Supply chain integration in the industry 4.0 era: a systematic literature review

Integração da cadeia de suprimentos na era industrial 4.0: uma revisão sistemática da literatura

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ABSTRACT
From an Industry 4.0 perspective, supply chain actors (suppliers, manufacturers, retailers, and third-party logistics operators) are integrated into a collaborative network based on information-sharing to improve the overall supply chain performance. Real data can be captured and systematically processed into information, hence dealing with uncertainty. Poor integration may lead to supply chain disruptions. This paper examines the role of Industry 4.0 (I4.0) for integrating the supply chain, to which a systematic literature review

(SLR) has been applied. First, according to the research questions, the I4.0 technologies adopted for supply chain integration were identified. Second, the approaches for integrating the supply chain at I4.0 were examined and classified by strategy (vertical, horizontal, and end-to-end integration). Third, the functional and cross-functional approaches for supply chain integration at I4.0 were also examined. Finally, it was discussed which traditional SCI approaches can be upgraded to the Industry 4.0 era and the future research directions.

Keywords: supply chain integration, industry 4.0, vertical integration.

ABSTRACT
Do ponto de vista da indústria 4.0, os atores da cadeia de abastecimento (fornecedores, fabricantes, varejistas e operadores logísticos terceirizados) estão integrados em uma rede colaborativa baseada no compartilhamento de informações para melhorar o desempenho geral da cadeia de abastecimento. Dados reais podem ser capturados e sistematicamente processados em informações, lidando, portanto, com a incerteza. A má integração pode levar a rupturas na cadeia de suprimentos. Este documento examina o papel da indústria 4.0 (I4.0) na integração da cadeia de abastecimento, à qual foi aplicada uma revisão sistemática da literatura (SLR). Primeiro, de acordo com as perguntas da pesquisa, foram identificadas as tecnologias I4.0 adotadas para a integração da cadeia de abastecimento. Segundo, as abordagens para a integração da cadeia de abastecimento na I4.0 foram examinadas e classificadas por estratégia (integração vertical, horizontal e de ponta a ponta). Terceiro, as abordagens funcionais e interfuncionais para a integração da cadeia de abastecimento na I4.0 também foram examinadas. Finalmente, foi discutido quais abordagens tradicionais da SCI podem ser atualizadas para a era da Indústria 4.0 e as futuras direções de pesquisa.

Palavras-chave: integração da cadeia de suprimentos, indústria 4.0, integração vertical.

1 INTRODUCTION

Supply chain integration (SCI) is defined as a strategy for information-sharing, joint decision-making, and system-coupling within a supply chain using collaborative techniques for improving the overall supply chain performance (Shou *et al.,* 2017, Pinto & Diemer, 2020). Traditionally, an SCI strategy depends on the company's organizational level.

An example of SCI at the operational level is integrating raw material suppliers with third-party logistics, using standard logistical equipment and containers, and developing collaborative schedules. At the planning level, SCI strategies seek for joint planning approaches based on information-sharing. The integration strategies include partnership maintaining, cultural adaptation, and collaborative politics with suppliers and customers at the strategic level.

Other real-world examples of traditional SCI approaches could be milk-run (MR) operations connected with supplying strategies and joint production and transport scheduling problems (PTSP). These two SCI approaches are based on a cross-functional method for integrating different functions in a supply chain. In an MR scheme, an assembly manufacturer, a set of suppliers, and a third-party logistics coordinates and integrates the production and transportation of components and their assembly at the manufacturer production line.

Some researchers and practitioners have studied MR models for SCI (Huang *et al*., 2017; Yi & Su, 2017; Eroglu *et al.*, 2017; Bocewicz *et al*., 2019). On the other hand, the PTSP is one of the most traditional models for cross-functional integration. Two sub-problems compose a machine scheduling - production and a vehicle routing problem - transportation (Sholz-Reiter *et al.*, 2011; Lacomme *et al.*, 2015, 2016; Lacomme *et al.*, 2018). Other cross-functional extensions include inventory – transportation models (Teng *et al.*, 2019) and warehouse – inventory – transportation models (Sainathuni *et al.*, 2014).

Milk-run and PTSP are optimization-based models. However, these approaches are limited when dealing with uncertainty due to its deterministic and static nature. In deterministic and static models, solutions are based on fixed information, as in Bocewicz *et al.* (2019), Huang *et al.* (2017), Jia *et al.* (2019), and He *et al.* (2019). On the other hand, most real-world environments are dynamic and stochastic. Therefore, sophisticated models considering real-time capability, decentralization, agility, and integrated business processes, are demanded. In this line, with the adoption of I4.0 technologies, it is possible to transform MR and PTSP models.

The traditional SCI practices, such as joint production planning, joint demand forecasting, packaging congruence, and collaborative politics, seek to integrate manufacturers with customers and suppliers. Today, these practices are prevailing in supply chain management. However, these practices are supported by more sophisticated tools than before, which allow rapid joint decision-making — for example, cloud-based collaborative tools for joint production planning with supply chain members. In the literature review performed by Van der Vaart and Van Donk (2008), the authors analyzed some of these traditional SCI practices.

On the other hand, some SCI publications concentrate on systematic literature reviews to explore and discuss the effects of integration strategies on supply chain performance. For example, Alfalla-Luque *et al.* (2013) developed an SLR to identify dimensions and variables affecting the overall supply chain performance. The mentioned dimensions and variables discuss the integration strategies adopted in the literature, such as shared use of third-party logistics, agreements on delivery frequency, cross-functional teams, and information technology integration.

In Khanuja & Jain (2018), the authors also adopted an SLR to discuss enablers, dimensions, and SCI performance. As a result, the authors identified current SCI practices, such as customer integration, supplier integration, information sharing, process coordination, and strategic alliance. Other authors also proposed SLR for exploring SCI practices (Abreu & Alcântara, 2017; Kamal & Irani, 2014).

However, most of these SLR has only considered traditional practices for SCI. Therefore, there is a lack of a systematic literature review considering Industry 4.0 practices and SCI technologies. Some studies on supply chain management have considered Industry 4.0. Nevertheless, these reviews focused on I4.0 technologies applied to supply chain management and supply chain sustainability (Bag *et al.*, 2018; Dallasega *et al.*, 2018) without considering SCI.

Nowadays, in the Industry 4.0 era, the world is evolving rapidly, and companies are seeking to transform their business structure to be part of the digitalization and data revolution era. With the massive growth of data and advanced methods for their analysis, some business operations are becoming data-driven. Data is the new oil (Rotella, 2012) and represents an opportunity for companies aiming the Industry 4.0. Therefore, traditional SCI approaches can be transformed into the Industry 4.0 era. Ustundag and Cevikcan (2017) affirm that for a significant transformation to Industry 4.0, the vertical, horizontal, and end-to-end integration strategies should be considered to enable highly flexible manufacturing, customization, and real-time data sharing, accurate planning, and others.

In the fourth industrial revolution era, some business operations turn into data-driven due to new technologies allowing real-time monitoring of the entire supply chain. With the adoption of new technologies from Industry 4.0, people, machines, and products are integrated and exchange information in real-time (Rodríguez *et al.*, 2018). Some of these new technologies are big data (BD), internet of things (IoT), cloud computing (CC), simulation, cyber-physical systems (CPS), autonomous guided vehicles (AGVs), and autonomous robots (AR).

In the literature, considerable amounts of SCI practices involve Industry 4.0 technologies. This paper aims to apply a systematic literature review to identify the Industry 4.0 technologies supporting SCI approaches, describe the SCI approaches in the

Industry 4.0 era by integration strategy (vertical, horizontal, and end-to-end), and discuss which traditional SCI approaches can be transformed to the Industry 4.0 era. Therefore, the SLR proposed will consider only studies in which the SCI approaches adopt Industry 4.0 practices and technologies.

This paper is structured as follows. The first section describes the systematic literature review, presents the research protocol, and some SLR results. The second part seeks to discuss each research question and analyses the related findings. Finally, the paper presents conclusions and opportunities for future research.

2 SYSTEMATIC LITERATURE REVIEW

In this paper, a systematic literature review was followed to study the SCI in the Industry 4.0 era. This paper follows the SLR proposed by Tranfield *et al.* (2003). As in Carvalho *et al.* (2019), this paper formulates the following research protocol:

- Research questions

Q1: What are the technologies used to integrate the supply chain in the Industry 4.0 era?

Q2: What are the SCI approaches in the Industry 4.0 era?

Q3: Which supply chain functions are integrated into the Industry 4.0 era?

Q4: Which traditional SCI approaches can be upgraded to the Industry 4.0 era?

- E-Databases

Two online E-Databases were used for the literature searching: Scopus and Engineering Village. The main reason for selecting these two E-Databases is that both include a wide variety of Supply Chain Management publications. Also, during systemic searching, these two E-Databases resulted in many publications aligned with the research questions than other E-Databases.

- Exclusion criteria

E1: Works dated before 2011.

E2: Works no related to SCI strategies or modeling, applying Industry 4.0 practices.

E3: Literature review works.

- Data extraction fields

D1: SCI approaches based on Industry 4.0 practices.

D2: Supply chain functions integrated by SCI strategies based on Industry 4.0 technologies.

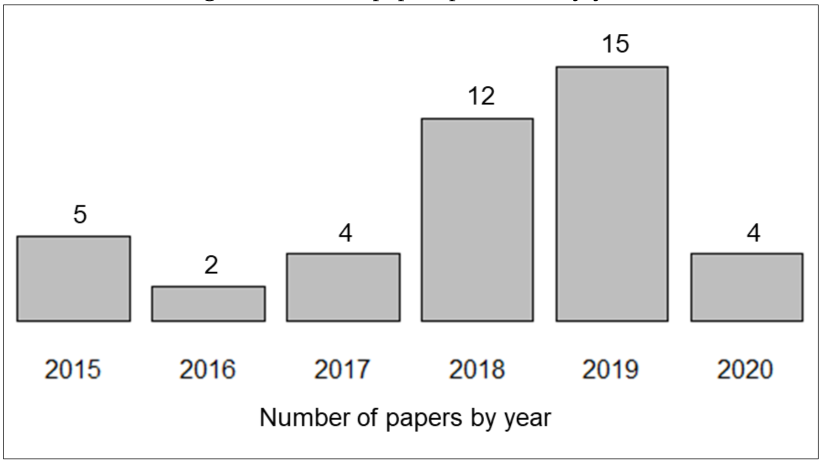
D3: Technologies from Industry 4.0 adopted for SCI.

For the SLR execution, the research questions were converted to keywords. Before defining the query string for the research, the adherence of the keywords was tested. The query was searched on two E-Databases: Scopus and Engineering Village. The following queries were defined:

- *Scopus*: title, abstract, and keywords (supply chain integration AND industry 4.0),
- *Engineering Village*: title, abstract, and keywords (supply chain integration AND industry 4.0).

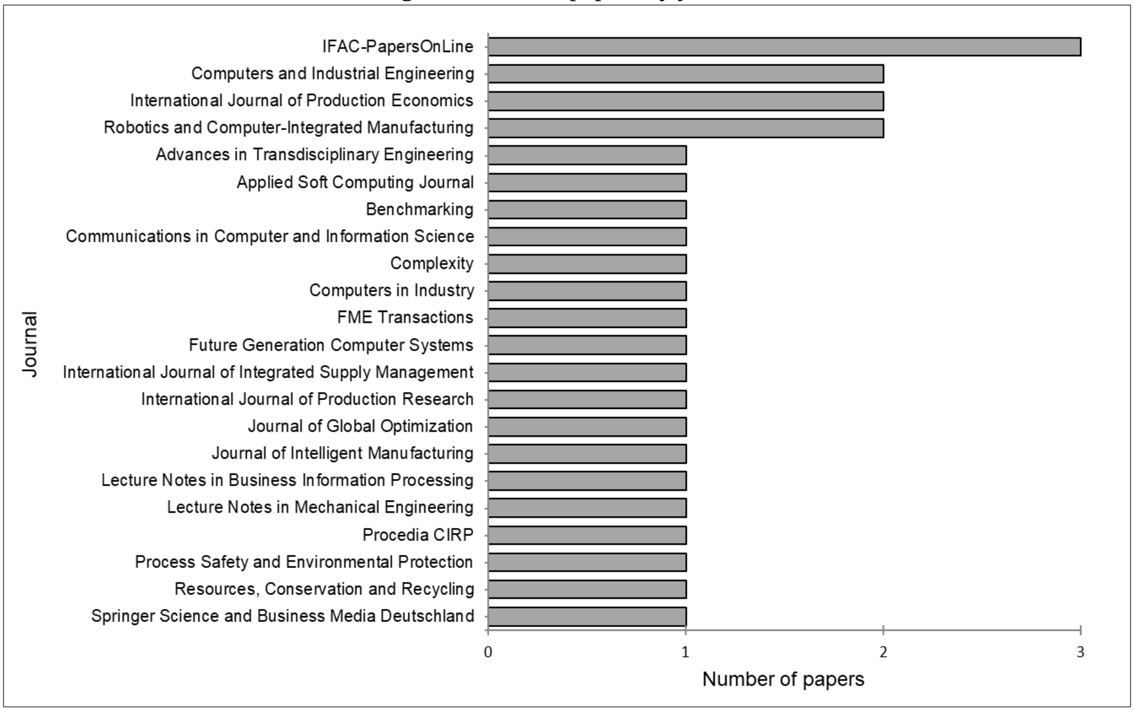
As a result of the systemic searching performed on April 9, 2020, 244 papers were found on journals and proceedings conferences. On the Scopus were found 113 articles (12 selected), and on Engineering Village were found 131 articles (30 selected), 42 papers in total. Most of the selected works (31) were published during the last three years, as shown in Figure 1. Today, SCI and Industry 4.0 practices are attracting more researchers than in the early years.

Fig. 1 Number of papers published by year



In total, it was found that 22 journals had been published academic works on SCI approaches based on Industry 4.0 practices. From the selected works, 64% (27) were divulged on journals. The emphasis of the journals is on industrial engineering and manufacturing technologies. The number of works divulged by each journal is summarized in Figure 2.

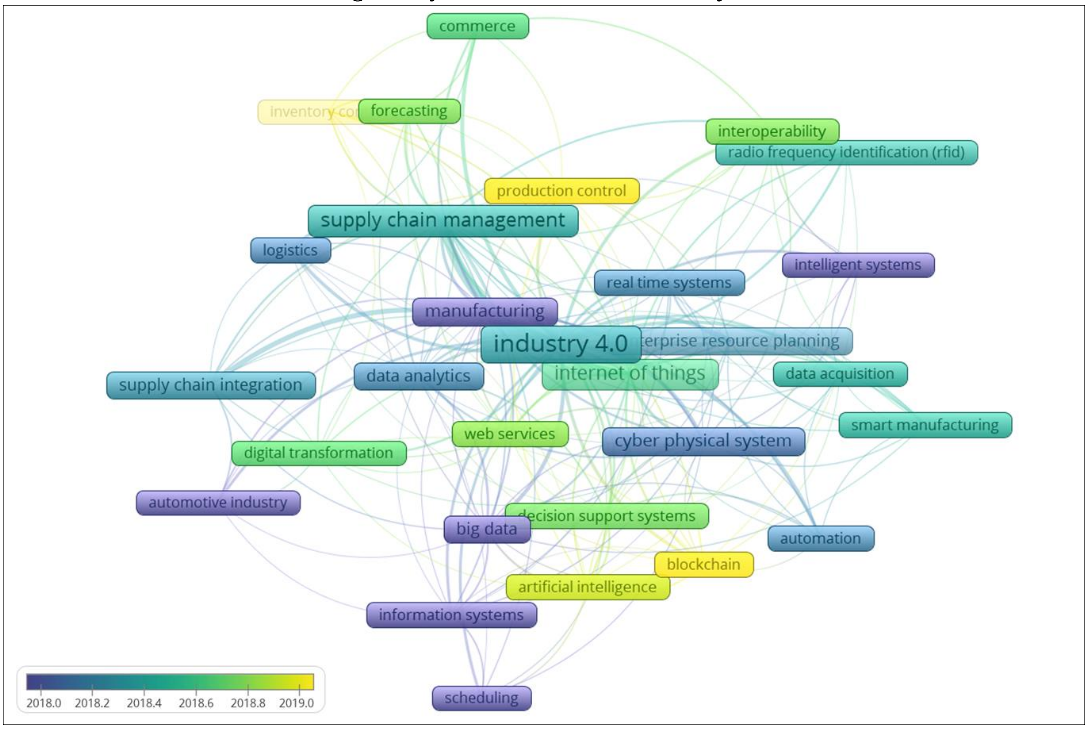
Fig. 2 Number of papers by journal



On the other hand, 36% (15) of the works were divulged at conferences. Each paper was presented at one conference. The general emphasis of these academic meetings was computation and industrial engineering. Other works were added based on the references of the 42 papers.

With the references found (244) on Scopus and Engineering Village, it was developed a co-occurrence analysis, as seen in Figure 3. Industry 4.0, supply chain management, and the internet of things are the top-three primary selected references. Figure 3 evidence the strong relation between industry 4.0 and supply chain management, which means that most of the works collected focus on supply chain management and Industry 4.0 practices and technologies. Another important finding is that the most recent published references have adopted blockchain and artificial intelligence, two emerging areas.

Fig. 3 Keywords co-occurrence analysis



The purpose of this work is to explore and examine the SCI in the Industry 4.0 era. Figure 3 shows that some connections exist between Industry 4.0, supply chain management, and SCI. This work aims to examine and review these connections to respond to the formulated research questions. Thus, in the following section, the research questions are discussed.

4 FINDINGS AND DISCUSSION

As a result of the systematic literature review, a set of 42 publications were selected. Then, the selected papers were classified and examined, considering each research question. For each research question, articles are classified by Industry 4.0 technology, integration approach, and supply chain function. The last subsection discusses which traditional SCI approaches and models can be upgraded to the Industry 4.0 era.

4.1 INDUSTRY 4.0 TECHNOLOGIES FOR SUPPLY CHAIN INTEGRATION – Q1

The supply chain's physical and digital integration can result in high flexibility, performance, and competitive advantage for complex environments. Technology in many times has supported this physical and digital integration. Some traditional SCI technologies are based on Electronic Data Interchange (EDI), Enterprise Resource

Planning (ERP), or IT systems. However, these technologies' main limitations are the significant investment in hardware, maintenance, and low-speed data transmission across the supply chain compared with today's internet-based solutions.

In the Industry 4.0 era, traditional SCI technologies such as ERP and EDI based on the Industrial Internet have become more efficient tools. For example, with the supply chain's digitalization, real-time access to information is provided for all the participating supply chain members (Brettel *et al.*, 2014). Industry 4.0 technologies could ensure real-time information-sharing, rapid joint decision-making, and system-coupling. Table 1 summarizes some of the Industry 4.0 technologies for integrating supply chain operations and introduces each technology's relevant aspects.

Table 1 Industry 4.0 technologies highlights

I4.0 technology	Highlights	Pros (+) / Cons (-)
RFID	Identification of objects and collection of data automatically using radiofrequency.	+ Visibility and security. + Flexible data management. - Interference problems. - Infrastructure challenge.
Internet-of-Things	Data and information-sharing in real-time across the entire supply chain using the internet.	+ Accessibility to data. + Tracking machines, vehicles, products, and persons in real-time. - Data security risks.
Big data	With the use of analytic tools, data turns into valuable information.	+ Data-driven operations. + Better decision-making. - Some tools are not compatible.
Cloud computing	It allows supply chain stakeholders to work from robust platforms with more capabilities.	+ Data scalability. + Faster collaboration, communication, and solution of problems. - Risk of data confidentiality.
ERP	It integrates the main functions of a company.	+ Integrated information for all customers. + Collaboration between different areas. - Cost of ERP software.
CPS	Interconnects digital and physical systems.	+ High degree of autonomy. + Increases the efficacy of physical systems. - Complexity when modeling a CPS.
AGV	A system that autonomously transports and handles goods.	+ Reduction of labor costs. + Increase in productivity - High investment and maintenance costs. - Lost of flexibility during operations.
Digital twins	A focused application of CPS.	+ Simulation of different possible scenarios. + Avoid disruptions. - Complexity when modeling entire supply chains.
Blockchain	Set of blocks linked, which contain immutable information. Information is decentralized.	+ High-speed transactions between members.

		+ Security and information immutability. - Development and implementation demands significant time.
Ubiquitous computing	Connects electronic devices (microprocessors) to transmit data.	+ Devices are always available and online. + Captures real-time information.

Today, some of the I4.0 technologies summarized in Table 1 have reached a critical maturity level. However, the lack of infrastructure, regulations, or digital skills is a barrier to the adoption of Industry 4.0. Despite these barriers, researchers and practitioners have studied and adopted I4.0 for integrating the supply chain.

As a result of the systematic literature review carried out in Section 2, it was identified Industry 4.0 technologies supporting the SCI approaches. Some of these I4.0 technologies identified were: IoT (6 approaches), big data (5), cloud computing (6), RFID (8), enterprise resource planning - ERP (4), CPS (2), AGV (1), digital twins (1), blockchain (3) and ubiquitous computing – UC (1). Industry 4.0 technologies found in the SLR for SCI are shown in Figure 4.

Fig. 4 Industry 4.0 technologies for supply chain integration

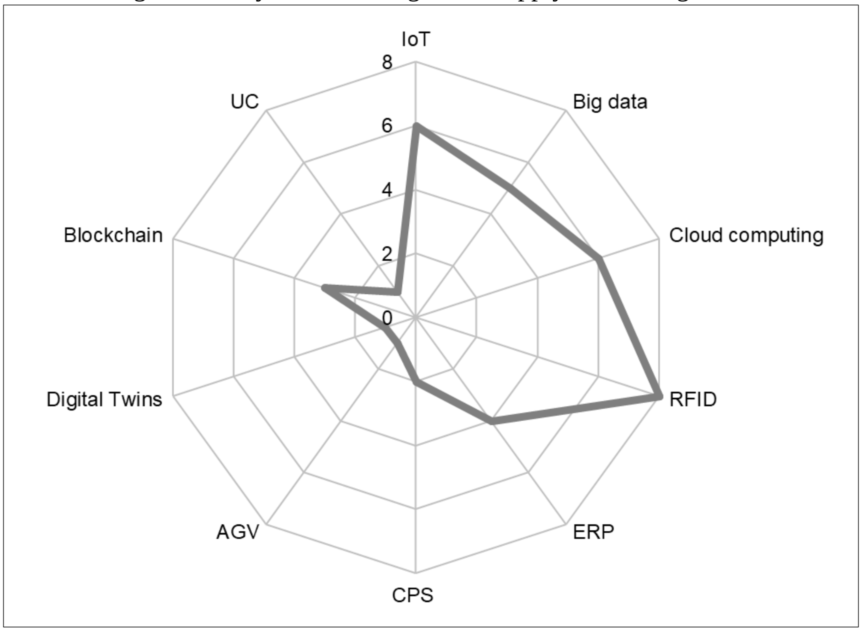


Figure 4 compares the I4.0 technologies that ensure SCI in the fourth revolution era. For example, RFID (8) is the most adopted technology for SCI, followed by IoT (6), cloud computing (6), and big data (5). Emerging technologies such as blockchain (3) and digital twins (1) appear in four approaches, due to these technologies were recently introduced.

The RFID technology was discovered in the 40s. However, its diffusion and industrial application approximately begin twenty years ago (Angeles, 2005). RFID technology identifies objects and collects data automatically. Some SCI approaches were based on RFID (Dev *et al.*, 2020; Ding *et al.*, 2018; Frazzon *et al.*, 2015; Freitas *et al.*, 2017; Hegedus *et al.*, 2019; Qu *et al.*, 2015; Nukala *et al.*, 2017). The significant number of supply chain approaches using RFID technologies could be explained by its introduction twenty years ago, and most of the SCI strategies based on RFID are combined with IoT.

Internet-of-things allows for collecting real-time data from different sources in the supply chain. Then, IoT ensures information-sharing across the entire supply chain. Some SCI approaches in the Industry 4.0 era are based on IoT technology (Ali *et al.*, 2019; Cao *et al.*, 2015; Chaudhary *et al.*, 2018; Qu *et al.*, 2015; Santos *et al.*, 2018; Schulz & Freund, 2019). RFID and IoT technologies are generally used at the shop floor for data collecting.

Nowadays, researchers and practitioners have known the power of big data. This technology examines a vast amount of data collected by IoT and RFID tags and turns data into valuable information to support decision-making or anticipate unexpected disturbances. In the fourth revolution era, supply chains are data-driven then big data technology is a vital tool in this era. Many works have adopted big data for integrating supply chain operations (Ali *et al.*, 2019; Cao *et al.*, 2015; González *et al.*, 2020; Lee, 2016; Vieira *et al.*, 2019).

On the other hand, cloud computing is a virtualized information technology (IT) service. It can be used as software as a service - SaaS, infrastructure as a service - IaaS, or platform as a service – PaaS (Wu *et al.*, 2013). For example, big data platforms are stored in clouds to ensure that all the stakeholders have access to information. Some SCI approaches were supported by cloud computing technology (Anton *et al.*, 2020; Cao *et al.*, 2015; Chaudhary *et al.*, 2018; Lee, 2016; Santos *et al.*, 2018; Sundarakani *et al.*, 2019). Cloud computing and big data can support the decision-making process at the planning level of the company. A detailed literature review of cloud computing use on the supply chain is presented by Novais *et al.* (2019).

Some emerging technologies such as blockchain, ubiquitous computing, autonomous vehicle guiding, and digital twins were also found in the systematic literature review. Nowadays, blockchain is a trending topic in researchers and practitioners, and then, several efforts are focused on this new technology. Some SCI approaches based on blockchain have been developed (Lallas *et al.*, 2019; Longo *et al.*, 2019; Schulz & Freund, 2019).

On the other hand, a digital twin involves Industry 4.0 technologies for creating a duplicated digital representation of a production system to simulate different situations on the duplicated model. For example, Hegedus *et al*. (2019) developed a digital replica of a tracking system across the supply chain. Finally, Table 2 summarizes the Industry 4.0 technologies found in the SLR for SCI.

Table 2 Industry 4.0 technologies for supply chain integration

I4.0 technology	**Authors**
RFID	Dev *et al.*, 2020; Ding *et al.*, 2018; Frazzon *et al.*, 2015; Freitas *et al.*, 2017; Hegedus *et al.*, 2019; Qu *et al.*, 2015; Nukala *et al.*, 2017.
Internet-of-Things	Ali *et al.*, 2019; Cao *et al.*, 2015; Chaudhary *et al.*, 2018; Qu *et al.*, 2015; Santos *et al.*, 2018; Schulz & Freund, 2019.
Big data	Ali *et al.*, 2019; Cao *et al.*, 2015; González *et al.*, 2020; Lee, 2016; Vieira *et al.*, 2019.
Cloud computing	Anton *et al.*, 2020; Cao *et al.*, 2015; Chaudhary *et al.*, 2018; Lee, 2016; Santos *et al.*, 2018; Sundarakani *et al.*, 2019.
ERP	Mageed & Rupasinghe, 2017; Telukdarie *et al.*, 2018; Mantravadi *et al.*, 2018; Dev *et al.*, 2020.
CPS	Dev *et al.*, 2020, Juhász & Banyai, 2018.
AGV	Fontes & Homayouni, 2019.
Digital twins	Hegedus *et al.*, 2019.
Blockchain	Lallas *et al.*, 2019; Longo *et al.*, 2019; Schulz & Freund, 2019.
Ubiquitous computing	Luo *et al.*, 2017.

In this section have been discussed the technologies ensuring supply integration in the Industry 4.0 era. Therefore, the following subsection will examine the SCI approaches based on Industry 4.0 technologies.

4.2 SUPPLY CHAIN INTEGRATION APPROACHES IN THE INDUSTRY 4.0 ERA – Q2

Traditional SCI practices emphasize on the customer, supplier, and internal integration (Flynn *et al.*, 2010), on functional integration (Lambert & Cooper, 2000), and the integration of information/data and physical flows (Cagliano *et al.*, 2006).

On the other hand, from an Industry 4.0 perspective, integration approaches are more extensive than traditional. For SCI, Industry 4.0 adopts three strategies: vertical, horizontal, and end-to-end (Stock & Seliger, 2016). Then, this section aims to discuss and classify the SCI approaches by each Industry 4.0 integration strategy.

As seen in Figure 5, i-Scoop (2016) represents vertical integration as integrating IT systems at various hierarchical manufacturing levels (enterprise planning, operations, control, and field level). This integration strategy allows for flexible and reconfigurable manufacturing systems of customized products (Wang *et al.*, 2017).

Fig. 5 Vertical integration in Industry 4.0

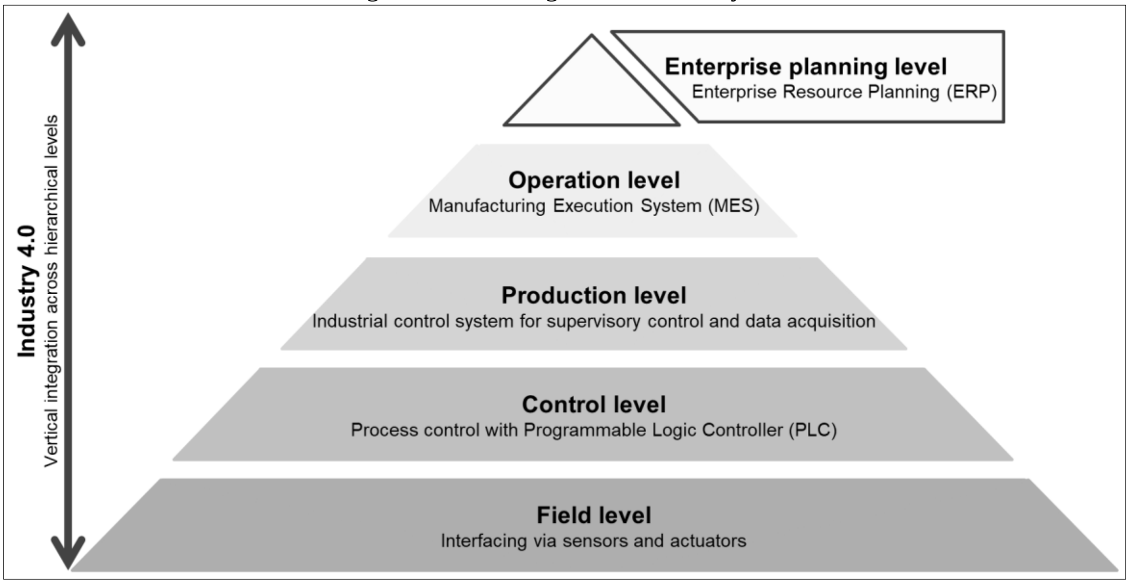


Figure 5 shows that sensors collect data at the field level, and actuators receive control commands to produce a physical system change. Next, at the control level, machines and devices are regulated through a PLC. Industrial control systems such as SCADA allow monitoring, controlling, and supervising the production line at the production level. Next, at the operations level, MES (manufacturing execution system) can provide operations real-time information, and then support the production planning and quality management. At the pyramid top, the enterprise planning level is the strategic level where the company goals and objectives are defined (i-Scoop, 2016).

Traditionally, companies have used ERP, MES, and SCADA to plan, coordinate, manage, and control operations vertically. Therefore, nowadays, these systems need to be upgraded to Industry 4.0. The sum of traditional methods with Industry 4.0 technologies has improved vertical integration. Based on this idea, some academic works have proposed models for this integration strategy. For example, Mageed & Rupasinghe (2017) developed a modeling framework to integrate an ERP system with an RFID application for improving inbound and outbound operations.

RFID technology captures data automatically and transmits it in real-time. Nukala *et al.* (2017) developed a real-time application using RFID and temperature sensors to monitor the delivery process of perishable products on the food supply chain, in which superior levels manage and control field-level operations. On RFID applications, data collected is accessed by all the hierarchical levels to support the decision-making process.

Other Industry 4.0 applications for vertical integration are based on the Business Process Management (BPM) approach. Suri *et al.* (2017) applied the BPM approach for developing a framework that integrates IoT resources, such as sensors and tags, in the business processes. Neubauer & Krenn (2017) also developed a BPM modeling framework for enabling real-time data processing in all the hierarchical levels.

Cloud-based applications also allow vertical integration. For example, Wang *et al.* (2016) introduced a flexible and reconfigurable smart factory incorporating wireless networks, cloud computing, and mobile terminals for improving integration between the hierarchical levels.

Although Industry 4.0 applications allow vertical integration across hierarchical levels, horizontal integration allows integration in four manners: (i) across the production shop floor, (ii) across multiple production facilities, (iii) across multiple supply chain functions, (iv) and across the entire supply chain covering all tasks. Industry 4.0 technologies supporting vertical integration are also used for supporting horizontal integration. Cloud computing, big data, cyber-physical systems, and IoT are Industry 4.0 technologies for horizontal integration.

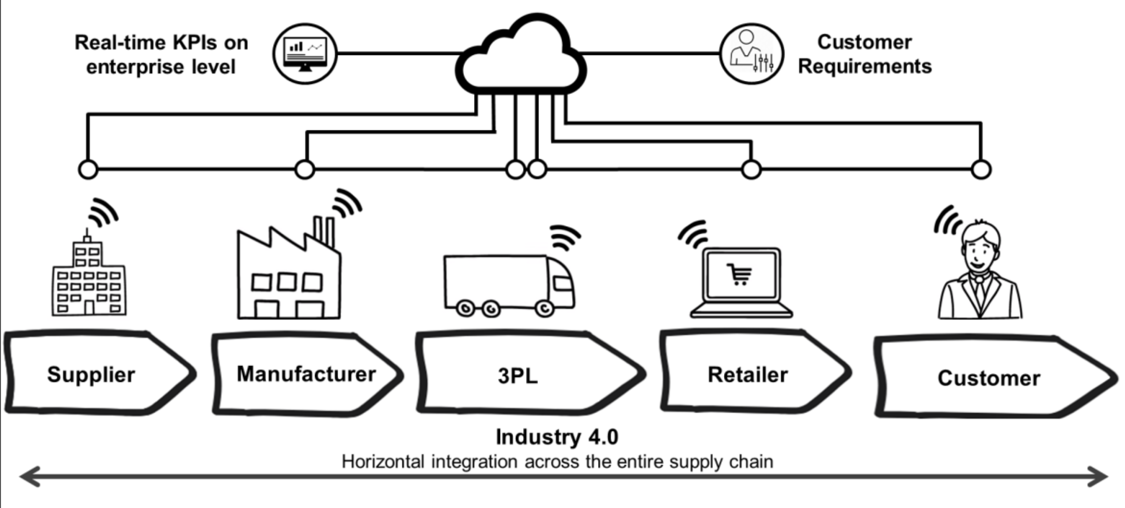
Horizontal integration refers to the digitalization across the entire supply chain, improving the interrelation between stakeholders (partners, suppliers, and customers), and the responsiveness and flexibility to unforeseen changes (Marques *et al*., 2017).

The integration between the supply chain members leads to the availability of a large set of data. Then IT infrastructure enables information-sharing and other collaborative techniques between members.

Figure 6 illustrates horizontal integration across the supply chain in the Industry 4.0 era. All stakeholders are integrated through Industry 4.0 technologies, allowing information-sharing, joint decision-making, and system-coupling. Customer requirements are known rapidly by suppliers and manufacturers. Thus, the entire supply chain performance can be monitored in real-time.

For example, in the modeling framework proposed by Barata *et al*. (2018), the authors argued that mobile computing is a critical Industry 4.0 technology for real-time monitoring and integration across the supply chain. In Oesterreich & Teuteberg (2016), authors also argued that mobile computing is essential for complete SCI. Then, a digital integration across the value chain can be reached using cyber-physical systems.

Fig. 6 Horizontal integration in Industry 4.0



Some of the horizontal Industry 4.0 approaches integrate equipment and production units on the shop floor. For example, in Anton *et al.* (2020) model, the authors developed a cloud manufacturing system to integrate robots' tasks and control the manufacturing cell remotely by users. In Lallas *et al.* (2019), the authors proposed a peer-to-peer blockchain architecture to monitor machine conditions and detect faults in an integrated manufacturing scheme. Other examples of horizontal integration at the shop floor are tracking and traceability systems (Raschinger *et al.*, 2016; Freitas *et al.*, 2017; Hegedus *et al.*, 2019).

On the other hand, some Industry 4.0 approaches supported integration across multiple production facilities. In Santos *et al.* (2018), the authors developed a unified hub for smart plants using cloud computing, the internet of things, and others for supporting data integration and collaborative processes between plants, corporative groups, and third-party entities.

For the digitalization of large multinational businesses, the horizontal integration represents an opportunity. For example, in Telukdarie *et al.* (2018), the authors proposed an architecture framework for inter-functional integration in the context of global operations based on I4.0 technologies. In work developed by Sun *et al.* (2020), the authors also studied a multi-site production planning problem. They proposed a model for parallel production (horizontal integration) supported by Industry 4.0 technologies.

The integration across the supply chain members have also been examined, as in Longo *et al.* (2019). The authors developed a blockchain simulation model for information-sharing, check data authenticity and visibility between stakeholders (manufacturers, wholesalers, retailers, and consumers). In the study conducted by

Wakenshaw *et al*. (2017), the authors explore the integration between manufacturers and retailers using an IoT application.

Advanced strategies for SCI will not consider only horizontal or vertical integration. On the contrary, it will consider a total business integration practice. The end-to-end integration strategy is more complicated than the vertical and the horizontal. Due to the end-to-end approach refers to the complete integration from a raw material supplier to end customer using CPSs (Brettel *et al.*, 2014).

Thus, some authors have developed models for end-to-end integration. For example, in Singh *et al.* (2015), the authors integrated the entire beef supply chain by developing a cloud computing repository framework to reduce carbon emissions. Then, the carbon emission data is collected from farms, third-party logistics, abattoirs, and retailers, and then stored and used by the stakeholders for improving the coordination between them and reduce the carbon emissions.

Another end-to-end model is developed by Ud-Din *et al.* (2019). The authors developed the architecture of an Agent-Oriented Smart Factory model (AOSF) for integrating an end-to-end supply chain based on a Cyber-Physical System framework. The AOSF integrates all the functional areas of a business on an ERP system. Thoben *et al.* (2017) provide an overview of cyber-physical Systems' potential applications for the end-to-end SCI. Lastly, Nguyen *et al.* (2018) affirmed that the end-to-end supply chain could be integrated by aligning Big Data applications. Table 3 provides an overview of the Industry 4.0 approaches reviewed for vertical, horizontal, and end-to-end integration.

Table 3 Supply chain integration approaches in the Industry 4.0 era

Integration strategy	**Industry 4.0 approaches**	**Author**
Vertical	Modeling framework based on an ERP system with RFID technology.	Mageed & Rupasinghe (2017)
	A real-time model integrated with RFID technology and temperature sensors for monitoring quality.	Nukala *et al.* (2017)
	Modeling framework for integrating IoT resources, such as sensors and tags in the business processes.	Suri *et al.* (2017)
	BPM modeling framework for enabling real-time data processing in all the hierarchical levels.	Neubauer & Krenn (2017)
	Modeling framework using wireless networks, cloud computing, and mobile terminals for a smart factory.	Wang *et al.* (2016)
	Prediction and detection of unexpected events within a manufacturing unit using IoT.	Ali *et al.* (2019)
	Decision-making system based on machine learning within a production plant integrated with a Closed-Loop Supply Chain.	Rodrigues *et al.* (2019)

Horizontal	Modeling framework using mobile Computing technology for real-time integration.	Barata *et al.* (2018)
	Model for allowing data integration, collaborative processes between plants, corporative groups, and third-party entities.	Santos *et al.* (2018)
	Framework for integrating global operations.	Telukdarie *et al.* (2018)
	A blockchain model for information-sharing, check data authenticity, and visibility between stakeholders.	Longo *et al.* (2019)
	Cloud manufacturing system to integrate the tasks developed by a set of robots in a manufacturing cell.	Anton *et al.* (2020)
	Parallel production model to integrate multi-site production operations.	Sun *et al.* (2020)
	A milk-run model based on an ERP solution for integrating suppliers and manufacturers.	Qu *et al.* (2015).
	A reverse logistic system based on IoT and RFID.	Dev et al. (2020)
	A peer-to-peer blockchain network for integrating entities of the physical world.	Lallas *et al.* (2019)
	A big data platform for predicting customer purchases.	Lee (2016)
	A hybrid supply chain cloud platform.	Sundarakani *et al.* (2019)
End-to-end	Cloud computing model for measuring carbon emission in a beef supply chain.	Singh *et al.* (2015)
	Agent-based model using a CPS and ERP system.	Ud-Din *et al.* (2019)

Horizontal integration also allows integration across multiple supply chain functions, as procurement-production and production-logistics. However, cross-functional integration exceeds the focus of this section. Therefore, the following section will be discussed the strategies for SCI in the Industry 4.0 era by function to answer Question 3.

4.3 INTEGRATION IN THE INDUSTRY 4.0 ERA BY SUPPLY CHAIN FUNCTION – Q3

Supply chain management comprises a set of functions, such as demand planning, supply planning, procurement, manufacturing, warehousing, and transportation (Cooper *et al.*, 1997). Therefore, this section will be examined the supply chain functions integrated by Industry 4.0 approaches. This analysis will be considered the following supply chain functions: procurement (PC), warehousing (WH), production (PR), logistics (LG), transportation (TR), and retail (RT). Firstly, it will be examined the Industry 4.0 approaches for internal activities integration by function, and secondly, for cross-functional integration.

Some researchers have adopted information-sharing strategies such as real-time tracking and traceability systems to integrate logistics shop floor activities. With the adoption of these systems, material deviation, planning errors, and overstock can be avoided. For example, Freitas *et al.* (2017) developed a raw material traceability system based on RFID technology, internal activities such as reception, warehousing, picking, and internal milk-run were integrated into this system.

A similar study was conducted by Hegedus *et al.* (2019). However, in this case, the tracking system integrates all the internal logistics activities. It is based on a digital twin module combined with RFID tags.

Other approaches based on information-sharing were adopted, as in Chaudhary *et al.* (2018). In this work, the authors developed a machine learning framework based on cloud computing and big data for supporting decision-making in the logistics planning process. Thus, information concerning procurement, warehousing, and transportation are integrated into one platform.

At this point, the reviewed approaches for integrating internal activities in logistics are based on information-sharing. However, the model developed by Banyai *et al.* (2018) adopted a joint decision-making strategy due to the model integrates the assignment of delivery tasks for the first mile and the last mile based on an algorithmic scheme and Industry 4.0 technologies. Table 4 presents some of the logistics shop floor activities integrated using I4.0 technologies.

Table 4 Integration of logistics activities in the Industry 4.0 era

Author	**Integrated activities**	**I4.0 technology**
Freitas *et al.* (2017)	Reception, warehousing, picking, and internal milk-run.	RFID
Chaudhary *et al.* (2018)	Procurement, warehousing, and transportation.	Cloud computing and big data
Banyai *et al.* (2018)	First-mile and last-mile tasks.	Simulation

For Nguyen *et al.* (2018), SCI in the Industry 4.0 era must focus on cross-functional integration approaches. In the literature, many studies have attended this affirmation. They have proposed models for integrating two or more supply chain functions. Some of these approaches have focused on integrating production and transportation tasks, as in Ding *et al.* (2018). The authors proposed a radio frequency identification-enabled social manufacturing system (RFID-SMS) to realize the real-time monitoring and dispatching of inter-enterprise production and transportation tasks.

Another example is the work developed by Fontes and Homayouni (2019). In this work, a joint production and transportation scheduling model is formulated for integrating the machine operations with the tasks of a set of Automated Guided Vehicles (AGV). As a result of the cross-functional integration model between production and transportation, the supply chain actors win flexibility and efficiency in their operations. As mentioned previously, in the Industry 4.0 era, flexibility is critical because customers are closer to manufacturers than in traditional SCI strategies.

Other approaches for cross-functional integration have focused on integrating production and logistic. In this case, logistics includes warehousing and transportation tasks. Due to customized manufacturing requires significant collaboration between production and logistics, Guo *et al.* (2017) developed an integrated framework based on an IoT application, specifically, a cloud service platform to provide the basis for self-adaptive collaboration of production – logistics systems.

A second approach was presented by Luo *et al.* (2016). In this case, the authors proposed a synchronized make-to-order (MTO) production with a cross-docking (CD) scheme. For reaching coordination among MTO and CD operations, an IoT infrastructure was proposed, creating a closed decision-execution loop by linking the frontline real-time data, user feedback, and optimized computation together.

One year later, in Luo *et al.* (2017), the authors developed a synchronized production and logistics model framework using ubiquitous technology. The results demonstrated that the proposed approach improves the overall performance in both production and logistics operations. Examples of ubiquitous technologies are artificial intelligence and wireless computing. These models also link real-time data, user feedback, and optimized decision.

Another model is proposed by Juhász & Banyai (2018) for integrating procurement and production functions. It was developed a cyber-physical architecture (RAMI 4.0) to represent a just-in-sequence supply between a set of suppliers and manufacturers.

In nowadays manufacturing schemes, manufacturers collaborate with product development, then an integrated production and logistic monitoring are required. In Ding & Jiang (2016), the authors developed a graphical formalized deduction method called RFID driven state block model to represent an integrated production and logistic service flow monitoring.

Some cross-functional integration approaches have been applied to reverse logistics due to its complexity, which involves many transactions and activities. For example, in Dev *et al.* (2020), the authors developed a reverse logistic system according to Industry 4.0 technologies. Therefore, production planning, manufacturing, remanufacturing, and delivery are integrated into a cyber-physical system based on the Internet of Service (IoS), IoT, and RFID.

When sharing real-time information between the supply chain stakeholders, the operations' uncertainty can be mitigated, or some activities can be anticipated. In Mantravadi *et al.* (2018), the authors presented an information-sharing framework between manufacturers and wholesalers in a fresh food supply chain to achieve a competitive advantage in which manufacturers provide real-time information to wholesalers based on a manufacturing execution system (MES).

Another example is the work developed by Lee (2016). The author proposes an anticipatory shipping model to predict customer purchase and ensure fast product delivery based on a big data platform designed for information-sharing between the omnichannel supply chain actors. This model results in high coordination between the shipping and commercialization functions.

Some of the approaches for integrating supply chain functions in the Industry 4.0 era have a large amplitude and combines more than two functions. For example, in Qu *et al*. (2015), the authors proposed a milk-run scheme in which procurement, production, and transportation functions are integrated. The proposed milk-run system integrates the ERP system of a manufacturer with the route planning process of third-party logistics using the internet of things. The IoT based milk-run model construct iterative routes for collecting the raw material based on real-time information of the manufacturer material demand.

In Pires *et al.* (2018), the authors presented an adaptive simulation-based optimization model to integrate material inventory, production, and transportation using real-time data provided by Industry 4.0 technologies to deal with uncertainty. Finally, in Vieira *et al.* (2019), the authors developed a sophisticated model that integrated four supply chain functions. The Vieira *et al.* (2019) model has adopted a big data solution for supporting the decision-making process at the logistics planning. A big data repository integrates data from some functions, such as materials purchase, materials shipment, materials receipt, warehousing, and manufacturing, to study the impacts of disruptions.

Table 5 provides an overview of the cross-functional integration approaches supported by Industry 4.0 technologies.

Table 5 Cross-functional integration in the Industry 4.0 era

	Supply chain functions					
I4.0	**PC**	**WH**	**PR**	**LG**	**TR**	**RT**
IoT	Qu *et al.* (2015).		Dev *et al.* (2020), Qu *et al.* (2015), Luo *et al.* (2016), Guo *et al.* (2017).	Luo *et al.* (2016), Guo *et al.* (2017).	Qu *et al.* (2015).	
BD	Vieira *et al.* (2019).	Vieira *et al.* (2019).	Vieira *et al.* (2019).	Vieira *et al.* (2019), Lee (2016).		Lee (2016).
RFID			Ding *et al.* (2018), Dev *et al.* (2020), Ding & Jiang (2016).	Ding & Jiang (2016).	Ding *et al.* (2018).	
ERP	Qu *et al.* (2015).		Qu *et al.* (2015).		Qu *et al.* (2015).	
CPS	Juhász & Banyai (2018).		Juhász & Banyai (2018).			
AGV			Fontes & Homayouni (2019).		Fontes & Homayouni (2019).	
Simulation		Pires *et al.* (2018).	Pires *et al.* (2018).		Pires *et al.* (2018).	
IoS			Dev *et al.* (2020).			
UT			Luo *et al.* (2017).	Luo *et al.* (2017).		
MES			Mantravadi *et al.* (2018).			Mantravadi *et al.* (2018).

As shown in Table 5, most of the SCI approach in the Industry 4.0 era focuses on integrating production with other functions. It confirms that manufacturing is a crucial function of supply chain management. The 39% (5 papers) of the reviewed approaches focuses on production-logistics integration, the 15% (2) on production – transportation, the remaining 46% (6) on procurement – production, production – retail, logistics – retail, procurement – production – transportation, warehousing – production – transportation and procurement – warehousing – production – logistics.

Table 5 also provides which I4.0 technologies had been researched in which supply chain functions. This table confirms that IoT, BD, and RFID are the most adopted technologies on the different supply chain functions. Researchers have adopted IoT, BD, ERP, and CPS to procure raw material and components. For warehousing, models based on BD and simulation have been developed for cross-functional integration with procurement, production, logistics, and retail.

In production, all the I4.0 technologies mentioned were adopted for cross-functional integration with other functions. For logistics, IoT, BD, RFID, and UT have been the most researched technologies for cross-functional integration with procurement, warehousing, production, and transportation. For transportation, IoT, RFID, ERP, and simulation have been adopted. The adoption of AGV technology is punctual. It has been used for integrating production and transportation on the internal milk-run.

Finally, cross-functional integration across the supply chain can rapidly increase competitive advantage for attending today's dynamic markets. Therefore, traditional SCI practices must be upgraded to the I4.0 era. The next subsection discusses some traditional SCI approaches and suggests some practices for upgrading them to Industry 4.0.

4.4 WHICH TRADITIONAL SCI APPROACHES CAN BE UPGRADED TO THE INDUSTRY 4.0 ERA? – Q4

Industry 4.0 is still in an early stage (Masdefiol & Stavmo, 2016). Therefore, a plan for transforming traditional SCI approaches to Industry 4.0 is still unpredictable. However, this subsection will discuss how the mentioned traditional SCI approaches can be upgraded to the Industry 4.0 era. Some examples are also provided.

For upgrading traditional SCI approaches to the Industry 4.0 era, access to hardware, electronic devices, and communication networks is critical. A significant transformation to Industry 4.0 requires a robust telecommunication network to enable machine-to-machine and human-machine communication based on internet protocols. For example, in developing countries, the poor infrastructure and lack of electronic device markets are barriers during the adoption of Industry 4.0 practices (Islam *et al*., 2018).

For Ustundag and Cevikcan (2017), the transformation to Industry 4.0 must be supported by tags, sensors, electronic devices, computers, machines, workplaces, and information technology systems to integrate physical systems with digital (cyber-physical systems). The I4.0 technologies mentioned in Subsection 3.1 combined with the I4.0 principles (real-time capability, virtualization, interoperability, agility, service orientation, business process integration, and decentralization) proposed by Wang and Wang (2016) can assist researchers and practitioners to perform a transformation of the traditional SCI approaches.

Traditional SCI approaches can be classified by hierarchical level. Some practices, such as using standard logistical equipment, packaging congruence, and exchanging information, are still practiced at the operational level. Traditional SCI approaches at the operational level demands more physical effort instead of analytical effort. In most of these activities, the analytical effort is moderate. Therefore, some of these practices could be automatized or mechanized using I4.0 technologies, enabling coordination and connection with humans and machines. For example, the adoption of RFID for exchanging information or augmented reality for warehouse picking.

In the other hand, traditional SCI approaches at the planning, and strategic level such as PTSP, milk-un, joint production planning, and joint demand forecasting requires significant analytical effort due to its complexity. Today, with the advances in computation power combined with I4.0 technologies, these complex problems could be solved in less time than in the early era of computation.

In this line, much of the current literature on SCI pays particular attention to traditional approaches as the PTSP (Cheng *et al.*, 2019; He *et al.*, 2019; Jalil *et al.*, 2019). The PTSP objective is to find the joint scheme that minimizes the manufacturing and delivery time, or the total logistics and delivery cost. Nowadays, large industries generally use a capacity-oriented planning and scheduling framework to integrate multi-echelon manufacturing networks. Of particular interest is the coordination of production scheduling of finished and intermediate products in the planning level.

Most of traditional PTSP for integrating production and transportation operations are deterministic and static, ignoring uncertainty parameters. All the relevant parameters are known in the planning phase and stay constant during the production and logistics operation. Some traditional models for production and transportation integration were found in the literature (Beheshtinia *et al*., 2018; He *et al*., 2019; Jiang *et al*., 2019).

However, most real-world problems occur in dynamic environments, where unpredictable real-time events cause probable changes in the scheduled plans. Examples of such dynamic real-time events include machine failures, demand for urgent jobs, road traffic congestions, and production delays. In this way, traditional SCI approaches are unfeasible for dealing with it.

In Weckenborg *et al.* (2020), the authors developed a traditional SCI approach to optimize capacity scheduling. This model reaches the end-to-end integration without the adoption of I4.0 technologies and principles. Nowadays, many traditional approaches reach horizontal, vertical, or end-to-end integration with the adoption of conventional tools. However, for transforming traditional PTSP, the adoption of advanced planning and scheduling (APS) systems combined with Industry 4.0 technologies could allow real-time capability and information decentralization. In this way, a cloud-based PTSP model could deal with unexpected events. For example, in Hsu *et al.* (2018) and Liu *et al.* (2019), the authors developed a joint planning and scheduling platform based on cloud computing. In this case, the planning and scheduling process is hosted on an intelligent and dynamic cloud platform.

On the other hand, as traditional PSTP models, most of the traditional milk-run models are static. In static milk-run models, the route planning is performed only at the beginning of the working day because the route stays fixed during the collecting trip. Therefore, real-time information is unavailable for changing the route, such as new demands, traffic conditions, supplier tardiness, machine breakdown, or extreme weather conditions.

The first step for upgrading the milk-run to Industry 4.0 era is to allow real-time communication between the vehicles and the dispatch center using onboard computers and IoT devices (sensors and tags). IoT devices can monitor some parameters such as vehicle capacity, traffic conditions, or supplier tardiness in real-time. Therefore, when the system detects that a parameter is exceeding a limit, a preventive action is performed, changing the vehicle's route. In some works, as in Güner *et al.* (2017) and Adriano *et al.* (2019), traditional milk-run models have been upgraded to the Industry 4.0 era for dealing with traffic congestions.

On the other hand, traditional SCI practices such as joint production planning and joint demand forecasting can be upgraded to Industry 4.0, adopting big data or IoT technologies. Production-planning and demand forecasting analyze a significant amount of data from different sources (customers, retailers, or 3PL). Then, data could be collected and transmitted using sensors and IoT devices. The collected data could be stored in a repository in which big data algorithms can determine the best production schedule or the best demand prevision. For example, in Zhang and Lee (2019), the authors developed a joint production model based on IoT, enabling real-time capability.

Finally, traditional SCI approaches could be upgraded to the Industry 4.0 era with the advance and emergence of new technologies such as blockchain and 5G. Therefore, with the increase of computational power, data transmission speed, and the development of low-cost electronic devices, high integration levels could be reached in the future. The next section discusses the conclusions and directions for future research.

5 CONCLUSIONS

This paper starts by contextualizing the traditional SCI approaches and standing that nowadays, SCI approaches must adopt Industry 4.0 technology and practices. It was then developed a systematic literature review to examine 42 papers and discuss the approaches, strategies, and technologies for integrating the supply chain in the Industry 4.0 era. For attending the objective of this paper, it was formulated three research questions. According to the research questions, the 42 articles were examined.

As a result, it was possible to identify the most adopted Industry 4.0 technologies for SCI. RFID, IoT, cloud computing, and big data support the majority of the approaches for integrating the supply chain. Emerging technologies such as blockchain, digital twins, ubiquitous computing, and autonomous guided vehicles were also identified. These findings suggest that emerging technologies have gained the researcher's attention, and the number of works using these technologies for SCI could increase in the next years.

The results of the SLR reaffirms that at the shop floor level, companies adopt RFID and IoT technologies for capturing data, and technologies such as big data, digital twins, ERP, and cloud computing ensure the integration at the planning level.

It was also noted that Industry 4.0 approaches adopt the vertical, horizontal, and end-to-end strategy for SCI and, most of the vertical integration approaches are based on ERP systems and RFID technologies to integrate all the hierarchical levels at the company. Another important finding is that Industry 4.0 horizontally integrates supply chain on the shop floor, across multiple production facilities, across the entire supply chain, and the supply chain functions. It was also noted that it is a lack of end-to-end integration approaches. This lack could be explained by the complexity and technological infrastructure required for integrating the entire supply chain.

Although the current study is based on a limited number of papers, the findings suggest that most cross-functional integration approaches consider production as the key-function for integration.

Further studies regarding SCI must consider the adoption of Industry 4.0 practices and technologies. Achieving industry 4.0 paradigms is a long term objective for companies. Then, today researchers and practitioners might explore the digital integration of the supply chain.

The cross-functional integration across the supply chain is complex. Therefore, further modeling work is required to deal with this challenge. For Nguyen *et al.* (2018), the entire supply chain functions should be integrated using Big Data, and then future studies should propose the integration of production and logistics based on real-time data acquisition systems for cost reduction and higher service level. More research is required better to understand the SCI in the Industry 4.0 era.

Finally, in future research, it will be essential to explore the potential use of emerging technologies such as blockchain, 5G, and digital twins for SCI.

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REFERENCES

Abreu, A., & Alcântara, R. (2017). Internal integration in supply chain integration: a systematic literature review. *Revista Reuna*, *22*(4), 40 – 64. https://revistas.una.br/reuna/article/view/938

Adriano, D. D., Novaes, A. G., & Wangham, M. S. (2019, November). Providing a Dynamic Milk-Run Vehicle Routing Using Vehicular Ad hoc Networks. 9th ACM Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications (DIVANet), Miami Beach, United States. https://doi.org/10.1145/3345838.3356006

Alfalla-luque, R., Medina-Lopez, C., & Dey, P. (2013). Supply chain integration framework using literature review. *Production Planning & Control*, *24*(8-9), 800 – 817. https://doi.org/10.1080/09537287.2012.666870

Ali, M., Patel, P., & Breslin, J. (2019, May). Middleware for Real-Time Event Detection and Predictive Analytics in Smart Manufacturing. 15th International Conference on Distributed Computing in Sensor Systems (DCOSS), Santorini Island, Greece. https://doi.org/10.1109/DCOSS.2019.00079

Angeles, R. (2005). RFID technologies: supply-chain applications and implementation issues. *Information systems management*, *22*(1), 51 – 65. https://doi.org/10.1201/1078/44912.22.1.20051201/85739.7

Anton, F., Borangiu, T., Răileanu, S., Anton, S., Ivănescu, N., & Iacob, I. (2020). Secure Sharing of Robot and Manufacturing Resources in the Cloud for Research and Development. In K. Berns, & D. Görges (Eds.), *Advances in Service and Industrial Robotics* (pp. 535 – 543). Cham: Springer. https://doi.org/10.1007/978-3-030-19648-6_61

Bag, S., Telukdarie, A., Pretorius, J., & Gupta, S. (2018). Industry 4.0 and supply chain sustainability: framework and future research directions. *Benchmarking: An International Journal*. https://doi.org/10.1108/BIJ-03-2018-0056

Bányai, T., Illés, B., & Bányai, A. (2018). Smart scheduling: An integrated first mile and last mile supply approach. *Complexity*. https://doi.org/10.1155/2018/5180156

Barata, J., Da Cunha, P., & Stal, J. (2018). Mobile supply chain management in the Industry 4.0 era. *Journal of Enterprise Information Management*, *31*(1), 173 – 193. https://doi.org/10.1108/JEIM-09-2016-0156

Beheshtinia, M. A., Ghasemi, A., & Farokhnia, M. (2018). Supply chain scheduling and routing in multi-site manufacturing system (case study: a drug manufacturing company). *Journal of Modelling in Management*, *13*(1), 27 – 49. https://doi.org/10.1108/JM2-10-2016-0094

Bocewicz, G., Nielsen, P., & Banaszak, Z. (2019). Declarative Modeling of a Milk-Run Vehicle Routing Problem for Split and Merge Supply Streams Scheduling. In J. Świątek, L. Borzemski, & Z. Wilimowska (Eds.), *Information Systems Architecture and Technology: Proceedings of 39th International Conference on Information Systems Architecture and Technology – ISAT 2018* (pp. 157 – 172). Cham: Springer. https://doi.org/10.1007/978-3-319-99996-8_15

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 8*(1), 37 – 44.

Cagliano, R., Caniato, F., & Spina, G. (2006). The linkage between supply chain integration and manufacturing improvement programmes. *International Journal of Operations & Production Management,26*(3), 282 – 299. https://doi.org/10.1108/01443570610646201

Cao, B., Wang, Z., Shi, H., & Yinet, Y. (2015, November). Research and practice on Aluminum Industry 4.0. Sixth International Conference on Intelligent Control and Information Processing (ICICIP), Wuhan, China. https://doi.org/10.1109/ICICIP.2015.7388226

Carvalho, T., Soares, F., Vita, R., Francisco, R., Basto, J., & Alcalá, S. (2019). A systematic literature review of machine learning methods applied to predictive maintenance. *Computers & Industrial Engineering, 137*, 106024. https://doi.org/10.1016/j.cie.2019.106024

Chaudhary, K., Singh, M., Tarar, S., Chauhan, D., & Srivastava, M. (2018). Machine Learning Based Adaptive Framework for Logistic Planning in Industry 4.0. In M. Singh, P. Gupta, V. Tyagi, J. Flusser, & T. Ören (Eds.) *Advances in Computing and Data Sciences* (pp. 431 – 438). Singapore: Springer. https://doi.org/10.1007/978-981-13-1810-8_43

Cheng, B., Leung, J. Y. T., Li, K., & Yang, S. (2019). Integrated optimization of material supplying, manufacturing, and product distribution: Models and fast algorithms. *European Journal of Operational Research, 277*(1), 100 – 111. https://doi.org/10.1016/j.ejor.2019.02.024

Cooper, M., Lambert, D., & Pagh, J. (1997). Supply chain management: more than a new name for logistics. *The international journal of logistics management, 8,* (1), 1 – 14. https://doi.org/10.1108/09574099710805556

Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry, 99,* 205 – 225. https://doi.org/10.1016/j.compind.2018.03.039

Dev, N., Shankar, R., & Qaiser, F. (2020). Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance. *Resources, Conservation and Recycling, 153,* 104583. https://doi.org/10.1016/j.resconrec.2019.104583

Ding, K., & Jiang, P. (2016). A Graphical Formalized Deduction for Integrated Production and Logistic Service Flow Monitoring in Social Manufacturing. In E. Qi (Eds.), *Proceedings of the 6th International Asia Conference on Industrial Engineering and Management Innovation* (pp. 603 – 613). Paris: Atlantis Press. https://doi.org/10.2991/978-94-6239-145-1_57

Ding, K., Jiang, P., & Su, S. (2018). RFID-enabled social manufacturing system for inter-enterprise monitoring and dispatching of integrated production and transportation tasks.

Robotics and Computer-Integrated Manufacturing, *49*, 120 – 133. https://doi.org/10.1016/j.rcim.2017.06.009

Eroglu, D. Y., Cagliano, A. C., & Rafele, C. (2017). A multi-capacity integrated vehicle routing and loading model for pickup milk run. *International Journal of Mechanics and Control*, *18*(2), 107 – 122.

Flynn, B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of operations management*, *28*(1), 58 – 71. https://doi.org/10.1016/j.jom.2009.06.001

Fontes, D., & Homayouni, S. (2019). Joint production and transportation scheduling in flexible manufacturing systems. *Journal of Global Optimization*, *74*(4), 879 – 908. https://doi.org/10.1007/s10898-018-0681-7

Frazzon, E., Albrecht, A., Hurtado, P., Silva, L., & Pannek, J. (2015). Hybrid modelling approach for the scheduling and control of integrated production and logistic processes along export supply chains. *Ifac Papersonline*, *48*(3), 1521 – 1526. https://doi.org/10.1016/j.ifacol.2015.06.302

Freitas, A. *et al.* (2017, October). Savings in internal logistics using a RFID-based software system in a lean context. Proceedings of the 47th International Conference on Computers and Industrial Engineering (CIE47), Lisbon, Portugal.

Guo, Z., Zhang, Y., Zhao, X., & Song, X. (2017). A timed colored petri net simulation-based self-adaptive collaboration method for production-logistics systems. *Applied Sciences*, *7*(3). https://doi.org/10.3390/app7030235

Güner, A. R., Murat, A., & Chinnam, R. B. (2017). Dynamic routing for milk-run tours with time windows in stochastic time-dependent networks. Transportation Research Part E: Logistics and Transportation Review, 97, 251-267. https://doi.org/10.1016/j.tre.2016.10.014

He, Z., Guo, Z., & Wang, J. (2019). Integrated scheduling of production and distribution operations in a global MTO supply chain. *Enterprise Information Systems*, *13*(4), 490-514. https://doi.org/10.1080/17517575.2018.1428770

Hegedűs, C., Frankó, A., & Varga, P. (2019, May). Asset and production Tracking through Value Chains for Industry 4.0 using the Arrowhead Framework. 2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS). Taipei, Taiwan, Taiwan. https://doi.org/10.1109/ICPHYS.2019.8780381

Hou, L., & Qiu, W. (2008). Coordinating the three-level supply chain with combined contracts under demand uncertainty. *Journal of Beijing University of Aeronautics and Astronautics*, *21*(1), 1 – 5.

Huang, M., Yang, J., Ma, T., Li, X., & Wang, T. (2017). The modeling of milk-run vehicle routing problem based on improved CW algorithm that joined time window. *Transportation Research Procedia*, *25*, 716 – 728. https://doi.org/10.1016/j.trpro.2017.05.453

i-Scoop. Industry 4.0: the fourth industrial revolution – guide to Industrie 4.0. (2016). https://www.i-scoop.eu/industry-4-0/#Vertical_integration_in_Industry_40 Accessed April 23 2020.

Islam, M. A., Jantan, A. H., Hashim, H., Chong, C. W., Abdullah, M. M., & Abdul Hamid, A. B. (2018). Fourth Industrial Revolution in Developing Countries: A Case on Bangladesh. *Journal of Management Information and Decision Sciences*, *21*(1). https://ssrn.com/abstract=3417813

Jalil, S. A., Hashmi, N., Asim, Z., & Javaid, S. (2019). A decentralized bi-level multi-objective model for integrated production and transportation problems in closed-loop supply chain networks. *International Journal of Management Science and Engineering Management*, *14*(3), 206 – 217. https://doi.org/10.1080/17509653.2018.1545607

Jia, Z. H., Zhuo, X. X., Leung, J. Y., & Li, K. (2019). Integrated production and transportation on parallel batch machines to minimize total weighted delivery time. *Computers & Operations Research*, *102*, 39-51. https://doi.org/10.1016/j.cor.2018.07.026

Jiang, Y., Zhou, X., & Xu, Q. (2019). Scenario Analysis–Based Decision and Coordination in Supply Chain Management with Production and Transportation Scheduling. *Symmetry*, *11*(2). https://doi.org/10.3390/sym11020160

Juhász, J., & Bányai, T. (2018). What Industry 4.0 Means for Just-In-Sequence Supply in Automotive Industry? In K. Jármai, & B. Bolló (Eds.), *Vehicle and Automotive Engineering 2* (pp. 226 – 240). Cham: Springer. https://doi.org/10.1007/978-3-319-75677-6_19

Kamal, M., & Irani, Z. (2014). Analysing supply chain integration through a systematic literature review: a normative perspective. *Supply Chain Management: An International Journal*, *19*(5-6), 523 – 557. https://doi.org/10.1108/SCM-12-2013-0491

Khanuja, A., & Jain, R. (2019). Supply chain integration: a review of enablers, dimensions and performance. Benchmarking: An International Journal, *27*(1), 264 – 301. https://doi.org/10.1108/BIJ-07-2018-0217

Lacomme, P., Moukrim, A., Quilliot, A., & Vinot, M. (2015, October). A graspxels approach for the resolution of the integrated production and transportation scheduling problem. Proceedings of the 45th International Conference on Computers and Industrial Engineering (CIE45). Metz, France.

Lacomme, P., Moukrim, A., Quilliot, A. & Vinot, M. (2016). The Integrated Production and Transportation Scheduling Problem based on a GRASPxELS resolution scheme. *Ifac Papersonline*, *49*(12), 1466 – 1471.

Lacomme, P., Moukrim, A., Quilliot, A., & Vinot, M. (2018). Supply chain optimisation with both production and transportation integration: multiple vehicles for a single perishable product. *International Journal of Production Research*, *56*(12), 4313 – 4336. https://doi.org/10.1080/00207543.2018.1431416

Lallas, E., Xenakis, A., & Stamoulis, G. (2019, September). A generic framework for a Peer to Peer Blockchain based Fog Architecture in Industrial Automation. 4th South-East

Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM). Piraeus, Greece. https://doi.org/10.1109/SEEDA-CECNSM.2019.8908360

Lambert, D., & Cooper, M. (2000). Issues in supply chain management. *Industrial marketing management*, *29*(1), 65 – 83.

Lee, H. (2016). A GA-based optimisation model for big data analytics supporting anticipatory shipping in Retail 4.0. *International Journal of Production Research*, *55*(2), 593 – 605. https://doi.org/10.1080/00207543.2016.1221162

Lee, H. (2019). Effective Dynamic Control Strategy of a Key Supplier with Multiple Downstream Manufacturers Using Industrial Internet of Things and Cloud System. *Processes*, *7*(3), 172 – 190. https://doi.org/10.3390/pr7030172

Longo, F., Nicoletti, L., Padovano, A., D'Atri, G., & Forte, M. (2019). Blockchain-enabled supply chain: An experimental study. *Computers & Industrial Engineering*, *136*, 57 – 69. https://doi.org/10.1016/j.cie.2019.07.026

Luo, H, Chen, J., & Huang, G. (2016). IoT Enabled Production-Logistic Synchronization in Make-to-Order Industry. In E. Qi, J. Shen, & R. Dou (Eds.), *Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management 2015* (pp. 527 – 538). Paris: Atlantis Press. https://doi.org/10.2991/978-94-6239-180-2_51

Luo, H., Wang, K., Kong, X., Lu, S., & Qu, T. (2017). Synchronized production and logistics via ubiquitous computing technology. *Robotics and Computer-Integrated Manufacturing*, *45*, 99 – 115. https://doi.org/10.1016/j.rcim.2016.01.008

Mageed, A., & Rupasinghe, D. (2017). Internet of things (IoT) embedded future supply chains for industry 4.0: An assessment from an ERP-based fashion apparel and footwear industry. *International Journal of Supply Chain Management*, *6*(1), 25 – 40.

Mantravadi, S., Moller, C., & Christensen, M. (2018, October). Perspectives on Real-Time Information Sharing through Smart Factories: Visibility via Enterprise Integration. 2018 International Conference on Smart Systems and Technologies (SST). Osijek, Croatia. 10.1109/SST.2018.8564617

Marques, M., Agostinho, C., Zacharewicz, G., & Jardim-Gonçalves, R. (2017). Decentralized decision support for intelligent manufacturing in Industry 4.0. *Journal of Ambient Intelligence and Smart Environments*, *9*(3), 299 – 313. https://doi.org/10.3233/AIS-170436

Masdefiol, M., & Stävmo, F. (2016). Industry 4.0–Only designed to fit the German automotive industry: A multiple case study on the feasibility of Industry 4.0 to Swedish SMEs. http://urn.kb.se/resolve?urn=urn:nbn:se:hj:diva-30238

Neubauer, M., & Krenn, F. (2017). Subject-oriented design of smart hyper-connected logistics systems. In M. Mühlhäuser, & C. Zehbold (Eds.), *Proceedings of the 9th Conference on Subject-oriented Business Process Management* (pp. 1 – 8). New York: Association for Computing Machinery. https://dl.acm.org/doi/10.1145/3040565.3040572

Nguyen, T., Splieger, V., Ieromonachou, P., & Lin, Y. (2018). Big data analytics in supply chain management: A state-of-the-art literature review. *Computers & Operations Research*, *98*, 254 – 264. https://doi.org/10.1016/j.cor.2017.07.004

Novais, L., Maqueira, J., Ortiz-Bas, Á. (2019). A systematic literature review of cloud computing use in supply chain integration. *Computers & Industrial Engineering*, *129*, 296 – 314. https://doi.org/10.1016/j.cie.2019.01.056

Nukala, R., Panduru, K., Shields, A., Riordan, D., Doody, P., & Walsh, J. (2016, June). Internet of Things: A review from 'Farm to Fork'. 27th Irish Signals and Systems Conference (ISSC). Londonderry, United Kingdom. https://doi.org/10.1109/ISSC.2016.7528456

Oesterreich, T., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121 – 139. https://doi.org/10.1016/j.compind.2016.09.006

Pinto, J., & Diemer, A. (2020). Supply chain integration strategies and circularity in the European steel industry. *Resources, Conservation and Recycling*, *153*, 104517. https://doi.org/10.1016/j.resconrec.2019.104517

Pires, M., Frazzon, E., Danielli, A., Kuck, M., & Freitag, M. (2018). Towards a simulation-based optimization approach to integrate supply chain planning and control. *Procedia Cirp*, *72*, 520 – 525.

Qu, T., Chen, Y., Wang, Z., Nie, D., Luo, H., & Huang, K. (2015, April). Internet-of-Things-based just-in-time milk-run logistics routing system. IEEE 12th International Conference on Networking, Sensing and Control. Taipei, Taiwan, Taiwan. https://doi.org/10.1109/ICNSC.2015.7116045

Raschinger, M., Kipouridis, O., & Gunthner, W. (2016, May). A service-oriented cloud application for a collaborative tool management system. 2016 International Conference on Industrial Engineering, Management Science and Application (ICIMSA). Jeju, South Korea. https://doi.org/10.1109/ICIMSA.2016.7503987

Rodríguez, J., Contreras, L., & Rivas, E. (2018). Industry Knowledge Management Model 4.0. In Á. Rocha, & T. Guarda (Eds.), *Proceedings of the International Conference on Information Technology & Systems* (pp. 275 – 283). Cham: Springer. https://doi.org/10.1007/978-3-319-73450-7_27

González, G., Gonzalez, J., & Méndez, J. (2020). An intelligent decision support system for production planning based on machine learning. *Journal of Intelligent Manufacturing*, *31*, 1257 – 1273. https://doi.org/10.1007/s10845-019-01510-y

Rotella, P. Is Data The New Oil? (2012). https://www.forbes.com/sites/perryrotella/2012/04/02/is-data-the-new-oil/#899cd67db3dd Accessed February 20 2020.

Sainathuni, B., Parikh, P., Zhang, X., & Kong, N. (2014). The warehouse-inventory-transportation problem for supply chains. *European Journal of Operational Research*, *237*(2), 690 – 700. https://doi.org/10.1016/j.ejor.2014.02.007

Santos, N. *et al*. (2018, September). UH4SP: a software platform for integrated management of connected smart plants. 2018 International Conference on Intelligent Systems (IS). Madeira, Portugal. https://doi.org/10.1109/IS.2018.8710468

Scholz-Reiter, B., Makuschewitz, T., Novaes, A., Frazzon, E., & Lima Jr, O. (2011). An approach for the sustainable integration of production and transportation scheduling. *International Journal of Logistics Systems and Management*, *10*(2), 158 – 179. https://doi.org/10.1504/IJLSM.2011.042626

Schulz, K., & Freund, D. (2019). A multichain architecture for distributed supply chain design in industry 4.0. In W. Abramowicz, & A. Paschke (Eds.), *Business Information Systems Workshops, BIS 2018* (pp. 277 – 288). Cham: Springer. https://doi.org/10.1007/978-3-030-04849-5_25

Shou, Y., Li, Y., Park, Y., & Kang, M. (2017). The impact of product complexity and variety on supply chain integration. *International Journal of Physical Distribution & Logistics Management*, *47*(4), 297 – 317. https://doi.org/10.1108/IJPDLM-03-2016-0080

Singh, A., Mishra, N., Ali, S., Shukla, N., & Shankar, R. (2015). Cloud computing technology: Reducing carbon footprint in beef supply chain. *International Journal of Production Economics*, *164*, 462 – 471. https://doi.org/10.1016/j.ijpe.2014.09.019

Stock, T., & Seliger, G. (2016). Opportunities of sustainable manufacturing in industry 4.0. Procedia Cirp, 40, 536 – 541. https://doi.org/10.1016/j.procir.2016.01.129

Sun, J., Yamamoto, H., & Matsui, M. (2020). Horizontal integration management: An optimal switching model for parallel production system with multiple periods in smart supply chain environment. *International Journal of Production Economics, 221*, 107475. https://doi.org/10.1016/j.ijpe.2019.08.010

Sundarakani, B., Kamran, R., Maheshwari, P., & Jain, V. (2019). Designing a hybrid cloud for a supply chain network of Industry 4.0: a theoretical framework. *Benchmarking: An International Journal.* https://doi.org/10.1108/BIJ-04-2018-0109

Suri, K., Gaaloul, W., Cuccuru, A., & Gerard, S. (2017, June). Semantic framework for internet of things-aware business process development. IEEE 26th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE). Poznan, Poland. https://doi.org/10.1109/WETICE.2017.54

Telukdarie, A., Buhulaiga, E., Bag, S., Gupta, S., & Luo, Z. (2018). Industry 4.0 implementation for multinationals. *Process Safety and Environmental Protection*, *118*, 316 – 329. https://doi.org/10.1016/j.psep.2018.06.030

Teng, L., Zhang, Z., Li, P., & Gong, D. (2019). Integrated Inventory-Transportation Problem in Vendor-Managed Inventory System. *IEEE Access*, *7*, 160324 – 160333. https://doi.org/10.1109/ACCESS.2019.2950036

Thoben, K., Wiesner, S., & Wuest, T. (2017). "Industrie 4.0" and smart manufacturing-a review of research issues and application examples. *International journal of automation technology*, *11*(1), 4 – 16. https://doi.org/10.20965/ijat.2017.p0004

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of management, 14*(3), 207 – 222. https://doi.org/10.1111/1467-8551.00375

Ud-Din, F., Henskens, F., Paul, D., & Wallis, M. (2019). Agent-Oriented Smart Factory (AOSF): An MAS Based Framework for SMEs Under Industry 4.0. In G. Jezic, YH. Chen-Burger, R. Howlett, L. Jain, L. Vlacic, & R.Šperka (Eds.), *Agents and Multi-Agent Systems: Technologies and Applications 2018* (pp. 44 – 54). Cham: Springer. https://doi.org/10.1007/978-3-319-92031-3_5

Ustundag, A., & Cevikcan, E. (2017). Industry 4.0: managing the digital transformation. Springer. https://doi.org/10.1007/978-3-319-57870-5

Van Der Vaart, T.,Van Donk, D. (2008). A critical review of survey-based research in supply chain integration. *International journal of production economics*, *111*, 42 – 55. https://doi.org/10.1016/j.ijpe.2006.10.011

Vieira, A., Dias, L., Santos, M., Pereira, G., & Oliveira, J. (2019). Simulation of an automotive supply chain using big data. *Computers & Industrial Engineering, 137*, 106033, https://doi.org/10.1016/j.cie.2019.106033

Wakenshaw, S., Maple, C., Chen, D., & Micillo, R. (2017, September). An IoT-enabled supply chain integration framework: empirical case studies. 15th International Conference on Manufacturing Research (ICMR 2017). London, United Kingdom. https://doi.org/10.3233/978-1-61499-792-4-263

Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. *Computer Networks, 101*, 158 – 168. https://doi.org/10.1016/j.comnet.2015.12.017

Wang, S., Ouyang, J., Li, D., & Liu, C. (2017). An integrated industrial ethernet solution for the implementation of smart factory. *IEEE Access, 5*, 25455 – 25462. https://doi.org/10.1109/ACCESS.2017.2770180

Wang, L., & Wang, G. (2016). Big data in cyber-physical systems, digital manufacturing and industry 4.0. *International Journal of Engineering and Manufacturing, 6*(4), 1-8. https://doi.org/10.5815/ijem.2016.04.01

Wu, X., Zhang, R., Zeng, B., & Zhou, S. (2013). A trust evaluation model for cloud computing. *Procedia Computer Science, 17*, 1170 – 1177. https://doi.org/10.1016/j.procs.2013.05.149

Yi, J., & Su, Z. (2017). A Study on a Specific Vehicle Routing Problem Under the Cargo Loading and Stacking by Milk-run Operations. *Journal of Wuhan University of Technology*. https://doi.org/10.3963/j.issn.2095-3844.2017.02.001

Zhang, Y., Liu, S., Liu, Y., Yang, H., Li, M., Huisingh, D., & Wang, L. (2018). The 'Internet of Things' enabled real-time scheduling for remanufacturing of automobile engines. *Journal of cleaner production, 185*, 562 – 575. https://doi.org/10.1016/j.jclepro.2018.02.061