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Industry 4.0 and Lean Six Sigma integration in manufacturing: A literature review, an integrated framework and proposed research perspectives

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ABSTRACT
This article 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 SS; 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 SS and Industry 4 which will be of great value to academics and practitioners working in this area.

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Digitalization; Industry 4.0; Lean manufacturing; Lean Six Sigma; literature review; Six Sigma

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; Cherrafi et al. 2016; Lameijer, Pereira, and Antony 2021; Psomas and Antony 2019). 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 (Ghobakhloo 2020a). 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 (Jayaram 2016). 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).

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Similarly, I4.0 enables the transformation of manufacturing tools into smart and efficient ones (Cresnar et al. 2020), 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, Pereira, and Antony 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 (SS) tools will provide enormous potential for improvement and help companies achieve better performance (Anass et al. 2021; Sodhi 2020; Park et al. 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 (Alexander, Antony, and Cudney 2022; Anass et al. 2021; Antony et al. 2022; Anvari, Edwards, and Yuniarto 2021; Arcidiacono and Pieroni 2018; Belhadi et al. 2020; Bittencourt, Alves, and Leão 2021; Narula et al. 2022; Sony 2020; Tissir et al. 2022; Tortorella, Giglio, and van Dun 2019b; Yadav, Shankar, and Singh 2020).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, Edwards, and Yuniarto 2021; Arcidiacono and Pieroni 2018; Bittencourt, Alves, and Leão 2021; Duarte, Cabrita, and Cruz-Machado 2020; Tissir et al. 2022).The majority of studies have addressed lean and I4.0 integration (Al-Futaih and Demirkol 2020; Antony et al. 2022; Buer et al. 2021; Duarte, Cabrita, and Cruz-Machado 2020; Mahdavisharif, Cagliano, and Rafele 2022; Narula et al. 2022; Prinz, Kreggenfeld, and Kuhlenkötter 2018; Rossini et al. 2019; Sanders, Elangeswaran, and Wulfsberg 2016) 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 (Pasi et al. 2020). An organization that has Industry 4.0 technologies as dynamic capabilities will be able to smoothly move its processes and operations toward LSS and operational excellence.

To fill this gap, the main purpose of this article 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 article 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.

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.

Lean management

Lean is an organizational philosophy and approach to business efficiency developed by the Japanese company Toyota, designed to reduce waste and nonvalue added activities in manufacturing. Lean manufacturing uses a set of tools and philosophies that impacts positively quality and productivity and reduces manufacturing costs (Sanders, Elangeswaran, and Wulfsberg 2016) including value stream mapping (VSM), Just in time(JIT), Kanban, Jiduka, among others. LM 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 (Cherrafi et al. 2016; Garza-Reyes 2015; Leong et al. 2019), improving customer satisfaction and increasing process efficiency (Bhattacharya, Nand, and Castka 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 SS methodology (Lai et al. 2020). 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 SS for better process efficiency and business performance. Six-Sigma, therefore, aims to identify defects, determine their cause and eliminate them.

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 nonstatistical 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 (Antony and Sony 2020; Hseng-Long Yeh 2011; Jiménez et al. 2020; Pardamean Gultom and Wibisono 2019).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, SS does not drive innovation within companies. SS can generate higher results when combined with LM.

Lean Six Sigma

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 SS methodologies are being used and examined as a whole (Shah, Chandrasekaran, and Linderman 2008).

The LSS approach can solve complex industrial problems that generate financial and operational improvements (Alexander et al. 2021). Manufacturers are applying the LSS methodology to achieve better performance and reduce losses and nonvalue added activities (Panayiotou et al. 2021).

Industry 4.0

The term I4.0 refers to the fourth industrial revolution, which represents a technological alongside an economic, sociological and strategic revolution (Arcidiacono and Pieroni 2018). 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, Vijaya, and Wicaksono 2020; 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, Orzes, and Jia 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, Alves, and Leão 2019; Buer, Fragapane, and Strandhagen 2018a; Dogan and Gurcan 2018; Karadayi-Usta 2020; Kolberg and Zühlke 2015; Powell et al. 2018; Raji and Rossi 2019; Rossini et al. 2019; Sanders et al. 2017a, 2017b; Shrouf, Ordieres, and Miragliotta 2014).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, Vijaya, and Wicaksono 2020; Chettri and Bera 2020; Culot et al. 2020; Gallab et al. 2021; Haddud et al. 2017, 2017; Kamble, Gunasekaran, and Sharma 2018; Karadayi-Usta 2020; Lee, Bagheri, and Kao 2015; Machado et al. 2019; Raj et al. 2020; Schumacher, Erol, and Sihn 2016; Sony and Naik 2020; 2020; Tay et al. 2018) 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 I4.0 and are often used by authors to talk about the fourth industrial revolution (Romero et al. 2018). In our study, we build on this interpretation of I4.0, which means the integration of I4.0 enabling technologies into manufacturing processes.

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, Denyer, and Smart (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, Denyer, and Smart 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).

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?

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, Stecke, and Li 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 (Mrugalska and Wyrwicka 2017; Uriarte, Ng, and Moris 2020).

To define a set of synonyms for "I4.0," we studied the highest ranked literature reviews on Scopus and the

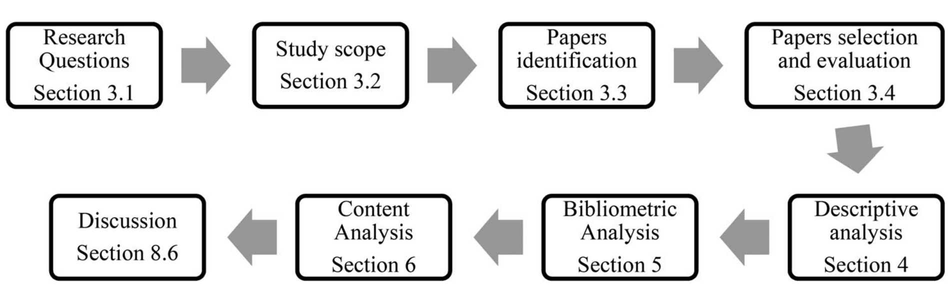


Figure 1. Research protocol.

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 experts 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.

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	

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

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.

Descriptive analysis

The descriptive analysis focuses on the following five parameters:

Publication Year (Figure 3): The distribution of publications by year, to identify the trend in the number of studies on the research theme.

Geography Distribution (Figure 4): Considering the affiliation of the first author, we aim to identify the country's most active on the research theme.

Publications breakdown (Figure 5) and Distribution across 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 (Figure 6): 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 (Figure 7): We aim to identify the different technologies discussed in the field of I4.0 and LSS.

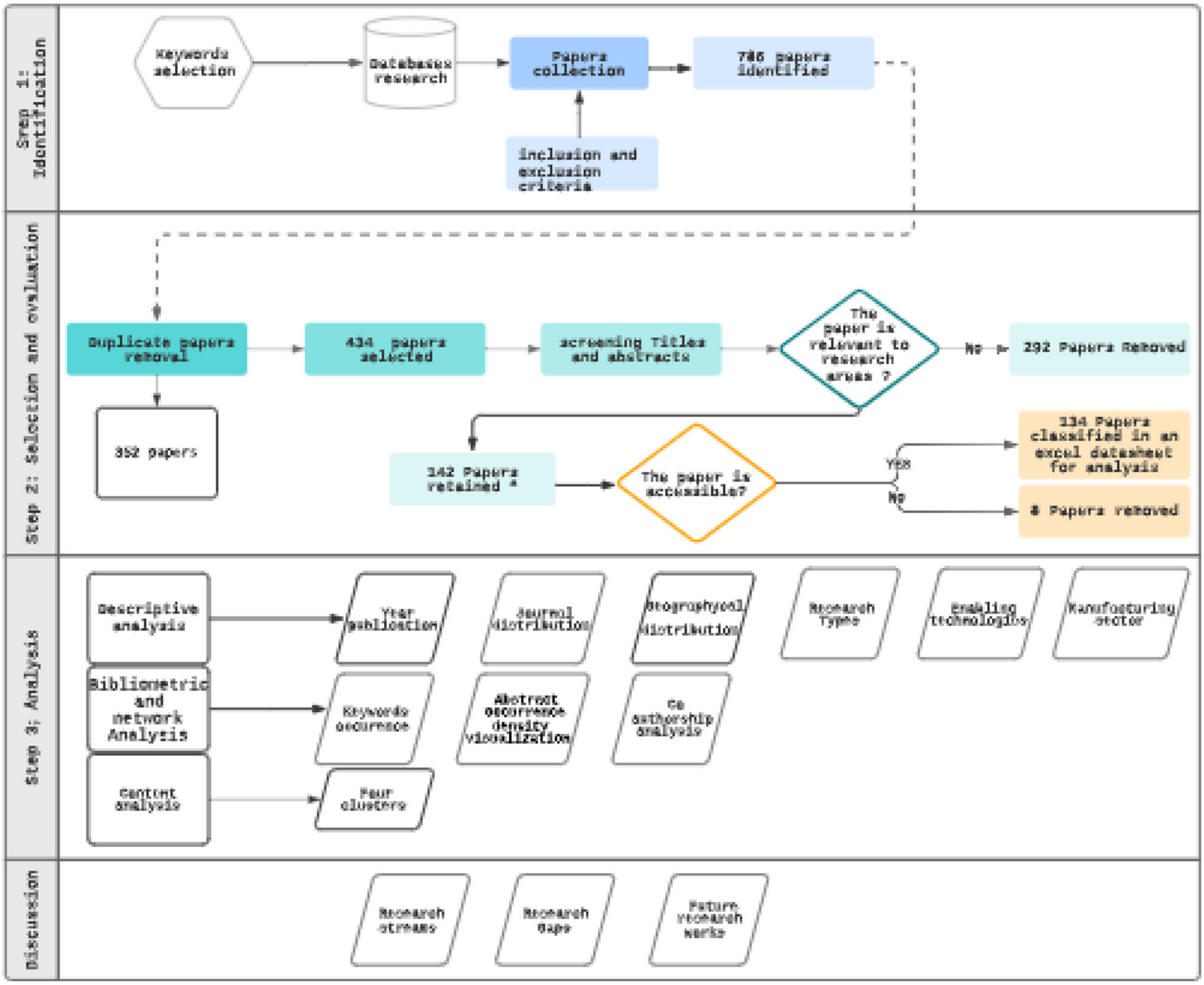


Figure 2. Literature review process.

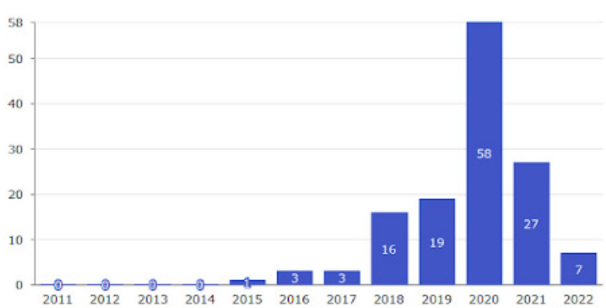


Figure 3. Distribution of publications by years.

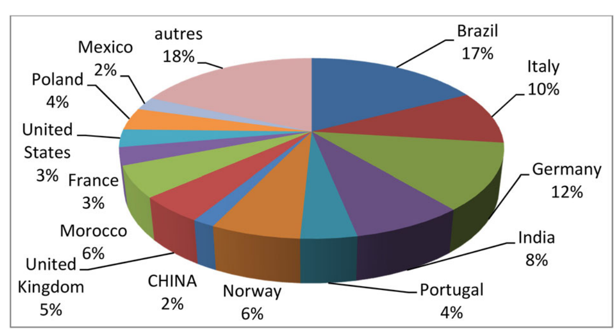


Figure 4. Geography distribution.

Distribution of empirical studies across industry sectors (Figure 8): We seek to identify and define the industrial sectors most affected by this integration.

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.

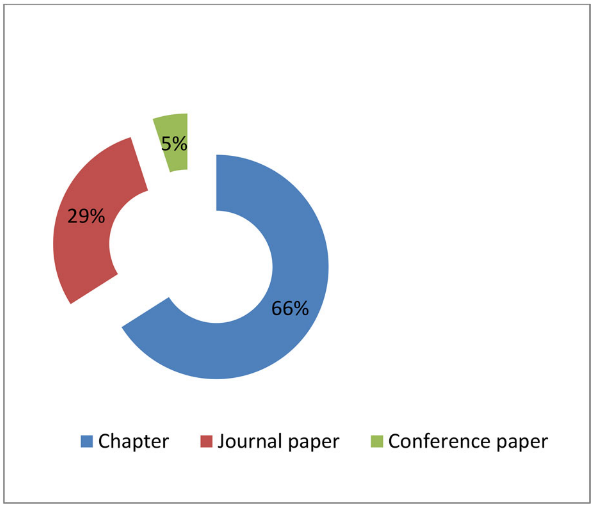


Figure 5. Breakdown of publications by sources.

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
Procedia Manufacturing	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 Manufacturing Research	2
The International Journal of cleaner production	2
Sensors	2
Production and Manufacturing Research	2
Others (13 journals with 1 paper)	13

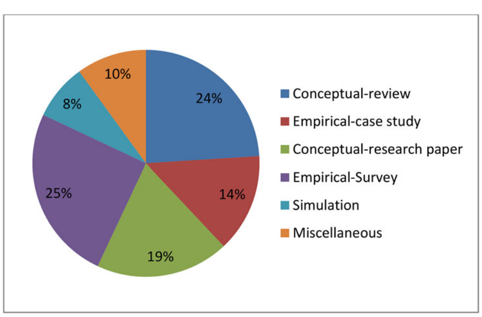


Figure 6. Distribution by search method.

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 LSS headed by Germany (12 articles) and Italy (12 articles). It is explained by the number of conferences organized since 2016 in

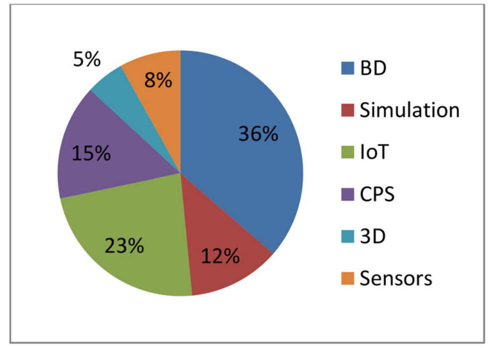


Figure 7. I4.0 enabling technologies.

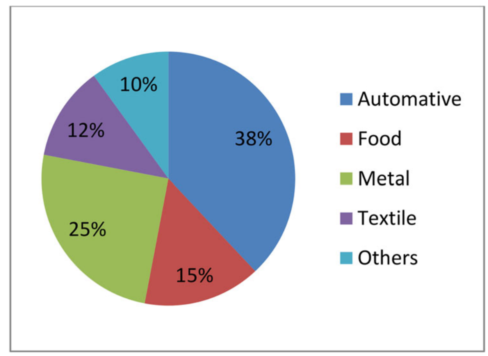


Figure 8. Distribution of studies across manufacturing Industry sectors.

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. Figure 4 shows the most active countries in the research field.

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). Fifty-five percent 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.

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.

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."

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).

Distribution of studies across manufacturing industry sectors

Figure 8 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 multisectors.

Bibliometrics analysis

The bibliometric analysis serves as a tool to create, visualize and analyze maps based on network data (Laengle et al. 2020). We conducted a bibliometric analysis using VOS software. Three co-occurrence networks have been evolved to identify the relationship between the concepts discussed: the coauthor network, abstract co-occurrence terms and keyword clusters.

Coauthorship analysis

In terms of coauthorship analysis, we have set three 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 five 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.

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.

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

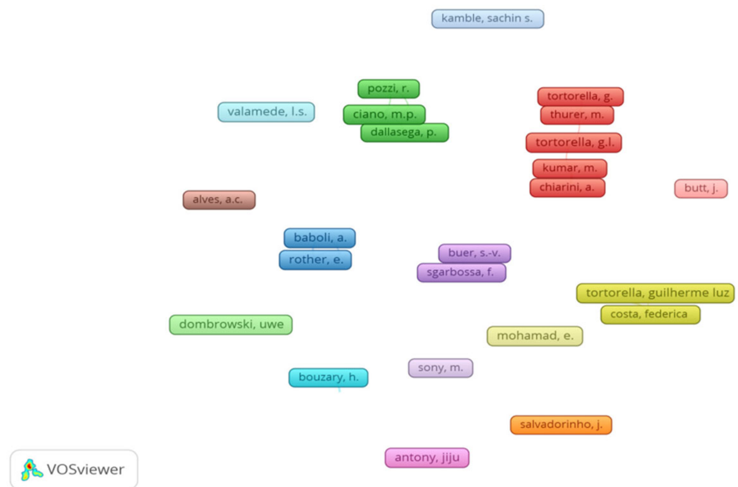


Figure 9. Coauthorship cluster network.

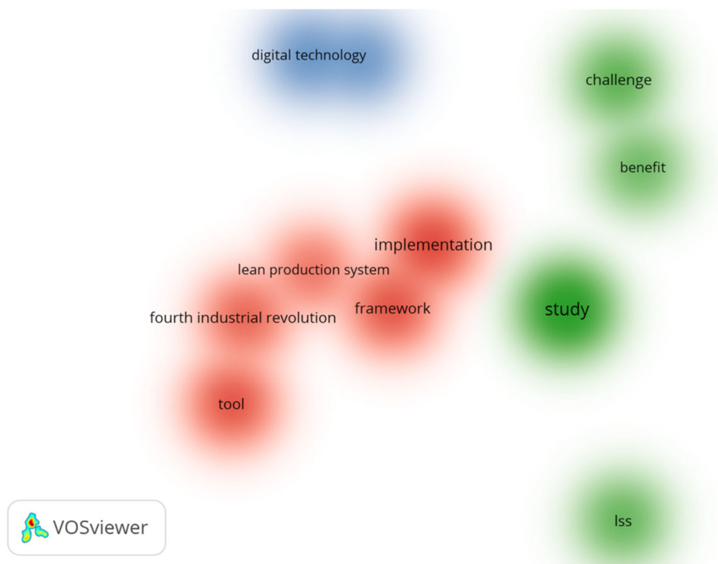


Figure 10. The abstract cluster network.

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.

Content analysis

A content analysis's main purpose is to identify, organize and categorize ideas about a particular topic. 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.

Industry 4.0 and LSS correlation

The majority of publications have discussed the correlation and synergies between LSS and I4.0. An

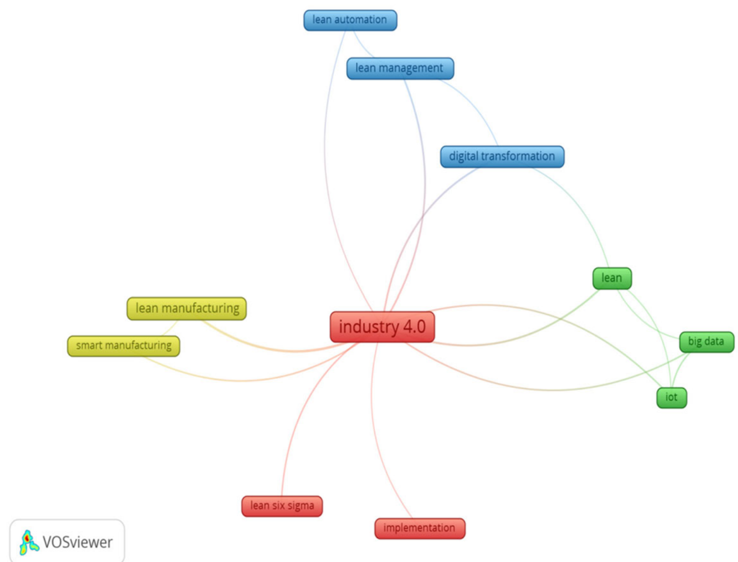


Figure 11. Keywords cluster network.

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 Subsection 7.3 and summarized in Figure 13.

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 LSS 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, Page, and Olsen 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.

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

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, Kreggenfeld, and Kuhlenkötter (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. 2021; 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.

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	++					++	++		

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 Figure 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 favor 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 (Figure 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.

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 toward 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 digitalization initiative. The successful deployment of every continuous improvement initiative depends heavily on the people which represent the most strategic asset of any company (Buer, Fragapane, and Strandhagen 2018a; Ciano et al. 2019).

Conversely, 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 tradeoffs 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

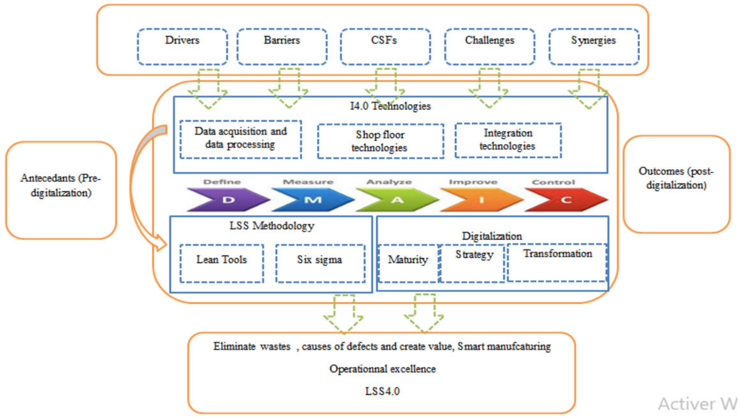


Figure 12. The proposed smart LSS framework.

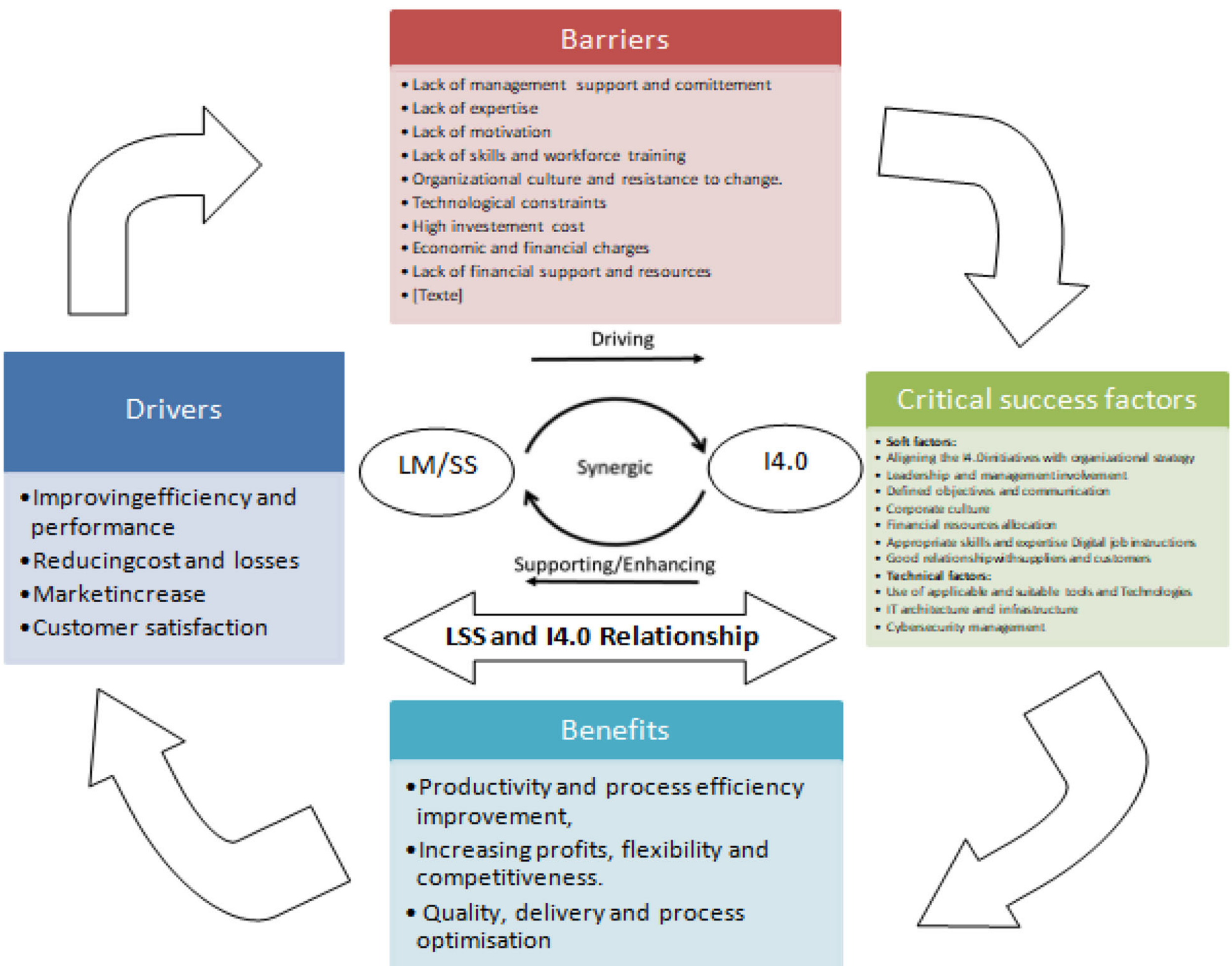


Figure 13. Comprehensive theoretical elements of the LSS4.0 model.

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, Erol, and Sihn 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 Figure 13.

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 (Ghobakhloo 2020b) and market image (Stentoft et al. 2021). The discussed drivers are summarized in Table 6. Conversely, the barriers that may hinder the LSS4.0 implementation are financial constraints, poor management support, low awareness, resistant behaviors and lack of skills, which are also the main barriers to I4.0 implementation (Butt 2020; Sony et al. 2021; Khan and Turowski 2016) presents some I4.0 adoption barriers that include lack of expertise, lack of quantified financial benefits and lack of skilled labor. The factors that emerged from the literature were regrouped into five family factors: managerial, environmental, people, financial and technological and listed in Table 14.

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. (2022) studied the critical factors and subfactors for I4.0 adoption in manufacturing industries and observed that nontechnical 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.

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 labor, agile and flexible process, better regulations conformity, better customer satisfaction, cost savings and increased business profits.

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, Strandhagen, and Chan (2018b) 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 of 108 European manufacturers that have already adopted lean philosophy. Their conclusions align strongly with (Buer, Strandhagen, and Chan 2018b) 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, da Silva, and Vargas (2018) as a

Table 5. Summary of literature papers.

Title	Authors	Year	Country	Research stream	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, Ferràs Hernández, and Agell Jané (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	Buer, Fragapane, and Strandhagen (2018a)	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
Toward 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, Cagliano, and Rafele (2022)	2022	Italy	L I4.0	Applied sciences
Lean Six Sigma in Smart Factories based on Industry 4.0	Anvari, Edwards, and Yuniarto (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, Tortorella, and Ferreira (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
Toward "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

(*Continued*)

Table 5. Continued.

Title	Authors	Year	Country	Research stream	Source
Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review	Bittencourt, Alves, and Leão (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	Gupta, Modgil, and Gunasekaran (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, Ng, and Moris (2020)	2021	SWED	L I4.0	International Journal of Production Research
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	Fortuny-Santos Santos et al. (2020)	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, Strandhagen, and Chan (2018b)	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	Sordan et al. (2022)	2021	Brazil	LSS4.0	International Journal of Quality & Reliability Management
Stories Told by Publications about the Relationship between Industry 4.0 and Lean: Systematic Literature Review and Future Research Agenda	Salvadorinho and Teixeira (2021)	2021	Portugal	LI4.0	MDPI
Big data in Lean Six Sigma: a review and further research directions	Gupta, Modgil, and Gunasekaran (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, Page, and Olsen (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 drivers, barriers, CSFs and benefits from literature papers.

Factors	Drivers	Barriers	CSFs	Benefits	References
Improvinge efficiency and performance	X				Belhadi et al. 2020; Burggräf et al. 2019; Kamble, Gunasekaran, and Dhone 2020; Sanders, Elangeswaran, and Wulfsberg 2016; Tortorella et al. 2019c
Reducing cost and losses	X				Amjad, Rafique, and Khan 2021; Antony et al. 2022, 2018; Gupta, Modgil, and Gunasekaran 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			Al-Futaih and Demirkol 2020; Kumar, Singh, and Dwivedi 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, Vijaya, and Wicaksono 2020; Gill and VanBoskirk 2016
Environmental factors: culture and resistance to change.		X			Alexander, Antony, and Cudney 2022; Raj et al. 2020; Schumacher, Erol, and Sihn 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		Antony et al. 2022; Belhadi, Touriki, and Elfezazi 2019; Cherrafi et al. 2017; Javaid and Haleem 2020; Kumar 2007; Lameijer, Pereira, and Antony 2021; Pozzi, Rossi, and Secchi 2021; Sony and Naik 2020; Yadav, Shankar, and Singh 2020
Technical factors: Use of applicable and suitable tools and Technologies, IT architecture and infrastructure, Cyber security			x		Antony et al. 2022; Pozzi, Rossi, and Secchi 2021; Sony and Naik 2020; Sony et al. 2021; Yadav, Shankar, and Singh 2020
Cost, Quality and Productivity				X	Haddud et al. 2017; Kiel et al. 2017; Lameijer, Pereira, and Antony 2021; Mohamed 2018; Olaitan et al. 2019; Sony et al. 2021
Organizational capabilities(Flexibility, agility, resilience)				x	Amjad, Rafique, and Khan 2021; Belhadi et al. 2020; Cherrafi et al. 2016; Kamble, Gunasekaran, and Dhone 2020; Lameijer, Pereira, and Antony 2021; Moghaddam et al. 2018.

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, Edwards, and Yuniarto 2021; Buer et al. 2021) (Anass et al., 2019) 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, Edwards, and Yuniarto 2020) 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, Gunasekaran, and Dhone 2020; Wagner et al., 2017) investigated the impact of I4.0 on LM based on a survey of 115 Indian manufacturing firms and found that I4.0 positively and directly impacts LM. (Tortorella et al. 2021) 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 organizations 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 (Arcidiacono and Pieroni 2018).

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

Research gaps, implications for practitioners and future research directions

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 (Figure 14) in the literature.

We listed the future research paths for LSS4.0 (Figure 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 modeling can be performed to analyze the effect of I4.0 on LSS and Operational excellence.

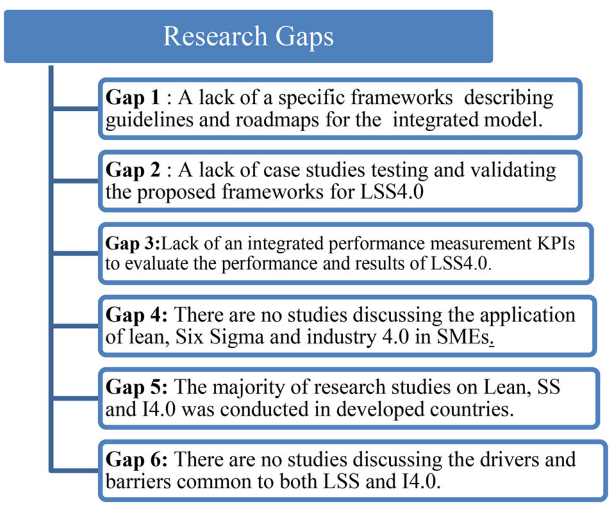


Figure 14. Research gaps.

Implications for practitioners and researchers

The findings of the SLR study presented in the proposed framework will guide manufacturing companies in their journey toward 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 article 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.

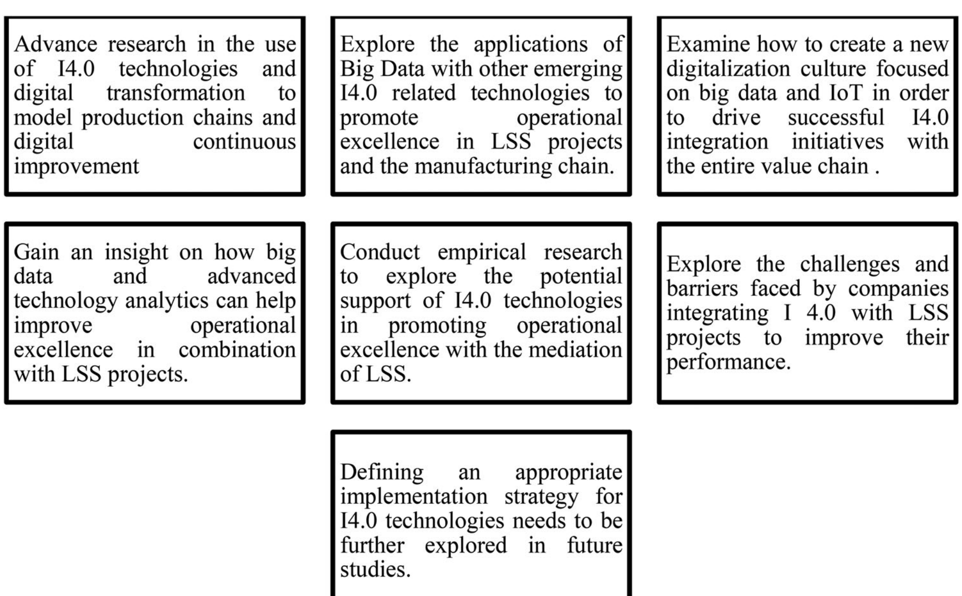


Figure 15. Future research perspectives.

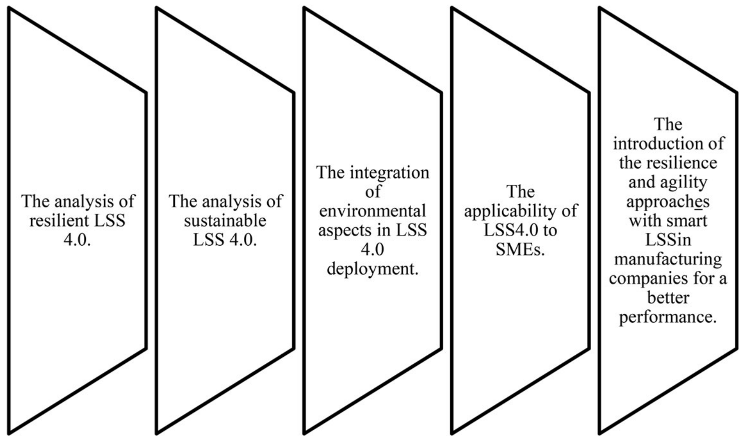


Figure 16. The emerging LSS4.0 trends.

- 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 (Figure 16).

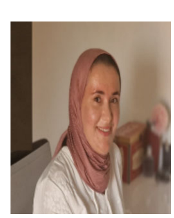
Conclusions

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 three 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.

Disclosure statement

No potential conflict of interest was reported by the authors.

About the Authors



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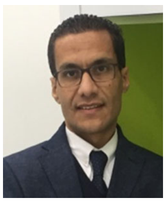

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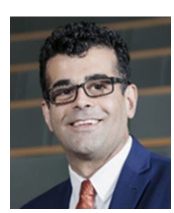

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