Núñez-Merino, M.; Maqueira, J.M.; Moyano-Fuentes, J.; Martínez-Jurado, P. (2020): "Information and Digital Technologies of Industry 4.0 and Lean supply chain management: a systematic literature review", Taylor & Francis, International Journal of Production Research, Vol. 58, No. 16, pp. 5034-5061.
https://doi.org/10.1080/00207543.2020.1743896

Information and Digital Technologies of Industry 4.0 and Lean Supply Chain Management: A Systematic Literature Review

1. Introduction

Lean Management (LM) is an efficiency-oriented socio-technical management system whose main purpose is to eliminate any source of waste through the simultaneous reduction or minimization of the sources of internal and external variability (Womack, Jones, and Roos 1990; Shah and Ward 2007). The systematic reduction of these sources of variability at both the company level and throughout the supply chain enables business results to be improved and provides the ability to achieve a competitive advantage (Womack and Jones 1996; Moyano-Fuentes and Sacristán-Díaz 2012).

On one hand, Supply Chain Management (SCM) has been used for planning and control of physical and information flows, internal and external logistics activities, and processes with other companies, and to address the relationship developed and the processes shared with customers and suppliers (Chen and Paulraj 2004; Kache and Seuring 2014). In recent years, SCM has come to be considered a key factor for increasing companies' efficacy and competitiveness (Frohlich and Westbrook 2001; Ataseven and Nair 2017). So, a suitable SCM strategy enables improvements to operating results in terms of greater efficiency in processes, a lower level of inventory, higher customer satisfaction, better quality, cost reductions, and improved delivery (Christopher and Towill 2000). This, along with an increase in global competitive pressure, has led to Lean principles spreading to the supply chain level with a view to optimizing interorganizational processes from the point-of-view of the end customer (Swenseth and Olson 2016). This has given rise to what is known as Lean Supply Chain Management (LSCM). LSCM consists of organizations directly linked by upstream and downstream flows of goods, services, finances, and information that work together to reduce costs and waste by efficiently and effectively pulling what is required to meet the needs of individual customers (Vitasek, Manrodt, and Abbott 2005; Swenseth and Olson 2016; Moyano-Fuentes, Bruque, and Maqueira 2019).

However, supply chains are facing several challenges, such as uncertainty, costs, complexity, and vulnerability. Supply chains must be smart to overcome these issues and equipped with a technological infrastructure that enables information and physical flows to be integrated into supply chain processes (Abdel-Basset, Manogaran, and Mohamed 2018). In this line, supply chain is undergoing a digital transformation commonly referred to as Industry 4.0 (I4.0) driven by the emergence of advanced Information and Digital Technologies (IDT) (Ghobakhloo 2019). Information and Digital Technologies (IDT) of I4.0 refers to the application of a set of technologies related to digital transition whose scope extends beyond organizational boundaries and involves intelligent supply chain and connected customers (Gilchrist 2016; Ghobakhloo 2018). So, IDT of I4.0 includes the application of e-commerce tools such as Electronic Data Interchange (EDI); the adoption of Advanced Manufacturing Technologies (AMT) such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Industrial Simulation, and Enterprise Resource Planning (ERP); and the most advanced IDT such as the Internet of Things (IOT), Augmented Reality (AR), Additive Manufacturing, Blockchain, Cloud Computing, and Big-Data analytics (Gilchrist, 2016; Lu, 2017; Ghobakhloo, 2019).

Several studies find a positive link between LSCM strategy adoption and improved efficiency both—at the internal level—of the commercial sectors involved in the strategy and—at the external level—of the supply chain as a whole (Marodin et al. 2017; Tortorella, Miorando, and Marodin 2017). However, IDT also enhance efficiency and reliability when applied to intra- and interorganizational processes (Da Xu, He, and Li 2014; Pfohl, Yahsi, and Kurnaz 2016). So, the concurrent implementation of LSCM and IDT of I4.0 has been demonstrated to be a complementary and synergistic strategic initiative. In this synergistic effect, LSCM is a change in company mentality compared to SCM and it also makes specific principles and practices available for firms to apply. For its part, I4.0 digital transition would enable a greater level of flexibility and automatization to be achieved in processes which would make it easier to apply these LSCM practices, and so raise efficiency in the entire supply chain. For this reason, IDT of I4.0 have the ability to enable Lean principles and practices to be extended throughout the entire Supply Chain (Tortorella and Fettermann 2018; Rossini et al. 2019; Tortorella, Miorando and Cawley 2019). It has also been observed that firms and supply chains that aspire to be among the top I4.0 levels must simultaneously implement IDT of I4.0 and LSCM to support the improvement process (Sanders, Elangeswaran, and Wulfsberg 2016; Pinho and Mendes 2017; Buer, Strandhagen, and Chan 2018; Rossini et al. 2019).

Despite the IDT of I4.0-LSCM complementary effect and the multiple studies that analyze a range of digital transition-related aspects in the LSCM context, there is no literature review that presents the current situation of research on the interrelationships between IDT of 4.0 and LSCM. Literature reviews do exist that analyze the IT-Lean Management relationship at a more general level (Pinho and Mendes 2017) or the I4.0-Lean Management relationship at a more specific level (Buer, Strandhagen, and Chan 2018; Pagliosa, Tortorella, and Espindola-Ferreira 2019). In both cases, the focus is on LM at the internal level, not at the supply chain level. The aim of this study is, precisely, to cover this gap and the goal is to offer an overview of the current state of research on IDT of I4.0 in LSCM contexts. It also seeks to contribute a new literature classification with the research lines developed, their findings, the key aspects and implications of the IDT of I4.0/LSCM relationship, existing gaps, and paths for future research. For this, a Systematic Literature Review (SLR) (Denyer and Tranfield 2009) will be conducted.

To achieve the proposed objectives, this article presents the following structure. The next section after this introduction details the background literature. Next, the SLR methodology used is presented. This is followed by the results section, which classifies the literature on the interrelationships between IDT of I4.0 and LSCM and describes the findings and contributions of the identified research lines and sublines, the gaps, and future research lines. Next, a discussion, some implications, and the study's limitations are included. The last section includes the conclusions.

2. Theoretical background

2.1 Key concept conceptualization: Lean Supply Chain Management and Information *and Digital Technologies of I4.0*

On the one hand, the LSCM concept refers to the application and management of LM principles and practices in the supply chain to reduce costs and waste by efficiently and effectively pulling what is required to meet the needs of individual customers (Lamming 1996; Reichhart and Holweg 2007; Moyano-Fuentes, Bruque, and Maqueira

2019). The application and management of Lean principles and practices at the supply chain level is much more complex than LM application at the company internal level, as it entails the need for greater coordination and management of physical, information, and financial flows between the various agents involved (Moyano-Fuentes, Bruque, and Maqueira 2019).

Meanwhile, digitalization is defined as the use of computer and Internet technology for a more efficient and effective economic value creation process (Reddy and Reinartz 2017). Digitalization is not only changing business processes and company products but also the processes of the entire supply chain. It is leading to major changes in what has come to be called the digital transformation (Horváth and Szabó 2019). In digital transformation, Internet technologies, and the connectivity that they enable, play a core role in the deployment and use of more traditional IT and of more innovative or emerging IT (Ghobakhloo 2018; Ghobakhloo 2019). This joint use of different technologies, using the connectivity that the Internet allows, has given rise to the concept of Information and Digital Technologies (IDT) (Ghobakhloo 2018; Ghobakhloo 2019) and the digitalization concept is strongly linked to intensive IDT use in the creation of business value (Ivanov, Dolgui, and Sokolov 2019). Applying IDT in the manufacturing industry to raise efficiency and efficacy has sparked its digital transformation and the coining of the term Industry 4.0 (I4.0) (Kagermann, Wahlster, and Helbig 2013; Lee et al. 2018). Digitalization can be considered an over-arching concept and I4.0 a sub-concept (Horváth and Szabó 2019). The term I4.0 was introduced at the 2011 "Hannover Messe" to be precise and since 2013 (the year in which the "Industrie 4.0 Working Group" final report was published) has been fashioned into a technological framework (Kagermann, Wahlster, and Helbig 2013) that embraces a wide variety of technologies, principles, and methods to make production systems and supply chains more autonomous, dynamic, flexible, and precise (Tortorella and Fettermann 2018). Emerging digital technologies such as Cloud Computing, Big-Data, and the Internet of Things (IoT), inter alia, coexist in I4.0 alongside more traditional technologies such as, for example, Computer Integrated Manufacturing (CIM), a type of AMT (Monostori et al. 2016). These technologies are currently integrated in the so-called Cyber-Physical System (CPS) that links the virtual and physical worlds by establishing smart factories (Kang et al. 2016; Monostori et al. 2016;

Strozzi et al. 2017). I4.0 is marked by highly developed automation and digitization processes and the use of electronics and information technologies in manufacturing (Lu 2017). IDT of I4.0 (Ghobakhloo 2018; Ghobakhloo 2019) allows processes to be integrated at both the intraorganizational and the interorganizational levels and provides a set of solutions that meets the growing needs for company informatization and automatization (Xu, Xu, and Li 2018) under a smart factory paradigm in which machines interact with each other (Ivanov et al. 2015; Strozzi et al. 2017). In addition, IDT of I4.0 enables information integration throughout the supply chain and the real-time transmission and processing of information for decision-making (Subramani 2004; Novais, Maqueira, and Ortiz-Bas 2019).

In line with the current followed by a number of other authors, in this study all the IT applied and used in industry to achieve efficacy and efficiency in conjunction with the connectivity provided by the Internet are considered to be IDT of I4.0 (Drath and Horch 2014; Ghobakhloo 2018; Frank, Dalenogare, and Ayala 2019; Ghobakhloo 2019). This article specifically spotlights the application of IDT of I4.0 in LSCM contexts.

2.2. Lean Management - IDT relationship

Although there are no previous SLR studies that focus on LSCM and IDT of I4.0, SLRs exist that analyze the relationship between LM at the internal level and general IT usage (Pinho and Mendes 2017) and LM at the internal level and I4.0 in particular (Buer, Strandhagen, and Chan 2018; Plagiosa, Tortorella, and Espindola-Ferreira 2019).

With respect to the Lean-IT relationship, the results of an analysis of the existing literature show that the greatest consensus and empirical support can be found for the interdependence between the two concepts, i.e., a complementary or synergistic relationship exists between the two (Pinho and Mendes 2017). With respect to Lean-I4.0, the results of the analysis of the existing literature also highlight that this relationship has a complementary or synergistic effect (Buer, Strandhagen, and Chan 2018). Delving further into these works, there is a clear majority of studies that find that IDT of I4.0 act as a support mechanism for LM (Karre et al. 2017; Wagner, Herrmann, and Thiede 2017) with only a token number of studies that have found the opposite effect, i.e., that LM acts as a support to IDT of I4.0 use (Wang et al. 2016). Moreover, the literature stresses that when IDT of I4.0 and LM manifest themselves in conjunction with one another, the impact that this joint effect has on business results is greater (Ma, Wang, and Zhao 2017; Sanders, Elangeswaran, and Wulfsberg 2017; Tortorella and Fettermann 2018). The literature (Plagiosa, Tortorella, and Espindola-Ferreira 2019) clearly states that the intensity of the synergistic effect of this complementary or synergic relationship depends on the specific Lean practices and the specific technologies used (Plagiosa, Tortorella, and Espindola-Ferreira 2019). As such, the mid-high synergistic effect predominates among the majority of internal-level LM practices and some specific IDT of I4.0, such as IoT, CPS, Cloud Computing, Big-Data, and horizontal/vertical integration technologies (web technologies); whereas a mid-low synergistic effect predominates among more the usual internal-level LM and some other IDT of I4.0, such as Robotics, Augmented Reality (AR), Simulation and Additive Manufacturing (Plagiosa, Tortorella, and Espindola-Ferreira 2019).

The results presented above and the greater complexity entailed in the use of Lean at the Supply Chain level mean that it is coherent to think that, as in the case of I4.0-internal LM, the IDT of I4.0-LSCM relationship is also complementary and synergic. It would be interesting to dig deeper into the results found in the literature on the I4.0-LSCM relationship in order to shed more light on this, scrutinizing the specific role played by specific types of IDT of 4.0.

3. Methodology

The applied methodology is SLR. This is a method that enables the location, selection, and evaluation of the contributions that the literature has made to a research topic. The main advantages of this method that can be highlighted are that it guarantees a structured, repeatable, and scientific process that enables existing information to be synthesized in a rigorous and objective process (Tranfield, Denyer, and Smart 2003; Denyer and Tranfield 2009). SLR has been implemented successfully in the area of Operations Management (Morgan and Gagnon 2013; Cherrafi et al. 2017), in SCM (Glock, Grosse, and Ries 2017; Bastas and Liyanage 2018), and in the I4.0 context (Liao et al. 2017; Machado, Winroth, and Ribeiro da Silva 2019; Pagliosa, Tortorella, and Espindola-Ferreira 2019).

This study follows the typical five established SLR steps (Tranfield, Denyer, and Smart 2003; Denyer and Tranfield 2009) and the recommendations and proposed best practices for its specific application in the area of Operations Management (Thomé, Scavarda, and Scavarda 2016), SCM (Durach, Kembro, and Wieland 2017) and IS (Okoli and Schabram 2010). As these best practices recommend, the study begins by laying down a protocol as a kind of road map. This describes specific issues as well as the search strategy, the study inclusion and exclusion criteria, criteria to identify contributions, and details on how to encode the information obtained in the articles. The protocol prevents any bias and guarantees coherence and consistency when a number of different researchers are involved (Thomé, Scavarda, and Scavarda 2016; Okoli and Schabram 2010).

The specific phases followed were (Tranfield, Denyer, and Smart 2003; Denyer and Tranfield 2009): (1) formulating the research question; (2) locating the studies; (3) selecting and evaluating relevant studies; (4) analyzing and synthesizing the findings; (5) reporting the results. These phases have been enriched with the extant best practices for developing an SLR in Operations Management (Thomé, Scavarda, and Scavarda 2016), SCM (Durach, Kembro, and Wieland 2017), and IS (Okoli and Schabram 2010).

Each of the phases is described in greater detail below.

3.1. Phase 1. Formulating the research question

This phase identifies the scope, purpose, and goals foreseen in the SLR and these are reflected in the general research question (RQ):

RQ. Analysis of the state of knowledge that exists in the literature on the relationships between IDT of I4.0 and LSCM.

This general research question is broken down into the following specific questions:

RQ1. What categories of papers have been published to date?

RQ2. Is it possible to identify a taxonomy of the current research on IDT of I4.0 and Lean Supply Chain Management and the relationship between the IDT of I4.0 and LSCM?

RQ3. What gaps exist in the literature on IDT of I4.0 and LSCM and what direction should future research go in?

3.2. Phase 2. Locating the studies

The second stage consists of locating relevant studies related to the research question. This step is essential as, if the selected literature is inadequate, inappropriate or irrelevant, the contribution of the following phases will be amiss (Sangwa and Sangwan 2018). There are two key aspects in this stage: the choice of search engines and the choice of search word strings (Tranfield, Denyer, and Smart 2003; Denyer and Tranfield 2009). The search engines used should correspond to the typical databases in the area of study (Okoli and Schabram 2010; Thomé, Scavarda, and Scavarda 2016; Durach, Kembro, and Wieland 2017). The search words strings must allow precise results to be found, with no false positives or false negatives (Tranfield, Denyer, and Smart 2003; Denyer and Tranfield 2009).

In the specific case of this research, the most relevant databases in the area of study have been used as the search engines, i.e., Web of Science (WoS), Scopus, and ABI/Inform, as these are the databases that are usually used in SLRs in Operations Management. Using more than one database to locate the literature helps to prevent any relevant studies being missed and reduces any possible publication bias (Thomé, Scavarda, and Scavarda 2016; Durach, Kembro, and Wieland 2017).

The research objective, in this case, is in the area where the IDT of I4.0 set, the Lean Management set, and the Supply Chain Management set intersect. The search chains were therefore specifically designed to locate documents in this intersection area (see Figure 1).

Figure 1. Objective of the SLR

---Insert Figure 1 about here---

For this, the search strings have been constructed by combining the most representative key search words for each of the three mentioned sets. The key search words should be sufficiently broad so as not to restrict the number of studies but sufficiently specific to locate only studies related to the topic (Thomé, Scavarda, and Scavarda 2016; Durach, Kembro, and Wieland 2017). Therefore, the key search words were determined jointly by the researchers, established experts in IDT and LSCM, in a brainstorming session.

The search string has then been constructed using logical and Boolean operators. The design of the search string seeks to ensure that the located articles contain at least one of the key search words for each of the three blocks (IDT of I4.0, Lean Management, and Supply Chain) either in the title, abstract or document author's keywords (in the case of Scopus and ABI/Inform) or more broadly in the topic (in the case of WoS; title, abstract, author's keywords, expanded keywords). The key search words used in these search strings have been honed down with multiple pilot tests in the three databases in order to prevent any hits on false positives or false negatives and to ensure the identification of relevant papers (Denyer and Tranfield 2009; Durach, Kembro, and Wieland 2017). Bearing that the search engines present differences in the syntax that they use for searches, the specific form of these search strings had to be adapted to each of the databases used. Some of the key search words considered in the pilot tests were later eliminated to cut down the length of the search strings, given that individual searches using these terms individually did not yield any valid results. Eliminated terms included Cyber-Physical, Blockchain, Cybersecurity, Augmented Reality, Virtual Reality, Warehouse Management System and Transportation Management System. The search words and search strings used in each of the databases are given in Table 1. It should be made clear that the eliminated terms do not appear in Table 1, as when they are included in the search string their contribution is zero results. In addition, the papers in which technology is used only as a methodological technique and its relationship to LSCM is not analyzed, are not considered (for example, several papers on Simulation were discarded for this very reason).

Table 1. Search words and search strings

---Insert Table 1 about here---

A total of 3,829 papers have been identified in this step. 824 have been identified in WoS, 1,131 in Scopus and 1,874 in ABI/Inform.

3.3. Phase 3. Selecting and evaluating the studies

The purpose of the third step is to discard any studies that are not relevant. This is achieved by defining some criteria that establish the studies that should be considered in the review (inclusion criteria) and those that should be discarded with no further scrutiny (exclusion criteria) (Denyer and Tranfield 2009; Okoli and Schabram 2010). The criteria established in this phase should be explicit and substantiate the exhaustiveness of the resulting review. It is also necessary to establish which studies do not have sufficient quality so that they can be excluded from the review (Okoli and Schabram 2010). Application of these criteria eliminates articles that clearly do not belong in the review and those that could be included are selected. The chosen articles are then evaluated. For this, the abstracts are reviewed to confirm the inclusion of the studies that comply with the established search criteria (Denyer and Tranfield 2009; Thomé, Scavarda, and Scavarda 2016).

In this research, the search was limited to works published in English between 1996 and December 2019. The beginning of the search period corresponds to the first publication on LSCM (Lamming 1996). The search was limited to the research areas of the study (business economics, business, management and accounting, economics, econometrics and finance, decision sciences, computer science, automation control systems, engineering, environmental science, multidisciplinary, operations research management science, transportation, and logistics) and areas that were clearly not related were not considered. Only articles, articles in press and reviews published in journals indexed in the Journal Citation Reports (JCR) and/or SCImago Journal Rank (SJR) were considered to ensure the quality of the selected works. In addition, in the case of the ABI/Inform database, it was possible to select only peer-reviewed studies. These inclusion and exclusion criteria were agreed upon by the researchers, which prevents any bias that might be associated with a single decision-maker (Thomé, Scavarda, and Scavarda 2016).

With the application of the above-mentioned inclusion and exclusion criteria, a total of 1,188 publications were selected out of the 3,829 initially identified. Duplicate papers found in the databases were subsequently eliminated, giving rise to a set of 798 studies. WoS was taken as the reference database for the detection of duplicate papers and the papers identified in Scopus that had already been identified in WoS were duly eliminated (253 exclusions). Finally, papers selected in ABI/Inform that had already been located in WoS and Scopus were also discarded (137 exclusions).

The next step was to evaluate the articles, which entailed examining the title, the abstract and the keywords. This enabled the articles to be determined that were clearly related and those that were clearly not related to the research question. Articles were discarded that clearly did not have any links to the research question, which gave rise to a total of 108 articles. In a second step, in cases found that were not conclusively related, the theoretical framework, the main results, and the conclusions were read and, when necessary, the entire article (Thomé, Scavarda, and Scavarda 2016; Durach, Kembro, and Wieland 2017). As good SLR practices in Operations Management and IS advocate, article selection and evaluation was conducted jointly by the researchers in an interactive review process. The level of agreement was high and any discrepancies were discussed and solved (Okoli and Schabram 2010; Thomé, Scavarda, and Scavarda 2016), eliminating in this way all single researcher bias. At the end of this phase, a total of 73 papers were selected for detailed analysis and synthesis (step 4).

3.4. Phase 4. Analysis and synthesis of the results

The next step has been to review and analyze each of the selected articles by reading them in their entirety. Pre-defined structured coding of the information has been done in this phase in order to mine the relevant details in each of the studies and enable researcher involvement in this process (Denyer and Tranfield 2009; Thomé, Scavarda, and Scavarda 2016) and so reduce all single researcher bias (Thomé, Scavarda, and Scavarda 2016).

Forward and back searches were done to ensure a full and exhaustive literature review and new articles were identified by means of the snowballing effect (Okoli and Schabram 2010; Thomé, Scavarda, and Scavarda 2016). Five new articles were detected as a result of examining the references used in the articles selected in step 3 (forward search) and the references in these papers (back search) (snowballing effect) and added to those identified in direct database searches, with a final total of 78 articles eventually obtained.

During the article coding process, a database was designed in a spreadsheet containing the main ideas, objectives, and contributions of each of the papers. The main technologies involved have also been identified, as have the research lines and sublines, and other complementary information such as the title, author, journal, year of publication, methodology, sector, journal quality index and impact, and number of times the paper has been cited.

3.5. Phase 5. Presentation of results

The last step consists of reporting the final results of the analysis and the synthesis of the literature. For this, all the information mined from the articles was combined and a descriptive overview of the reviewed literature sought, with a discussion of the findings and the identification of any extant research gaps and future research lines (Denyer and Tranfield 2009; Okoli and Schabram 2010; Durach, Kembro, and Wieland 2017). The results of this step are given in Section 3.

Figure 2 has been prepared to illustrate the methodological procedure followed in this study and described in this section. The Figure shows the different phases established for an SLR (Denyer and Tranfield 2009), enriched with the best practices for its application to Operations Management (Thomé, Scavarda, and Scavarda 2016), SCM (Durach, Kembro, and Wieland 2017) and IS (Okoli and Schabram 2010), and the way that they have been applied in the specific context of this research. As best practices in Operations Management recommend (Thomé, Scavarda, and Scavarda 2016), the PRISMA Flow Diagram has been used to draw up this Figure. The flow diagram depicts the flow of information through the different SLR phases, mapping out the number of records identified, included, and excluded and the reasons for their exclusions.

Figure 2. Summary of the Systematic Literature Review

---Insert Figure 2 about here---

4. Results

As commented, 78 articles were identified that fulfilled the established criteria and, therefore, contributed to explaining the literature on the interrelationships between IDT of I4.0 and LSCM and responding to the specific research questions proposed. In the results section, a descriptive analysis of the literature is presented with a description of the way that the articles are grouped in research lines and sublines that together provide a novel classification of the existing literature on IDT of I4.0 and LSCM; the findings in each of the identified lines and sublines are set out and analyzed and the gaps and avenues for future research are identified.

4.1. Descriptive analysis of the literature on IDT of I4.0 and LSCM

First, the chronological evolution of the literature published on any type of IDT of I4.0 in LSCM was analyzed. Figure 3 sets out the number of articles by year of publication. The absolute and cumulative frequencies of the number of studies published annually are given in a graph.

Figure 3. Absolute and cumulative frequencies of number of papers, IDT of I4.0 in LSCM

---Insert Figure 3 about here---

The number of publications has not evolved steadily over the years. However, interest in this area has been observed to have risen gradually in the last 11 years (82.05% of the works) and, especially, in the last 5 years (47.43% of the works). There is a logical explanation for this, for although some obsolete IDT considered under the umbrella of I4.0 in LSCM contexts have been analyzed since 1996, it has only been since 2008 that the sudden rise in manufacturing areas of emerging IDT such as Cloud Computing, Big-Data, and IoT, among others, with their potent effects on the supply chain, has spurred the interest of researchers in IDT of I4.0 and SCM in general (Novais, Maqueira, and Ortiz-Bas 2019) and in IDT of I4.0-LSCM in particular. In addition, growing interest in these relationships has been seen from academia, industry, and States since 2013—when the final report of the "Industrie 4.0 Working Group" was published (Kagermann, Wahlster, and Helbig 2013; p. 77)—with the aim of driving up efficiency and competitiveness. Table 2, below, gives a classification of the studies by methodology employed.

Table 2. Classification by methodology used

---Insert Table 2 about here---

By methodology used, studies that are quantitative in type are most common and represent 39.74% of the total, followed by studies that are qualitative in type and technical development (20.51% and 19.23%, respectively). In addition, 12.82% of the studies found are conceptual in type. Lastly, 7.69% have applied joint quantitative and qualitative techniques (6 papers). The studies applying a quantitative methodology generally use statistical techniques such as linear regression and logistics models, structural equations, simulation models, and linear programming techniques, among others. The most used qualitative techniques are case studies and in-depth interviews with experts. The studies classified as technical development apply and/or develop software and/or algorithms. Lastly, the studies that are conceptual in type have no empirical content and focus on developing a conceptual framework.

It should be highlighted that no authors stand out regarding the number of publications in the field. Finally, Table 3 presents the journals that have published the highest number of papers on IDT of I4.0 and LSCM.

Table 3. Classification by journal

---Insert Table 3 about here---

Table 3 shows that 12 journals have published 2 or more papers (50% of papers). International Journal of Production Research (9 papers) and International Journal of

Production Economics (5) stand out in the field of Operations Management for the number of papers published. These two popular journals also stand out in a related SLR (Pinho and Mendes, 2017). They are followed by other journals in the area: Production Planning & Control and Supply Chain Management An International Journal (3), while Production and Operations Management and International Journal of Logistics Management both have 2 papers. The 78 selected papers appear in 51 journals in all. With 1 paper there are 39 journals, some of which are high quality, such as International Journal of Physical Distribution and Logistics Management, Computers & Operations Research, and Computers in Industry.

4.2. Classification of articles on IDT of I4.0 and LSCM

In the analysis and synthesis process, researcher consensus was used to establish the criteria for grouping the chosen studies into research lines and sublines and the coding and final classification, which ensures inter-coding reliability (Thomé, Scavarda, and Scavarda 2016).

Article coding has helped identify the research line that each of the articles falls into. So, those identified in IDT of I4.0 and LSCM have been classified by the specific technology identified (research subline) and the position that each occupies in the Technology Life Cycle (TLC) (Kim 2003; Taylor and Taylor 2012) (research line).

TLC shows how technology evolves over time. A generation of technology enters into the market, grows and matures, and finally falls into decline and is replaced by the following generation of technologies (Kim 2003). In this evolution, the technologies are identified as emerging when they reach the marketplace, as mature (key and basic) when their usage spreads, and obsolete when they enter into a state of decline (Kim 2003; Taylor and Taylor 2012). In the field of IDT and analogously to this classification, Ghobakhloo (2019) states that these technologies can be classified into four categories: generic, applied to e-commerce, advanced, and most advanced.

Considering TLC in the classification is important for companies because time is a major variable associated with IDT and, in LSCM contexts, the use that organizations can make of it to achieve a competitive advantage depends on the position that IDT occupy in the TLC. As such, even though their effect is uncertain due to their novelty, emerging IDT may represent a competitive advantage, especially when they become critical (key) to an organization. Mature IDT tend to be staples or widespread in a sector and so are no longer generators of competitive advantage, although their use is a strategic requirement just to be able to compete. Obsolete IDT are already being discarded in the sector.

The Gartner Hype Cycle for Emerging Technologies (Gartner 2016) has been used to determine where each of the technologies is in the TLC and that each is related to the Ghobakhloo (2019) IDT classification and the Industry 4.0 transition process. This is a model developed by Gartner Technology Consultants that gives an annual forecast of the way that the technologies will evolve that are currently in the emerging phase. Figure 4 shows the classification, in which four lines have been identified: (1) Obsolete IDT in LSCM, (2) Mature IDT in LSCM, (3) Emerging IDT in LSCM, and (4) General approach IS and IDT in LSCM. This last research line represents a specific group in the literature classification related to a generic group of technologies indicated in Ghobakhloo (2019). Articles classified in this group deal with IDT of I4.0 and/or IS in a general way and as a set, which means that they cannot be classified in a specific TLC stage. So, in this group can be found articles that are characterized by the study of the impact, relationships, and implications that IDT of I4.0 have for LSCM in general terms, without any of the technologies being analyzed in isolation.

Figure 4 shows the proposed classification. On the first classification level is the IDT grouping in the I4.0 and LSCM context according to its status in the TLC (research line). On the second classification level are the research sublines that show each of the specific identified and analyzed IDT in their relationships with and effect on LSCM.

Figure 4. IDT classification in the I4.0-LSCM context by TLC

---Insert Figure 4 about here---

Table 4 groups the articles found and analyzed in accordance with the established classification. As there are studies in our review that focus their research on more than one technology, some articles appear in more than one subline in the classification.

Table 4. Classification of papers

---Insert Table 4 about here---

In relation to the number of articles published on each research line and subline, in Table 5 the number of papers is broken down into absolute and relative frequencies.

Table 5. Number of papers by research line and research subline

---Insert Table 5 about here---

As indicated previously, some papers are classified in more than one subline, 19 to be precise. Distribution by group is as expected (few papers in obsolete IDT, several in emerging IDT, and many in mature IDT). As can be seen in Table 5, web technologies for e-business and RFID have attracted the most interest from researchers. The fact that no emerging IDT such as Blockchain, Additive Manufacturing and Augmented Reality appear stands out.

The evolution of each of the groups is shown below based on the proposed classification (Figure 5).

Figure 5. Cumulative frequency of number of papers by research lines, I4.0 IDT in LSCM

---Insert Figure 5 about here---

The mature IDT in LSCM can be observed to have received the greatest attention in the literature, while obsolete IDT play a residual role with only 4 publications, with the last in 2002. Research on emerging IDT in LSCM begins in 2012 and is being developed and is on the increase at the current time. IS/IDT in the LSCM general approach group has evolved steadily in number of annual publications since 2008 and is currently a topic of interest. These results can be explained by the most representative IDT of I4.0 being, precisely, those that are emerging and the overview of IS/IDT as a set.

4.3. Analysis of content of IDT of I4.0 and LSCM research lines and sublines

The following analyzes in detail each of the four research lines and their respective sublines.

4.3.1. L1, Obsolete IDT in LSCM

Only one research subline related to the effects and implications of Electronic Data Interchange (EDI) in LSCM contexts has been identified in the obsolete technologies group.

(1) SL1.1, Electronic Data Interchange (EDI) in LSCM

EDI is a technology that emerged prior to the Internet reaching the business domain. Its use has currently been adapted to web environments (EDI-web) or it is used as a legacy system integrated into more up-to-date IS (van der Aalst 1999; Medjahed et al. 2003; Witte, Grünhagen, and Clarke 2003).

EDI has had a strong impact on the Supply Chain and its efficiency (LSCM objective) from the very beginning as it contributed to improving communication between customers and suppliers, business partners and organizations at a time when the Internet did not exist (Evans, Naim, and Towill 1993). EDI enables large volumes of information to be sent at a much greater speed than in paper form and reduces costs, delays, and errors (Abernathy et al. 2000), which is in line with LM objectives at the supply chain level. In general terms, EDI has enabled companies to make faster decisions and bring down waiting times by reducing the time needed to send information, thus contributing to the goal of more efficient supply chains (Mason-Jones and Towill 1997). In particular, EDI has allowed the level of inventory to be brought down and control of replenishment to be had throughout the entire Lean supply chain, which has enabled companies to work with smaller lots and pull system demand management (Abernathy et al. 2000; McMichael, MacKay, and Altmann 2000; Danas, Ketikidis, and Roudsari 2002).

4.3.2. L2, Mature IDT in LSCM

The following research sublines have been identified in the mature IDT group that analyze the relationships of some given IDT of I4.0 and LSCM: (1) Barcode systems in LSCM; (2) Radio Frequency Identification (RFID) in LSCM; (3) E-business web technologies in LSCM; (4) workflow systems in LSCM; (5) Enterprise Resources Planning (ERP) in LSCM; (6) Advanced Manufacturing Technology (AMT) in LSCM. Each of these research sublines is analyzed below.

(1) SL2.1, Barcode systems in LSCM

Barcode systems have contributed to achieving LSCM objectives by enabling the automatic generation, capture, and sending of information from one supply chain member to another, thus rendering the supply chain more efficient. So, for example, barcode systems are used in retail to automate the payment process, thus reducing labor costs and the opportunity for check-out errors (Abernathy et al. 2000). Using these systems standardizes information exchanged between different chain agents and so enables physical, information, and financial flows to be integrated. This brings down costs, eliminates errors and wastage, and, therefore, increases supply chain efficiency (Abernathy et al. 2000). Standardization also provides a tool to collect real-time demand information and to share this with suppliers/customers, thus producing better coordination between Lean Supply Chain (LSC) members (McMichael, MacKay, and Altmann 2000). For example, the use of these systems was a determinant of the transformation of hospital pharmacy supply chains thanks to the benefits that it provides to merchandise flows and inventory control, and less wastage (Danas, Ketikidis, and Roudsari 2002).

(2) SL2.2, Radio Frequency Identification (RFID) systems in LSCM

The impact of RFID technologies on the LSCM environment has been evaluated by multiple authors who have highlighted the benefits that it offers, such as greater physical, information, and financial flow integration between the members of an LSC. They provide greater integration than other systems such as barcodes, as RFID overcomes many of the latter's limitations, such as incorrect readings when the barcode is damaged or incorrectly positioned. It has, therefore, been found that RFID implementation in LSCM: (1) Enables traceability of material flows and inventory control, allowing stock to be reduced to the bare minimum (Saygin and Sarangapani 2011; Powell and Skjelstad 2012; Sanders, Elangeswaran, and Wulfsberg 2016; Shahin, Khazaei, and Khalili 2016; Hofmann and Rüsch 2017; Yap, Low, and Chong 2018); (2) Reduces waiting times between supply chain members and increases reliability thanks to the elimination of information processing errors (Otamendi, García-Higuera and García-Ansola 2011; Zelbst et al. 2014; Tsao, Linh, and Lu 2017); (3) Enables processes to be automatized throughout the entire supply chain, reducing costs and improving service quality (Chen, Cheng, and Huang 2013; Nabelsi and Gagnon 2017; Shahin, Khazaei, and Khalili 2016); (4) Contributes to greater LSCM flexibility (Shin et al. 2011).

The role of RFID systems in LSCM has been the object of practical studies in a range of environments and sectors. This has enabled supply chain level functions to be automatized, with improved levels of efficiency in information management (Chen, Cheng, and Huang 2013; Nabelsi and Gagnon 2017; Shahin, Khazaei, and Khalili 2016). So, for example, materials flow traceability and location in construction environments has been enabled thanks to the automatization that RFID technologies provide (Shin et al. 2011; Moon et al. 2018); idem baggage in tourist air transport (Otamendi, García-Higuera and García-Ansola 2011) and the management of portable medical kits in hospitals (Nabelsi and Gagnon 2017). Automatization involves different supply chain members and has allowed waiting times to be reduced, which has had a direct knock-on effect on customers and increased the general service level (Otamendi, García-Higuera and García-Ansola 2011; Nabelsi and Gagnon 2017).

A concern for key aspects of RFID implementation in LSCM has also been observed in the literature. Huang et al. (2012) develop a platform that eliminates technological barriers to RFID implementation and enables its use in operations by all members of an LSC, thus enabling the traceability and visibility of materials and reducing the bullwhip effect. Dai et al. (2012) stress the way that RFID devices should be deployed to collect and interpret information and conclude that their proper implementation enables data to be processed in real-time, thus reducing the time needed for decision-making (Dai et al. 2012, Huang et al. 2012, Moon et al. 2018). The economic performance of RFID implementation in LSCM has also been verified thanks to a reduction in warehousing costs that can be achieved through the use of this IDT (Tsao, Linh, and Lu 2017).

(3) SL2.3, E-business web technologies in LSCM

Web technologies and the Internet have played a fundamental role in the development and improvement of interorganizational IDT for LSCM. They have done so by improving customer-supplier relationships by optimizing communications and information flows, thus playing a major role in technology integration of customer and supplier IDT infrastructure (internal/external integration with e-business web technologies) in LSCM (Homer and Thompson 2001; Williamson, Harrison, and Jordan 2004; Adamides et al. 2008; Garcia-Sabater, Maheut, and Garcia-Sabater 2012). This customer-supplier integration can be observed in e-commerce (McMichael, MacKay, and Altmann 2000) and the IT-based Kanban systems (e-Kanban) (Wan and Chen 2008) that are another type of web technology for e-business.

In addition, e-business web technology adoption has enabled coordination between supply chain members to be improved (Bruun and Mefford 2004; Coleman, Lyons, and Kehoe 2004; So and Sun 2010; So and Sun 2011; Garcia-Sabater, Maheut, and Garcia-Sabater 2012; Kovács and Kot 2017) by significantly reducing waiting times (Iijima, Komatsu, and Katoh 1996; So and Sun 2010; Garcia-Sabater, Maheut, and Garcia-Sabater 2012), inventory levels (Bruun and Mefford 2004; Coleman, Lyons, and Kehoe 2004; Kart, Moser, and Melliar-Smith 2010; Williamson, Harrison, and Jordan 2004; So and Sun 2010; So and Sun 2011) and operating costs (Coleman, Lyons, and Kehoe 2004; Williamson Harrison, and Jordan 2004; Kart, Moser, and Melliar-Smith 2010). It has also enabled flexibility to be increased and reduced the risk of the bullwhip effect (Coleman, Lyons, and Kehoe 2004; So and Sun 2010; So and Sun 2011), thus improving service and, consequently, customer satisfaction (Williamson, Harrison, and Jordan 2004).

E-commerce web technologies are used in sales, distribution, and customer service processes, where they integrate physical, information, and financial flows between supply chain members (McMichael, MacKay, and Altmann 2000; Homer and Thompson 2001). These technologies are tools that facilitate communication and coordination between supply chain members and allow inventory levels and distribution costs to be reduced, which means it is possible to cater for a large number of customers with the same resources and contribute to obtaining the benefits derived from scale economies (Kinsey 2000; Homer and Thompson 2001).

The implementation of Internet- or web environment-based technologies in complex supply chain environments has enabled the adoption of Just-in-Time (JIT) principles and practices thanks to the creation of networks to manage information between supply chain members and general improvements to management-associated processes, with increases to delivery speed and reductions in customer waiting time (Iijima, Komatsu, and Katoh 1996; Missopoulos and Dergiades 2007).

Electronic Kanban or e-Kanban have also been implemented in LSCM environments through web technologies and are used to control production and inventory flow (Kumar and Panneerselvam 2006; Wang and Sarker 2006). Kanban systems play a major role in the control of physical and information flows in the supply chain and make it possible to work in JIT environments (Wang and Sarker 2006). The use of web technologies to implement e-Kanban systems makes these more efficient (Wan and Chen 2008). The combination of the conceptual simplicity of the Kanban and the capabilities of web technologies makes automatized data processing possible, enables real-time scheduling, and reduces the possibility of human error and the monitoring limitations of physical cards. In addition, it enables the information provided by Kanban systems to be complemented with information on demand and manufacturing requirements, allows manufacturing priorities to be established to afford suppliers flexibility and reaction capability and enables the decentralization of decision-making (Ardalan and Diaz 2012a). So, e-Kanban enable the entire LSC to be aligned with end-customer demand and, therefore, the minimization of inventory and work in process (Wan and Chen 2008; Ardalan and Diaz 2012b). They also allow better monitoring and visibility of stocks in real-time (Wan and Chen 2008).

(4) SL2.4, Workflow systems in LSCM

Workflow systems are IS that allow the development of business processes (van der Aalst 1999). These business processes can be collaborative between organizations, in which case they act as a support for operations in the supply chain (Hsieh and Lin 2012). Workflow systems can achieve efficiency in supply chain processes by contributing to LSCM objectives. In this sense, Ma, Wang, and Xu (2011) propose the modeling and analysis of the interorganizational workflow through the use of Petri networks and the standardization of business processes in the LSCM context, enabling organizations to be more efficient and productive, optimizing resources and improving the service that they provide to their customers. Dallasega, Rauch, and Frosolini (2018) propose the use of workflow systems to break down large work orders into smaller, more controllable parts, which enables information to be collected in real-time throughout the entire supply chain and problems and their causes to be identified. This provides the ability to react rapidly to changes in customer demand and any errors identified to be improved. It also allows the inventory level to be reduced thanks to a reduction in delivery times and improved planning. So, LM objectives are achieved at the supply chain level (Dallasega, Rauch, and Frosolini 2018).

(5) SL2.5, Enterprise Resources Planning (ERP) Systems in LSCM

ERP is being used in LSCM contexts (Parry and Turner 2006; Green, Whitten, and Inman 2007; Zelbst et al. 2014). Organizations adopting JIT principles and practices for LSC are implementing ERP systems as these are designed to eliminate wastage in the information management process (Green, Whitten, and Inman 2007). In this research subline, Green, Whitten, and Inman (2007) uphold that an ERP system is required as part of the JIT strategy applied to the supply chain so as to provide all chain members with a common database. Information is managed in real-time and has a positive impact on the response capability and on delivery speed, reliability and flexibility, and customer satisfaction. All this has an impact on better organizational and supply chain results (Green, Whitten, and Inman 2007). Information availability is not usually a problem: it is the communication of this information that is ineffective (Bilalis et al. 2002). As a result, information can be presented visually, which makes it easier to interpret and communicate and so manage operations and processes in real-time (Parry and Turner 2006). The link between ERP and RFID devices has enabled Lean supply chains to be more efficient by eliminating waste in raw material management, work in process, and finished product inventory, thus enabling manufacturers to better satisfy customers as to the quality of their products and their delivery response capability. This improvement to supply chain efficiency translates into an improvement to the operational performance of the companies in the supply chain (Zelbst et al. 2014).

(6) SL2.6, Advanced Manufacturing Technologies (AMT) in LSCM

AMT describes a broad variety of technologies used directly or indirectly in manufacturing activities. These technologies have been classified as AMT for design (CAD; CAE, and Industrial Simulation; Computer-Aided Production Planning or CAPP), process (CAM; Robotics), and production management (Material Requirements Planning or MRP). In I4.0 environments, the confluence of a variety of AMT technologies together comprises CIM and its evolution toward what is known as CPS (Kang et al. 2016; Monostori et al. 2016).

AMT not only have an impact at the internal level, but also on planning, administrative management, and the flexibility of processes throughout the supply chain (Levary 2001; Khanchanapong et al. 2014). Levary (2001) extends the CIM concept to LSCM and introduces the term "computer-integrated supply chain". Moreover, the use of IT for process management helps companies to manage the flow of materials from suppliers to customers and also enables information sharing (Levary 2001; Khanchanapong et al. 2014). Design and process management AMT afford companies the ability to increase or reduce manufacturing volumes, economically allowing great flexibility in volumes and contributing to bringing down costs while increasing product quality (Khanchanapong et al. 2014). In conjunction with LM, AMT technologies have a positive impact on the supply chain, with additive and synergistic effects on cost reduction, increased product quality, improved delivery times, and increased flexibility, which affects customers and suppliers throughout the LSC (Khanchanapong et al. 2014).

In the construction industry, specific management approaches and IDT tools are increasingly used in LSCM to maximize value and minimize waste (Deng et al. 2019; Meng 2019; Bortolini, Formoso, and Viana 2019). CAD/CAE AMT use in LSCM construction processes (Building Information Modeling or BIM) in conjunction with geographical information systems (GIS) provide solutions to support decision-making for supplier selection, for determining the number of deliveries and the allocation of consolidation centers in congested regions with long transportation distances (Deng et al. 2019). BIM CAD/CAE AMT encourages optimal supply chain collaboration during a construction project (Deng et al. 2019; Meng 2019). When BIM is applied in a project, a new culture is fostered in the project environment. As a result, better supply chain collaboration raises the possibility of improving LM construction practices (Meng 2019). Joint use of BIM CAD/CAE AMT and LSCM presents a synergistic effect that significantly improves delivery costs, increases the reliability of component delivery, increases productivity for site assembly of prefabricated building systems, keeps inventories organized on-site and reduces lead-time (Bortolini, Formoso, and Viana 2019). It also reduces the number of ongoing jobs and so increases productivity throughout the entire construction process, achieving an earlier completion date with very high quality (Bortolini, Formoso, and Viana 2019).

CAE/Industrial Simulation has also been used in LSCM environments to achieve process efficiency (Mason-Jones and Towill 1997; Saygin and Sarangapani 2011; Chen et al. 2013; Khanchanapong et al. 2014; Li et al. 2018; Baradaran and Akhavan 2019; Miclo et al. 2019; Novais et al. 2019; Ruiz, Fontanini, and Corrêa 2019; Weraikat et al. 2019). Simulation has been used to analyze the efficiency of processes in which EDI (Mason-Jones and Towill 1997), RFID (Saygin and Sarangapani 2011; Chen et al. 2013) or ATM (Khanchanapong et al. 2014) are used. Materials Planning and Scheduling have also been determined with Simulation with better results (Miclo et al. 2019), as has the evolution of the relationship between strategic factors (Novais et al. 2019), the impact of materials flow delays on the supplier chain (Ruiz, Fontanini, and Corrêa 2019), stock minimization in Vendor Management Inventory (VMI) systems (Weraikat et al. 2019), and optimization of the number of Kanbans in JIT systems (Baradaran and Akhavan 2019). VR learning environments have also been developed using RFID and BIM, enabling different supply chain agents to learn how to be efficient in prefabricated component construction projects (Li et al. 2018).

4.3.3. L3, Emerging IDT in LSCM

The following research sublines have been identified in the group of emerging IDT technologies in I4.0: (1) Cloud Computing in LSCM; (2) Internet of Things (IoT) in

LSCM; (3) Artificial Intelligence (AI) in LSCM; (4) Virtual Reality (VR) in LSCM; (5) Autonomous Vehicles (AV) and (6) Big-Data in LSCM. Each of these research sublines is described below.

(1) SL3.1, Cloud Computing in LSCM

Cloud Computing provides services that offer many advantages aligned with LSCM objectives, such as lower costs, best resource exploitation, a need for smaller direct investments, and greater accessibility, inter alia.

Cloud Computing technologies afford flexible integration between a variety of different systems and technologies and facilitate synchronization and collaboration across the LSC (Dave et al. 2016; Sanders, Elangeswaran, and Wulfsberg 2016; Hofmann and Rüsch 2017; Xu et al. 2018). Cloud Computing has enabled traditional communication mechanisms between supply chain members to be modernized. Thanks to this technology and the use of intelligent devices such as cellphones and tablets, it is possible to have quicker access to information at any time and in any place (Sanders, Elangeswaran, and Wulfsberg 2016). Cloud technologies enable a large volume of data to be stored and the real-time monitoring of processes, with information accessible to all supply chain members (Vazquez-Martinez et al. 2018; Xu et al. 2018).

A digital-format product distribution and delivery model underpinned by Cloud Computing has been proposed inspired by LSCM principles (Vázquez-Martinez et al. 2018). Evaluation of this model in comparison to solutions constructed in web environments has shown that this model offers increasingly better delivery results as the number of participants in a collaboration environment grows. In addition, this model has demonstrated the viability of applying this technology to Lean principles in the supply chain for the distribution and delivery of digital products, given the improvements that it achieves in terms of efficiency, flexibility, and security (Vázquez-Martinez et al. 2018). Moreover, Cloud Computing allows to prevent, reduce and mitigate the bullwhip effect thanks to the ability to react and make decisions in real-time (Hofmann and Rüsch 2017; Xu et al. 2018). Finally, it should be highlighted that Cloud Computing technologies have been implemented in supply chains in a variety of sectors and in Small and Medium-sized Enterprises (SMEs), thus enabling more flexible, efficient, and economic process management (Xu et al. 2018).

(2) SL3.2, Internet of Things (IoT) in LSCM

IoT in LSCM contexts provides product visibility and traceability and, even more importantly, information integration (Xu et al. 2018; Wang et al. 2018). By adopting IoT-based technologies, buffer time, inventory level, productivity, re-work, and so on can all be easily identified and duly addressed (Wang et al. 2018). Implementing IoT among supply chain members enables real-time links and information sharing, thus improving interoperability between the main IS of different organizations (Dave et al. 2016; Wang et al. 2018). IoT allows the generation of Big-Data, resulting in significantly improved streamlining of operations (Roy and Roy 2019). Real-time information transmission between buyers and sellers enables the integration of physical flows, which affords greater agility (by reducing reaction and waiting times) and flexibility to respond to fluctuations in demand (Hofmann and Rüsch 2017; Dave et al. 2016; Roy and Roy 2019; Wang et al. 2018). The use of VMI in LSCM in conjunction with IoT affords rapid and coordinated real-time inventory management across the supply chain and so permits a minimum yet nonetheless flexible inventory level that is able to address any customer demand fluctuations (Yerpude and Singhal 2017). In conjunction with other information management and merchandise flow technologies, IoT ensures on-time product delivery and transport route optimization. The use of IoT in article labeling enables the monitoring and intelligent reallocation of orders through an improved replenish pull system, which is extremely useful in JIT for goods deliveries by suppliers (Sanders, Elangeswaran, and Wulfsberg 2016) and improves efficiency and costs reduction (Wang et al. 2018).

(3) SL3.3, Artificial Intelligence (AI) in LSCM

In LSCM contexts, decision-making is a challenge due to the complexity, dynamism, and uncertainty of the environment, so being able to use knowledge management is a great advantage (Liu et al. 2012). Inaccurate demand forecasts and a lack of shared information between chain members can lead to greater production than necessary, unnecessary logistics costs being borne, increased delivery times, and reduced flexibility.

AI can be used for decision-making to achieve Lean objectives in supply chains (Liu et al. 2012). In this sense, Liu et al. (2012) have developed a decision-making support system for LSCM using AI systems that provide decision-makers with a tool for making the right decisions to eliminate any activity that does not add value throughout the supply chain. The system improves the decision-making process through knowledge management and enables the elimination of wastage such as production and inventory surpluses, waiting times, and the unnecessary movement of materials and products, thus raising performance and productivity in the entire Lean supply chain (Liu et al. 2012). With a similar AI-based focus, intelligent routing systems that analyze traffic information in real-time have been designed to manage JIT deliveries and provide a general improvement to deliveries with reduced waiting times and higher customer satisfaction (Güner, Murat, and Chinnam 2012). Similarly, an AI approach has been developed for planning and scheduling parcel delivery with the consideration of multiple delivery vehicles, JIT pickup and delivery, minimum fuel consumption, and maximum profitability (Kang, Lee, and Chung 2019). In addition, using AI systems in conjunction with other technologies allows orders to be located and information on load status in transport to be managed in learning systems (Hofmann and Rüsch 2017).

(4) SL3.4, Virtual Reality (VR) in LSCM

VR application in LSCM is linked to learning in complex processes where several different agents are involved (Li et al. 2018). So, virtual environments have been implemented using RFID and BIM and used for management learning in the manufacture of prefabricated components in the construction sector (Prefabrication Housing Production, PHP). As a type of advanced simulation game, the proposed tool facilitates the manufacture, logistics, and assembly process, helping to reduce uncertainty and constraints and to improve information sharing and eliminate PHP construction mistakes (Li et al. 2018).

(5) SL3.5, Autonomous Vehicles (AV) in LSCM

In supply chains, AV contribute to achieving Lean objectives. In this sense, autonomous control in operational functions provides flexibility (Mehrsai, Thoben, and Scholz-Reiter 2014). Autonomous vehicles applied to production and logistics environments establish a continuous flow of materials in LSCM contexts, favoring pull-type flow and JIT replenishment (Mehrsai, Thoben, and Scholz-Reiter 2014). Using these systems in conjunction with automatization and robotics enables performance, efficiency, efficacy, and response time increases and reduces waiting times throughout the LSC (Mehrsai, Thoben, and Scholz-Reiter 2014).

(6) SL 3.6, Big-Data in LSCM

The use of multiple IDT of I4.0 has led to companies and supply chains generating and storing enormous amounts of information. This information is crucial for being able to mine useful knowledge with the purpose of improving supply chain efficiency and productivity (Bevilacqua, Ciarapica y Antomarioni 2019). Big-Data analytics methods have shown their potential to facilitate communication between automation systems and the LSCM approach to reach common efficiency goals (Bevilacqua, Ciarapica, and Antomarioni 2019; Roy and Roy 2019; Deng et al. 2019). Big-Data enables LSCM visualization and metrics analysis. The decision system is more efficient and the decision-making process can be automatized or semi-automatized throughout the entire supply chain (Roy and Roy 2019). Thus, for example, thanks to the data generated by different systems used in the construction sector (BIM and GIS) and to the application of Big-Data, accurate estimates can be made of the costs incurred during the procurement process, thus providing a support system to the decision-making process in LSCM contexts (supplier selection, determination of the number of materials deliveries, and allocation of consolidation centers) (Deng et al. 2019).

4.3.4. L4, Information Systems and Information and Digital Technologies, general approach in LSCM

Articles included in this research line are characterized by studying the impact, the relations, and the implications that IS and IDT of I4.0 have in general in LSCM. In this line, IS/IDT of I4.0 are considered to be a toolset, with no one individual tool analyzed in isolation, acting as a support to the Lean supply chain and as a facilitator of its implementation (Lee et al. 2008).

A number of authors state that organizations should invest in IT infrastructure as this has a positive influence on Lean supply chain integration and flexibility, which in turn has a direct, positive impact on customer satisfaction and financial results (Bayraktar et al. 2010; Kashani and Baharmast 2017; Gorane and Kant 2017). In addition, IDT of I4.0 implementation is a facilitator of LSCM practices, which leads to best performance improvements (Lee et al. 2008; Kamble, Gunasekaran, and Dhone 2019). These statements are backed up by a range of authors. For example, Karakadilar and Hicks (2015) find that the different IDT used, their level of implementation, and the Lean practices applied have a positive effect on the supplier's operating performance (product quality, delivery times, and response to change). It has also been found that greater alignment between the Lean practices applied by suppliers and the IS used has a positive association with supply chain integration (information, physical, and financial flow coordination and integration) (Qrunfleh and Tarafdar 2014; Karakadilar and Hicks 2015) and with flexibility (Qrunfleh, Tarafdar, and Ragu-Nathan 2012).

IS/IDT have a positive impact on Mass Customization (MC) when LSCM practices are used (Hong, Dobrzykowski, and Vonderembse 2010) and on new product innovation and development (Kou, Chiang, and Chiang 2018). The level of IDT use and the level of supply chain integration are determinants that either directly or indirectly determine the level of Lean implementation at the internal level (Ghobakhloo et al. 2018). IS/IDT enable information and knowledge management, which has a positive impact on LSCM integration and results (Bayraktar et al. 2009; Sangari, Hosnavi, and Zahedi 2015; Sharma and Kulkarni 2016). So, IS/IDT use in LSCM achieves efficiency in the planning and management of supply and demand, supplier management, inventory management, and delivery management (Bayraktar et al. 2009; Sangari, Hosnavi, and Zahedi 2015; Sharma and Kulkarni 2016). In this line, recent research studies find that the adoption of technologies of I4.0 moderates the relationship between LSCM practices and supply chain performance improvement (Tortorella, Miorando, and Cawley 2019). This means that, the further that LSCM practices and IDT of I4.0 are developed, the greater the results are at the supply chain level.

However, not all IDT of I4.0 have the same effect on results. In a study of different supply chain strategies (Green, Lean, Agile and Resilient), IDT of I4.0, and performance, the Green and Lean paradigms are found to be established as the most influential on global performance. Several IDT of I4.0 only influence Green and Lean supply chain strategies: Autonomous Robots, Additive Manufacturing, Cloud Computing, Autonomous Vehicles, Cybersecurity, and Augmented Reality. Other IDT of I4.0 influence Green and Lean and, to a lesser extent, Agile and Resilient: Horizontal & Vertical Integration (web technologies), Big-Data, Blockchain, Industrial Simulation, IoT, and AI (Ramirez-Peña et al. 2019). So, the most suitable procedure is to first implement the first group of IDT of I4.0, which impact LSCM and Green and improve results, and subsequently, to implement the second group of IDT of I4.0 to achieve agility and resilience (Ramirez-Peña et al. 2019). Moreover, coordination is essential in contexts of IDT of I4.0 and LSCM (Singh, Kumar, and Chand 2019). It has been observed that in order to achieve this coordination in the supply chain, the most successful companies put a greater focus on organizational issues such as Lean organization structure, organization culture, and supply chain responsiveness factors rather than on IDT of I4.0 (Singh, Kumar, and Chand 2019).

4.4. Gaps and avenues for future research

The following sets out the aspects in each of the identified research lines that have not been studied at all or only to a limited extent (gaps) and the research that needs to be developed in the future to address these gaps.

In reference to the line of research "obsolete IDT in LSCM (L1)", these days EDI technologies are out-of-date. Nonetheless, they have been adapted by some companies to web environments due to their proven efficacy and the difficulty and/or cost of replacing them completely. At the current time, the cost of web technologies has been seen to have decreased and, so, there may be a change to the convenience that continued use of first-generation EDI systems represents. Legacy EDI systems, therefore, need to be investigated to ascertain whether they are profitable/efficient/valid in the Industry 4.0 digital transition and LSCM environment compared to other possible solutions such as EDI-web environments.

In reference to the line of research "mature IDT in LSCM (L2)", many companies use mature technology of the ERP system type. However, these systems are being transferred from internal organizations' environments to Cloud Computing platforms. Given the challenges that the digital transition of I4.0 in LSCM poses, it would be necessary to conduct comparative research with empirical studies to determine whether these internal systems continue to be efficient compared to other possibilities that are in the marketplace, such as ERP in Cloud Computing environments. With regard to RFID, it would be interesting to determine how the adoption of an advanced initiative called RAIN-RFID, which combines RFID and Cloud Computing and uses Ultra High Frequency (UHF), Electronic Product Code (EPC) and standardized RFID protocol in conjunction with Cloud infrastructure, is able to open up new ways to achieving greater efficiency in LSCM environments. This is an as-yet unexplored issue. In relation to other mature IDT such as AMT, technologies such as CAD, CAM, and CAE/Industrial Simulation, which give the firm volume and product flexibility, have been analyzed in LSCM environments. Nonetheless, other technologies such as robotics has not been analyzed in the LSCM context. In this sense, the use of Collaborative Robots or Cobots could be analyzed in the future in LSCM contexts, as they add efficiency and flexibility to manufacturing processes. The application of Robots and Cobots to repetitive logistics tasks such as merchandise picking and packing could be investigated in LSCM contexts. A further interesting topic for future research would be the incorporation of the digital twin (CAD) and its connecting to Additive Manufacturing (CAM or CAE) machines with the involvement of a variety of supply chain members (suppliers and customers) to achieve LSCM objectives, as the evolution of more traditional AMT systems.

In reference to the line of research "emerging IDT in LSCM (L3)", from a general perspective, more in-depth research needs to be done of the possible implications of emerging IDT use for LSCM results. It would be interesting to analyze the way that Cloud Computing, Big-Data, IoT, and AI affect LSC results at both the operating level (flexibility, quality, delivery, and service), and in relation to financial results (revenue, profit margin, and business volume). Also, Big-Data and advanced analytics could be investigated to determine whether they might help give a better understanding of consumer behavior and needs, enabling a proactive response to be given to customer requirements. Another issue that requires further research is the effect of emerging technologies adoption on Lean supply chain integration. It would also be interesting to investigate the way that environmental variables, for example, the degree of technological intensity in the sector in which companies operate, might condition the effects and implications of the Industry 4.0 transition in LSCM contexts. Yet another interesting area to investigate would be issues relating to the adoption, integration, risks, and economic viability of the implementation of certain emerging IDT of I4.0 in LSCM environments.

From a more concrete perspective, VR has been used in LSCM environments as a learning tool. However, technologies such as Augmented Reality (AR) have not been analyzed in LSCM contexts. AR allows virtual information to be added to physical objects and has great potential for application in logistics activities such as warehouse management and distribution, for example, or for picking and packing and expediting delivery. In both cases, AR facilitates the efficient and rapid location of products. For this, conceptual studies and case studies could be conducted that evaluate this technology's use in LSCM environments. Its application would be beneficial for last-mile logistics processes and could drastically reduce the time devoted to searching for and finding physical goods. Other emerging IDT that have still not been explored in the research in LSCM contexts, such as Blockchain and Additive Manufacturing, could also greatly help Lean objectives be achieved in the supply chain. In this sense, it would be interesting to evaluate the capacity for innovation that might result from knowledge generated throughout LSCM due to the use of certain emerging IDT of I4.0. For example, it would be interesting to determine the potential of an emerging IDT such as Blockchain, which renders information unalterable, for achieving efficiency in information processing across a Lean supply chain. Likewise, the utility of Additive Manufacturing could be examined for working with a very low inventory level and offering a highly customized product.

On the one hand, from the specific point-of-view of the IDT/IS general approach research line, the implications of IDT and IS have been investigated for Lean supply chain integration, including aspects such as the impact that they have on supply chain efficiency and flexibility and their effect on some specific operating results. However, one topic of great interest—sustainability—has barely been addressed in the research on

IDT of I4.0 and LSCM. The Green and Lean paradigms have been found to be very influential on global performance, mainly due to the effect of several IDT of I4.0 (Robots, Additive Manufacturing, Cloud Computing, AV, Cybersecurity, and AR) and, to a lesser extent, the effect of other IDT of I4.0 (web technologies for e-business, Big-Data, Blockchain, Simulation, IoT, and AI) (Ramirez-Peña et al. 2019). Notwithstanding, it would be interesting to analyze how companies could use the joint IDT of I4.0-LSCM effect to achieve results in different sustainability dimensions (social, environmental, and economic). In this sense, improving demand forecast abilities with Big-Data techniques could lead to more efficient production and responsible resource use. It would also be reasonable to think that Additive Manufacturing could delay manufacturing until the last links in the supply chain and this could have implications at the level of obtaining better environmental results.

On the other hand, from a general point-of-view, there is a lack of studies that analyze how LSCM principles and practices can facilitate the adoption of IDT of I4.0 (Wang et al. 2016; Singh, Kumar, and Chand 2019). In this regard, it would be especially interesting to ascertain how certain LSC characteristics or preconditions such as trust, coordination and integration, culture, mutual goals, long-term relationships, and risk-sharing partnerships, among others, are able to facilitate or boost the adoption of certain IDT of I4.0. In the same way, it is important to analyze the way that the degree of LSCM implementation along with contextual factors (e.g., sector, complexity of Lean supply chains) can facilitate or inhibit the adoption of certain IDT of I4.0. In this regard, researchers should focus their efforts on identifying facilitators/drivers and inhibitors/barriers of LSCM 4.0 initiatives. Along with this, there is a lack of roadmaps or implementation frameworks to support managers in their push toward an LSCM 4.0 transition. This could be explained by the fact that companies are currently digitizing their internal processes through door-to-door value streams to subsequently deploy an LSCM 4.0 strategy to their Lean partners. Lastly, also from a general point-of-view, the analyzed articles on I4.0 and LSCM have mostly focused on manufacturing sectors, especially the automotive and construction sectors. The implication of IDT of I4.0 and LSCM has only been minimally analyzed in sectors such as the medical, aerospace, agrifood and textile sectors and in retailing, public administration, and services. As such, and given that the benefits of jointly implementing IDT of I4.0 and LSCM in the most studied sectors are evident, greater research is necessary in other sectors such as those mentioned above.

5. Discussion

The results obtained in this study are original and novel compared to the prior literature (Sony 2018; Pinho, and Mendes, 2017; Buer, Strandhagent, and Chan, 2018; Plagiosa, Tortorella, and Espindola-Ferreira 2019). Whereas previous SLR have analyzed the interrelationship between IT in general (Pinho, and Mendes 2017), or IDT of I.4 in particular (Buer, Strandhagent, and Chan, 2018; Plagiosa, Tortorella, and Espindola-Ferreira 2019), and LM applied on the internal level in a single organization (Pinho, and Mendes, 2017; Buer, Strandhagent, and Chan 2018; Plagiosa, Tortorella, and Espindola-Ferreira 2019), this is the first SLR that broadens the focus to the study of the IDT of I4.0-LM relationship at the supply chain level, and this is one of its main contributions.

What stands out in this new focus is the finding that several IDT of I4.0 are being used by companies in the supply chain as an aid to implement Lean practices (LSCM). This effect coincides with the effect that also stands out in the internal-level IT-Lean relationship (Pinho, and Mendes, 2017; Buer, Strandhagent, and Chan 2018; Sony 2018;). Nevertheless, as this paper shows, when extended to the supply chain, a large group of companies uses a large number of IDT of I4.0 and several Lean practices at the same time. The result is a strong accumulated effect on efficiency and, ultimately, on the supply chain results. So, for example, IoT use in LSCM usually occurs alongside the use of RFID, GPS, CPS, Cloud Computing and Big-Data, acting on several Lean practices and having a multiplying effect on the results.

Another of this paper's main contributions is, precisely, that it shows that the complementary or synergistic effect between IDT of I4.0 and LSCM is very strong and has a tremendous impact on the supply chain results (for example, some of the many benefits are flexibility, agility, information sharing, synchronization and collaboration, integration, coordination, speed, reduced costs, deliveries, and errors, reduced inventory levels, enabling a pull system, enabling traceability and inventory control, reduced risk, improved service quality, and customer satisfaction).

This positive impact on the results has also been found in the joint use of IDT of I4.0 and internal LM (Buer, Strandhagent, and Chan, 2018; Plagiosa, Tortorella, and Espindola-Ferreira 2019). However, the novelty of this paper is that it has been proven that when IDT of I4.0 are applied at the LSCM level, the effect on the results is multiplied.

This paper also clearly shows that the joint effect of IDT of I4.0 and LSCM provides the supply chain with great flexibility by fulfilling the LM objectives. This finding coincides with prior research focused on the effect of IDT of I4.0 on SCM (Ben-Daya, Hassini, and Bahron 2017; Baryannis et al. 2019). Recent studies have found that applying IoT in SCM enables supply, manufacturing, and delivery processes to be simultaneously optimized (Ben-Daya, Hassini, and Bahron 2017) and the IDT of I4.0 enable the risk associated with the supply chain to be managed and minimized (Ivanot et al. 2019; Baryannis et al. 2019). Nevertheless, prior studies only offer a partial version of the effect of IDT of I4.0 on SCM, whereas this paper gives a holistic view of the way that the supply chain is managing to become more efficient and flexible (LSCM) in conjunction with various IDT of I4.0.

From its holistic perspective, this paper also offers a vision of the present and future of IDT of I4.0 and LSCM in the digital era. The classification presented in this article gives a vision of the present and situates different IDT of I4.0 that are being applied in LSCM contexts in the TLC, whilst also identifying the digital transformation that they provide. This classification is a tool with strategic utility for academics and senior management, both of whom can use it to see the present based on existing research. And, according to the avenues for future research shown in this paper, senior managers can act on various IDT with the objective of achieving the future digital transformation of their supply chains in the quest for competitive advantages over their rivals, turning their supply chains into what some authors have already referred to as the Digital Supply Network (Ghobakhloo 2019), Smart LSCM or LSCM 4.0.

5.1 Implications

The following sets out a series of implications that may be useful from an academic, management and policymaker focus.

First, from an academic point-of-view, this paper aims to serve as a framework for current and future researchers who are interested in advancing research on LSCM and I4.0. Thus, the existing literature's novel proposed classification according to the Technology Life Cycle of IDT of I4.0 could help academics to understand the evolution of the prior research and the digital transition toward a Lean Supply Chain 4.0. In addition, the identified gaps and the proposed future research avenues can be especially useful for moving forward in the relationships between IDT of I4.0 and LSCM.

Regarding management implications, this paper can act as a reference on the relationship between the IDT of I4.0 and LSCM. Specifically, it shows the synergic and complementary effects of IDT of I4.0 and LSCM on performance. Thus, using this as a guide, Lean supply chain managers can increase internal and external (Lean supply chain partners) awareness, understanding, and acceptance of an LSCM 4.0 strategy with the main aim of improving mutual efficiency and effectiveness by their Lean supply chain partners triggering the adoption of an internal I4.0 strategy and/or moving forward in a digital transition towards LSCM 4.0. In fact, the lack of understanding of the implications of I4.0 and its expansion to the supply chain level, as well as a lack of knowledge about the potential benefits or uncertain outcomes of investments, have been identified as a challenge in SCM 4.0 research (Luthra and Kumar, 2018). Furthermore, the demonstrated relationship between IDT of I4.0 and LSCM via the TLC is a tool with strategic interest for managers and can act as an aid to making decisions on the use of some specific IDT of I4.0 in LSCM contexts when seeking to obtain competitive advantages, competing not individually, but at the supply chain level.

Finally, there is no doubt about the crucial role that the Public Sector can play to ensure that I4.0 becomes a success at the internal and SC levels (Smit et al. 2016). In fact, a lack of weak government policy has been identified as one of the main barriers to the adoption of I4.0 in the SCM research field (Luthra and Kumar, 2018). In this regard, the main gaps and weaknesses identified by this research could be used as a reference to develop technological forecasting and policies for overcoming them and promoting a roadmap transition towards LSCM 4.0. Thus, this research humbly intends to act as a reference for policymakers.

It is important to remark that several studies on SCM 4.0 in general (e.g., Smit et al. 2016; Barata, Da Cunha and Stal, 2018; Ali et al. 2019) emphasize the lack of digital know-how, training, managers' awareness of IDT of I4.0 and their potential benefits, the investment capacity of certain supply chain partners (e.g., SMEs), the ability to run pilot projects at the supply chain level, standards, and interoperability concerns, cybersecurity problems, and legal conditions, among other relevant inhibitors or barriers. Therefore, Government policies (at the regional, national, and supranational levels) could support and fund research, coordinate I4.0 initiatives at the SCM level, develop platforms where best practices could be shared and lessons learned, raise awareness of challenges/opportunities, support the development of standards, enable SMEs to have access to funding or boost multidisciplinary consortia, among others.

5.2 Limitations

This work is not without its limitations. Three databases were used for the literature review, which means that any works not indexed in these will not have been considered. However, this could be considered as a minor limitation, as the use of various databases reduces publication bias (Thomé, Scavarda, and Scavarda 2016). In addition, using the inclusion criterion for papers published in JCR and/or SJR impact journals might have resulted in some other article of interest not being located. However, this is a criterion that is habitually used in SLR to ensure the quality of the articles (Schmeisser 2013; Vural 2017; Martinelli and Tunisini 2019). In other respects, SLR comes under criticism for the subjectivity of key search word selection and of the classification criteria used. But the involvement of several researchers and the consensus that they arrived at in the choice of key search words and the coding and classification of chosen articles reduces the subjectivity linked to single researcher bias (Thomé, Scavarda, and Scavarda 2016), with the use of research line and subline identification criteria being the norm for classification in SLR (Garza-Reyes 2015; Vural 2017). And yet, despite these limitations, we believe that this study provides a broad view of the IDT of I4.0 - LSCM relationship that can kindle thought and offer useful implications for other researchers to further explore some concrete aspects of the Industry 4.0 transition and LSCM.

6. Conclusions

This paper has reviewed the extant literature on the interrelationships between IDT of I4.0 and LSCM. For this, an SLR has been conducted that has enabled the identification of articles of interest and a novel literature classification. TLC has been used as the grouping criterion to construct the classification, which has enabled the interrelationships between LSCM and the specific technologies to be understood according to their lifecycle position. Using the position of IDT of I4.0 in the TLC as a grouping criterion is important due to the consideration of time as a variable and the utility that it has as a tool for decision-making in the pursuit of competitive advantages. The description and analysis of the findings of the individual lines have allowed the state of the research to be evaluated for each of these and a broad overview to be given of the state-of-the-art for researchers, managers, and policymakers who want to find out about the role that IDT of I4.0 play in LSCM contexts, whether they are novices or seeking to dig deeper into the matter. This paper provides knowledge of the most researched aspects, the gaps that exist, and directions for possible future research.

Notwithstanding, research still needs to be continued on the use of emerging IDT in LSCM contexts as they require greater attention from researchers, given their potential for development and their ability to achieve LSCM objectives. In addition, emerging IDT of I4.0 exist whose effect has still not been explored in the LSCM context, such as the cases of Blockchain, AR, and Additive Manufacturing.

SLR References

Abernathy, F. H., J. T. Dunlop, J. H. Hammond, and D. Weil. 2000. "Retailing and supply chains in the information age." *Technology in Society* 22 (1): 5–31.

Adamides, E. D., N. Karacapilidis, H. Pylarinou, and D. Koumanakos. 2008. "Supporting collaboration in the development and management of lean supply networks." *Production Planning & Control* 19 (1): 35–52.

Ardalan, A., and R. Diaz. 2012a. "NERJIT: Using net requirement data in kanban-controlled jumbled-flow shops." *Production and Operations Management* 21 (3): 606–618.

Ardalan, A., and R. Diaz. 2012b. "An evaluation of the NERJIT priority rule in a kanban-controlled flowshop." *Production and Operations Management* 21 (5): 923–938.

Baradaran, V. and B. Akhavan. 2019. "Determining number of withdrawal Kanban using bi-level optimization and simulation approaches." *The International Journal of Industrial Engineering: Theory, Applications and Practice* 26 (2): 156–172.

Bayraktar, E., A. Gunasekaran, S. C. L. Koh, E. Tatoglu, M. Demirbag, and S. Zaim. 2010. "An efficiency comparison of supply chain management and information systems practices: A study of Turkish and Bulgarian small- and medium-sized enterprises in food products and beverages." *International Journal of Production Research* 48 (2): 425–451.

Bayraktar, E., M. Demirbag, S. C. L. Koh, E. Tatoglu, and H. Zaim. 2009. "A causal analysis of the impact of information systems and supply chain management practices on operational performance: Evidence from manufacturing SMEs in Turkey." *International Journal of Production Economics* 122 (1): 133–149.

Bevilacqua, M., F. E. Ciarapica, and S. Antomarioni. 2019. "Lean principles for organizing items in an automated storage and retrieval system: an association rule mining – based approach." *Engineering* 10 (1): 29–36.

Bortolini, R., C. T. Formoso, and D. D. Viana. 2019. "Site logistics planning and control for engineer-to-order prefabricated building systems using BIM 4D modeling." *Automation in Construction* 98: 248–264.

Bruun, P., and R. N. Mefford. 2004. "Lean production and the Internet." *International Journal of Production Economics* 89 (3): 247–260.

Chen, J. C., C. H. Cheng, and P. B. Huang. 2013. "Supply chain management with lean production and RFID application: A case study." *Expert Systems with Applications* 40 (9): 3389–3397.

Coleman, J., A. Lyons, and D. Kehoe. 2004. "The glass pipeline: Increasing supply chain synchronisation through information transparency." *International Journal of Technology Management* 28 (2): 172–190.

Dai, Q., R. Zhong, G. Q. Huang, T. Qu, T. Zhang, and T. Y. Luo. 2012. "Radio frequency identification-enabled real-time manufacturing execution system: A case study in an automotive part manufacturer." *International Journal of Computer Integrated Manufacturing* 25 (1): 51–65.

Dallasega, P., E. Rauch, and M. Frosolini. 2018. "A Lean approach for real-time planning and monitoring in engineer-to-order construction projects." *Buildings* 8 (38): 1–22.

Danas, K., P. Ketikidis, and A. Roudsari. 2002. "A virtual hospital pharmacy inventory: An approach to support unexpected demand." *Journal of Medical Marketing* 2 (2): 125–129.

Dave, B., S. Kubler, K. Främling, and L. Koskela. 2016. "Opportunities for enhanced lean construction management using Internet of Things standards." *Automation in Construction* 61: 86–97.

Deng, Y., V. J. L. Gan, M. Das, J. C. P. Cheng, and C. Anumba. 2019. "Integrating 4D BIM and GIS for Construction Supply Chain Management." *Journal of Construction Engineering and Management* 145 (4): 1-14.

Garcia-Sabater, J. P., J. Maheut, and J. J. Garcia-Sabater. 2012. "A two-stage sequential planning scheme for integrated operations planning and scheduling system using MILP: The case of an engine assembler." *Flexible Services and Manufacturing Journal* 24 (2): 171–209.

Ghobakhloo, M., M. Fathi, D. B. M. M. Fontes, and N. Tan Ching. 2018. "Modeling lean manufacturing success." *Journal of Modelling in Management* 13 (4): 908–931.

Gorane, S., and R. Kant. 2017. "Supply chain practices and organizational performance." *The International Journal of Logistics Management* 28 (1): 75–101.

Green, K. W., D. Whitten, and R. A. Inman. 2007. "The impact of timely information on organisational performance in a supply chain." *Production Planning & Control* 18 (4): 274–282.

Güner, A. R., A. Murat, and R. B. Chinnam. 2012. "Dynamic routing under recurrent and non-recurrent congestion using real-time ITS information." *Computers & Operations Research* 39 (2): 358–373.

Hofmann, E., and M. Rüsch. 2017. "Industry 4.0 and the current status as well as future prospects on logistics." *Computers in Industry* 89: 23–34.

Homer, G., and D. Thompson. 2001. "The contribution of Internet technology in achieving lean management within British automotive supply chains." *International Journal of Automotive Technology and Management* 1 (2/3): 369–378.

Hong, P. C., D. D. Dobrzykowski, and M. A. Vonderembse. 2010. "Integration of supply chain IT and lean practices for mass customization." *Benchmarking: An International Journal* 17 (4): 561–592.

Huang, G. Q., T. Qu, Y. F. Zhang, and H. D. Yang. 2012. "RFID-enabled product-service system for automotive part and accessory manufacturing alliances." *International Journal of Production Research* 50 (14): 3821–3840.

Iijima, M., S. Komatsu, and S. Katoh. 1996. "Hybrid just-in-time logistics systems and information networks for effective management in perishable food industries." *International Journal of Production Economics* 44 (1/2): 97–103.

Kamble, S., A. Gunasekaran, and N. C. Dhone. 2019. "Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies." *International Journal of Production Research* (in press): 1–19.

Kang, Y., S. Lee, and B. D. Chung. 2019. "Learning-Based Logistics Planning and Scheduling for Crowdsourced Parcel Delivery." *Computers & Industrial Engineering* 132: 271–279.

Karakadilar, I. S., and B. J. Hicks. 2015. "Exploring the moderating role of Lean production on supplier performance: An empirical study of Turkish automotive part suppliers." *Boğaziçi Journal Review of Social, Economic and Administrative Studies* 29 (2): 73–97.

Kart, F., L. E. Moser, and P. M. Melliar-Smith. 2010. "An automated supply chain management system and its performance evaluation." *International Journal of Information Systems and Supply Chain Management* 3 (2): 84–107.

Kashani, F. H., and S. Baharmast. 2017. "Effect of supply chain information systems on firm performance: An empirical case study." *Engineering, Technology & Applied Science Research* 7 (2): 1552–1558.

Khanchanapong, T., D. Prajogo, A. S. Sohal, B. K. Cooper, A. C. L. Yeung, T. C. E. Cheng. 2014. "The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance." *International Journal of Production Economics* 153: 191–203.

Kinsey, J. 2000. "A faster, leaner, supply chain: New uses of Information Technology." *American Journal of Agricultural Economics* 82 (5): 1123–1129.

Kou, T. C., C. T. Chiang, and A. H. Chiang. 2018. "Effects of IT-based supply chains on new product development activities and the performance of computer and communication electronics manufacturers." *Journal of Business & Industrial Marketing* 33 (7): 869–882.

Kovács, G., and S. Kot. 2017. "Economic and social effects of novel supply chain concepts and virtual enterprises." *Journal of International Studies* 10 (1): 237–254.

Lee, S. M., D. L. Olson, S. H. Lee, T. Hwang, and M. S. Shin. 2008. "Entrepreneurial applications of the lean approach to service industries." *The Service Industries Journal* 28 (7): 973–987.

Levary, R. R. 2001. "Computer integrated supply chain." *International Journal of Materials and Product Technology* 16 (6/7): 463–483.

Li, X., G. Q. Shen, P. Wu, H. Fan, H. Wu, and Y. Teng. 2018. "RBL-PHP: Simulation of lean construction and information technologies for prefabrication housing production." *Journal of Management in Engineering* 34 (2): 1–18.

Liu, S., M. Leat, J. Moizer, P. Megicks, and D. Kasturiratne. 2012. "A decision-focused knowledge management framework to support collaborative decision making for lean supply chain management." *International Journal of Production Research* 51 (7): 2123–2137.

Ma, J., K. Wang, and L. Xu. 2011. "Modelling and analysis of workflow for lean supply chains." *Enterprise Information Systems* 5 (4): 423–447.

Mason-Jones, R., and D. R. Towill. 1997. "Information enrichment: Designing the supply chain for competitive advantage." *Supply Chain Management: An International Journal* 2 (4): 137–148.

McMichael, H., D. Mackay, and G. Altmann. 2000. "Quick response in the Australian TCF industry." *International Journal of Physical Distribution & Logistics Management* 30 (7/8): 611–626.

Mehrsai, A., K. D. Thoben, and B. Scholz-Reiter. 2014. "Bridging lean to agile production logistics using autonomous carriers in pull flow." *International Journal of Production Research* 52 (16): 4711–4730.

Meng, X. 2019. "Lean management in the context of construction supply chains". *International Journal of Production Research* 57 (11): 3784–3798.

Miclo, R., M. Lauras, F. Fontanili, J. Lamothe, and S. A. Melnyk. 2019. "Demand Driven MRP: assessment of a new approach to materials management." *International Journal of Production Research* 57 (1): 166–181.

Missopoulos, F. S., and T. Dergiades. 2007. "Decisive factors for the adoption of just-in-time in Greek SMEs: A probit model." *International Journal of Logistics Systems and Management* 3 (3): 344–355.

Moon, S., S. Xu, L. Hou, C. Wu, X. Wang, and V. W. Y. Tam. 2018. "RFID-aided tracking system to improve work efficiency of scaffold supplier: Stock management in Australasian supply chain." *Journal of Construction Engineering and Management* 144 (2): 1–9.

Nabelsi, V., and S. Gagnon. 2017. "Information technology strategy for a patient-oriented, lean, and agile integration of hospital pharmacy and medical equipment supply chains." *International Journal of Production Research* 55 (14): 3929–3945.

Novais, L., J. M. Maqueira, Á. Ortiz, and S. Bruque. 2019. "Strategic simulation models as a new methodological approach: an application to information technologies integration, lean/just-in-time and lead-time." *Central European Journal of Operations Research* (in press).

Otamendi, F. J., A. García-Higuera, and P. García-Ansola. 2011. "New business opportunities along the air tourism supply chain: The combination of identification technologies and just-in-time." *African Journal of Business Management* 5 (11): 4007–4022.

Parry, G. C., and C. E. Turner. 2006. "Application of lean visual process management tools." *Production Planning & Control* 17 (1): 77–86.

Powell, D., and L. Skjelstad. 2012. "RFID for the extended lean enterprise." *International Journal of Lean Six Sigma* 3 (3): 172–186.

Qrunfleh, S., and M. Tarafdar. 2014. "Supply chain information systems strategy: Impacts on supply chain performance and firm performance." *International Journal of Production Economics* 147: 340–350.

Qrunfleh, S., M. Tarafdar, and T. S. Ragu-Nathan. 2012. "Examining alignment between supplier management practices and information systems strategy." *Benchmarking: An International Journal* 19 (4/5): 604–617.

Ramirez-Peña, M., A. J. Sánchez-Sotano, V. Pérez-Fernandez, F. J. Abad and M. Batista. 2019. "Achieving a Sustainable Shipbuilding Supply Chain under I4.0 perspective." *Journal of Cleaner Production* (in press).

Roy, M., and A. Roy. 2019. "Nexus of Internet of Things (IoT) and Big Data: Roadmap for Smart Management Systems (SMgS)." *IEEE Engineering Management Review* 47 (2): 53–65.

Ruiz, P. V., P. S. P. Fontanini, and F. R. Corrêa. 2019. "Materials Flow Investigation: an Aluminum Frames Supply Chain Simulation." *International Review on Modelling and Simulations* 12 (1): 30–36.

Sanders, A., C. Elangeswaran, and J. Wulfsberg. 2016. "Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing." *Journal of Industrial Engineering and Management* 9 (3): 811–833.

Sangari, M. S., R. Hosnavi, and M. R. Zahedi. 2015. "The impact of knowledge management processes on supply chain performance." *The International Journal of Logistics Management* 26 (3): 603–626.

Saygin, C., and J. Sarangapani. 2011. "Radio Frequency Identification (RFID) enabling lean manufacturing." *International Journal of Manufacturing Research* 6 (4): 321–336.

Shahin, A., J. Khazaei, and A. Khalili. 2016. "Investigating the impact of RFID technology utilisation on supply chain and performance with a case study in Iran's manufacturing industries." *International Journal of Procurement Management* 9 (6): 751–770.

Sharma, P., and M. S. Kulkarni. 2016. "Framework for a dynamic and responsive: time separated lean-agile spare parts replenishment system in army." *International Journal of Productivity and Performance Management* 65 (2): 207–222.

Shin, T. H., S. Chin, S. W. Yoon, and S. W. Kwon. 2011. "A service-oriented integrated information framework for RFID/WSN-based intelligent construction supply chain management." *Automation in Construction* 20 (6): 706–715.

Singh, R. K., P. Kumar, and M. Chand. 2019. "Evaluation of supply chain coordination index in context to Industry 4.0 environment." *Benchmarking: An International Journal* (in press).

So, S., and H. Sun. 2010. "Supplier integration strategy for lean manufacturing adoption in electronic-enabled supply chains." *Supply Chain Management: An International Journal* 15 (6): 474–487.

So, S., and H. Sun. 2011. "An extension of IDT in examining the relationship between electronic-enabled supply chain integration and the adoption of lean production." *International Journal of Production Research* 49 (2): 447–466.

Tortorella, G., R. Miorando, and A. F. Mac Cawley. 2019. "The moderating effect of Industry 4.0 on the relationship between lean supply chain management and performance improvement." *Supply Chain Management: An International Journal* 24 (2): 301–314.

Tsao, Y. C., V. T. Linh, and J. C. Lu. 2017. "Closed-loop supply chain network designs considering RFID adoption." *Computers & Industrial Engineering* 113: 716–726.

Vazquez-Martinez, G. A., J. L. Gonzalez-Compean, V. J. Sosa-Sosa, M. Morales-Sandoval, and J.C. Perez. 2018. "CloudChain: A novel distribution model for digital products based on supply chain principles." *International Journal of Information Management* 39: 90–103.

Wan, H., and F. F. Chen. 2008. "A Web-based Kanban system for job dispatching, tracking, and performance monitoring." *The International Journal of Advanced Manufacturing Technology* 38 (9/10): 995–1005.Wang, M., M. S. Altaf, M. Al-Hussein, and Y. Ma. 2018. "Framework for an IoT-based shop floor material management system for panelized homebuilding." *International Journal of Construction Management* (in press): 1–16.

Wang, M., Altaf, M. S., Al-Hussein, M., and Y. Ma. 2018. "Framework for an IoT-based shop floor material management system for panelized homebuilding." *International Journal of Construction Management* 1–16.

Weraikat, D., M. K. Zanjani, and N. Lehoux. 2019. "Improving sustainability in a two-level pharmaceutical supply chain through Vendor-Managed Inventory system." *Operations Research for Health Care* 21: 44–55.

Williamson, E. A., D. K. Harrison, and M. Jordan. 2004. "Information systems development within supply chain management." *International Journal of Information Management* 24 (5): 375–385.

Xu, G., M. Li, C. H. Chen, and Y. Wei. 2018. "Cloud asset-enabled integrated IoT platform for lean prefabricated construction." *Automation in Construction* 93: 123–134.

Yap, Z. H., F. S. Low, and H. Y. Chong. 2018. "Case study: Lean-RFID based waste identification system on example of small-medium manufacturing industries." *Management and Production Engineering Review* 9 (2): 52–68.

Yerpude, S., and T. K. Singhal. 2017. "Augmentation of effectiveness of Vendor Managed Inventory (VMI) operations with IoT data - A research perspective." *International Journal of Applied Business and Economic Research* 15 (16): 469–482.

Zelbst, P. J., K. W. Green Jr., V. E. Sower, and R. D. Abshire. 2014. "Impact of RFID and information sharing on JIT, TQM and operational performance." *Management Research Review* 37 (11): 970–989.

Complementary references

Ali, S. S., D. Bailey, L. De Propris, G. Guzzo, and Ludovica Munari. 2019. Policy Report: An industrial policy for EU New Manufacturing. Makers 2019. Marie Curie Actions and European Commission. Accessed 15 December 2019. Available:

http://www.makers-rise.org/wp-content/uploads/2019/05/Policy-Report-May-2019.pdf

Abdel-Basset, M., G. Manogaran, and M. Mohamed. 2018. "Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems." *Future Generation Computer Systems* 86: 614–628.

Ataseven, C., and A. Nair. 2017. "Assessment of supply chain integration and performance relationships: A meta-analytic investigation of the literature." *International Journal of Production Economics* 185, 252–265.

Baryannis, G., S. Validi, S. Dani, and G. Antoniou. 2019. "Supply chain risk management and artificial intelligence: State of the art and future research directions." *International Journal of Production Research* 57 (7): 2179-2202.

Barata, J., P. R. Da Cunha, and J. Stal. 2018. "Mobile supply chain management in the Industry 4.0 era: An annotated bibliography and guide for future research." *Journal of Enterprise Information Management* 31(1): 173–192.

Bastas, A., and K. Liyanage. 2018. "Sustainable supply chain quality management: A systematic review." *Journal of Cleaner Production* 181: 726–744.

Ben-Daya, M., E. Hassini, and Z. Bahroun. 2019. "Internet of things and supply chain management: A literature review." *International Journal of Production Research* 57 (15/16): 4719–4742.

Bilalis, N., G. Scroubelos, A. Antonidadis, D. Emiris, and D. Koulouritotis. 2002. "Visual factory: Basic principles and the 'zoning' approach." *International Journal of Production Research* 40 (15): 3575–3588.

Buer, S. V., J. O. Strandhagen, and F. T. S. Chan. 2018. "The link between Industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda." *International Journal of Production Research* 56 (8): 2924–2940.

Chen, I. J., and A. Paulraj. 2004. "Towards a theory of supply chain management: The constructs and measurements." *Journal of Operations Management* 22 (2): 119–150.

Cherrafi, A., S. Elfezazi, J. A. Garza-Reyes, K. Benhida, and A. Mokhlis. 2017. "Barriers in Green Lean implementation: A combined systematic literature review and interpretive structural modeling approach." *Production Planning & Control* 28 (10): 829–842.

Christopher, M., and D. R. Towill. 2000. "Supply chain migration from lean and functional to agile and customized." *Supply Chain Management: An International Journal* 5 (4): 206–213.

Da Xu, L, W. He, and S. Li. 2014. "Internet of things in industries: A survey". *IEEE Transactions on Industrial Informatics* 10 (4): 2233–2243.

Denyer, D., and D. Tranfield. 2009. "Producing a systematic review." In The Sage Handbook of Organizational Research Methods, edited by D. A. Buchanan and A. Bryman, 671–689. London: Sage Publications.

Durach, C. F., J. Kembro, and A. Wieland. 2017. "A new paradigm for systematic literature reviews in supply chain management." *Journal of Supply Chain Management* 53 (4): 67–85.

Drath, R., and A. Horch. 2014. "Industrie 4.0: Hit or Hype?" *IEEE Industrial Electronics Magazine* 8 (2): 56–58.

Evans, G. N., M. M. Naim, and D. R. Towill. 1993. "Assessing the impact of information systems on dynamic supply chain performance." *Logistics Information Management* 6 (4): 15–25.

Frank, A.G., L. S. Dalenogare, and N. F. Ayala. 2019. "Industry 4.0 technologies: implementation patterns in manufacturing companies." *International Journal of Production Economics* 210: 15–26.

Frohlich, M. T., and R. Westbrook. 2001. "Arcs of integration: An international study of supply chain strategies." *Journal of Operations Management* 19 (2): 185–200.

Gartner Consulting. 2016. "Gartner Hype Cycle. Interpreting technology hype." Accessed 15 April 2019. Available: https://www.gartner.com/en/research/methodologies/gartner-hype-cycle.

Garza-Reyes, J. A. 2015. "Lean and green - a systematic review of the state of the art literature." *Journal of Cleaner Production* 102: 18–29.

Glock, C. H., E. H. Grosse, and J. M. Ries. 2017. "Decision support models for supplier development: Systematic literature review and research agenda." *International Journal of Production Economics* 193: 798–812.

Ghobakhloo, M. 2019. "Determinants of information and digital technology implementation for smart manufacturing." *International Journal of Production Research* (in press).

Ghobakhloo, M. 2018. "The future of manufacturing industry: A strategic roadmap toward Industry 4.0." *Journal of Manufacturing Technology Management* 29 (6): 910–936.

Horváth, D., and R. Z. Szabó. 2019. "Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?" *Technological Forecasting & Social Change* 146: 119–132.

Ivanov, D., A. Dolgui, B. Sokolov, F. Werner, and M. Ivanova. 2015. "A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0." *International Journal of Production Research* 54 (2): 386–402.

Ivanov, D., A. Dolgui, and B. Sokolov. 2019. "The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics." *International Journal of Production Research* 57 (3): 829–846.

Kache, F., and S. Seuring. 2014. "Linking collaboration and integration to risk and performance in supply chains via a review of literature reviews." *Supply Chain Management: An International Journal* 19 (5/6): 664–682.

Kagermann, H., W. Wahlster, and J. Helbig. 2013. Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative Industrie 4.0. Final report of the Industrie 4.0 Working Group. German National Academy of Science and Engineering. Accessed 15 April 2019. Available:

https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf.

Kang, H. S., J. Y. Lee, S. Choi, H. Kim, J. H. Park, J. Y. Son, B. Y. Kim, and S. D. Noh. 2016. "Smart manufacturing: Past research, present findings, and future directions." *International Journal of Precision Engineering and Manufacturing-Green Technology* 3 (1): 111–128.

Karre, H., M. Hammer, M. Kleindienst, and C. Ramsauer. 2017. "Transition towards an Industry 4.0 State of the LeanLab at Graz University of Technology." *Procedia Manufacturing* 9: 206–213.

Kim, B. 2003. "Managing the transition of technology life cycle." *Technovation* 23 (5): 371–381.

Kumar, C. S., and R. Panneerselvam. 2006. "Literature review of JIT-KANBAN system." *The International Journal of Advanced Manufacturing Technology* 32 (3/4): 393–408.

Lamming, R. 1996. "Squaring lean supply with supply chain management." *International Journal of Operations & Production Management* 16 (2): 183–196.

Lee, M., J. J. Yun, A. Pyka, D. Won, F. Kodama, G. Schiuma, H. Park, J. Jeon, K. Park, K. Jung, M.R. Yan, S. Lee, and X. Zhao. 2018. "How to respond to the fourth industrial revolution, or the second information technology revolution? Dynamic new combinations between technology, market, and society through open innovation." *Journal of Open Innovation: Technology, Market and Complexity* 4 (3): 1–24.

Liao, Y., F. Deschamps, E. Roch, and L. F. Pierin. 2017. "Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal." *International Journal of Production Research* 55 (12): 3609–3629.

Lu, Y. (2017). "Industry 4.0: A survey on technologies. Applications and open research issues." *Journal of Industrial Information Integration* 6 (1): 1–10.

Luthra, S., and M. S. Kumar. 2018. "Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies". *Process Safety and Environmental Protection* 117: 168–179.

Ma, J., Q. Wang, and Z. Zhao. 2017. "SLAE-CPS: Smart lean automation engine enabled by cyber-physical systems technologies." *Sensors* 17 (7): 1–22.

Machado, C. G., M. P. Winroth, and E. H. D. Ribeiro da Silva. 2019. "Sustainable manufacturing in Industry 4.0: an emerging research agenda." *International Journal of Production Research* (in press).

Marodin, G. A., G. L. Tortorella, A. G. Frank, and M. G. Filho. 2017. "The moderating effect of Lean supply chain management on the impact of Lean shop floor practices on quality and inventory." *Supply Chain Management: An International Journal* 22 (6): 473–485.

Martinelli, E. M., and A. Tunisini. 2019. "Customer integration into supply chains: Literature review and research propositions." *Journal of Business & Industrial Marketing* 34 (1): 24–38.

Medjahed, B., B. Benatallah, A. Bouguettaya, A. H. H. Ngu, and A. K. Elmagarmid. 2003. "Business-to-business interactions: Issues and enabling technologies." *The International Journal on Very Large Data Bases (VLDB)* 12 (1): 59–85.

Monostori, L., B. Kádár, T. Bauernhansl, S. Kondoh, S. Kumara, G. Reinhart, O. Sauer, G. Schuh, W. Sihn, and K. Ueda. 2016. "Cyber-physical systems in manufacturing." *CIRP Annals* 65 (2): 621–641.

Morgan, S. D., and R. J. Gagnon. 2013. "A systematic literature review of remanufacturing scheduling." *International Journal of Production Research* 51 (16): 4853–4879.

Moyano-Fuentes, J., and M. Sacristán-Díaz. 2012. "Learning on lean: A review of thinking and research." *International Journal of Operations & Production Management* 32 (5): 551–582.

Moyano-Fuentes, J., S. Bruque, and J. M. Maqueira. 2019. "Development and validation of a lean supply chain management measurement instrument." *Production Planning & Control* 30 (1): 20–32.

Novais, L., J. M. Maqueira, and A. Ortiz-Bas. 2019. "A systematic literature review of cloud computing use in supply chain integration." *Computers & Industrial Engineering* 129: 296–314.

Okoli, C., and K. Schabram. 2010. "A guide to conducting a systematic literature review of information systems research." *Sprouts: Working Papers on Information Systems*, 10 (26): 1–49.

Pagliosa, M., G. Tortorella, and J. C. Espindola-Ferreira. (2019). "Industry 4.0 and Lean Manufacturing a systematic literature review and future research directions". *Journal of Manufacturing Technology Management* (in press).

Pfohl, H. C., B. Yahsi, and T. Kurnaz. 2016. "Concept and diffusion factors of Industry 4.0 in the supply chain". In Freitag, M., H. Kotzab, and J. Pannek (2016), *Lectures Notes in Logistics*. Germany: Springer.

Pinho, C., and L. Mendes. 2017. "IT in lean-based manufacturing industries: Systematic literature review and research issues." *International Journal of Production Research* 55 (24): 7524–7540.

Reddy, S. K., and W. Reinartz. 2017. "Digital transformation and value creation: Sea change ahead". *Marketing Intelligence Review* 9 (1): 11–17.

Reichhart, A., and M. Holweg. 2007. "Lean distribution: Concepts, contributions, conflicts." *International Journal of Production Research* 45 (16): 3699–3722.

Rossini, M., F. Costa, G. L. Tortorella, and A. Portioli-Staudacher. 2019. "The interrelation between Industry 4.0 and lean production: An empirical study on European manufacturers." *The International Journal of Advanced Manufacturing Technology* 102 (9-12): 3963–3976.

Sangwa, N. R., and K. S. Sangwan. 2018. "Leanness assessment of organizational performance: A systematic literature review." *Journal of Manufacturing Technology Management* 29 (5): 768–788.

Schmeisser, B. 2013. "A Systematic Review of Literature on offshoring of value chain activities." *Journal of International Management* 19 (4): 390–406.

Shah R., and Ward, P. T. 2007. "Defining and developing measures of lean production." *Journal of Operations Management* 25 (4): 785–805.

Smit, J., S. Kreutzer, C. Moeller, M. Carlberg. 2016. Industry 4.0. Directorate General for Internal Policies, Policy Department A: Economic and Scientific Policy, European Parliament. Available: http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf

Sony (2018): "Industry 4.0 and lean management: A proposed integration model and research propositions", *Production & Manufacturing Research* 6 (1): 416-432.

Strozzi, F., C. Colicchia, A. Creazza, and C. Noè. 2017. "Literature review on the 'smart factory' concept using bibliometric tools." *International Journal of Production Research* 55 (22): 6572–6591.

Subramani, M. 2004. "How do suppliers benefit from Information Technology use in supply chain relationships?" *MIS Quarterly* 28 (1): 45–73

Swenseth, S. R., and D. L. Olson. 2016. "Trade-offs in lean vs. outsourced supply chains." *International Journal of Production Research* 54 (13): 4065–4080.

Taylor, M., and A. Taylor. 2012. "The technology life cycle: Conceptualization and managerial implications." *International Journal of Production Economics* 140 (1): 541–553.

Thomé, A. M. T., L. F. Scavarda, and A. J. Scavarda. 2016. "Conducting systematic literature review in operations management." *Production Planning & Control* 27 (5): 408–420.

Tortorella, G. L., and D. Fettermann. 2018. "Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies." *International Journal of Production Research* 56 (8): 2975–2987.

Tortorella, G. L., Miorando, R., and G. Marodin. 2017. "Lean supply chain management: Empirical research on practices, contexts and performance." *International Journal of Production Economics* 193: 98–112.

Tortorella, G., R. Miorando, and A. F. Mac Cawley. 2019. "The moderating effect of Industry 4.0 on the relationship between lean supply chain management and performance improvement." *Supply Chain Management: An International Journal* 24 (2): 301–314.

Tranfield, D., D. Denyer, and P. Smart. 2003. "Towards a methodology for developing evidence-informed management knowledge by means of systematic review." *British Journal of Management* 14 (3): 207–222.

van der Aalst, W. 1999. "Process-oriented architectures for electronic commerce and interorganizational workflow." *Information Systems* 24 (8): 639–671.

Vitasek, K., K. Manrodt, and J. Abbott. 2005. "What makes a lean supply chain." *Supply Chain Management Review* 9 (7), 39–45.

Vural, C. A. 2017. "Service-dominant logic and supply chain management: A systematic literature review." *Journal of Business & Industrial Marketing* 32 (8): 1109–1124.

Wagner, T., C. Herrmann, and S. Thiede. 2017. "Industry 4.0 Impacts on Lean Production Systems." *Procedia CIRP* 63: 125–131.

Wang, B., J. Y. Zhao, Z. G. Wan, J. H. Ma, H. Li, and J. Ma. 2016. "Lean Intelligent Production System and Value Stream Practice." *In proceeding 3rd International Conference on Economics and Management, ICEM 2016,* Jiangsu, China: 442–447.

Wang, S., and B. R. Sarker. 2006. "Optimal models for a multi-stage supply chain system controlled by kanban under just-in-time philosophy." *European Journal of Operational Research* 172 (1): 179–200.

Witte, C. L., M. Grünhagen, and R. L. Clarke. 2003. "The Integration of EDI and the Internet." *Information Systems Management* 20 (4): 58–65.

Womack, J. P., and D. T. Jones. 1996. Lean Thinking: Banish Waste and Create Wealth in Your Corporation. New York: Simon and Schuster.

Womack, J. P., D. T. Jones, and D. Roos. 1990. The Machine that Changed the World. New York: MacMillan/Rawson Associates.

Xu, L. D., E. L. Xu, and L. Li. 2018. "Industry 4.0: State of the art and future trends." *International Journal of Production Research* 56 (8): 2941–2962.

Table 1. Search words and search strings

Search words	**Lean:** lean, JIT, just in time **Supply Chain:** supply chain, logistic **Industry 4.0:** industry 4.0, information system, information technology, information and communication technology, ICT , technological innovation, internet of things, IoT, cloud, web, e-business, e-commerce, enterprise resources planning, ERP, material requirement planning, MRP, electronic data interchange, EDI, customer relation management, CRM, radiofrequency identification, RFID, business intelligence, BI, software, artificial intelligence, big data, business to business, B2B, business to consumer, B2C, e-procurement, VMI, vendor managed inventory, CRM, consumer relationship management, EPC, GPS, simulation
Web of Science	TS= (lean OR "just in time" OR jit) AND TS= ("supply chain*" OR logistic*) AND TS= ("Industr* 4.0" OR "information system*" OR "information technolog*" OR "information and communication technolog*" OR "ICT" OR "technological innovation" OR "internet of things" OR "IoT" OR cloud OR web OR e-business OR e-commerce OR "enterprise resources planning" OR ERP OR "material requirement planning" OR MRP OR "electronic data interchange" OR "EDI" OR "customer relation management" OR "Radiofrequency Identification" OR "RFID" OR "business intelligence" OR "BI" OR software* OR "artificial intelligence" OR "big data" OR "business to business" OR "B2B" OR "Business to Consumer" OR "B2C" OR e-procurement OR VMI OR "Vendor Managed Inventory" OR CRM OR "Consumer Relationship Management" OR "EPC" OR "GPS" OR "simulation")
Scopus	TITLE-ABS-KEY (lean OR {just in time} OR jit) AND TITLE-ABS-KEY ({supply chain} OR {supply chains} OR logistic*) AND TITLE-ABS-KEY ({Industry 4.0} OR {information system} OR {information systems} OR {information technology} OR {information and communication technology} OR {ICT} OR {technological innovation} OR {internet of things} OR {IoT} OR cloud OR web OR e-business OR e-commerce OR {enterprise resources planning} OR ERP OR {material requirement planning} OR MRP OR {electronic data interchange} OR EDI OR {customer relation management} OR {Radiofrequency Identification} OR {RFID} OR {business intelligence} OR {BI} OR software* OR {artificial intelligence} OR {big data} OR {business to business} OR {B2B} OR {Business to Consumer} OR {B2C} OR e-procurement OR VMI OR {Vendor Managed Inventory} OR CRM OR {Consumer Relationship Management} OR {EPC} OR {GPS} OR {simulation})
ABI Inform	AB,TI (lean OR "just in time" OR jit) AND AB,TI ("supply chain*" OR logistic*) AND AB,TI ("Industr* 4.0" OR "information system*" OR "information technolog*" OR "information and communication technolog*" OR "ICT" OR "technological innovation" OR "internet of things" OR "IoT" OR cloud OR web OR e-business OR e-commerce OR "enterprise resources planning" OR ERP OR "material requirement planning" OR MRP OR "electronic data interchange" OR "EDI" OR "customer relation management" OR "CRM" OR "Radiofrequency Identification" OR "RFID" OR "business intelligence" OR "BI" OR software* OR "artificial intelligence" OR "big data" OR "business to business" OR "B2B" OR "Business to Consumer" OR "B2C" OR e-procurement OR VMI OR "Vendor Managed Inventory" OR CRM OR "Consumer Relationship Management" OR "EPC" OR "GPS" OR "simulation")

Source: Developed by the authors

Table 2. Classification by the methodology used

Methodology	Number of papers	%
Quantitative	31	39,74%
Qualitative	16	20,51%
Quantitative and qualitative	6	7,69%
Technical development	15	19,23%
Conceptual	10	12,82%
Total	78	100%

Source*:* Developed by the authors

Table 3. Classification by journals

Journals	Number of papers	%
International Journal of Production Research	9	11.54%
International Journal of Production Economics	5	6.41%
Automation in Construction	4	5.13%
Benchmarking: An International Journal	3	3.85%
Production Planning & Control	3	3.85%
Supply Chain Management - An International Journal	3	3.85%
Computers & Industrial Engineering	2	2.56%
International Journal of Information Management	2	2.56%
International Journal of Logistics Management	2	2.56%
Journal of Industrial Engineering and Management	2	2.56%
Management and Production Engineering Review	2	2.56%
Production and Operations Management	2	2.56%
Others (39 journals with 1 paper)	39	50.00%
Total	**78**	**100%**

Source*:* Developed by the authors

Table 4. Classification of papers

IDT position in TLC in LSCM context (first classification level; research line)	IDT in LSCM context (second level of classification; research subline)	Papers
L1, Obsolete	**SL1.1, Electronic Data Interchange (EDI)**	Mason-Jones and Towill (1997); Abernathy et al. (2000); McMichael, MacKay, and Altmann (2000); Danas, Ketikidis, and Roudsari (2002)
L2, Mature	**SL2.1, Barcode systems**	Abernathy et al. (2000); McMichael, MacKay, and Altmann (2000); Danas, Ketikidis, and Roudsari (2002)
	SL2.2, Radio Frequency Identification (RFID)	Otamendi, García-Higuera and García-Ansola (2011); Saygin and Sarangapani (2011); Shin et al. (2011); Dai et al. (2012); Huang et al. (2012); Powell and Skjelstad (2012); Chen, Cheng, and Huang (2013); Zelbst et al. (2014); Shahin, Khazaei, and Khalili (2016); Sanders et al. (2016); Hofmann and Rüsch (2017); Kovács and Kot (2017); Nabelsi and Gagnon (2017); Tsao, Linh, and Lu (2017); Moon et al. (2018); Yap, Low, and Chong (2018)
	SL2.3, Web Technologies for e-Business	Iijima, Komatsu, and Katoh (1996); Kinsey (2000); McMichael, MacKay, and Altmann (2000); Homer and Thompson (2001); Bruun and Mefford (2004); Coleman, Lyons and Kehoe (2004); Williamson, Harrison, and Jordan (2004); Missopoulos and Dergiades (2007); Adamides et al. (2008), Wan and Chen (2008); Kart, Moser, and Melliar-Smith (2010); So and Sun (2010); So and Sun (2011); Ardalan and Diaz (2012a); Ardalan and Diaz (2012b); Garcia-Sabater, Maheut, and Garcia-Sabater (2012); Kovács and Kot (2017)
	SL2.4 ,Workflow systems	Ma, Wang, and Xu (2011); Dallasega, Rauch, and Frosolini (2018)
	SL2.5, Enterprise Resources Planning (ERP)	Parry and Turner (2006); Green, Whitten and Inman (2007); Zelbst et al. (2014)
	SL 2.6, Advanced Manufacturing Technologies (AMT)	Mason-Jones and Towill (1997); Levary (2001); Saygin and Sarangapani (2011); Chen, Cheng, and Huang (2013); Khanchanapong et al. (2014); Li et al. (2018); Miclo et al. (2019); Baradaran and Akhavan (2019); Bortoloni, Formoso and Viana (2019); Deng et al. (2019); Meng (2019); Novais et al. (2019); Ruiz, Fontanini, and Corrêa (2019); Weraikat et al. (2019)
L3, Emerging	**SL3.1, Cloud Computing**	Dave et al. (2016); Sanders, Elangeswaran, and Wulfsberg (2016); Hofmann and Rüsch (2017); Vázquez-Martinez et al. (2018); Xu et al. (2018)
	SL3.2, Internet of Things (IoT)	Dave et al. (2016); Sanders, Elangeswaran, and Wulfsberg (2016); Hofmann and Rüsch (2017); Yerpude and Singhal (2017); Xu et al. (2018); Roy and Roy (2019); Wang et al. (2018)
	SL3.3, Artificial Intelligence (AI)	Güner, Murat, and Chinnam (2012); Liu et al. (2012); Hofmann and Rüsch, 2017; Kang, Lee and Chung (2019)
	SL3.4, Virtual Reality (VR)	Li et al. (2018)
	SL3.5, Autonomous Vehicles (AV)	Mehrsai, Thoben, and Scholz-Reiter (2014)
	SL3.6, Big-Data	Bevilacqua, Ciarapica, and Antomarioni (2019); Deng et al. (2019); Roy and Roy (2019)
L4, Information Systems / Information Technology, general approach		Lee et al. (2008); Bayraktar et al. (2009); Bayraktar et al. (2010); Hong, Dobrzykowski, and Vonderembse (2010); Qrunfleh, Tarafdar, and Ragu-Nathan (2012); Qrunfleh and Tarafdar (2014); Karakadılar and Hicks (2015); Sangari, Hosnavi, and Zahedi (2015); Sharma and Kulkarni (2016); Kashani and Baharmast (2017); Gorane and Kant (2017); Kou, Chiang, and Chiang (2018); Ghobakhloo et al. (2018); Kamble, Gunasekaran and Dhone (2019); Ramirez-Peña et al. (2019); Singh, Kumar, and Chand (2019); Tortorella, Miorando, and Cawley (2019)

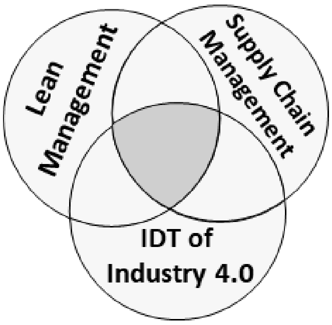
Source: Developed by the authors

Table 5. Number of papers by research lines and research subline

Research lines and research sublines		Number of papers	%
1.	**Obsolete IDT in LSCM**	**4**	4,12%
	1.1. Electronic Data Interchange (EDI)	4	4,12%
2.	**Mature IDT in LSCM**	**55**	56,70%
	2.1. Barcode system	3	3,09%
	2.2. RFID	16	16,49%
	2.3. Web Technologies for E-Business	17	17,53%
	2.4. Workflow systems	2	2,06%
	2.5. Enterprise Resource Planning (ERP)	3	3,09%
	2.6. Advanced Manufacturing Technologies (AMT)	14	14,43%
3.	**Emerging IDT in LSCM**	**21**	21,65%
	3.1. Cloud Computing	5	5,15%
	3.2. Internet of Things	7	7,22%
	3.3. Artificial Intelligence	4	4,12%
	3.4. Virtual Reality	1	1,03%
	3.5. Autonomous Vehicles	1	1,03%
	3.6. Big-Data	3	3,09%
4.	**IS and IDT, general approach in LSCM**	**17**	17,53%
	Total	**97**	**100,00%**

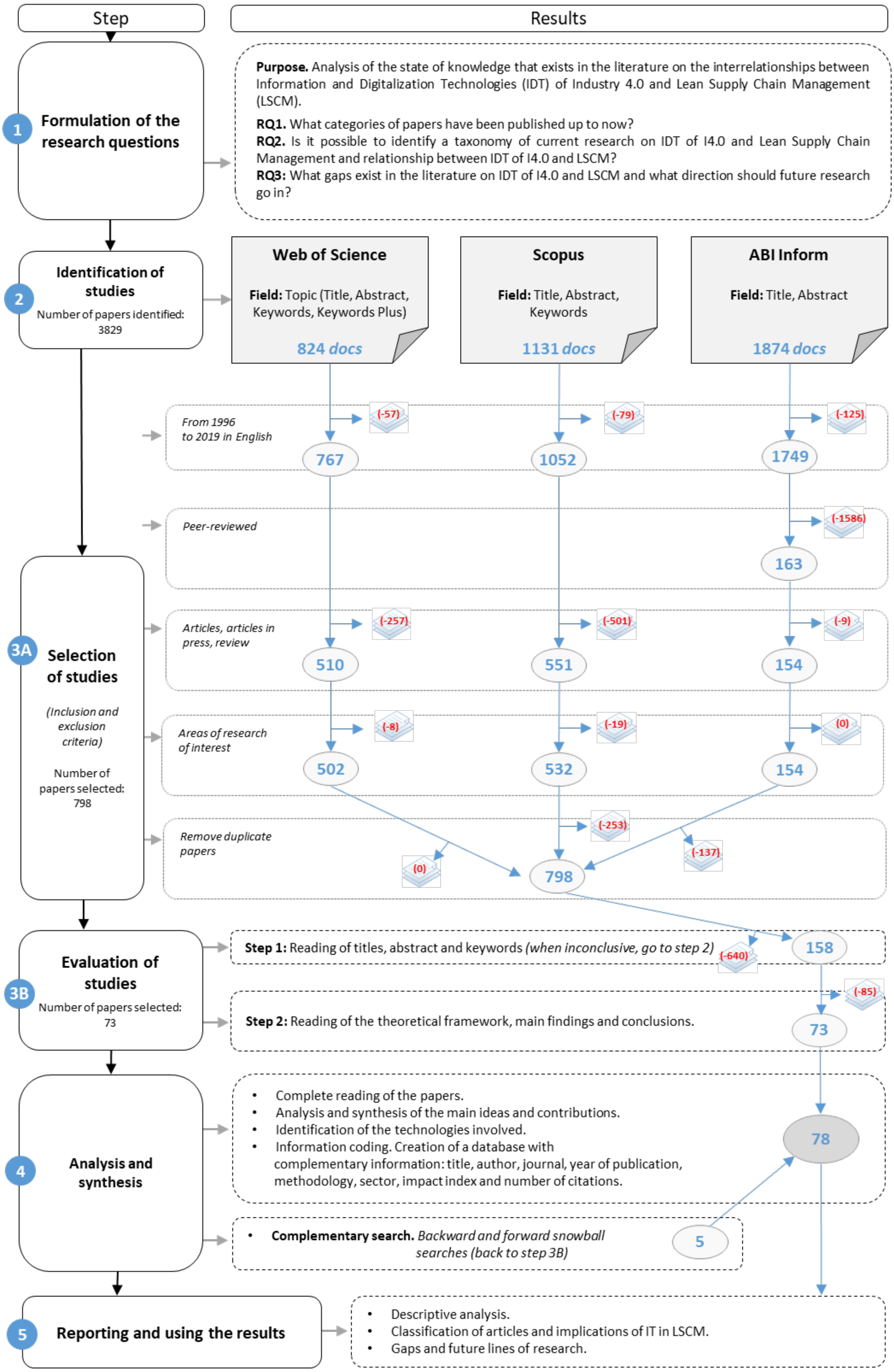
Source*:* Developed by the authors

Figure 1. Objective of the SLR



Source: Developed by the authors

Figure 2. Summary of the Systematic Literature Review



Purpose. Analysis of the state of knowledge that exists in the literature on the interrelationships between Information and Digitalization Technologies (IDT) of Industry 4.0 and Lean Supply Chain Management (LSCM).

RQ1. What categories of papers have been published up to now?

RQ2. Is it possible to identify a taxonomy of current research on IDT of I4.0 and Lean Supply Chain Management and relationship between IDT of I4.0 and LSCM?

RQ3: What gaps exist in the literature on IDT of I4.0 and LSCM and what direction should future research go in?

Step 1: Reading of titles, abstract and keywords *(when inconclusive, go to step 2)*

Step 2: Reading of the theoretical framework, main findings and conclusions.

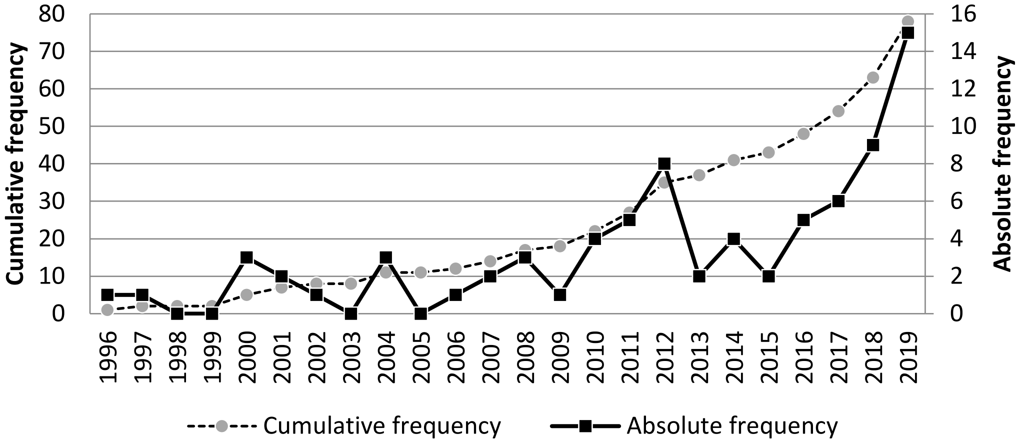
- Complete reading of the papers.
- Analysis and synthesis of the main ideas and contributions.
- Identification of the technologies involved.
- Information coding. Creation of a database with complementary information: title, author, journal, year of publication, methodology, sector, impact index and number of citations.

- **Complementary search.** *Backward and forward snowball searches (back to step 3B)*

- Descriptive analysis.
- Classification of articles and implications of IT in LSCM.
- Gaps and future lines of research.

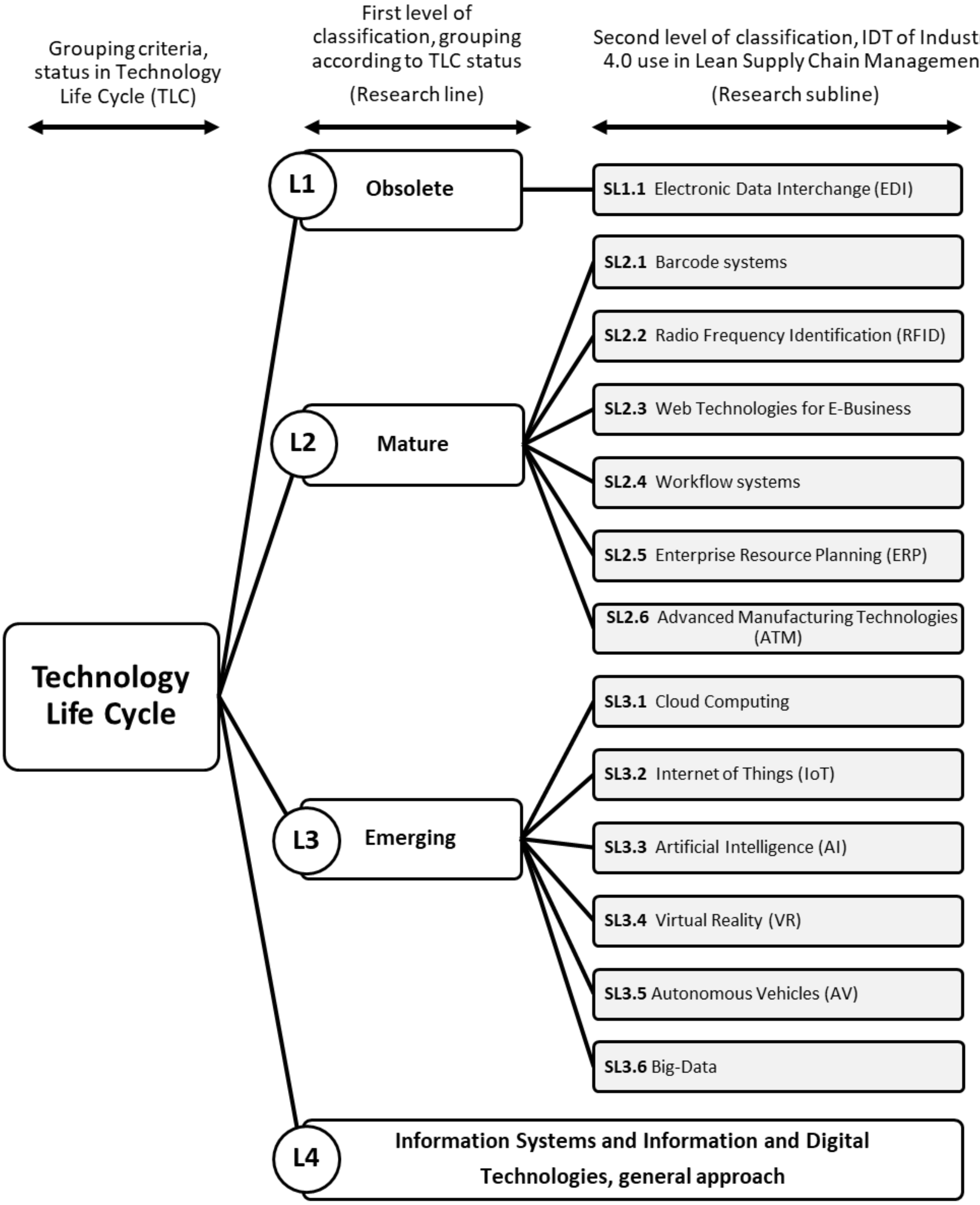
Source: Developed by the authors

Figure 3. Absolute and cumulative frequencies of number of papers, IDT of I4.0 in LSCM



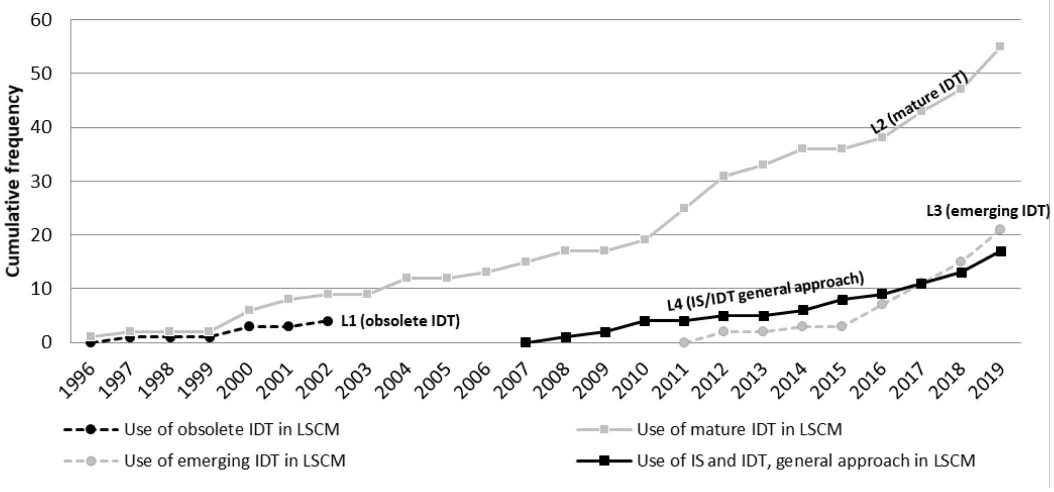
Source: Developed by the authors

Figure 4. IDT classification in the I4.0/LSCM context by TLC



Source: Developed by the authors

Figure 5. Cumulative frequency of number of papers by research lines, IDT of I4.0 in LSCM



Source: Developed by the authors

Figure captions

Figure 1. Objective of the SLR.

Figure 2. Summary of the Systematic Literature Review.

Figure 3. Absolute and cumulative frequencies of number of papers, IDT of I4.0 in LSCM.

Figure 4. IDT classification in the I4.0/LSCM context by TLC.

Figure 5. Cumulative frequency of number of papers by research lines, IDT of I4.0 in LSCM.