

Chettri, L., Bera, R., 2020. Industry 4.0: Communication technologies, challenges and research perspective towards 5G systems. Lect. Notes Electr. Eng. 662, 67–77. https://doi.org/10.1007/978-981-15-4932-8_9

Chiarini, A., 2020. Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research. TQM J. 32, 603–616. https://doi.org/10.1108/TQM-04-2020-0082

Ciano, M.P., Strozzi, F., Minelli, E., Pozzi, R., Rossi, T., 2019. The link between lean and human resource management or organizational behaviour: A bibliometric review, in: Proceedings of the Summer School Francesco Turco. pp. 321–328.

Costa, F., Portioli-Staudacher, A., 2020. On the Way of a Factory 4.0: The Lean Role in a Real Company Project. Lect. Notes Netw. Syst. 122, 251–259. https://doi.org/10.1007/978-3-030-41429-0_25

Cresnar, R., Potocan, V., Nedelko, Z., 2020. Speeding Up the Implementation of Industry 4.0 with Management Tools: Empirical Investigations in Manufacturing Organizations. Sensors 20, 3469. https://doi.org/10.3390/s20123469

Culot, G., Nassimbeni, G., Orzes, G., Sartor, M., 2020. Behind the definition of Industry 4.0: Analysis and open questions. Int. J. Prod. Econ. 226, 107617. https://doi.org/10.1016/j.ijpe.2020.107617

Denyer, D., Tranfield, D., 2009. Producing a systematic review. undefined.

de Sousa Jabbour, A., Chiappetta-Jabbour, C., Filho, M., Roubaud, D., 2018. Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann. Oper. Res. 270. https://doi.org/10.1007/s10479-018-2772-8.

Ding, B., Ferràs Hernández, X., Agell Jané, N., 2021. Combining lean and agile manufacturing competitive advantages through Industry 4.0 technologies: an integrative approach. Prod. Plan. Control 1–17. https://doi.org/10.1080/09537287.2021.1934587

Dogan, O., Gurcan, O.F., 2018a. Data perspective of lean six sigma in industry 4.0 era: A guide to improve quality, in: Proceedings of the International Conference on Industrial Engineering and Operations Management. pp. 943–953.

Dogan, O., Gurcan, O.F., 2018b. Data perspective of lean six sigma in industry 4.0 era: A guide to improve quality. Presented at the Proceedings of the International Conference on Industrial Engineering and Operations Management, pp. 943–953.

Dombrowski, U., n.d. The Lean Production System 4.0 Framework – Enhancing Lean Methods by Industrie 4.0 7.

Duarte, S., Cabrita, M. do R., Cruz-Machado, V., 2020. Business Model, Lean and Green Management and Industry 4.0: A Conceptual Relationship, in: Xu, J., Ahmed, S.E., Cooke, F.L., Duca, G. (Eds.), Proceedings of the Thirteenth International Conference on Management Science and Engineering Management, Vol 1. Springer International Publishing Ag, Cham, pp. 359–372.

Ejsmont, K., Gladysz, B., Corti, D., Castaño, F., Mohammed, W.M., Martinez Lastra, J.L., 2020. Towards 'Lean Industry 4.0′ – Current trends and future perspectives. Cogent Bus. Manag. 7, 1781995. https://doi.org/10.1080/23311975.2020.1781995

Fortuny-Santos, J., López, P.R.-D.-A., Luján-Blanco, I., Chen, P.-K., 2020. Assessing the synergies between lean manufacturing and Industry 4.0. Direccion Organ. 71–86. https://doi.org/10.37610/dyo.v0i71.579

Gallab, M., Bouloiz, H., Kebe, S.A., Tkiouat, M., 2021. Opportunities and challenges of the industry 4.0 in industrial companies: a survey on Moroccan firms. J. Ind. Bus. Econ. 48, 413–439. https://doi.org/10.1007/s40812-021-00190-1

Gallo, T., Cagnetti, C., Silvestri, C., Ruggieri, A., 2021. Industry 4.0 tools in lean production: A systematic literature review. Presented at the Procedia Computer Science, pp. 394–403. https://doi.org/10.1016/j.procs.2021.01.255

Garza-Reyes, J.A., 2015. Lean and green – a systematic review of the state of the art literature. J. Clean. Prod. 102, 18–29. https://doi.org/10.1016/j.jclepro.2015.04.064

Ghobakhloo, Morteza, 2020. Determinants of information and digital technology implementation for smart manufacturing. Int. J. Prod. Res. 58, 2384–2405. https://doi.org/10.1080/00207543.2019.1630775

Ghobakhloo, M., 2020. Industry 4.0, digitization, and opportunities for sustainability. J. Clean. Prod. 252. https://doi.org/10.1016/j.jclepro.2019.119869

Gill, M., VanBoskirk, S., 2016. The Digital Maturity Model 4.0 17.

Gupta, S., Modgil, S., Gunasekaran, A., 2020. Big data in lean six sigma: a review and further research directions. Int. J. Prod. Res. 58, 947–969. https://doi.org/10.1080/00207543.2019.1598599

Gupta, Shivam, Modgil, S., Gunasekaran, A., 2020. Big data in lean six sigma: a review and further research directions. Int. J. Prod. Res. 58, 947–969. https://doi.org/10.1080/00207543.2019.1598599

Haddud, A., DeSouza, A., Khare, A., Lee, H., 2017. Examining potential benefits and challenges associated with the Internet of Things integration in supply chains. J. Manuf. Technol. Manag. 28, 1055–1085. https://doi.org/10.1108/JMTM-05-2017-0094

Haddud, A., Khare, A., 2020. Digitalizing supply chains potential benefits and impact on lean operations. Int. J. Lean Six Sigma 11, 731–765. https://doi.org/10.1108/IJLSS-03-2019-0026

Hseng-Long Yeh, 2011. Applying lean six sigma to improve healthcare: An empirical study. Afr. J. Bus. Manag. 5. https://doi.org/10.5897/AJBM11.1654

Javaid, M., Haleem, A., 2020. Critical components of industry 5.0 towards a successful adoption in the field of manufacturing. J. Ind. Integr. Manag. 5, 327–348. https://doi.org/10.1142/S2424862220500141

Javaid, M., Haleem, A., Singh, R.P., Rab, S., Suman, R., Khan, S., 2022. Exploring relationships between Lean 4.0 and manufacturing industry. Ind. Robot Int. J. Robot. Res. Appl. 49, 402–414. https://doi.org/10.1108/IR-08-2021-0184

Jayaram, A., 2016. Lean six sigma approach for global supply chain management using industry 4.0 and IIoT. Presented at the Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics, IC3I 2016, pp. 89–94. https://doi.org/10.1109/IC3I.2016.7917940

Jiménez, M., Romero, L., Fernández, J., Espinosa, M.M., Domínguez, M., 2020. Application of lean 6s methodology in an engineering education environment during the sars-cov-2 pandemic. Int. J. Environ. Res. Public. Health 17, 1–25. https://doi.org/10.3390/ijerph17249407

Jordan, E., Kušar, J., Rihar, L., Berlec, T., 2019. Portfolio analysis of a Lean Six Sigma production process. Cent. Eur. J. Oper. Res. 27, 797–813. https://doi.org/10.1007/s10100-019-00613-4

Kamble, S., Gunasekaran, A., Dhone, N.C., 2020. Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies. Int. J. Prod. Res. 58, 1319–1337. https://doi.org/10.1080/00207543.2019.1630772

Kamble, S.S., Gunasekaran, A., Sharma, R., 2018. Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. Comput. Ind. 101, 107–119. https://doi.org/10.1016/j.compind.2018.06.004

Kane, G.C., Palmer, D., Phillips, A.N., Kiron, D., Buckley, N., n.d. Learning, Leadership, and Legacy 33.

Karadayi-Usta, S., 2020. An Interpretive Structural Analysis for Industry 4.0 Adoption Challenges. IEEE Trans. Eng. Manag. 67, 973–978. https://doi.org/10.1109/TEM.2018.2890443

Khan, A., Turowski, K., 2016. A Survey of Current Challenges in Manufacturing Industry and Preparation for Industry 4.0, in: Abraham, A., Kovalev, S., Tarassov, V., Snášel, V. (Eds.), Proceedings of the First International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'16), Advances in Intelligent Systems and Computing. Springer International Publishing, Cham, pp. 15–26. https://doi.org/10.1007/978-3-319-33609-1_2

Kiel, D., Müller, J.M., Arnold, C., Voigt, K.-I., 2017. SUSTAINABLE INDUSTRIAL VALUE CREATION: BENEFITS AND CHALLENGES OF INDUSTRY 4.0. Int. J. Innov. Manag. 21, 1740015. https://doi.org/10.1142/S1363919617400151

Koh, L., Orzes, G., Jia, F. (Jeff), 2019. The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management. Int. J. Oper. Prod. Manag. 39, 817–828. https://doi.org/10.1108/IJOPM-08-2019-788

Kolberg, D., Zuehlke, D., 2015. Lean Automation enabled by Industry 4.0 Technologies. Ifac Pap. 48, 1870–1875. https://doi.org/10.1016/j.ifacol.2015.06.359

Kolberg, D., Zühlke, D., 2015. Lean Automation enabled by Industry 4.0 Technologies. Presented at the IFAC-PapersOnLine, pp. 1870–1875. https://doi.org/10.1016/j.ifacol.2015.06.359

Kumar, M., 2007. Critical success factors and hurdles to Six Sigma implementation: the case of a UK manufacturing SME. Int. J. Six Sigma Compet. Advant. 3, 333. https://doi.org/10.1504/IJSSCA.2007.017176

Kumar, P., Bhadu, J., Singh, D., Bhamu, J., 2021. Integration between Lean, Six Sigma and Industry 4.0 technologies. Int. J. Six Sigma Compet. Advant. 13, 19. https://doi.org/10.1504/IJSSCA.2021.120224

Kumar, R., Singh, R.Kr., Dwivedi, Y.Kr., 2020. Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges. J. Clean. Prod. 275, 124063. https://doi.org/10.1016/j.jclepro.2020.124063

Lameijer, B.A., Pereira, W., Antony, J., 2021. The implementation of Lean Six Sigma for operational excellence in digital emerging technology companies. J. Manuf. Technol. Manag. 32, 260–284. https://doi.org/10.1108/JMTM-09-2020-0373

Laureani, A., Antony, J., 2012. Critical success factors for the effective implementation of Lean Sigma: Results from an empirical study and agenda for future research. Int. J. Lean Six Sigma 3, 274–283. https://doi.org/10.1108/20401461211284743

Lee, J., Bagheri, B., Kao, H.-A., 2015. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manuf. Lett. 3, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

Leong, W.D., Lam, H.L., Ng, W.P.Q., Lim, C.H., Tan, C.P., Ponnambalam, S.G., 2019. Lean and Green Manufacturing—a Review on its Applications and Impacts. Process Integr. Optim. Sustain. 3, 5–23. https://doi.org/10.1007/s41660-019-00082-x

Machado, C.G., Winroth, M., Carlsson, D., Almström, P., Centerholt, V., Hallin, M., 2019. Industry 4.0 readiness in manufacturing companies: challenges and enablers towards increased digitalization. Procedia CIRP 81, 1113–1118. https://doi.org/10.1016/j.procir.2019.03.262

Mahdavisharif, M., Cagliano, A.C., Rafele, C., 2022. Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review. Appl. Sci. 12, 586. https://doi.org/10.3390/app12020586

Mayr, A., Weigelt, M., Kühl, A., Grimm, S., Erll, A., Potzel, M., Franke, J., 2018. Lean 4.0-A conceptual conjunction of lean management and Industry 4.0. Presented at the Procedia CIRP, pp. 622–628. https://doi.org/10.1016/j.procir.2018.03.292

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., Barbaray, R., 2018. The industrial management of SMEs in the era of Industry 4.0. Int. J. Prod. Res. 56, 1118–1136. https://doi.org/10.1080/00207543.2017.1372647

Mohamed, M., 2018. Challenges and Benefits of Industry 4.0: an overview. https://doi.org/10.22034/2018.3.7

Mrugalska, B., Wyrwicka, M.K., 2017. Towards Lean Production in Industry 4.0. Procedia Eng. 182, 466–473. https://doi.org/10.1016/j.proeng.2017.03.135

Narula, S., Prakash, S., Dwivedy, M., Talwar, V., Tiwari, S.P., 2020. Industry 4.0 adoption key factors: an empirical study on manufacturing industry. J. Adv. Manag. Res. 17, 697–725. https://doi.org/10.1108/JAMR-03-2020-0039

Narula, S., Puppala, H., Kumar, A., Luthra, S., Dwivedy, M., Prakash, S., Talwar, V., 2022. Are Industry 4.0 technologies enablers of lean? Evidence from manufacturing industries. Int. J. Lean Six Sigma ahead-of-print. https://doi.org/10.1108/IJLSS-04-2021-0085

Nicoletti, B., 2013. Lean Six Sigma and digitize procurement. Int. J. Lean Six Sigma 4, 184–203. https://doi.org/10.1108/20401461311319356

Ojha, R., 2022. Lean in industry 4.0 is accelerating manufacturing excellence – A DEMATEL analysis. TQM J. ahead-of-print. https://doi.org/10.1108/TQM-11-2021-0318

Olaitan, O., Rotondo, A., Geraghty, J., Young, P., 2019. Benefits and challenges of lean manufacturing in make-to-order systems, Lean Manufacturing: Implementation, Opportunities and Challenges.

Oztemel, E., Gursev, S., 2020. Literature review of Industry 4.0 and related technologies. J. Intell. Manuf. 31, 127–182. https://doi.org/10.1007/s10845-018-1433-8

Pagliosa, M., Tortorella, G., Ferreira, J.C.E., 2019. Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions. J. Manuf. Technol. Manag. https://doi.org/10.1108/JMTM-12-2018-0446

Palaci-Lopez, D., Borras-Ferris, J., da Silva de Oliveria, L.T., Ferrer, A., 2020. Multivariate Six Sigma: A Case Study in Industry 4.0. Processes 8, 1119. https://doi.org/10.3390/pr8091119

Panayiotou, N.A., Stergiou, K.E., Panagiotou, N., 2021. Using Lean Six Sigma in small and medium-sized enterprises for low-cost/high-effect improvement initiatives: a case study. Int. J. Qual. Reliab. Manag. ahead-of-print. https://doi.org/10.1108/IJQRM-01-2021-0011

Pardamean Gultom, G.D., Wibisono, E., 2019. A framework for the impact of lean six sigma on supply chain performance in manufacturing companies. https://doi.org/10.1088/1757-899X/528/1/012089

Park, S.H., Dahlgaard-Park, S.M., Kim, D.-C., 2020. New Paradigm of Lean Six Sigma in the 4th Industrial Revolution Era. Qual. Innov. Prosper. 24, 1. https://doi.org/10.12776/qip.v24i1.1430

Pasi, B.N., Mahajan, S.K., Rane, S.B., 2020. The current sustainability scenario of Industry 4.0 enabling technologies in Indian manufacturing industries. Int. J. Product. Perform. Manag. https://doi.org/10.1108/IJPPM-04-2020-0196

Pepper, M.P.J., Spedding, T.A., 2010. The evolution of lean Six Sigma. Int. J. Qual. Reliab. Manag. 27, 138–155. https://doi.org/10.1108/02656711011014276

Powell, D., Romero, D., Gaiardelli, P., Cimini, C., Cavalieri, S., 2018. Towards digital lean cyber-physical production systems: Industry 4.0 technologies as enablers of leaner production. IFIP Adv. Inf. Commun. Technol. 536, 353–362. https://doi.org/10.1007/978-3-319-99707-0_44

Pozzi, R., Rossi, T., Secchi, R., 2021. Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies. Prod. Plan. Control 1–21. https://doi.org/10.1080/09537287.2021.1891481

Prinz, C., Kreggenfeld, N., Kuhlenkötter, B., 2018. Lean meets Industrie 4.0 – a practical approach to interlink the method world and cyber-physical world. Procedia Manuf. 23, 21–26. https://doi.org/10.1016/j.promfg.2018.03.155

Psomas, E., Antony, J., 2019. Research gaps in Lean manufacturing: a systematic literature review. Int. J. Qual. Reliab. Manag. 36, 815–839. https://doi.org/10.1108/IJQRM-12-2017-0260

Radziwill, N.M., 2018. The Fourth Industrial Revolution: Klaus Schwab. 2016. World Economic Forum, Geneva, Switzerland. 184 pages. Qual. Manag. J. 25, 108–109. https://doi.org/10.1080/10686967.2018.1436355

Raj, A., Dwivedi, G., Sharma, A., Lopes de Sousa Jabbour, A.B., Rajak, S., 2020. Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. Int. J. Prod. Econ. 224, 107546. https://doi.org/10.1016/j.ijpe.2019.107546

Raji, I.O., Rossi, T., 2019. Exploring industry 4.0 technologies as drivers of lean and agile supply chain strategies, in: Proceedings of the International Conference on Industrial Engineering and Operations Management. pp. 292–303.

Rojko, A., 2017. Industry 4.0 Concept: Background and Overview. Int. J. Interact. Mob. Technol. IJIM 11, 77. https://doi.org/10.3991/ijim.v11i5.7072

Romero, D., Gaiardelli, P., Powell, D., Wuest, T., Thürer, M., 2018. Digital Lean Cyber-Physical Production Systems: The Emergence of Digital Lean Manufacturing and the Significance of Digital Waste, in: Moon, I., Lee, G.M., Park, J., Kiritsis, D., von Cieminski, G. (Eds.), Advances in Production Management Systems. Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing, IFIP Advances in Information and Communication Technology. Springer International Publishing, Cham, pp. 11–20. https://doi.org/10.1007/978-3-319-99704-9_2

Rosin, F., Forget, P., Lamouri, S., Pellerin, R., 2020. Impacts of Industry 4.0 technologies on Lean principles. Int. J. Prod. Res.

Rossini, M., Costa, F., Staudacher, A.P., Tortorella, G., 2019. Industry 4.0 and Lean Production: an empirical study. IFAC-Pap., 9th IFAC Conference on Manufacturing Modelling, Management and Control MIM 2019 52, 42–47. https://doi.org/10.1016/j.ifacol.2019.11.122

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

Sanders, A., Elangeswaran, C., Wulfsberg, J., 2016. Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. J. Ind. Eng. Manag. 9, 811–833. https://doi.org/10.3926/jiem.1940

Sanders, A., K. Subramanian, K.R., Redlich, T., Wulfsberg, J.P., 2017. Industry 4.0 and lean management – synergy or contradiction?: A systematic interaction approach to determine the compatibility of industry 4.0 and lean management in manufacturing environment. IFIP Adv. Inf. Commun. Technol. 514, 341–349. https://doi.org/10.1007/978-3-319-66926-7_39

Sanders, Adam, Subramanian, K.R.K., Redlich, T., Wulfsberg, J.P., 2017. Industry 4.0 and Lean Management - Synergy or Contradiction? A Systematic Interaction Approach to Determine the Compatibility of Industry 4.0 and Lean Management in Manufacturing Environment, in: Lodding, H., Riedel, R., Thoben, K.D., VonCieminski, G., Kiritsis, D. (Eds.), Advances in Production Management Systems: The Path to Intelligent, Collaborative and Sustainable Manufacturing. Springer International Publishing Ag, Cham, pp. 341–349. https://doi.org/10.1007/978-3-319-66926-7_39

Schumacher, A., Erol, S., Sihn, W., 2016. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. Procedia CIRP 52, 161–166. https://doi.org/10.1016/j.procir.2016.07.040

Schwab, K., n.d. The Global Competitiveness Report 2019 666.

Shah, R., Chandrasekaran, A., Linderman, K., 2008. In pursuit of implementation patterns: the context of Lean and Six Sigma. Int. J. Prod. Res. 46, 6679–6699. https://doi.org/10.1080/00207540802230504

Shrouf, F., Ordieres, J., Miragliotta, G., 2014. Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm, in: 2014 IEEE International Conference on Industrial Engineering and Engineering Management. Presented at the 2014 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), IEEE, Selangor Darul Ehsan, Malaysia, pp. 697–701. https://doi.org/10.1109/IEEM.2014.7058728

Sodhi, H., 2020. When Industry 4.0 meets Lean Six Sigma: A review. Ind. Eng. J. 13. https://doi.org/10.26488/IEJ.13.1.1214

Sony, M., 2020. Design of cyber physical system architecture for industry 4.0 through lean six sigma: conceptual foundations and research issues. Prod. Manuf. Res. 8, 158–181. https://doi.org/10.1080/21693277.2020.1774814

Sony, M., 2018. Industry 4.0 and lean management: a proposed integration model and research propositions. Prod. Manuf. Res. 6, 416–432. https://doi.org/10.1080/21693277.2018.1540949

Sony, M., Antony, J., Mc Dermott, O., Garza-Reyes, J.A., 2021. An empirical examination of benefits, challenges, and critical success factors of industry 4.0 in manufacturing and service sector. Technol. Soc. 67, 101754. https://doi.org/10.1016/j.techsoc.2021.101754

Sony, M., Naik, S., 2020. Critical factors for the successful implementation of Industry 4.0: a review and future research direction. Prod. Plan. Control 31, 799–815. https://doi.org/10.1080/09537287.2019.1691278

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., Haug, A., 2021. Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. Prod. Plan. Control 32, 811–828. https://doi.org/10.1080/09537287.2020.1768318

Tay, S.I., Malaysia, T.H.O., Raja, P., Pahat, B., Hamid, N.A.A., Ahmad, A.N.A., 2018. An Overview of Industry 4.0: Definition, Components, and Government Initiatives. Control Syst. 10, 10.

Tissir, S., Cherrafi, A., Chiarini, A., Elfezazi, S., Bag, S., 2022. Lean Six Sigma and Industry 4.0 combination: scoping review and perspectives. Total Qual. Manag. Bus. Excell. 1–30. https://doi.org/10.1080/14783363.2022.2043740

Tortorella, Guilherme, Miorando, R., Francisco, A., Cawley, M., 2019. The moderating effect of Industry 4.0 on the relationship between lean supply chain management and performance improvement (vol 24, pg 301, 2019). Supply Chain Manag.- Int. J. 24. https://doi.org/10.1108/SCM-03-2019-495

Tortorella, G., Sawhney, R., Jurburg, D., de Paula, I.C., Tlapa, D., Thurer, M., 2020. Towards the proposition of a Lean Automation framework: Integrating Industry 4.0 into Lean Production. J. Manuf. Technol. Manag. ahead-of-print. https://doi.org/10.1108/JMTM-01-2019-0032

Tortorella, G.L., da Silva, E.F., Vargas, D.B., 2018. An empirical analysis of Total Quality Management and Total Productive Maintenance in Industry 4.0, in: Proceedings of the International Conference on Industrial Engineering and Operations Management. pp. 742–753.

Tortorella, Guilherme Luz, Giglio, R., van Dun, D.H., 2019. Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement. Int. J. Oper. Prod. Manag. 39, 860–886. https://doi.org/10.1108/IJOPM-01-2019-0005

Tortorella, G.L., Rossini, M., Costa, F., Portioli Staudacher, A., Sawhney, R., 2019. A comparison on Industry 4.0 and Lean Production between manufacturers from emerging and developed economies. Total Qual. Manag. Bus. Excell. https://doi.org/10.1080/14783363.2019.1696184

Touriki, F.E., Benkhati, I., Kamble, S.S., Belhadi, A., El fezazi, S., 2021. An integrated smart, green, resilient, and lean manufacturing framework: A literature review and future research directions. J. Clean. Prod. 319, 128691. https://doi.org/10.1016/j.jclepro.2021.128691

Tranfield, D., Denyer, D., Smart, P., 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. Br. J. Manag. 14, 207–222. https://doi.org/10.1111/1467-8551.00375

Uriarte, A.G., Ng, A.H.C., Moris, M.U., 2020. Bringing together Lean and simulation: a comprehensive review. Int. J. Prod. Res. 58, 87–117. https://doi.org/10.1080/00207543.2019.1643512

Vinodh, S., Antony, J., Agrawal, R., Douglas, J.A., 2020. Integration of continuous improvement strategies with Industry 4.0: a systematic review and agenda for further research. TQM J. ahead-of-print. https://doi.org/10.1108/TQM-07-2020-0157

Wagner, T., Herrmann, C., Thiede, S., 2017. Industry 4.0 impacts on lean production systems, in: Tseng, M.M., Tsai, H.Y., Wang, Y. (Eds.), Manufacturing Systems 4.0. Elsevier Science Bv, Amsterdam, pp. 125–131.

Weking, J., Stöcker, M., Kowalkiewicz, M., Böhm, M., Krcmar, H., 2020. Leveraging industry 4.0 – A business model pattern framework. Int. J. Prod. Econ. 225, 107588. https://doi.org/10.1016/j.ijpe.2019.107588

Yadav, N., Shankar, R., Singh, S.P., 2020. Impact of Industry4.0/ICTs, Lean Six Sigma and quality management systems on organisational performance. TQM J. 32, 815–835. https://doi.org/10.1108/TQM-10-2019-0251

Yin, Y., Stecke, K.E., Li, D., 2018. The evolution of production systems from Industry 2.0 through Industry 4.0. Int. J. Prod. Res. 56, 848–861. https://doi.org/10.1080/00207543.2017.1403664

Zhang, K., Qu, T., Zhou, D., Thürer, M., Liu, Y., Nie, D., Li, C., Huang, G.Q., 2019. IoT-enabled dynamic lean control mechanism for typical production systems. J. Ambient Intell. Humaniz. Comput. 10, 1009–1023. https://doi.org/10.1007/s12652-018-1012-z

Zocca, R., Lima, T.M., Gaspar, P.D., Charrua-Santos, F., 2019. Kaizen Approach for the Systematic Review of Occupational Safety and Health Procedures in Food Industries. Adv. Intell. Syst. Comput.

Table 5 : summary of literature papers

Title	Authors	Year	Country	Researchstream	Source
Lean Six Sigma and Industry 4.0 combination: scoping review and perspectives	(Tissir et al., 2022)	2022	Morocco	LSS I 4.0	Total Quality Management & Business Excellence
The evolution and future of lean Six Sigma 4.0	(Antony et al., 2022)	2022	UAE	LSS I 4.0	TQM Journal
An integrated smart, green, resilient, and lean manufacturing framework: A literature review and future research directions	(Touriki et al., 2021)	2021	Morocco	L I4.0	Journal of Cleaner Production
Combining lean and agile manufacturing competitive advantages through Industry 4.0 technologies: an integrative approach	(Ding et al., 2021)	2021	Spain	L I4.0	Production Planning & Control
The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda	(S.-V. Buer et al., 2018)	2018	Norway	LI4.0	International Journal of Production Research
Integration between Lean, Six Sigma and Industry 4.0technologies	(Kumar et al., 2021)	2021	India	LSS I4.0	Int. J. Six Sigma and Competitive Advantage
Towards the proposition of a Lean Automation framework: Integrating Industry 4.0 into Lean Production	(Tortorella et al., 2020)	2020	Brazil	LI4.0	Journal of Manufacturing Technology Management

Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review	(Mahdavisharif et al., 2022)	2022	Italy	L I4.0	Applied sciences
Lean Six Sigma in Smart Factories based on Industry 4.0	(Anvari et al., 2021)	2021	UK	LSS I 4.0	International Journal of Emerging Trends in Energy and Environment
Exploring relationships between Lean 4.0 and manufacturing industry	(Javaid et al., 2022)	2022		L I4.0	Industrial Robot
Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions	(Pagliosa et al., 2019)	2019	Brazil	L I4.0	Journal of Manufacturing Technology Management
When Industry 4.0 meets Lean Six Sigma: A review	(Sodhi, 2020)	2020	India	LSS I 4.0	Industrial Engineering Journal
Towards 'Lean Industry 4.0′–Current trends and future perspectives	(Ejsmont et al., 2020)	2020	Poland	L I4.0	Cogent Business & Management
Industry 4.0 tools in lean production: A systematic literature review	(Gallo et al., 2021)	2021	Italy	L I4.0	Procedia Computer Science
Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review	(Bittencourt et al., 2021)	2020	Portugal	L I4.0	International Journal of Production Research

Integration of continuous improvement strategies with Industry 4.0: a systematic review and agenda for further research	(Vinodh et al., 2020)	2020	India	LSS I 4.0	The TQM Journal
Big data in lean six sigma: a review and further research directions	(Shivam Gupta et al., 2020)			LSS I4.0	International Journal of Production Research
A strategic roadmap for the manufacturing industry to implement industry 4.0	(Butt, 2020)	2020	UK	LSS I 4.0	designsmdpi
« Bringing together Lean and simulation: a comprehensive review ». .	(Uriarte et al., 2020)	2021	SWED	L I4.0	International Journal of Production Research
Coordinating Knowledge Creation: A Systematic Literature Review on the Interplay Between Operational Excellence and Industry 4.0 Technologies	T Miandar	2020	Italy	LSS I 4.0	in book Knowledge Management and Industry 4.0
Lean 4.0, Six Sigma-Big Data Toward Future Industrial Opportunities and Challenges: A Literature Review	(Rifqi et al., 2021)	2021	Moroccco	LSS I 4.0	Advances on Smart and Soft Computing
Lean six sigma and digitize procurement	(Nicoletti, 2013)	2013	Italy	LSS I 4.0	International Journal of Six Sigma and Competitive
Continuous improvement programs and industry 4.0: Descriptive bibliometric analysis	(Santos et al., 2018)	2020	Brazil	L I4.0	Proceedings of the 4th ICQEM Conference

The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda	(Buer et al., 2018)	2018	Norway	L I4.0	International Journal of Production Research
Design of cyber physical system architecture for industry 4.0 through lean six sigma: conceptual foundations and research issues	(Sony, 2020)	2020	Namibia	LSS I 4.0	Production &ManufacturingResearch
Assessing the synergies between lean manufacturing and Industry 4.0	(Fortuny-Santos et al., 2020)	2020	Spain	L I4.0	Procediamanufacturing
Ergonomic analysis in lean manufacturing and industry 4.0-A systematic review	(Brito et al., 2019)	2019	Portugal	L I4.0	In book: Lean Engineering for Global Development
The Lean Production System 4.0 Framework – Enhancing Lean Methods by Industrie 4.0	(Dombrowski, n.d.)	2018	Germany	LI4.0	IFIP International Conference on Advances in Production Management Systems
Contact points between Lean Six Sigma and Industry 4.0: a systematic review and conceptual framework	JulianoEndrigoSordan,	2021	Brazil	LI4.0	International Conference on Quality Engineering and Management
Stories Told by Publications about the Relationship between Industry 4.0 and Lean: Systematic Literature Review and Future Research	(Salvadorinho and Teixeira, 2021)	2021	Portugal	LI4.0	MDPI

Agenda					
Big data in lean six sigma: a review and further research directions	(Shivam Gupta et al., 2020)	2020	Spain	LI4.0	International Journal of Production Research
Enhancing Six Sigma methodology using simulation techniques: Literature review and implications for future research	(Ahmed et al., 2020)	2020	Australia	SS4.0	International Journal of Lean Six Sigma
When Industry 4.0 meets Lean Six Sigma: A review	(Sodhi, 2020)	2020		LSS4.0	Industrial Engineering Journal
Industry 4.0 and lean management: a proposed integration model and research propositions	(Sony, 2018)	2018		LI4.0	Production and ManufacturingResearch

Table 6: Summary of literature papers

Factors	Drivers	Barriers	CSFs	Benefits	References
Improvinge fficiency and performance	X				(Belhadi et al., 2020; Burggräf et al., 2020; Kamble et al., 2020; Sanders et al., 2016; G.L. Tortorella et al., 2019)
Reducing cost and losses	X				(Amjad et al., 2021a; Antony et al., 2022, 2018; S. Gupta et al., 2020)
Market increase	X				(Cherrafi et al., 2016; Sony et al., 2021; Touriki et al., 2021)
Customer satisfaction	x				(Antony et al., 2018; Cherrafi et al., 2016; Sony et al., 2021)

Financial factors : High investement cost, Economic and financial charges, Lack of financial support and resources		x			(A. Al-Futaih and Demirkol, 2020; Kumar et al., 2020)
Managerial factors : Lack of management support and comittement		X			(Raj et al., 2020)
Employee factors Lack of expertise , lack of motivation, Lack of skills and workforce training		X			(Angreani et al., 2020; Gill and VanBoskirk, 2016)
Environmental factors: culture and resistance to change.		X			(Alexander et al., 2021; Raj et al., 2020; Schumacher et al., 2016)
Technological factors : Technological constraints, Cyber security		X			(Stentoft et al., 2021)
Soft factors : 1.Leadership and management involvement 2.Defined objectives and communication 3.Corporate culture 4.Financial resources allocation 5.Appropriate skills and expertise 6.Digital job instructions			X		(Belhadi et al., 2019; Cherrafi et al., 2017; Javaid and Haleem, 2020; Kumar, 2007; Lameijer et al., 2021) Antony et al., 2022; Cherrafi et al., 2017; Pozzi et al., 2021; Sony and Naik, 2020; Yadav et al., 2020)
Technical factors : Use of applicable and suitable tools and Technologies, IT architecture and infrastructure, Cyber security			x		(Antony et al., 2022; Pozzi et al., 2021; Sony et al., 2021; Sony and Naik, 2020; Yadav et al., 2020)
Cost, Quality and Productivity				X	(Haddud et al., 2017; Kiel et al., 2017; Lameijer et al., 2021; Mohamed, 2018; Olaitan et al., 2019; Sony et al., 2021)
Organizational capabilities(Flexibility, agility, resilience)				x	(Amjad et al., 2021a; Lameijer et al., 2021)Moghaddam and Nof (2018) (Belhadi et al., 2020; Cherrafi et al., 2016; Kamble et al., 2020;