

REVIEW

An analysis of the literature on lean supply chain management in relation to I4.0

Harini Abrilia Setyawati ¹, Irfan Helmy ^{2*}

¹ Economics and Business Faculty Universitas Putra Bangsa, Kebumen, Indonesia; harini.abrilia.setyawati@gmail.com

² Economics and Business Faculty Universitas Putra Bangsa, Kebumen, Indonesia; risetirfan@gmail.com

* Correspondence: risetirfan@gmail.com

Abstract

The integration of Lean Supply Chain Management (LSCM) and Industry 4.0 (I4.0) technologies, although recent, has garnered significant interest. Due to its recent emergence as a field of practice and research, along with the rapid proliferation of works in this domain, it is essential to regularly update the viewpoints on this area of inquiry. This study seeks to examine the integration of LSCM and I4.0 by examining their relationships at operational, tactical, and strategic levels. Design, methodology, and approach A systematic literature review was performed to discover and elucidate the integration of LSCM and I4.0 from scholarly sources published prior to March 2021. The research of the literature indicated that the integration of LSCM and I4.0 exists at various managerial levels. Furthermore, when the integration is examined across several management tiers, it becomes evident that LSCM facilitates the implementation of I4.0 at a strategic level, whilst I4.0 technologies are poised to improve LSCM practices at the operational level. The primary contribution of this study is the framework demonstrating that LSCM facilitates the strategic adoption of I4.0, while I4.0 technologies are expected to improve LSCM practices at the operational level. This study presents a novel perspective on the works published within the themes of LSCM and I4.0. Furthermore, it presents an analytical framework for utilisation by other researchers. Ultimately, it presents the latest applications of LSCM and I4.0, highlighting current trends, advancements, and significant deficiencies.

Keywords: Supply chain management, Lean production, Industry 4.0, Digitalization, Lean supply chain

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1. Introduction

Over the past few decades, Lean Supply Chain Management (LSCM) strategies and ideas have been effectively implemented across various sectors (Chakrabarty and Wang, 2020). The growing interest is attributed to the advantages of LSCM deployment, which

include cost reduction, decreased throughput time, enhanced quality, and other factors (MoyanoFuentes et al., 2020; Vanichchinchai, 2019).

The emergence of Industry 4.0 (I4.0) has reignited the discussion over the integration of innovative technology into existing managerial frameworks guided by a human-centered philosophy, such as lean management (Ghadge et al., 2020). The contemporary information and communication technologies (ICT) of Industry 4.0 facilitate connectivity across products, machines, and processes. Numerous authors have highlighted the prospective advantages of incorporating technologies such as Big Data analytics, the Internet of Things, and Cloud Computing into lean systems, fostering significant anticipation and enthusiasm (Buer et al., 2020; Tortorella et al., 2019a, 2019b).

Literature has articles examining the interaction between LSCM and I4.0; nonetheless, the subject remains in its nascent stage (Núñez-Merino et al., 2020).

Furthermore, the literature presents several analytical perspectives that do not substantiate the framework of this interaction, hence engendering confusion regarding the significance of the interplay.

This paper aims to address the existing gap in the literature by providing the current status of the interplay between LSCM and I4.0, establishing a framework to delineate this interaction, so laying the groundwork for future research in this domain. Consequently, we propose the subsequent research question:

RQ1. Is there a correlation between Lean Supply Chain Management and Industry 4.0?

This study does a systematic literature review (SLR) to address the research issue.

2. Material and Methods

In the present context of significant fluctuations in customer demand and a swiftly evolving competitive environment, companies face the problem of meeting customer expectations (Vanpoucke et al., 2014).

Krajewski et al. (2015) assert that the most successful organisations incorporate external consumers and suppliers into their internal enhancement processes. Consequently, collaboration between suppliers and consumers serves as an external support to enhance competitiveness and efficiency (Flynn et al., 2010). A method that can assist supply chains in minimising waste and attaining sustainability is Lean Production (LP), which is founded on the Toyota Production System (Rossini et al., 2019). In a competitive climate where organisations strive for reduced lead times, enhanced quality, and cost efficiency, Lean Production practices can be adopted within the framework of a supply chain integrative strategy (Guilherme Luz Tortorella et al., 2017).

LSCM involves the administration of several organisations that integrate both upstream and downstream flows of diverse entities, enhancing value while minimising costs and waste by swiftly addressing consumer demands (Anand and Kodali, 2008).

Saxby et al. (2020). The objective of LSCM is to guarantee the efficient creation and transfer of value to the downstream. The notion of LSCM is not limited to automotive, construction, or manufacturing sectors but also encompasses service industries such as hospitality, healthcare, and retail (Borges et al., 2019). Nonetheless, numerous studies on the subject have concentrated solely on specific facets of LSCM. Numerous studies have predominantly focused on assessing "upstream" lean techniques, with minimal attention afforded to their implementation in the "downstream" (Reichhart and Holweg, 2007; Reitsma et al., 2020). The incremental implementation of LP methods "downstream" in the process can be rationalised by the concept of production levelling (*heijunka*), which necessitates production adjustments to accommodate swings in high market demand variability (Mason-Jones et al., 2000). However, it has been determined that complete sustainable outcomes cannot be attained solely by implementing LP principles among upstream participants in the supply chain.

Hines et al. (2004) noted that the evolution of Lean Production principles and practices has progressed over the years from the shop floor to all participants across the supply chain. They can be utilised in several stages, including product and service development, order placement with suppliers, and transportation of items to clients (Bittencourt et al., 2021). The objective is to perpetually enhance all actions that will benefit the customers. In this context, LSCM underscores the significance of properly implementing LP principles to establish an efficient production and logistics system that fulfils consumer expectations (Chu et al., 2021).

Agarwal et al. (2006) assert that LSCM necessitates an alternative business model that emphasises strategic relationships with various supply chain participants and aims to eradicate waste through a collaborative and systematic methodology. The emergence of new technologies presents numerous opportunities for LSCM, enhancing coordination and collaboration among supply chain partners and promoting integration to achieve greater competitiveness (Tortorella G., Miorando R., 2019).

The term I4.0 was initially introduced in 2011 by the German Industry–Science Research Alliance (Buhr, 2017). Currently, Industry 4.0, or digital transformation, presents numerous problems for manufacturing enterprises from various perspectives. The I4.0 represents a horizontal expansion of ICT (Lee et al., 2018). Indeed, ICT is currently utilised more comprehensively across all domains, including commerce, governance, and daily existence. The digitalisation of Industry 4.0 facilitates the connection of many entities along the whole supply chain via real-time information (Chiarini et al., 2020). This link enables many entities to manage variations in environmental conditions through artificial intelligence (Hecklau et al., 2016). Mario et al. (2017) characterised I4.0 as “[...] a comprehensive term for technologies and concepts pertaining to value chain organization.”

Digitisation is impacting all sectors by either substituting old products with digital alternatives or augmenting such products with innovative digital functionalities (Prem, 2015). The digital transformation resulting from a transition to I4.0 extends beyond enhancements in product and process dimensions. While technology has revolutionised production and commercial methods, it has also presented obstacles for companies (Bleicher and Stanley, 2018). The primary objective of manufacturing digitalisation is to create connectivity among all participants in manufacturing value chains. Digitalisation improves not just physical items but also corporate operations and the overarching goal of the organisational framework (Matt et al., 2015). Meier (2016) asserts that for comprehensive digital transformation, firms must first investigate and ascertain client desires; next, they should implement organisational changes aligned with these needs. However, the problem for businesses persists regarding the velocity and comprehensiveness with which enterprises can implement digital transformation (Rossini et al., 2021).

A definitive correlation has been established between the adoption of Industry 4.0 technologies and lean systems (G.L. Tortorella et al., 2019b); however, the research predominantly concentrates on individual plant implementations and lacks a comprehensive examination of the interrelations beyond the confines of a single facility, particularly concerning the supply chain.

This article seeks to examine and debate the potential synergy for organisations who embrace both LSCM and I4.0, as these two significant business opportunities remain unstructured in their interaction.

To investigate the integration of LSCM with I4.0, we employed a systematic literature review (SLR). Fink (2005) defines a systematic literature review (SLR) as a procedure that is systematic, explicit, comprehensive, and reproducible for discovering, evaluating, and synthesising the current body of finished and documented work generated by researchers, academics, and practitioners.

This section delineates the technique employed for the literature review. The authors assert that it can be regarded as systematic to a considerable extent, given the employed technique.

According to Xiao and Watson (2017), a successful review must encompass three phases: Planning, Conducting, and Reporting. Figure 1 illustrates the evaluations throughout eight distinct stages.

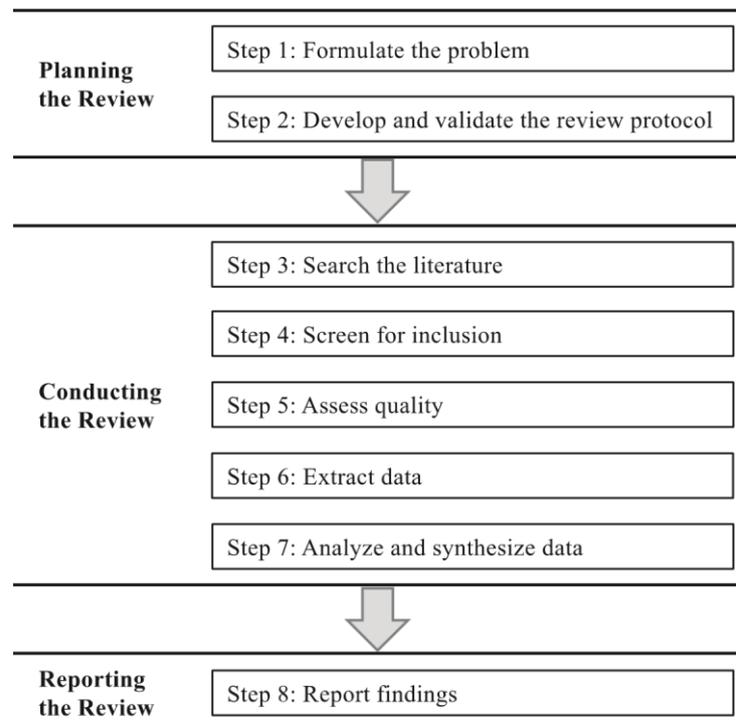


Figure 1. Literature review methodology

The subsequent paragraphs meticulously outline all the processes and elucidate their practical implementation.

The initial step in performing a systematic literature review is the articulation of the problem. The primary motivators of the SLR process are the research questions (Kitchenham and Charters, 2007), which serve as the foundation for issue development.

An excessively broad research question may compromise the systematic literature review due to the overwhelming volume of identified data (Cronin et al., 2008). Consequently, the appropriate research issue may be determined through an iterative procedure.

The basis of the SLR is the connection between the lean supply chain environment and that of Industry 4.0. Consequently, the initial objective was to examine the interaction between the two paradigms. As the first investigation progressed, a more structured and defined inquiry became essential. Various linkages between lean supply chains and Industry 4.0 can be discerned across different business sectors. Furthermore, these links may have been extensively examined in certain industries, whilst in others, this research is only commencing. This iterative procedure has been crucial in delineating the parameters of the research question for the SLR.

The review protocol is defined as "a preset plan that specifies the methods utilised in conducting the review" (Xiao and Watson, 2017), and it is essential for robust systematic reviews. It should markedly diminish bias in the analysis of the chosen data (Kitchenham and Charters 2007).

The systematic search comprises five stages. Initially, researchers must delineate the channels for the literature search. Given the limitless number of possible channels, researchers ought to select a subset of channels. The research question must be articulated

in keywords suitable for the study. Third, researchers must determine the sampling approach. The research may be either comprehensive or selective, as per the review criteria (Suri and Clarke, 2009; Bayliss and Beyer, 2015). Fourth, researchers ought to enhance results by imposing additional criteria, as there may be further practical considerations for excluding certain papers from the SRL. It is essential to establish a stopping rule that enables researchers to determine when the study can be deemed complete.

For the literature study, Scopus has been selected as the sole database from numerous available sources for this systematic literature review (SLR). This selection is due to the electronic repository providing "a comprehensive overview of global research output in the domains of science, technology, medicine, social sciences, and arts and humanities."

The subsequent stage is identifying the keyword utilised for the search. This study aims to examine the relationship between LSCM and I4.0, with the primary keywords being "Lean," "Supply Chain," and "Industry 4.0." To provide a thorough research environment, the inquiry must be broadened to include synonyms, alternate spellings, abbreviations, and pertinent terms. Specifically, a synonym for "Lean" is "JIT," whereas synonyms for "Industry 4.0" include "Digital" and "Smart." Additionally, the shorthand for "Industry 4.0" is "I4.0," while the alternate German version is "Industrie 4.0." To formulate the search strings, "AND" is employed to connect the primary phrases, however "OR" is utilised to incorporate synonyms and abbreviations. The final search string was {{{("JIT" OR "Lean") AND ("Supply Chain")} AND ("Industry 4.0" OR "I4.0" OR "Digital" OR "Smart" OR "Industrie 4.0")}. Table 1 consolidates the definitive collection of terms, categorised into the two themes explored in this literature study.

The sample technique may be either exhaustive or selective (Suri and Clarke, 2009; Bayliss and Beyer, 2015). This SLR is more selective and representative. Consequently, "grey literature," including conferences, was excluded from the search papers. This conclusion arises from the perception that grey literature is of worse quality compared to peer-reviewed articles (Xiao and Watson, 2017). Furthermore, "grey literature" may be subject to greater biases than peer-reviewed publications.

To enhance the results, supplementary constraints have been implemented, encompassing the publishing date range and the language of publication. Regarding the temporal scope, papers published prior to 2011 were omitted from the research, as the term "Industry 4.0" was first introduced at the Hannover Fair in that year. The conclusion date of the research period aligns with the end of 2020. The research has been restricted to the English language for publication purposes.

Ultimately, Levy and Ellis (2006) suggest that one should cease the search upon encountering identical references without any novel findings. The halting rule has been implemented for the research terms. Specifically, it has been demonstrated that using the new keywords "I4.0" and "Industrie 4.0" for the identification of I4.0 yields identical results. Consequently, no further keywords beyond those listed in Table 1 were incorporated.

Assess for inclusion, Upon completion of the article search, a list of papers has been prepared in the designated channel for literature review. Researchers must evaluate each article on this list to determine its suitability for data extraction and analysis. The writers should evaluate the previously generated articles list by reviewing the abstract of each article in accordance with the established inclusion and exclusion criteria. This approach must be conducted by each researcher to pick studies according to the inclusion and exclusion criteria (Gomersall et al., 2015). The criteria, derived from the research issue, must align with practical scenarios and be sufficiently adequate for classifying the research. Furthermore, they can be reliable and should yield a manageable body of literature (Xiao and Watson, 2017). Researchers should compare the two respective

outcomes of this process only after completing the screen of publications. In instances of divergent viewpoints, the manuscript should be incorporated.

The authors' exclusion criteria utilised in this literature study are defined below:

Not subjected to peer review (NR): Articles identified with the aforementioned keywords that are not peer-reviewed should be eliminated. Conference pieces are classified as "grey literature." Consequently, based on the established sample technique, these publications should be dismissed, while only articles and reviews should be regarded by researchers.

Entirely unrelated (CU): Literature not pertinent to the correlation between lean supply chain and Industry 4.0 should be excluded from the review. Indeed, due to certain keywords included, such as "Smart" and "Digital," articles including these terms

Table 1. Research keywords used

Lean supply chain	Industry 4.0
JIT supply chain	Industry 4.0
Lean supply chain Table 1.	Industrie 4.0
Research keywords used	I4.0
	Digital
	Smart

These terms have occurred in the search list of their abstract. Nonetheless, these publications are occasionally irrelevant to the correlation between lean supply chain and Industry 4.0, warranting their rejection.

Articles that are only tangentially connected to lean supply chain or Industry 4.0, without addressing the interrelationship between the two, should be omitted. Papers concentrating solely on one of these two topics while merely alluding to the others were excluded from the literature assessment.

Duplicates (D): Since it has been determined to utilise solely the Scopus database for the literature, there are no redundant findings that could arise from employing several databases. Additionally, the same database may contain duplicates that need to be subtracted from the total count of articles reviewed.

No access (NA): The literature review may include publications that are accessible by title and abstract, yet do not permit access to the full text. Consequently, these papers ought to be excluded from the final compilation of submissions.

Additionally, to attain a thorough understanding of the interaction between lean supply chains and Industry 4.0, the authors have opted to use the following inclusion criteria:

Backward related (BR): Certain publications cited in the reviewed literature should be incorporated into the literature study to enhance understanding of the two paradigms under examination.

Forward related (FR): Researchers must incorporate papers from the principal authors of the two examined paradigms utilising the identical database, Scopus.

The aforementioned inclusion and exclusion criteria have been enacted by researchers solely after the application of the criteria outlined in Step 3. The process of refining results with supplementary constraints enabled researchers to define the scope of the literature review. The precise rejection conditions employed have been:

Obsolete (O): Articles published prior to 2011 must be omitted from the literature evaluation, as the concept of "Industry 4.0" was first introduced at the Hannover Fair in 2011.

Language (L): Papers authored in a language other than English must be excluded from the literature review.

Figure 2 presents a summary of the exclusion and inclusion process together with the associated figures.

Following the implementation of the aforementioned inclusion and exclusion criteria, a conclusive list of publications for the literature review was determined, initially by each researcher independently, after which all researchers convened to debate and achieve consensus for inclusion in the study. We ensured that researchers possessed a diverse range of experience; for instance, one specialises in lean methodologies, another in Industry 4.0, and the third in both lean and Industry 4.0. A list of excluded papers has been maintained for future readers to perform the same search (Kitchenham and Charters, 2007).

Evaluating Quality Whitemore and Knafl (2005) assert that quality standards vary amongst reviews. Quality assessment is crucial for evaluating reviews

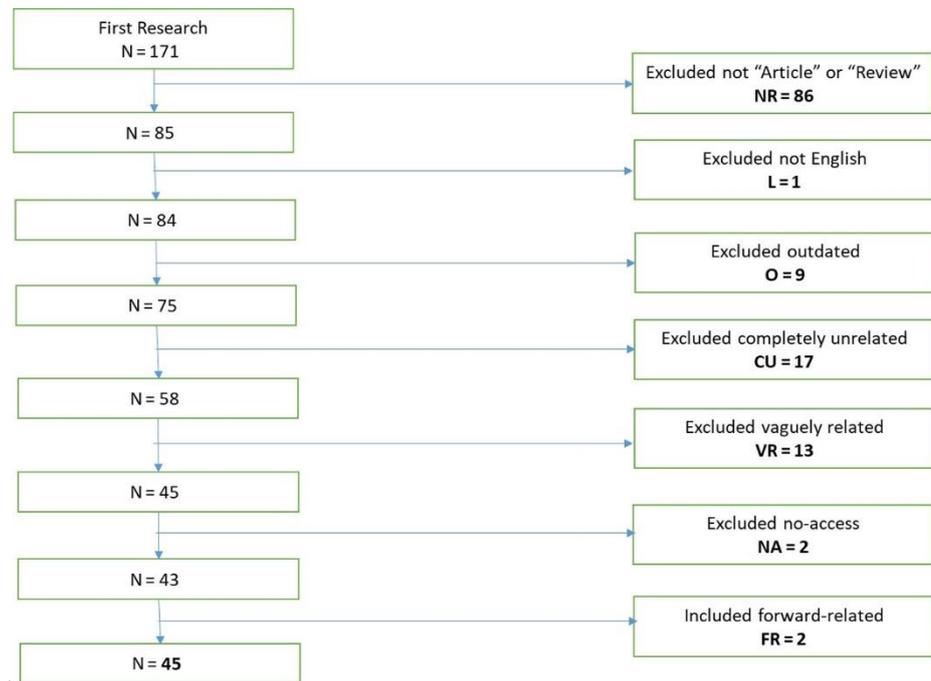


Figure 2. Literature review process

Primary objective is generalisation. This step is not significant for certain reviews, such as scoping reviews, which aim to explore the range of studies rather than assess quality. In accordance with the inclusion screening process, the authors concurrently conducted the quality assessment, as advised by Noordzij et al. (2009). All disputes have been settled via dialogue and consultation.

This literature review, classed as a scoping review, has not rejected publications from the pool based on the quality evaluation employed. This decision reflects the aspiration for extensive input and the originality of the subject matter.

Consequently, quality assessment has been a crucial method for evaluating the overall quality and dispersion of the chosen studies.

The focus of this assessment is the methodology employed in the study and the ranking of the publishing journal. Table 2 presents a compilation of 45 studies, detailing their titles, authors, publication years, journal names, rankings, and methodologies.

Figure 3 indicates a rising trend in interest regarding this topic. Notably, the majority of publications were published in the past three years, 2018–2020.

An examination of the research approaches (Figure 4) reveals that 31% of studies employed case study methodology, generally applied to particular domains.

Ramirez-Peña et al. (2020) examined shipbuilding, a multifaceted manufacturing sector requiring 4.0 guidelines to enhance supply chain efficiency, whereas Ge and Jackson (2014) explored the applicability of Big Data technologies as instruments for Six Sigma processes to attain cost reduction in the automotive industry..

Table 2. Selected papers for systematic literature review

No.	Authors	Year	Journal	Methodology
1	Homer, G. & Thompson, D.	2001	<i>International Journal of Automotive Technology and Management</i>	Case study
2	White, R.E. & Pearson, J.N.	2001	<i>International Journal of Physical Distribution and Logistics Management</i>	Framework
3	Heikkila, J.	2002	<i>Journal of Operations Management</i>	Case study
4	Tan, K.C., Lyman, S.B. & Wisner, J.D.	2002	<i>International Journal of Operations and Production Management</i>	Survey
5	Berkhout & Hertin	2004	<i>Futures</i>	Framework
6	Bruun, P. & Mefford, R.N.	2004	<i>International Journal of Production Economics</i>	Framework
7	Ward, P. & Zhou, H.	2006	<i>Decision Sciences</i>	Survey
8	Adamides, E.D., Karacapilidis, N., Pylarinou, H. & Koumanakos, D.	2008	<i>Production Planning and Control</i>	Case study
9	Hong, P.C., Dobrzykowski, D.D. & Vonderembse, M.A.	2010	<i>Benchmarking: An International Journal SAE International</i>	Survey
10	Ge, X. & Jackson, J.	2014	<i>Journal of Commercial Vehicles Business & Information Systems Engineering (BISE)</i>	Case study
11	Lasi, H., Kemper, H.G., Fettke, P., Feld, T. & Hoffmann, M.	2014	<i>Information Systems Engineering (BISE)</i>	Framework
12	Digiesi, S., Facchini, F., Mossa, G., Mummolo, G. & Verriello, R.	2015	<i>IFAC-PapersOnLine</i>	Case study
13	Haq, A.N. & Boddu, V.	2015	<i>International Journal of Business Performance and Supply Chain Modelling</i>	Case study
14	Jasti, N.V.K. & Kodali, R.	2015	<i>Production Planning and Control 49th Hawaii</i>	Framework
15	Hermann, M., Pentek, T. & Otto, B.	2016	<i>International Conference on System Sciences</i>	Case study

16	Sanders, A., Elangeswaran, C. & Wulfsberg, J.	2016	<i>Journal of Industrial Engineering and Management</i>	Literature review
17	Davies, R., Coole, T. & Smith, A.	2017	<i>Procedia Manufacturing</i>	Case study
18	Lu	2017	<i>Journal of Industrial Information Integration</i>	Survey
19	Mrugalska, B. & Wyrwicka, M.K.	2017	<i>Procedia Engineering</i>	Framework
20	Pinho, C. & Mendes, L.	2017	<i>International Journal of Production Research</i>	Literature review
21	Vazquez-Martinez, G.A., Gonzalez-Compean, J.L., Sosa-Sosa, V.J., Morales-Sandoval, M. & Perez, J.C.	2018	<i>International Journal of Information Management</i>	Simulation
22	Perboli, G., Musso, S. & Rosano, M.	2018	<i>IEEE Access</i>	Case study
23	Ante, G., Facchini, F., Mossa, G. & Digiesi, S.	2018	<i>IFAC-PapersOnLine</i>	Framework
24	Tortorella, G.L. & Fettermann, D.	2018	<i>International Journal of Production Research Technological</i>	Survey
25	Horváth, D. & Szabó, R.Z.	2019	<i>Forecasting and Social Change</i>	Interview
26	Rossini, M., Costa, F., Tortorella, G.L. & Portioli-Staudacher, A.	2019	<i>International Journal of Advanced Manufacturing Technology</i>	Survey
27	Haddud, A. & Khare, A.	2019	<i>International Journal of Lean Six Sigma</i>	Survey
28	Bittencourt, V.L., Alves, A.C. & Leão, C.P.	2019	<i>IFAC-PapersOnLine</i>	Literature review
29	Bevilacqua, M., Ciarapica, F.E. & Antomarioni, S.	2019	<i>Management and Production Engineering Review</i>	Framework
30	Ashrafian, A., Powell, D.J., Ingvaldsen, J.A., Dreyer, H.C., Holtskog, H., Schütz, P., Holmen, E., Pedersen, A. & Lodgaard, E.	2019	<i>IFIP Advances in Information Processing</i>	Literature review
31	Roy, M. & Roy, A.	2019	<i>IEEE Engineering Management Review</i>	Case study
32	De Giovanni, P. & Cariola, A.	2020	<i>Research in Transportation Economics</i>	Survey
33	Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. & Martínez-Jurado, P.J.	2020	<i>International Journal of Production Research</i>	Literature review
34	Chiarini, A., Belvedere, V. & Grando, A.	2020	<i>Production Planning and Control</i>	Survey

35	Pekarcikova, M., Trebuna, P., Kliment, M. & Rosocha, L.	2020	<i>International Journal of Simulation Modelling</i>	Simulation
36	Saxby, R., Cano-Kourouklis, M. & Viza, E.	2020	<i>The TQM Journal</i>	Interview
37	Alieva, J. & von Haartman, R.	2020	<i>Operations and Supply Chain Management</i>	Interview
38	Frontoni, E., Rosetti, R., Paolanti, M. & Alves, A.C.	2020	<i>Manufacturing Letters</i>	Case study
39	Ramirez-Peña, M., Sánchez Sotano, A.J., Pérez-Fernandez, V., Abad, F.J. & Batista, M.	2020	<i>Journal of Cleaner Production</i>	Case study
40	Buer, S.V., Semini, M., Strandhagen, J.O. & Sgarbossa, F.	2020	<i>International Journal of Production Research</i>	Survey
41	Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. & Martínez-Jurado, P.J.	2020	<i>International Journal of Production Research</i>	Literature review
42	Bittencourt, V.L., Alves, A.C. & Leão, C.P.	2021	<i>International Journal of Production Research</i>	Literature review
43	Ciano, M.P., Dallasega, P., Orzes, G. & Rossi, T.	2021	<i>International Journal of Production Research</i>	Case study
44	Raji, I.O., Shevtshenko, E., Rossi, T. & Strozzi, F.	2021	<i>International Journal of Logistics Management</i>	Framework
45	Spenhoff, P., Wortmann, J.C.H. & Semini, M.	2021	<i>Production Planning and Control</i>	Case study

A considerable number of research have established a framework linking the two paradigms of lean supply chain and Industry 4.0. Bevilacqua et al. (2019) developed a strategy grounded in lean principles to reduce both the quantity and duration of picking activities in a warehouse utilising an automated storage and retrieval system.

Subsequently, three studies employed interviews to collect unstructured data, yielding enlightening conclusions.

Third, 4% of studies utilised simulation to perform what-if analyses. Utilising this technique, Vazquez-Martinez et al. (2018) formulated a model capable of linking various customers, partners, and organisations while executing the phases of the digital product lifecycle among them.

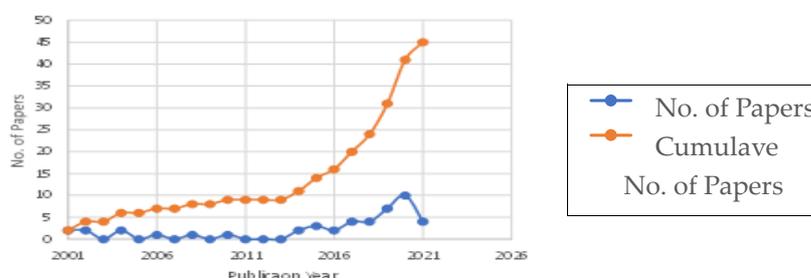


Figure 3. Yearly distribution of the papers considered

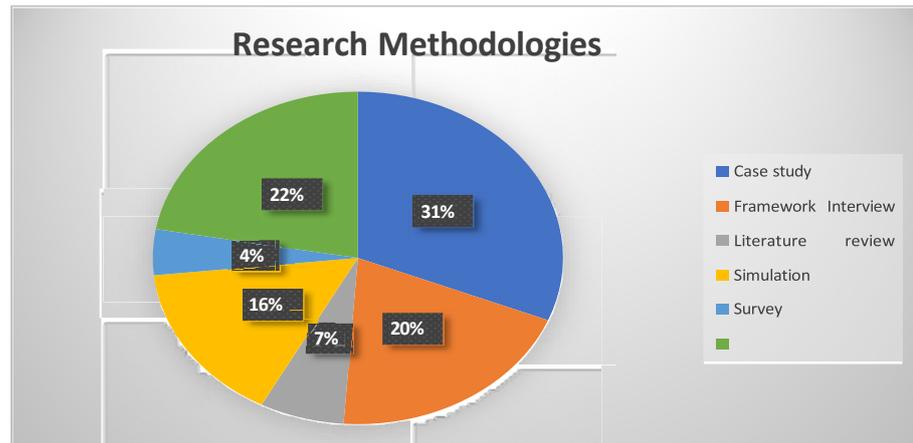


Figure 4. Methodology distribution of the papers considered

Subsequently, 16% of studies have employed the literature review approach to elucidate the current state of research about the interplay and simultaneous implementation of lean supply chain and Industry 4.0. The objective of De Giovanni and Cariola (2020) is to examine the impact of a process innovation strategy, implemented via I4.0 technologies, on the performance of lean practices and green supply chains.

Ultimately, the survey technique has been utilised by Rossini et al. (2019) and others (22%) to assess the influence of I4.0 technology adoption and LP practices on the operational performance of European firms.

The data extraction method typically entails coding. In accordance with the recommendations of Gomersall et al. (2015), the researchers independently coded the studies by thoroughly studying the complete articles, rather than solely depending on the primary interpretation. This approach prevents the deformation of the original document. The publications were analysed to discern the attributes of each study (e.g., research methodology) and variables that could elucidate emerging trends or disparities in the works (e.g., the interaction between lean and I4.0 techniques).

Upon completion of the data extraction procedure, reviewers must categorise the data according to the predetermined review type (Xiao and Watson, 2017). Each qualitative and quantitative literature retrieved through the aforementioned search criteria was thereafter evaluated individually by each researcher. Subsequently, reviewers convened to convert the quantitative findings presented in the articles into a qualitative output. The adopted methodology is integrated design, which concurrently analyses and synthesises quantitative and qualitative research. The results were consolidated into three emergent categories, achieved by consensus on the parallels and contrasts identified in the literature: lean favouring Industry 4.0, mutual reinforcement of lean and Industry 4.0, and Industry 4.0 supporting lean (see to the subsequent section for literature analysis).

The results of the literature search should ultimately be presented in a visual diagram following screening and quality assessment. New insights must be emphasised. Furthermore, the findings should encompass possibilities and guidance for future study (Okoli and Schabram, 2010).

3. Results and Discussion

This section analyses the literature on the interaction between Industry 4.0 and Logistics Supply Chain Management. Literature analysis revealed 45 papers that directly and indirectly met our criteria, facilitating the establishment of interrelationships between I4.0 and LSCM. An examination of the literature is provided, illustrating the trend of

papers. The findings for each detected line are subsequently presented, followed by a discussion.

The papers can be categorised into three primary groups: Lean advocating for I4.0; mutual reinforcement of lean and I4.0; and I4.0 facilitating lean. Table 3 presents the articles categorised accordingly.

Due to the limited quantity of articles and the novelty of the subject, the authors delineated two study trajectories that distinctly characterise divergent approaches within this domain: strategic and operational levels.

The previous study line encompasses all publications that examine the interaction between the two paradigms, emphasising a systemic approach and a long-term implementation trajectory. This research line encompasses all publications that examine the interaction between the two paradigms at the operational level, focussing on a singular implementation viewpoint and a short-term outlook associated with the unique practice or technology deployment in a particular environment.

The automation facilitated by Industry 4.0 has raised enquiries over its interoperability with the lean methodology. A lean workplace fosters a culture that is more amenable to adopting new technologies, particularly those that minimise waste (Bittencourt et al., 2019; Torri et al., 2021). In this regard, LSCM and I4.0, despite their divergent approaches, should be regarded collectively, as they share the common objective of minimising costs and enhancing productivity for enterprises. The authors reviewed this relationship, emphasising the potential importance of lean in the ongoing Fourth Industrial Revolution. They concluded that lean methodologies could aid in the implementation of Industry 4.0 in firms, as noted by Kolberg and Zühlke (2015). The maturity level of lean within a system is a crucial indicator that indicates its relationship with I4.0 (Saxby et al., 2020). Nevertheless, the writers emphasised the

Table 3.Literature details

Lean favouring Industry 4.0	Mutual support of Lean and Industry 4.0	Industry 4.0 supporting Lean
Berkhout & Hertin (2004)	Ge & Jackson (2014)	Homer & Thompson (2001)
Vazquez-Martinez et al. (2018)	Digiesi et al. (2015)	White & Pearson (2001)
Bittencourt et al. (2019)	Davies et al. (2017)	Tan et al. (2002)
Ramirez-Peña et al. (2019)	Lu (2017)	Adamides et al. (2008)
Rossini et al. (2019)	Mrugalska & Wyrwicka (2017)	Lasi et al. (2014)
Alieva & von Haartman (2020)	Ante et al. (2018)	Haq & Boddu (2015)
Saxby et al. (2020)	Tortorella & Fettermann (2018)	Jasti & Kodali (2015)
Bittencourt et al. (2021)	Buer et al. (2020)	Hermann et al. (2016)
	Núñez-Merino (2020)	Sanders et al. (2016)
	Ciano et al. (2021)	Pinho & Mendes (2017)
	Raji et al. (2021)	Perboli et al. (2018)
	Spenhoff et al. (2021)	Ashrafian et al. (2019)
		Bevilacqua et al. (2019)
		Haddud & Khare (2019)
		Horváth & Szabó (2019)

Lean favouring Industry 4.0	Mutual support of Lean and Industry 4.0	Industry 4.0 supporting Lean
		Roy & Roy (2019)
		Chiarini et al. (2020)
		Frontoni et al. (2020)
		De Giovanni & Cariola (2020)
		Pekarcikova et al. (2020)

Significance of comprehending which LSCM elements offer greater assistance for the implementation of I4.0. This is essential to prevent substantial investments, both financially and temporally, in reinventing operational systems, while a mere update of certain elements efficiently facilitates the introduction of Industry 4.0 technologies (Saxby et al., 2020).

Jasti and Kodali (2015) have also substantiated the connection between ICT and LSCM by incorporating Information Technology Management as a fundamental component of their LSCM framework, previously discussed in the literature review on lean supply chain. Furthermore, Tan et al. (2002) assert that information technology oversees the information flow throughout the supply chain and is essential for managing and regulating multi-organizational networks in the current context (White and Pearson, 2001). Adamides et al. (2008) emphasised the significance of ICTs as a catalyst for LSCM advancement, contingent upon enhanced integration with consumers and suppliers.

Numerous research indicate that I4.0 and LSCM are mutually reinforcing, with LSCM elements considered as catalysts for I4.0, while I4.0 is perceived to enhance lean methodologies (Uriarte et al., 2018). This finding is corroborated by Tortorella and Fettermann (2018), who conducted a survey research indicating that organisations who adopted both lean methodologies and Industry 4.0 attained superior performance enhancements compared to their counterparts.

Chiarini et al. (2020) in their exploratory research on I4.0 technology advancements have emphasised the assistance that I4.0 may offer to LSCM, corroborating the findings of other researchers (Kolberg and Zühle, 2015). They specifically emphasise the influence of Industry 4.0 on quality management procedures, notably the advent of the Quality 4.0 concept. Nonetheless, many expressed apprehension regarding the deployment of I4.0 technologies inside a dynamic and rapidly evolving lean context. They proposed that LSCM be employed to eliminate waste, which will be a prerequisite for I4.0 technologies and thus avert the automation of waste.

Alieva and von Haartman (2020) also examine the problem of waste, emphasising the detrimental effects of inefficient data utilisation in decision-making on factory performance. These authors asserted that technological solutions designed to leverage data analytics also generate a novel type of waste, termed digital waste. They assert that digital waste ought to be seen as a novel form of Muda and should prompt increased focus on data analytics.

Ashrafian et al. (2019) define digital lean manufacturing as the integration of digital technology, such as e-Kanbans or kaizen, within collaborative workplaces where lean principles are already established. It can augment lean principles through digitalisation, resulting in reduced waste.

Moreover, digitalisation in communication is crucial for all stakeholders in the supply chain (Ashrafian et al., 2019). Strategic supplier development aims to motivate and empower suppliers to enhance their lean skills. It will assist them in enhancing their performance through the application of lean practices (Sako, 2004). Moreover, the difficulties posed by competitive rivalry have been taken into account in the formulation of lean supplier networks.

The advantages of digital technology in enhancing performance are now broadly acknowledged, and certain contributions have been observed linking digital transformation with LSCM concepts (Pinho and Mendes, 2017). Nonetheless, the impact of digitalisation on the ability of manufacturing enterprises to implement and promote lean methods with their suppliers remains complex. Despite being conceptually complementary, the information technology of I4.0 and Lean Management are not necessarily compatible; therefore, firms should endeavour to embrace both in a manner that fosters sustainable competitiveness. Powell (2013) demonstrated methods by which ERP may facilitate LP and pull production, especially in small and medium-sized firms. Spenhoff et al. (2021) delineate the problems and potential associated with the integration of lean principles and Industry 4.0 from a technical standpoint. Therefore, we recommend that IT be utilised to address genuine organisational challenges, rather than indiscriminately embracing appealing new technologies. If companies start by identifying and defining challenges, the potential for exploring lean approaches and digital technology can be significantly enhanced. Consequently, the companies can enhance the advantages derived from LM and progressively evolve to be more digital and sustainable (Mo, 2009).

Kolberg and Zühlke (2015) examined a possible contradiction between the lean methodology and the Industry 4.0 paradigm. The former emphasised the disparity between lean's emphasis on human resources and Industry 4.0's concentration on machine technologies. Ruttimann and Stockli (2016) examined the distinct roles of employees in the two approaches: lean traditionally appreciates human resources for their expertise, whereas I4.0 perceives them as a source of variability and potential troubleshooters in their interactions with machine-operated tasks. Conversely, a limited number of authors underscored entirely distinct viewpoints and accentuated the possibilities for job enrichment that Industry 4.0 may offer employees, alleviating the monotony of physical tasks and providing greater intellectual stimulation (Lagorio et al., 2021).

Numerous authors emphasised the significance of ICTs as essential components for managing LSCM operations, facilitating not only the exchange of information among various supply chain actors but also the integration with external partners (Martínez-Jurado and José Moyano-Fuentes, 2014), including the identification and optimisation of value flows. Ward and Zhou (2006) discovered that the use of information technology for lean operations inside supply chains led to failures due to inadequate infrastructure and communication. Various forms of information technology exert distinct influences on the lean supply chain. Consequently, Hong et al. (2010) emphasised the significance of classifying information technology for supply chain effectiveness.

Ante et al. (2018) emphasised the importance of a comprehensive performance indicators system for achieving superior outcomes, predicated on the premise that a company's existence is contingent upon long-term competitiveness. In this respect, I4.0 signifies a significant opportunity, as it facilitates the analysis of machine data, hence improving quality, while also aiding in the prevention of problems in the manufacturing process. Nevertheless, the digital revolution has numerous downsides for various industries. Industry 4.0 necessitates an elevated degree of system control to enhance flexibility and competitiveness (Digiesi et al., 2015; Lu, 2017). Ante et al. (2018) developed a key performance indicators tree that effectively link key performance indicators with improvement methods. The KPI tree is structured into a five-level hierarchy: Value Contribution, Key Performance Result (KPR), Value Stream KPRs, Monitoring KPRs, and Improvement KPRs. These frameworks facilitate the oversight of I4.0 projects and propel the lean continuous improvement process.

In another sector of literature concerning the interaction between LSCM and I4.0, authors have concentrated on certain I4.0 technologies and applications, as well as their associations with specific LSCM elements. Ramirez-Peña et al. (2020)

assert that effective implementation of I4.0 necessitates a lean supply chain. I4.0 technologies can significantly impact several stakeholders within the supply chain.

Simulation is one method, as emphasised by Rossini and Staudacher (2016), who conducted a study utilising simulation to examine how lean practices might enhance supply chain planning performance. Haq and Boddu (2015) demonstrated that artificial intelligence is linked to lean supply chains through a fuzzy logic model that dramatically enhances system efficiency.

Ahmed et al. (2018) assert that Big Data influences supply chain management from an environmental perspective. Ramirez-Peña et al. (2020) examined and determined that Autonomous Robots, Additive Manufacturing, Cybersecurity, Cloud Computing, and Augmented Reality are the most pertinent for enhancing Green LSCM components. De Giovanni and Cariola (2020) examined the influence of the introduction of I4.0 technologies on lean and green practices inside supply chains. The authors asserted that process innovation with I4.0 technologies does not significantly impact green performance, whereas it enhances the efficacy of lean methods in enhancing operational and economic performance.

Roy and Roy (2019) already elucidated in the literature study on I4.0 regarding the development of their Smart Management System (SMgS). The innovative technology-driven SMgS will enhance industrial efficiency, sustainability, lean operations, safety, and cost-effectiveness. Specifically, "Lean and Efficient" appears among the system's advantages, indicating that SMgS may be utilised more swiftly and with reduced complexity compared to lean philosophy, while achieving equivalent outcomes. The system integration will enhance operational efficiency by eliminating waste (Heikkilä, 2002).

Recently, several authors examined the evolution of traditional LSCM aspects, such as Kanban, in light of the arrival of I4.0 technology. They specifically concentrated on the deployment of a CPS and the resulting advantages for the Kanban, intending to automate with minimal or no human involvement. The "e-Kanban" is predicated on a virtual system; the conventional card has transformed into a digital card and is transferred electronically. The e-Kanban substitutes conventional Kanban cards with barcodes, utilising technology to enhance material flow. The e-Kanban minimises manual labour in card management and offers real-time access to all pertinent Kanban information, directly connected online to the Cloud.

Bevilacqua et al. (2019) asserted that the contemporary manufacturing landscape, transitioning towards a 4.0 paradigm, increasingly emphasises Big Data Analytics methodologies. Data comprehension is crucial for deriving valuable insights and new information to leverage effectively. The authors asserted that, similar to lean manufacturing, factory automation aims to fulfil client satisfaction at the lowest possible cost. Manufacturing automation eliminates non-value-added processes and ensures consistent quality to attain these objectives. In this context, Big Data Analytics techniques facilitate communication between automation and linear programming methodologies (Bevilacqua et al., 2019).

Vazquez-Martinez et al. (2018) introduced a novel distribution model called CloudChain, which is based on LSCM principles and applicable to the supply chain of digital items. The approach utilises I4.0 technologies to establish secure containers and operational network configurations that facilitate transportation activities.

Managers can design CloudChain as a conventional packing and logistics service while leveraging Industry 4.0 capabilities. This distribution approach integrates applications from many partners throughout the supply chain, both upstream and downstream, and facilitates the construction of value chains with uninterrupted information flows across diverse cloud storage resources (Vazquez-Martinez et al., 2018). Previously, Blockchain, the predominant technological framework, was utilised exclusively for financial applications. In recent years, research trends in Blockchain technology have shifted to various domains;

specifically, Perboli et al. (2018) examined the application of Blockchain in supply chain and logistics.

The assurance of data immutability and public accessibility of data streams renders Blockchain a disruptive innovation. Furthermore, the decentralised architecture of Blockchain addresses the challenges associated with centralised systems, including trust deficiencies. Nonetheless, from its beginning, Blockchain possesses certain intrinsic flaws that must be rectified prior to its implementation in other areas. The implementation of Blockchain technology can serve as the foundation of a new digital supply chain. Alongside other technical elements, such as Business Analytics and artificial intelligence, it has facilitated the swift advancement of logistics during the past decade. Blockchain can address the security concerns associated with the Internet of Things. As emphasised, Blockchain can dismantle some hurdles of Industry 4.0 technologies throughout the supply chain, facilitating the integration of lean philosophy and Industry 4.0 within the supply chain. Ge and Jackson (2014) examined the recent implementation of Big Data to reduce expenses in the automobile industry. Authors observed that the implementation of Big Data is advantageous in proactively reducing costs and enhancing responsiveness. Furthermore, Big Data technology can facilitate the development of a circular economy for automobile companies. Big Data offers benefits that complement established approaches in the automotive engineering sector, including Continuous Product Improvement methodologies. DMAIC is a Continuous Product Improvement process based on the Plan-Do-Check-Act framework. The effective application of Big Data technologies in the DMAIC process indicates their potential to enhance data aggregation, facilitate preliminary analysis, and bolster the support that the DMAIC methodology provides for high-level decision-making. Consequently, there exists potential for the synergistic application of lean methodologies and Big Data regarding cost reduction and the enhancement of advanced methods.

Frontoni et al. (2019) introduced a project with a high-end fashion items company and its worldwide shipping partner, a third-party logistics (3PL) provider, aimed at addressing the emerging demands for increased sales volume and digital channels. In this context, they acknowledged that achieving a genuinely lean organisation with Just-In-Time (JIT) production throughout the value chain necessitates a synchronisation of material and information flows among suppliers, manufacturers, and distributors, which is difficult to attain. Integrating new emergent I4.0 technologies inside a lean framework can facilitate this achievement (Kagermann et al., 2013) by enabling:

- Comprehensive comprehension of client demand;
- Swift dissemination of demand data across the intricate supply chain;
- Accelerated production in intelligent manufacturing with reduced waste;
- Significantly expedited single-piece flow of tailored items;
- capability to significantly diminish inventory across the supply chain;
- real-time information dissemination via coordination throughout the whole supply chain; and
- Significantly enhanced instant just-in-time pull production, minimising or eradicating overproduction (Netland, 2015).

Rossini et al. (2019) investigated the influence of the correlation between lean adoption and Industry 4.0. Authors emphasised that, of the 16 principal I4.0 technologies identified in the literature, "big data" and "augmented reality" were the most prevalent. Conversely, "Collaboration with suppliers/customers via real-time data sharing" appears to be underexplored in the I4.0 literature. This substantiates that insufficient emphasis is placed on studies concerning I4.0 in the context of customer/supplier relationships (Rossini et al., 2019). This finding is

significantly crucial for the analysis at hand. This study elucidates the interrelationships between Industry 4.0 and lean methodologies within the operational environment of supply chains.

Haddud and Khare (2019) examined the effects of digitalisation on supply chains and propose that it may yield advantages in a lean setting. The study specifically investigated the potential effects of seven enabling digital technologies (Meier, 2016) on five chosen lean operations practices: Just-In-Time (JIT), Visual Management, Total Productive Maintenance, Continuous Improvement, and Autonomation (failure prevention) as well as Poka-Yoke (mistake-proofing). The digitalisation of supply networks significantly influenced all five aforementioned lean operations practices.

The systematic literature review clearly demonstrates that LSCM and I4.0 mutually reinforce each other from a synergistic standpoint. I4.0 technologies improve LSCM practices through the digitalisation of conventional LSCM components, whereas LSCM practices facilitate the integration of I4.0 technologies into the supply chain system. This mutual support is in complete accordance with the majority of recent studies about the interaction between lean systems and Industry 4.0 (Buer et al., 2018; Núñez-Merino et al., 2020). Nevertheless, further ideas distinctly arise. Indeed, if it is undisputed that LSCM and I4.0 mutually reinforce one another, this perspective shifts slightly when we differentiate between strategic and operational analysis.

The primary research stream emphasises the beneficial effects of digitalising LSCM procedures and the enhancement provided by the integration of Industry 4.0 technology into existing, often antiquated, LSCM practices. Conversely, the strategic research stream primarily emphasises the LSCM paradigm as an essential foundation for the implementation of I4.0 technologies, due to the efficacy of the supply chain operations system and the guiding principles for appropriate investment decisions.

The analysis reveals a distinct pattern regarding mutual assistance, as illustrated in Figure 5: at the strategic level, LSCM facilitates the implementation of I4.0, while at the operational level, I4.0 strengthens LSCM practices.

This paradigm enhances the understanding of the literature regarding the interaction between LSCM and I4.0, while also facilitating a broader comprehension of the relationship between lean principles and I4.0. It aligns with all research that demonstrated a positive association between lean and Industry 4.0 (Rossini et al., 2019; Tortorella et al., 2021). It endorses the research on the synergistic perspective of the two paradigms (Buer et al., 2020), providing a more explicit delineation of the paradigms' roles. This assertion is corroborated by recent literature, which demonstrates the integration of specific Industry 4.0 technologies with lean methodologies, ranging from the fundamental 5S to the more advanced Statistical Process Control and Total Productive Maintenance systems (Chiarini and Kumar, 2020; Bittencourt et al., 2021; Ciano et al., 2021; Raji et al., 2021; Spenhoff et al., 2021).

At a strategic level, lean supply chains are propelling Industry 4.0 by optimising various components of the supply chain to minimise waste. This is especially pertinent with the enhanced horizontal and vertical integration facilitated by ICT in Industry 4.0, such as the Industrial Internet of Things, Digital Twin, and sophisticated IT infrastructures that extend traditional ERP systems. In lean methodology, once customer value is established, the situation is analysed within and between organisations to identify and eliminate non-value-adding operations. Value stream mapping is augmented by Industry 4.0, with a focus on the digital environment over the physical environment.

At the operational level, continuous flow is a fundamental component of lean methodology. The production process must adhere to the takt time established with the customers. I4.0 seeks to facilitate the real-time flow of data rather of focussing on physical entities. Once more, it is evident that digital technologies,

like Big Data Analytics and digital twins, with worker-supportive tools such as augmented reality, virtual reality, and smart wearables, will indeed facilitate improved lean operations. The research primarily emphasises the LSCM paradigm as an essential foundation for the implementation of I4.0 technologies, due to the efficacy of the supply chain operations system and the guiding principles for appropriate investment decisions. The framework illustrated in Figure 5 delineates a distinct trend regarding what is supported and what provides support. At the strategic level, LSCM facilitates the implementation of I4.0, while at the operational level, I4.0 strengthens LSCM processes. This paradigm contributes to the understanding of the literature regarding the interaction between LSCM and I4.0, while also facilitating a broader comprehension of the relationship between lean principles and I4.0. It aligns with all research that demonstrated a positive association between lean and Industry 4.0 (Rossini et al., 2019; Tortorella et al., 2021). It endorses the research on the synergistic perspective of the two paradigms (Buer et al., 2020), providing a more explicit delineation of the paradigms' roles. This assertion is corroborated by recent literature indicating that specific Industry 4.0 technologies are integrated with lean methodologies, ranging from the fundamental 5S to the more advanced Statistical Process Control and Total Productive Maintenance systems (Chiarini and Kumar, 2020; Bittencourt et al., 2021; Ciano et al., 2021; Raji et al., 2021; Spenhoff et al., 2021).

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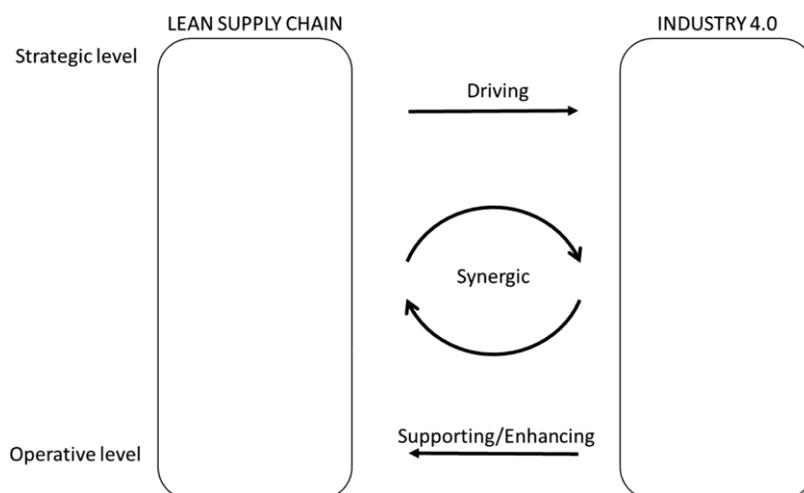


Figure 5. Relationship between lean supply chain management and Industry 4.0

The ultimate goal of lean is to manufacture solely in accordance with the timeframes and requirements dictated by the consumers. In addition to the products, I4.0 enables

customers to demand vital services associated with the offering. This will enhance consumer happiness. Consequently, the enhancement of products by Radio Frequency Identification will yield a transformative effect of Industry 4.0 in support of lean principles. The subsequent paragraphs will examine the theoretical and practical ramifications of the study.

This work constitutes the inaugural organised analysis of the relationship between LSCM and I4.0 in existing research. Currently, numerous scholarly articles address this point in the literature; nevertheless, they lack full coverage. This study serves as the foundational basis for academicians seeking to pursue further research in the domains of LSCM and I4.0 settings. The results obtained from the analysis presented in this paper validate the significance of I4.0 practices within an LSCM context. At the strategic level, LSCM impacts I4.0, whereas I4.0 inside LSCM improves integration and information flow with customers and suppliers, particularly in terms of horizontal and vertical integration, CloudChain, and Big Data. This study also emphasises the active involvement of Industry 4.0 in continuous improvement, a prominent characteristic of lean methodology. Consequently, this validates the knowledge trajectory endorsed by the prior research conducted by Ward and Zhou (2006) and Adamides et al. (2008). Therefore, this study provides scholars with the rationale supporting the literature that advocates for a mutually advantageous partnership between LSCM and I4.0. Furthermore, the relationship between these two paradigms and the comprehensive elucidation of these connections can be analysed by scholars.

This paper examines the relationships between LSCM and I4.0 from a managerial perspective, offering a comprehensive dual viewpoint. It provides recommendations for firms already employing the lean paradigm within their supply chain that wish to initiate a new project related to I4.0; conversely, it serves as a guideline for companies currently adopting I4.0 that aim to incorporate lean concepts as well.

Comprehending the ramifications of I4.0 and its extension to the supply chain will enable firms to effectively implement LSCM and I4.0 models simultaneously. The absence of understanding of the potential advantages or ambiguous results of investments has frequently hindered numerous companies from adopting both LSCM and I4.0. The research findings indicate a need to focus on the development of LSCM due to its significant role in enhancing the I4.0 paradigm, as it not only promotes the adoption of additional practices but also mitigates the obstacles associated with I4.0. Furthermore, the framework serves as a decision-making instrument for firms to maximise advantages when concurrently deploying LSCM and I4.0. Another significant conclusion to highlight pertains to I4.0 practices, namely the attributes of the most pertinent practices based on their potential impact on other practices or barriers.

To ensure the success of I4.0 in LSCM both internally and externally, the government or public sector should engage with the findings of this research as a reference to facilitate a roadmap for the transition towards the adoption of I4.0 and LSCM.

4. Conclusion

For numerous years, the idea of lean thinking and its principals have provided practitioners with a methodology to develop an efficient and competitive manufacturing system. Gradually, lean management is gaining significance for enhancing supply chain management, specifically LSCM, through successive achievements. Conversely, I4.0 emerged more recently as a revolution, presenting opportunities for enhancement in quality, flexibility, and productivity through the utilisation of digital technologies. Consequently, the link between the two paradigms is called into question about their coherence, opposition, alternation, or complementarity. We present a framework that illustrates the interdependence and interaction between the two perspectives.

The research commenced with the collection of information regarding the two paradigms under examination, LSCM and I4.0, as presented in the existing literature. The authors conducted a systematic literature review to examine the links between the two paradigms. The literature indicates a growing trend in publications addressing the significance of both lean methodologies and Industry 4.0. The literature study allows for the categorisation of the link between LSCM and I4.0 into two dimensions: strategic and operational levels. At the strategic level, LSCM is advancing Industry 4.0 to establish sustainability, while diverse consumer demand is propelling Digital LSCM. At the operational level, I4.0 is enhancing LSCM using sophisticated technologies and techniques such as Big Data, Augmented Reality, Digital Products, CloudChain, Blockchain, and additive manufacturing.

This work primarily contributes by identifying research trajectories derived from literature analysis, elucidating the interconnection between LSCM and I4.0, and investigating the critical domains necessitating substantial effort.

The following section outlines the research limitations and proposes directions for future studies.

The interconnections between LSCM and I4.0 have enriched the understanding of this domain, yielding both theoretical and practical ramifications, as previously noted. Nonetheless, this report is not devoid of limitations, akin to any other scientific study.

The authors have utilised only one database, Scopus, in the systematic literature review conducted. This suggests that there may be further insights regarding the connection between lean supply chains and Industry 4.0. Consequently, utilising several databases, including Google Scholar and Web of Science, or a mix of many databases, may yield diverse information. Moreover, it has proven challenging to identify practitioners who are implementing both industrial paradigms within their organisations or, at the very least, who possess expertise in both LSCM and I4.0. This feature illustrates the originality of the argument presented in this study.

Due to the paper's uniqueness, it may serve as a preliminary analysis for subsequent advanced research on the links between LSCM and I4.0, as emphasised in the theoretical implications. Consequently, the authors have delineated numerous additional enhancements for prospective supplemental investigations. To enhance the literature, pertinent findings may be derived by focussing exclusively on enterprises presently implementing LSCM and seeking to initiate their transition to I4.0, or conversely. This situation allows for the development of a case study to comprehend the practical ramifications of concurrently applying both paradigms and to corroborate the theoretical findings achieved. A potential subsequent step may entail the application of the analytical methodology established in this study to particular contexts, namely focussing on a distinct industry, firm size, or geographical region. Indeed, the consideration of small- and medium-sized enterprises vs large enterprises may yield distinct results in the concurrent implementation of LSCM and I4.0. Due to the argument's originality and its increasing significance, such analyses should be duplicated in a few years.

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