

Mapping the terrain for the Lean Supply Chain 4.0

Mapping Lean
Supply Chain
4.0

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Abstract

Purpose – This study aims to carry out a systematic literature review (SLR) on the integration of Lean, Industry 4.0 and the supply chain or the Lean Supply Chain (LSC) 4.0. The research analyses the current research on the LSC 4.0 concept in an increasingly digitalised world. The authors present the benefits, motivations, critical success factors and challenges of integrating the LSC with Industry 4.0 technologies within this emerging area of research.

Design/methodology/approach – An SLR is carried out on how Lean can be integrated with Supply Chain 4.0. Using the search strings of “Lean Supply Chain 4.0,” “Lean Supply Chain Management 4.0” and “Lean Supply Chain Digitalisation,” a review of published literature was carried out via searches on academic databases.

Findings – Industry 4.0 has a synergistic effect on the LSC and, depending on the technology and sector applied in, can complement and enhance the LSC. Similarly, the LSC is a precursor for digitalisation. There are considerable implications in the LSC 4.0 for green and sustainable processes.

Practical implications – Organisations can use this study to understand what the LSC 4.0 means to industry, the benefits and motivating factors for implementation, the critical success factors (CSFs) to implementation and the challenges for implementation.

Originality/value – This study adds to state of the art around the LSC 4.0 and future directions in this nascent research area. This study will aid organisations in understanding how Lean, supply chain management and Industry 4.0 can be integrated.

Keywords Lean, Supply chain, Industry 4.0, Digitalisation, Lean Supply Chain 4.0

Paper type Literature review

1. Introduction

With the dawn of the first Industrial Revolution, production evolved from craft production into mass production and ultimately into Lean production and supply chains. Lean

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Management (LM) is an operational excellence methodology to eliminate any source of waste and non-value-add activity in a value stream (Womack and Jones, 1996). The concept of Supply Chain Management (SCM) was put forward in the mid-1980s, incorporating a definition based on inter-organisational operations management, system integration and information sharing (Cooper *et al.*, 1997). The incorporation of Lean principles has evolved to what has become known as the Lean Supply Chain (LSC). LSC consists of stakeholder organisations and functions linked by flows of products, services and monies and information combined to improve profits and reduce waste by pulling what is required to meet the customer's needs (Núñez-Merino, 2020).

Thus, the LSC concept refers to the integration of LM principles in the supply chain to reduce costs and eliminate waste by utilising Lean to establish flow and pull processes to meet the needs of individual customers (Reyes *et al.*, 2021). However, the application of Lean practices at the supply chain level is much more complex than LM application internally within the company as it requires more coordination and management of physical, information and financial flows between the various stockholders involved (Moyano-Fuentes *et al.*, 2018).

The concept of LM and I4.0 integration has not been widely studied (Antony, 2021a; Antony *et al.*, 2021b, 2022; Tortorella *et al.*, 2020; Rossini *et al.*, 2022). However, the area as a research theme and integration into practice has been evolving in recent years (Antony, 2022) and indeed there has been a “synergistic” effect described between LM and I4.0 (Snee and Hoerl, 2018; Calabrese *et al.*, 2021). In terms of the concept of Supply Chain 4.0 or SCM 4.0 -this concept has also not been widely studied (Rossini *et al.*, 2022). Frazzon, 2019 found that the term has only started to increasingly appear in the literature (with more than 10 publications annually on the concept) since 2016.

Frazzon, 2019 defined SCM 4.0 as “*the integration and synchronisation of the product's entire value chain across different companies, using smart technologies (IoT, IoS and others) to build an interconnected and transparent system with real-time communication that can manage flows and optimise itself, leading to an autonomous, adaptive, intelligent, agile, and dynamic network that focuses on customers' requirements*”.

However, as traditional manufacturing and supply chains are now transitioning into increased digitalisation with the implementation and evolution of Industry 4.0 (I4.0) technologies, the LSC has become digitally ready or digitally enabled (Calabrese *et al.*, 2021). Thus, there is a new evolution of the LSC or LSC 4.0 digitalisation.

However, the integrated effect of Industry 4.0 technology and Lean manufacturing practice on the Supply Chain (SC) has not been empirically investigated. The authors of this paper recently carried out a study on the LSC 4.0 presented as part of the International Symposium on Logistics conference in July 2022 to establish the current research themes around The LSC 4.0 (McDermott, 2022). Whilst there have been limited studies on the literature related to the theme of the LSC 4.0 (Mahdavi Sharif *et al.*, 2022) in this study the authors proposed to answer a broader set of thematic questions in relation the LSC 4.0. We ask question as to how Lean; the Supply Chain and Industry 4.0 can support each other to deliver the LSC 4.0. Thus, this paper aims to contribute to this research area by investigating the themes within the LSC 4.0.

The research questions in this study are:

RQ1. What is the current research on the LSC integrated with I4.0?

RQ2. What are the motivations for integrating the LSC and I4.0?

RQ3. What are the benefits of integrating the LSC & I4.0?

RQ4. What are the critical success factors (CSFs) and challenges to integrating the LSC and I4.0?

The methodology is described in section 2 followed by the results in section 3. The discussion and conclusion are outlined in sections 4 and 5.

2. Methodology- systematic literature review

To aid understanding of the LSC 4.0, a systematic literature review (SLR) was utilised. In addition, systematic research was carried out for articles published between 2012 and 2022 using the academic databases Web of Science and Scopus. The body of literature was synthesised using [Tranfield *et al.*'s \(2003\)](#) approach to systematic literature research. A benefit of SLR is that large quantities of information can be reduced into digestible segments ([Mulrow, 1994](#)). The systematic approach also aids scientific voracity as the process is structured and, therefore, replicable ([Yang *et al.*, 2017](#)).

A SLR was carried out in stages following [Tranfield *et al.* \(2003\)](#) identifying the literature that was relevant to the research questions (RQs), a structured process of review and one that can be followed by future researchers through a research process flow. [Tranfield *et al.* \(2003\)](#) promoted 3 stages in an effective SLR process. These were Stage 1–5, which we planning the review, carrying out the review and reporting and dissemination of the review.

Stage 1: Planning the review

Once the RQs were decided upon and written, next a review protocol was decided upon. The research was only within the academic databases to publications that contain research, or models specific to the LSC 4.0 published between 2012 and 2022 (year to date) due to the nascency of the topic. Therefore, a search string was applied to search all the above databases: “Lean Supply Chain 4.0”, “Lean Supply Chain Management 4.0” and “Lean Supply Chain Digitalisation”. [Table 1](#) provides a detailed listing of the inclusion/exclusion criteria agreed before the review was carried out. As the research objectives for this study were specifically related to the combination of “Lean”, “supply chain” and “digitalisation (or 4.0)” this keyword combination was agreed to eliminate articles that concentrated on two rather than three of the theme words.

Stage 2: Carrying out the review

Utilising the search keywords, academic databases were searched utilising the inclusion/exclusion criteria from [Table 1](#) and extracted and exported utilising Excel. The first search resulted in a total of 3,252 articles (950 in Scopus, 2,302 in Web of Science) which were stored in the reference management software “Zotero” to aid the screening process. Once duplicates were removed in Zotero, the list resulted in 3,252 papers which were then further screened in two stages.

Within the 3,252 screened articles, a search was conducted of the titles, abstracts and keywords of the articles to identify their relevance to the RQ's. The main criteria reviewed at this stage were whether the articles specifically referred to the LSC 4.0. and Many articles referred to the LSC and SC 4.0 but not to the integration of the LSC and I4.0 and thus were disregarded at this stage. The four authors of this research reviewed and independently assessed whether the studies matched the criteria for inclusion based on the search criteria ([Parameswaran *et al.*, 2020](#)). The agreement as to whether to include was reached by discussions and consensus amongst reviewers. This stage concluded with a total of 56 articles.

Inclusion criteria	Exclusion criteria
Academic peer-reviewed journal articles, magazine-related articles, conference proceedings etc.) related to “Lean Supply Chain 4.0” or “Lean Supply Chain Management 4.0”	Grey literature (dissertations, magazines, workshops, editorials, books, prefaces)
Articles published in high-quality journals (part of ABS ranking)	Articles published in languages other than English
Articles published from 2012 to 2022	Articles published before 2012 as the term Industry 4.0 was only coined in 2011, and thus, LSC 4.0 is a nascent area
Source(s): Authors' own work	Articles published in non-refereed journals

Table 1.
Inclusion and
exclusion criteria for
the SLR

In this stage of the screening procedure, the 56 articles that remained were next thoroughly evaluated for their relation to the research themes (LSC 4.0 or LSCM 4.0). The second review stage concluded with 29 articles to be included in the main analysis. The articles that were selected from the second stage were then used in the results and discussion section of the paper.

A flowchart aided the illustration of the SLR steps (Figure 1). The analysis then was started using various themes in response to the research questions, for example the year of publication, authors, journals, research methods, the benefits of LSC & I4.0 integration, motivations for LSC & I4.0 integration, challenges of LSC & I4.0 integration, and finally, the CSFs for LSC & I4.0 integration. These themes arose from initial analysis of the literature.

Stage 3: Reporting and Dissemination of the SLR

Finally as part of stage 3 of the SLR process which was reporting and dissemination the insights from these publications were summarised through the review of any patterns and themes therein. The summary of the thematic analysis is documented in section 3 of this paper.

3. Results

Based on the research we see a tripartite relationship between Lean, the supply chain and Industry 4.0 is represented in Figure 2.

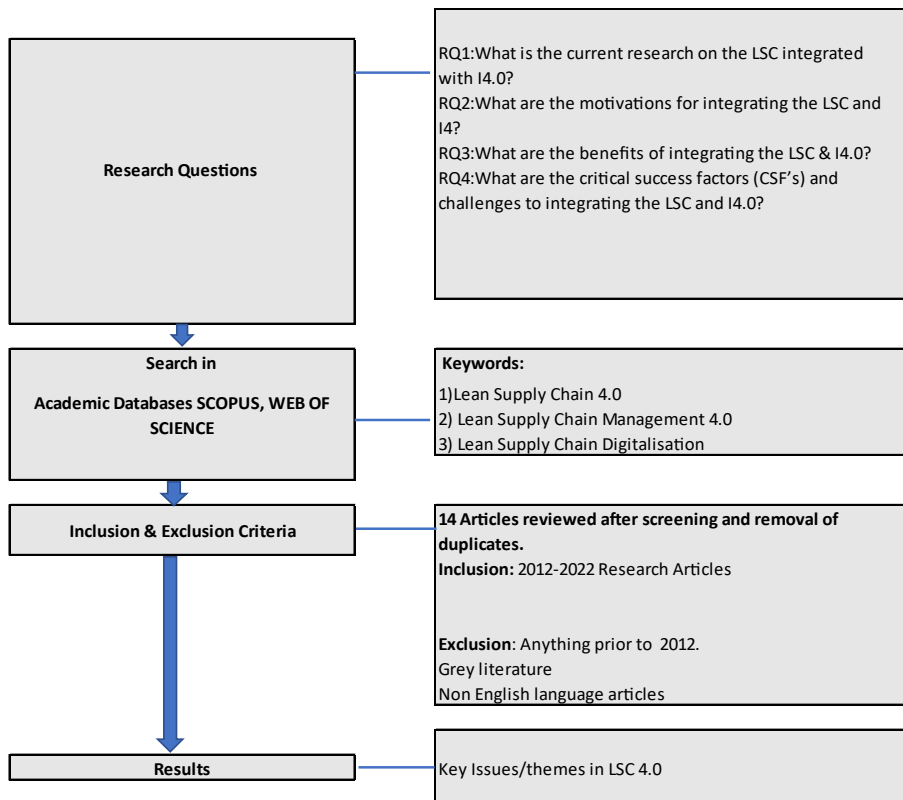


Figure 1.
A summary of the SLR process flow followed by the researchers

Source(s): Author's own work

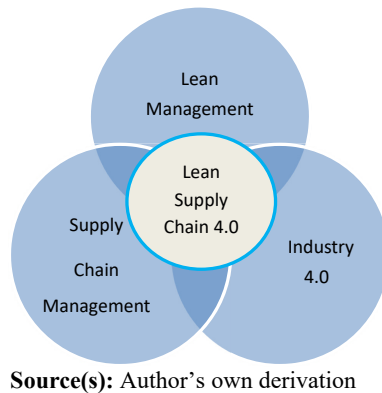


Figure 2.
The Lean Supply Chain
4.0 trilogy

The resulting journals from the final SLR selection were subsequently analysed based on the journal type and when published. The LSC and I4.0 is an evolving research area, as demonstrated by the relatively few remaining 14 journal articles in the final selection (Table 2). However there were 15 conference articles highlighting that the area is evolving and increasing.

Most of the final selection came from conference papers/proceedings (15) versus with just slightly fewer from peer-reviewed journals (14). There was one article each from 12 different journal titles and 2 articles from the *International Journal of Lean Six Sigma*. As demonstrated in Figure 3 – the theme of LSC 4.0 is a current theme of researcher interest, first appearing as recently as 2016 in conference proceedings and then in 2019 in peer reviewed journals with a very low steady stream of research since then. Three main conferences contributed to the research. These were the Proceedings of the International Conference on Industrial Engineering and Operations Management (IEOM) (3 papers), Annual International Conference on Management Science and Engineering Management (ICMSEM) (2 papers). As LSC 4.0 is a recent evolving area of research several authors who have written about the topic have commented on the sparse literature on the concept (Frazzon, 2019; Tay and Loh, 2022; Marodin, 2019). The LSC 4.0 as a concept is still very much in its infancy.

The final selection of articles were screened for themes related to the benefits of the LSC & I4.0 integration, the motivations for the LSC & I4.0 integration, the challenges of the LSC & I4.0 integration and the CSFs for the LSC & I4.0 integration. These articles were screened to ascertain their alignment with the RQ's and research themes and summarised in Table 3. All authors of the selected articles were supportive of the benefits of integrating the LSC and Industry 4.0. However, few articles discussed the CSF's and the challenge of integrating the LSC and Industry 4.0 as this is still an evolving research area lacking longitudinal studies.

4. Discussion

The SLR clearly shows that LSC and I4.0 support each other in a symbiotic and synergistical relationship. The SLR analysis supports this as the LSC and I4.0 are hand in hand in multiple publications suggest their synergy.

As I4.0 technologies enhance the LSC with the digitalisation of traditional LSC elements, Lean SC practices act as enablers for the introduction of I4.0 technologies in the supply chain system. This mutual relationship is perfectly aligned with the recent research about interdependences between lean systems and I4.0 (Buer *et al.*, 2021; Antony, 2022; Rossini *et al.*, 2022).

Paper	Year	Authors	Title	Journal
P1	2019	Tortorella, G; Miorando, R; Francisco, A; Cawley, M	The moderating effect of Industry 4.0 on the relationship between lean supply chain management and performance improvement	<i>International Journal of Operations & Production Management</i>
P2	Tiep <i>et al.</i> , 2020	Tiep, NC; Oanh, TTK; Thuan, TD; Tien, DV; Ha, TV	Industry 4.0, Lean Management and Organisational support: A case of supply chain operations	<i>Polish Journal of Management Studies</i>
P3	2020	Haddud, A; Khare, A	Digitalizing supply chains potential benefits and impact on lean operations	<i>International Journal of Lean Six Sigma</i>
P4	Núñez-Merino, 2020	Nunez-Merino, M; Maqueira-Marin, JM; Moyano-Fuentes, J; Martinez-Jurado, PJ	Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review	<i>International Journal of Production Research</i>
P5	Bag, 2020	Bag, S; Wood, LC; Xu, L; Dhamija, P; Kayikci, Y	Big data analytics as an operational excellence approach to enhance sustainable supply chain performance	<i>Resources Conservation And Recycling</i>
P6	Frontoni, 2020	Frontoni, E; Rosetti, R; Paolanti, M; Alves, AC	HATS project for lean and smart global logistic: A shipping company case study	<i>Manufacturing Letters</i>
P7	Raji, 2021	Raji, IO; Shevtshenko, E; Rossi, T; Strozzi, F	Industry 4.0 technologies as enablers of lean and agile supply chain strategies: an exploratory investigation	<i>International Journal of Logistics Management</i>
P8	2021	De Giovanni, P; Cariola, A	Process innovation through industry 4.0 technologies, lean practices and green supply chains	<i>Research in Transportation Economics</i>
P9	2021	Reyes, J; Mula, J; Diaz-Madroneo, M	Development of a conceptual model for lean supply chain planning in industry 4.0: multidimensional analysis for operations management	<i>Production Planning & Control</i>
P10	2021	Ciliberto, C; Szopik-Depczynska, K; Tarczynska-Luniewska, M; Ruggieri, A; Ioppolo, G	Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0	<i>Business Strategy and the Environment</i>
P11	2022	Mahdavissharif, M; Cagliano, AC; Rafele, C	Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review	<i>Applied Sciences-Basel</i>

Table 2.
Final selection of journal and conference articles from SLR review

(continued)

Paper	Year	Authors	Title	Journal
P12	2022	Tay, HL; Loh, HS	Digital transformations and supply chain management: a Lean Six Sigma perspective	<i>Journal of Asia Business Studies</i>
P13	2022	Rossini, M., Powell, D.J. and Kundu, K.	Lean supply chain management and Industry 4.0: a systematic literature review	<i>International Journal of Lean Six Sigma</i>
P14	2022	Kashyap, A., Yadav, A.K., Vatsa, O.N., Chandaka, T.N. and Shukla, O.J.	Investigation of the critical success factors in the implementation of the lean industry 4.0 in manufacturing supply chain: an ISM approach	<i>Management of Environmental Quality</i>
C1	2016	Jayaram, A.	Lean six sigma approach for global supply chain management using industry 4.0 and IIoT	<i>Proceedings of the International Conference on Contemporary Computing and Informatics, IC3I 2016</i>
C2	2016	Doh, S.W., Deschamps, F., Pinheiro De Lima, E.	Systems integration in the lean manufacturing systems value chain to meet industry 4.0 requirements	<i>Advances in Transdisciplinary Engineering</i>
C3	2017	Duarte, S., Cruz-Machado, V.	An investigation of lean and green supply chain in the Industry 4.0	<i>Proceedings of the International Conference on Industrial Engineering and Operations Management</i>
C4	2017	Pilinkienė, V., Gružauskas, V., Navickas, V.	Lean thinking and industry 4.0 competitiveness strategy: Sustainable food supply chain in the European Union	<i>Proceedings of the International Congress on Interdisciplinary Behavior and Social Science, ICIBSOS</i>
C5	Freitas, 2017	Freitas <i>et al.</i> , A.C., Maio, A.F., Maia, P., Gomes, N., Nogueira, A., Fernandes, J.M., Carvalho, M.S., Alves, A.C., Costa, A., Afonso, P., Silva, P.V., Barbosa, D., Machado, S.	Savings in internal logistics using a RFID-based software system in a lean context	<i>Proceedings of International Conference on Computers and Industrial Engineering, CIE</i>
C6	2018	Duarte, S; Cruz-Machado, V	Exploring Linkages Between Lean and Green Supply Chain and the Industry 4.0	<i>Annual International Conference on Management Science and Engineering Management (ICMSEM)</i>
C7	2018	Beifert, A; Gerlitz, L; Prause, G	Industry 4.0-For Sustainable Development of Lean Manufacturing Companies in the Shipbuilding Sector	<i>International Conference on Reliability and Statistics in Transportation and Communication (RelStat)</i>
C8	2018	Tortorella, G.L., Miorando, R.F., Fries, C.E., Vergara, A.M.C.	On the relationship between Lean Supply Chain Management and performance improvement by adopting Industry 4.0 technologies	<i>Proceedings of the International Conference on Industrial Engineering and Operations Management</i>
C9	2019	Raji, I.O., Rossi, T.	Exploring industry 4.0 technologies as drivers of lean and agile supply chain strategies	<i>Proceedings of the International Conference on Industrial Engineering and Operations Management</i>

(continued)

Table 2.

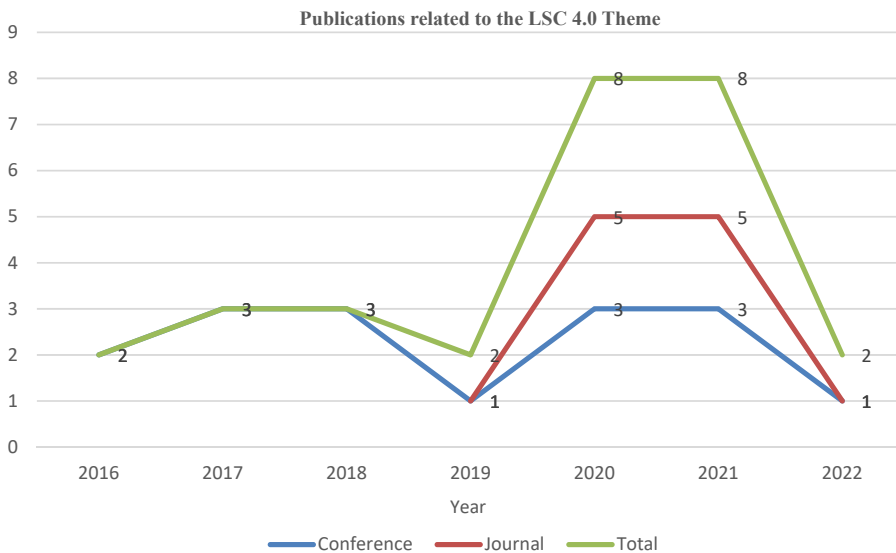
Paper	Year	Authors	Title	Journal
C10	2020	Dallasega, P., Revolti, A., Sauer, P.C., Schulze, F., Rauch, E	BIM, augmented and virtual reality empowering lean construction management: A project simulation game	<i>Procedia Manufacturing</i>
C11	2020	Duarte, S; Cabrita, MD; Cruz-Machado, V	Business Model, Lean and Green Management and Industry 4.0: A Conceptual Relationship	<i>International Conference on Management Science and Engineering Management (ICMSEM)</i>
C12	2020	Schulze, F; Dallasega, P	Industry 4.0 Concepts and Lean Methods Mitigating Traditional Losses in Engineer-to-Order Manufacturing with Subsequent Assembly On-Site: A Framework	<i>International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)</i>
C13	2021	Rifqi, H., Zamma, A., Ben Souda, S	Lean 4.0, Six Sigma-Big Data Toward Future Industrial Opportunities and Challenges: A Literature Review	<i>Advances in Intelligent Systems and Computing</i>
C14	Kale, 2022	Kale, V., Katke, C., Dayane, S., Thakar, P	Challenges of Introducing Lean Six Sigma, IoT in Industry 4.0 and Supply Chain Management: A Review	<i>Smart Innovation, Systems and Technologies</i>
C15	2022	Catellani, L., Bottani, E	Supply Chain Performance Metrics in the Lean, Agile, Resilient, Green Perspectives: a survey and model	<i>International Conference on Harbor, Maritime and Multimodal Logistics Modelling and Simulation, HMS 2022</i>

Table 2. Source(s): Authors' own work

RQ1: What is the current research on the LSC integrated with I4.0?

The literature reviewed in the SLR had a common theme of the benefits for integrating the LSC and I4.0. The challenges to the integration and CSF's to integrating the LSC and I4.0 were also very evident in the literature. As outlined in the previous section, this area is understudied at the moment, and very few research papers are devoted specifically to the LSC 4.0 or LSCM 4.0 in the literature (Tay and Loh, 2022). Lean and supply chain practices are positively aligned with Industry 4.0 technologies, and the concurrent implementation results in performance improvements (Chiarini, 2020). I4.0 and Lean practices are complementary to I4.0 technologies (Snee and Hoerl, 2018), and there is a synergistic relationship between both to increase operational excellence and supply chain improvement (Calabrese *et al.*, 2020).

Whilst there are many benefits and motivations to the LSC 4.0, many unknowns exist. For instance, there is importance to understand the technology being implemented in terms of what it can do for the LSC and look at one process and the applicability of that technology at a time (Mahdavishtarif *et al.*, 2022). A common thread across the literature around digital transformation and LM methodology are that both seek to continuously improve SC operational visibility and process performance and that I4.0 can enable a stronger LSC (Tay and Loh, 2022).



Source(s): Author's own work

Figure 3. Publications by year related to the LSC & I4.0 area

In summary this research is in consensus with other studies that demonstrate the literature linking Industry 4.0 with SCM strategies is still in its infancy. Similarly [Antony \(2021a\)](#), [Antony et al. \(2021b, 2022\)](#) and [Raji et al. \(2021\)](#) discussed the requirement for sector-specific studies to study the specificity of the Industry 4.0 technologies for the Lean practices adopted in different sectors to study if practices and their effects vary. Much of the LSC 4.0 research published to date is SLR related ([McDermott, 2022](#); [Rossini et al., 2022](#)) and that is a gap in itself in the literature as there are very few case studies on the LSC 4.0 with the exception of some studies for example from [Frontoni, 2020](#), [Tortorella and Fettermann \(2018\)](#), [Freitas, 2017](#) and [Woschank and Dallasega \(2021\)](#).

RQ2: What are the motivations the LSC and I4.0 integration?

The studies reviewed to discuss the interactive, symbiotic and synergistic nature of Lean with SCM and complemented and enhanced by the technologies of I4.0 ([Bag, 2020](#); [Raji, 2021](#); [Tay and Loh, 2022](#)). According to ([Tortorella and Fettermann, 2018](#); [Tortorella et al., 2019](#)), the adoption of Industry 4.0 technologies moderate the relationship between LSC practices and supply chain performance in organisations. Furthermore, [Tortorella et al. \(2019\)](#) emphasised that integrating product and service-related Industry 4.0 technologies into flow practices can lead to significant operational and supplier chain performance improvement.

There is a structured relationship amongst lean, agile, sustainable, resilient and flexible principles to enhance SC performance by the implementing of digitisation technologies ([Marodin, 2019](#); [Raji, 2021](#); [Mahdavissharif et al., 2022](#)). [Mahdavissharif et al. \(2022\)](#) proposed a conceptual model, or LSCP 4.0, which they piloted with a case study in a large footwear company and had associated supply chain operations improvements ([Mahdavissharif et al., 2022](#)).

Currently, Industry 4.0 is considered the essential improvement of business processes that could improve LM, high organisational support and effective supply chain practices ([Tiep et al., 2020](#)). Moreover, the synergistic effect between I4.0 and LSCM is high and impacts results positively (with benefits including agility, data sharing, increased synchronicity and

Cited article	Benefits of integrating the Lean Supply Chain with Industry 4.0	Motivations for integrating the Lean Supply Chain with Industry 4.0	Challenges for integrating the Lean Supply Chain with Industry 4.0	Critical success factors for integrating the Lean Supply Chain with Industry 4.0
Tortorella <i>et al.</i> (2019)	X	X	X	X
Tiep <i>et al.</i> (2020)	X	X	X	X
Haddud and Khare (2020)	X	X	X	
Núñez-Merino (2020)	X	X	X	X
Bag (2020)	X	X	X	X
Frontoni (2020)	X	X		
Raji (2021)	X	X	X	
De Giovanni and Cariola (2021)	X	X	X	
Reyes <i>et al.</i> (2021)	X	X	X	X
Ciliberto <i>et al.</i> (2021)	X	X		X
Mahdavisarif <i>et al.</i> (2022)	X	X	X	X
Tay <i>et al.</i> (2022)	X	X	X	
Jayaram (2016)	X	X		
Doh <i>et al.</i> (2016)	X	X	X	X
Duarte and Cruz-Machado (2017)	X	X	X	X
Pilinkiene <i>et al.</i> (2017)	X	X	X	X
Freitas (2017)	X	X		
Duarte and Cruz-Machado (2018)	X	X		
Beifert <i>et al.</i> (2018)	X	X	X	
Tortorella <i>et al.</i> (2018)	X	X	X	X
Raji (2021)	X	X		
Dallasega <i>et al.</i> (2020)	X	X		
Duarte <i>et al.</i> (2019)	X	X		
Schulze and Dallasega (2020)	X	X		
Rifqi <i>et al.</i> (2021)	X	X	X	X
Kale (2022)	X	X	X	X
Catellani and Bottani (2022)	X	X		
Source(s): Authors' own work				

Table 3. Themes discussed related to the Lean Supply Chain 4.0 within the final journal selected articles

partnerships, more speed, improved profits, on time deliveries, defect reduction, better inventory management and control, a pull system, enhanced, traceability, better risk management, improved quality of services and higher levels of customer satisfaction) (Bag, 2020).

Haddud and Khare (2020) examined the impact of digitalising supply chains on lean operations practices and found the explored lean operations practices were improved as were the overall supply chain and business performance. De Giovanni and Cariola (2021) posited

that implementing a process innovation strategy based on I4.0 technologies improves the effect of Lean on operational performance, which also leads to higher economic outcomes. Trust and information sharing amongst supply chain partners and members can be improved by using Industry 4.0 technologies to enable data sharing and transparent (Mahdavishtarif *et al.*, 2022).

Raji, 2021 analysed the understanding of the potential impact and level of importance of the main Industry 4.0 technologies on lean and agile practices and ultimately the potential implication on performances. Their findings revealed that Industry 4.0 technologies have a high impact on Lean SC practices with “total productive/preventive maintenance”, “lead time/Takt time reduction”, “inventory minimisation” and “just-in-time delivery” practices of Lean having the greatest affinity to be enabled by digital technologies. This correlates with previous studies suggesting that I4.0 is an enhancer and enabler of Lean (Tortorella and Fettermann, 2018; Antony, 2022).

The use of LSC 4.0 to enable a more green and sustainable supply chain was also a motivating theme for the LSC 4.0 Ciliberto *et al.* (2021), De Giovanni and Cariola (2021). Duarte and Machado have published two studies on the relationship and linkages between a green Lean and a digitalised supply chain (Duarte and Cruz-Machado, 2017, 2018). The theme of LSC 4.0 to enable a more sustainable construction processes has also started to emerge with several authors presenting case studies demonstrating the concepts. For example Dallasega *et al.* (2020) presented a case study on Business Information modelling to aid construction design and reduce waste and Beifert *et al.* (2018) discussed the opportunities for digitalisation to enhance non Lean processes in European shipbuilding.

RQ3: What are the benefits of integrating the LSC & I4.0?

All of the selected authors in this SLR research were unanimous in their conclusions that there were benefits to integrating the LSC and I4.0. Most authors are in agreement that the aim of the LSC is to reduce the amount of waste between supply chain partners whilst still providing high levels of customer satisfaction and value (Tortorella and Fettermann, 2018). Frontoni, 2020 demonstrated the application of Lean and smart technology in a global shipping logistics company to deliver lead time improvements, reduced costs, higher inventory security levels and enhanced real-time data sharing. Lean and agile are important SCM strategies that improve organisations performance and combining with I4.0 technologies offers the means to optimise and enhance processes (Raji, 2021). De Giovanni and Cariola (2021) found in a study that Lean facilitates improved supplier partnerships on environmental projects and contributes in a positive manner to environmental and operational performance and profitability. They also posited that integrating I4.0 technologies enhances the benefits of Lean on operational performance.

A positive association had been found between connecting Industry 4.0 and business processes and LM (Tiep *et al.*, 2020). Tiep *et al.* studied how the Supply Chain Operations Reference Model (SCORM) interacted with Lean and I4.0. SCORM was found to positively mediate the connecting of the role of I4.0 into business processes and LM. Their results revealed that SCORM is positively mediating amongst the nexus of the role of Industry 4.0 in the business processes and LM whilst organisational support positively moderated amongst the nexus of SCORM and LM. The Internet of things (IoT) coupled with Lean Supply Chain Management (SCM) helps in building relations with suppliers as well as with industries globally (Kale, 2022).

Digitalising supply chains have been found to positively impact the adoption of Just In Time (JIT), Value Stream Mapping (VSM), Total Preventative Maintenance (TPM), Continuous Improvement (CI) and error-proofing lean methods (Haddud and Khare, 2020).

Bag, 2020 discussed how big data analytics is an operational excellence approach to enhance sustainable supply chain performance.

Ciliberto *et al.* (2021) discussed the benefits of I4.0 to supply chain operations in providing real-time tracking and monitoring of all SC system functions including product identification, tracking, communication and control along the value stream. Thus, information systems for management of data and communication allow the development of integrated end-to-end SC digitally connected processes and leaner ones. The digital environment enables lean value add customer processes including the circular economy to accurately forecast customer demand and management of the entire supply chain from incoming logistics to production, outgoing logistics, marketing, sales and assistance (Ciliberto *et al.*, 2021).

RQ4: What are the CSFs and challenges of integrating the LSC & I4.0?

Adapting Lean principles outside of manufacturing and into the LSC is not straightforward (Hines *et al.*, 2004) because waste at the production floor level is more straightforward to identify and quantify than at the SCM level. Tortorella *et al.*'s (2019) research emphasised that integrating Industry 4.0 technologies for products and services into Lean flow principles can result in significant improvements, but only if integrated cautiously and in a structured manner. They also found that organisational size and the length of the duration of LM deployment were highly positively correlated but that the duration of LM deployment was highly negatively correlated with increasing technology.

As many organisations have struggled with implementing Lean in the SC due to a lack of understanding and poor implementation approaches – similarly, it is important to understand how Cloud Computing, Big Data, IoT and artificial intelligence (AI) affect the LSC results at both the operations level of flexibility, improving quality, achieving delivery and service levels as well as its impact on the financial results of revenue, profits and increased market share (Bag, 2020). Organisational support and leadership are important for the LSC 4.0 success – as they positively moderated the nexus of SCORM and LM (Tiep *et al.*, 2020).

Tay and Loh (2022) discussed the importance of having a conceptual framework based on a structured Define, Measure, Analyse, Improve and Control (DMAIC) problem-solving methodological approach to drive improvements in supply chains. Thus this conceptual framework as a CSF provides a systematic method for big data to be integrated into Lean initiatives to optimise greater supply chain performance.

Doh *et al.* (2016) put forward that it is necessary to consider some key points in implementing I4.0 along the value chain, as the LSC 4.0 requires the integration of production, systems and management stakeholders. They further elaborated that effective communication between all users and processes is key to systems working together with the same type of language which is a key challenge.

Many Industry 4.0 studies have discussed the importance of choosing the right technology and investing in the right digitalisation solution in readiness for Industry 4.0 deployment (Antony *et al.*, 2021b). However before implanting complex technology basic infrastructures must be in place. Doh *et al.* (2016) discussed examples from Brazil where there is a need for transport investment and Internet network infrastructure which is a challenge to the integration of the I4.0 and the LSC.

It is important to understand how different Lean tools interact and impact the SC operations when integrated with I4.0 technologies to not make the wrong investment decisions. For example, Lean tools, such as Kanban, Just in time (JIT) and Value Stream Mapping (VSM), can enhance SC operations management when integrated with I4.0. On the other hand, simulation can lead to more collaborative management between suppliers and manufacturers and aid risk management and risk contingency planning (Mahdavisarif

et al., 2022). A close cooperation with suppliers, which is a lean characteristic, is also critical for Industry 4.0, as through improved communications via hardware and software enables development of high compatibility (Duarte and Cruz-Machado, 2017).

Ciliberto *et al.* (2021) reiterated the theme of investments in digital infrastructures to enable the dissemination of digital services and technologies not only across Europe, but globally. Specifically the development of broadband plays a crucial role in the implementation of innovative and competitive digital systems to avoid the risk of increasing the digital divide. Concurrent application of different technologies within a SC situation can help determine which mix of technologies are the most profitable ones in which to invest in order to guarantee successful outcomes (Mahdavisarif *et al.*, 2022).

Tortorella *et al.* (2019) stressed also the importance of having the right balance between the adoption of Industry 4.0 technologies and Lean practices for improving operational performance within their companies between upstream and downstream with a focus on operational performance improvement achieved via novel technology adoption. Haddud and Khare (2020) discussed the CSF of top management involvement in determining the level of supply chain digitalisation and in promoting and justifying acceptance of digitalising and leaning supply chains projects prior to embarking on adoption journeys.

5. Conclusion

The research set out to establish the research related to the LSC 4.0 and whilst it is still a nascent area as specifically related to the Lean Supply chain and digitalisation theme or concept the area is gaining more researcher interest. This study also specifically ascertained the benefits and motivations for integrating the LSC 4.0 as well as the challenges and CSF's of doing so. With the dawn of the fourth industrial revolution and increased digitalisation both future and ongoing, the researchers find that the technologies of Industry 4.0 will enhance the LSC.

However, it is very important to reap the benefits from this increased digitalisation and wide availability of process-enhancing technologies to review and integrate these right technologies to enhance the LSC. A limitation of the study is the limited research in this area as it is an evolving area. Also, the researchers excluded from this SLR research papers that did not contain all of the three themes of Lean, the Supply Chain and Industry 4.0 -whereas a combination of 2 of the 3 themes may have offered further research insights related to the LSC and Industry 4.0 integration.

The implications for practice and society are to demonstrate how the LSC 4.0 can benefit organisations and enable leaner, greener and more efficient digitised supply chains. From a social and societal implications point of view understanding how the LSC 4.0 can eliminate waste and impact on both economic, social and environmental bottom-lines aids environmental sustainability.

Future research opportunities could include more longitudinal studies on organisations aiming to integrate their LSC's with the technologies of Industry 4.0 to understand further and benchmark the learnings in relation to the integration of the LSC and I4.0. In addition, further mixed methods studies with SC professionals working on the LSC and organisational digitalisation programs would be an opportunity to leverage further learnings around this new evolving area of the LSC 4.0.

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