Industry 4.0 and digital supply chain capabilities

A framework for understanding digitalisation challenges and opportunities

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Abstract

Purpose – The Industry 4.0 phenomenon is bringing unprecedented disruptions for all traditional business models and hastening the need for a redesign and digitisation of activities. In this context, the literature concerning the digital supply chain (DSC) and its capabilities are in the early stages. To bridge this gap, the purpose of this paper is to propose a framework for digital supply chain capabilities (DSCCs).

Design/methodology/approach – This paper uses a narrative literature approach, based on the main Industry 4.0 elements, supply chain and the emerging literature concerning DSC disruptions, to build an integrative framework to shed light on DSCCs.

Findings – The study identifies seven basic capabilities that shape the DSCC framework and six main enabler technologies, derived from 13 propositions.

Research limitations/implications – The proposed framework can bring valuable insights for future research development, although it has not been tested yet.

Practical implications – Managers, practitioners and all involved in the digitalisation phenomenon can utilise the framework as a starting point for other business digitalisation projects.

Originality/value – This study contributes to advancing the DSC literature, providing a well-articulated discussion and a framework regarding the capabilities, as well as 13 propositions that can generate valuable insights for other studies.

Keywords Supply chain disruption, Digital capabilities, Digital supply network, Supply chain digitalization

Paper type Conceptual paper

1. Introduction

The unprecedented development of information and communication technology (ICT) (Alshawi et al., 2003) has led to a phenomenon known as digital disruption. In this context, traditional business models based predominantly on physical activities are being disrupted and shifting towards digitalisation. The digitalisation process has consequences for all industries (Büyüközkan and Göçer, 2018). Therefore, digital disruption affects not only organisations’ business models; it also significantly affects all segments of society, including new relationships and interactions with organisations and people (World Economic Forum, 2016a).

Moreover, ICT has enabled a Fourth Industrial Revolution known as Industry 4.0 (Barreto et al., 2017; Hofmann and Rüsch, 2017), with its roots in German industry (Hecklau et al., 2016) and supported mainly by the Internet of Things (IoT) and cyber-physical system (CPS) technologies (Qin et al., 2016). This has led organisations around the world to reconsider digitalisation as a necessity for which strategies must be developed.
Thus ICT also has been supported by the transformation of organisations' relationships with their network. For example, smart cities present challenges for supply chain design (Kumar et al., 2016) in order to support new operations business models, connecting customers and organisations more efficiently (Li et al., 2016; Qin et al., 2016).

In this context, digital disruption is already affecting supply chains and requiring new manufacturing strategies (Holmström and Partanen, 2014), entailing a shift from traditional production planning and control to distributed manufacturing (DM) and from large scale to micro scale, with multiple manufacturing locations (Srai et al., 2016). Additionally, the decentralisation of manufacturing with 3D printing applications (Kapetaniou et al., 2018; Mohr and Khan, 2015), also known as additve manufacturing (Strong et al., 2018), is unlocking the potential for mass customisation (Srai et al., 2016). Thus, traditional supply chains will eventually face the challenge of updating to digital supply chains (DSCs) to support new productions models, transportation modes, customer experiences and relationships, based on, among other things, real-time information exchange.

Recently, top consulting firms have highlighted the necessity of supply chain digitalisation (A.T. Kearney, 2015; Accenture, 2014; Bain & Company, 2018; Boston Consulting Group, 2018; Deloitte, 2016; Ernst & Young, 2016; McKinsey & Company, 2017; PwC, 2016; Roland Berger, 2016). Despite advancements in digitalisation, however, understanding of DSCs is in its early stages (Büyüközkan and Göçer, 2018). Consequently, previous literature has neither organised nor discussed the digital supply chain capabilities (DSCCs) in order to support organisations and the digitalisation of their networks. Furthermore, there is scant current literature that includes frameworks to further understanding and support both scholars and practitioners in rethinking supply chains in the digital age.

Therefore, the question that guides this paper is: what new capabilities are required to support traditional supply chains becoming DSCs? Thus, this study aims to shed light on an unexplored topic in DSCs: “capabilities”. To answer this question, this study draws on literature covering Industry 4.0, supply chain management (SCM) and DSCs. The main objective is to propose a DSCC framework, considering cutting-edge technologies and interactions with human aspects, to support DSC business models.

This paper contributes to advancing the DSC literature, especially in terms of the introduction of DSCCs as a new research stream, and with 13 propositions related to DSCCs. The proposed framework can also provide insights for future research on DSC, as well as providing support to managers, decision-makers and practitioners interested in gaining an in-depth understanding of DSC disruptions.

The rest of this paper is organised as follows: Section 2 presents the theoretical underpinning and literature review, covering Industry 4.0, SCM, the digitalisation phenomena, DSCs and DSCCs. In Section 3, an integrative framework is proposed that describes the main interactions of the DSCCs, considering the basic capabilities and their enabler technologies. Section 4 highlights the main managerial implications, while Section 5 details the theoretical implications. The paper concludes with Section 6, which presents the final remarks, limitations and future research avenues.

2. Theoretical underpinning

2.1 Industry 4.0

Industry 4.0 is a broad term used to refer to the Fourth Industrial Revolution. There is a set of cutting-edge technologies related to Industry 4.0. In this regard, one of the main characteristics of Industry 4.0 is smart applications (Hecklau et al., 2016; Qin et al., 2016), in which objects (products) and machines can interact with each other, supported mainly by the IoT, CPSs, artificial intelligence (AI), big data analytics (BDA), among others technologies (Lee, 2015; Qin et al., 2016; Schumacher et al., 2016). In this vein, it is clear that the components of Industry 4.0 (e.g. machines, objects, vehicles, among others) can make
their own decisions and operates autonomously (Qin et al., 2016). Industry 4.0 has entailed new relationships concerning workers, objects and systems (Hecklau et al., 2016). These relationships have brought great complexity to organisations’ supply chains, mainly in terms of rethinking and redesigning their capabilities in the digital age.

In the Industry 4.0 view, new technologies are affecting traditional supply chains and accelerating the shift towards digitalised supply chains. In this context, the leading technologies affecting the supply chain are, among others: IoT (Bibri, 2018; Kumar et al., 2016); CPSs (Yu et al., 2015; Zhong et al., 2017); BDA (Kache and Seuring, 2017; Strandhagen et al., 2017); cloud computing (CC) (Korpela et al., 2017; Vazquez-Martinez et al., 2018); blockchain (Korpela et al., 2017; Li et al., 2018); and human–robot/machine interaction (Barreto et al., 2017; Oyekan et al., 2017). However, to achieve significant supply chain performance, organisations must develop basic capabilities, considering the digitalisation to use these technologies and their integration with workers, customers and suppliers through the entire supply chain.

Furthermore, organisations’ strategies are impacted by their resources and capabilities (Grant, 1991). In this perspective, and considering the complexities generated by the digital disruption (Kanarachos et al., 2018), all decision-makers and all types of companies are challenged to understand in depth the supply chain capabilities. However, in a digitalisation age, neither decision-makers nor organisations have complete awareness of what their capabilities are or how a set of resources and capabilities can be developed and managed to support global competition. From the supply chain digital-disruption perspective, capabilities cannot be denied as key to supporting performance improvement.

2.2 Supply chain management (SCM)

There is no clear standard definition for the term SCM. Previous studies (LeMay et al., 2017; Lummus and Vokurka, 1999; Mentzer et al., 2001; Stock and Boyer, 2009) have reported scholars’ efforts to establish a well-articulated definition. For instance, Stock and Boyer (2009) compiled 173 SCM definitions in the literature and provided the following definition:

The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction. (Stock and Boyer, 2009, p. 706)

Because of the consideration of “network relationships” in the Stock and Boyer’s definition, we believe that their approach is robust and suitable to understanding the complexities created by the various relationships in the product/service production process. However, their definition neither encapsulates the digital age transformation complexities nor the disruption caused in all SCM. In the next sections, this gap is discussed, and some ideas are suggested to improve SCM digitalisation awareness in a “smooth way”, based on the DSCC approach.

2.3 Digitalisation vs digitisation

The literature awareness about digitalisation is still limited. There is some confusion regarding the difference between the terms digitisation and digitalisation. According to Legner et al. (2017), digitisation refers to the process associated with converting analogue signals (physical activities) into a digital model, while digitalisation refers to the impact of these technologies, caused by adoption and operation, in organisational and societal perspectives. Figure 1 shows the interactions between digitisation and digitalisation concepts.

This study uses these terms interchangeably, although emphasis is given to the digitalisation phenomena. As reported in Figure 1, digitisation is a subset of the digitalisation concept. Therefore, there are capabilities implications for both aspects. For instance, from the digitisation
2.4 Digital supply chain (DSC)

The DSC concept is still developing (Kayikci, 2018). A DSC can be defined as “an intelligent best-fit technological system that is based on the capability of massive data disposal and excellent cooperation and communication for digital hardware, software, and networks to support and synchronize interaction between organizations by making services more valuable, accessible and affordable with consistent, agile and effective outcomes” (Büyüközkan and Göçer, 2018, p. 165). This definition implies a set of ICT resources that organisations have to combine with human resources.

In this context, the digitalisation phenomenon is already disrupting all types of supply networks (Korpela et al., 2017; Li et al., 2016; Srai et al., 2016). Recent studies have highlighted the importance of organisations gaining an in-depth understanding of DSC in various contexts. For instance, Scuotto et al. (2017) studied buyer–supplier relationships utilising ICTs in the service sector to support new partnerships and enhance transactions. From the ICT perspective, and considering the impact on DSCs, Korpela et al. (2017) showed how DSCs can be transformed through blockchain integration. The authors pointed out the security improvements and reduction in transaction costs that organisations applying blockchain technology can achieve.

Based on the automotive supply industry, Farahani et al. (2017) proposed six dimensions for DSCs: digital performance measurement; digital IT and technology; digital suppliers; digital production systems; digital logistics and inventory; and digital customers. One crucial
aspect of DSCs was provided by Büyüközkan and Göçer (2018) in which the DSC impacts product development through providing more information, thus leading to better integration with customers’ needs and enabling efficiency, both upstream and downstream.

The digitalisation process, supported by ICTs (Li et al., 2016; Scuotto et al., 2017), has emerged as a driver in organisations achieving competitive advantage in recent years (Korpela et al., 2017). It can be achieved by the introduction of new business models, thanks to digital technology adoption (Martin-Peña et al., 2018). In this sense, several industries have begun their business digitalisation process, including the retail segment (Hagberg et al., 2016; Plomp and Batenburg, 2010), steel production (Herzog et al., 2017), the food packaging industry (Vanderoost et al., 2017), manufacturing (Freddi, 2018; Strong et al., 2018) and the construction industry (Hautala et al., 2017). As a consequence, organisations have been challenged to develop a set of DSC capabilities to support the digitalisation process gradually, but continuously.

2.5 Digital supply chain capability (DSCC)

Similar to the lack of clarity regarding the DSC concept, the current literature does not yet offer a well-articulated definition to DSCC. DSCC, when highlighted by the literature, is discussed only from fragmented perspectives. For example, Srai et al. (2016) reported the necessity for organisations to develop the infrastructural capability to support DM. Moreover, to help the development of all DSCC capabilities, workers’ capability is mandatory and can be considered as a critical resource. Consequently, supply chain performance can be enhanced by workers’ capabilities management (Gunasekaran et al., 2017).

Based on the current DSC literature, and supported by the Industry 4.0’s main ideas, this study defines DSCC as: “A set of ICT resources that an organisation uses to interact with their network in order to shift physical activities to digital, applied in an integrated form both in physical and digital activities to minimise resource consumption and support productivity improvement, network visibility, and real-time feedback, including tools for custom production and suppliers’ cooperation in all stages of the network, supported by strong data-management techniques and skills”.

This definition implies not only organisations’ internal capabilities development, but also takes into account the importance and impact of the organisations’ capabilities, combined with the supply chain members. The definition of DSCC encapsulates a set of capabilities that is necessary for organisations to develop, maintain, improve and innovate to increase their levels of competitiveness in the digital era.

The level of DSCC competitiveness for any organisation is a function of the internal and external capabilities integration. In this landscape, it is clear that the integration level of the organisations’ basic capabilities with the supply chain members influences the organisation’s supply chain performance. In this perspective, one significant consequence of this integration is highlighted in Figure 2 as “critical digital supply chain integration” (CDSCI). CDSCI is an intersection of the ICTs’ capabilities, workers’ capabilities and stakeholders’ capabilities.

As shown in Figure 2, for organisations to understand their DSCC, there is a previous stage in which three sets of capabilities have to be developed; these dimensions work as a base to support strategies related to their operations, considering the digitalisation benefits and complexities. However, if any dimension has not achieved a mature level of understanding and operationalisation, an imbalance will arise. As a consequence, DSCC runs the risk of not meeting the desired performance levels. To implement DSCC in a balanced way, this paper’s proposed integrative framework maps the primary variables associated with DSCC taking into account the sustainability perspective. That is, organisations need to develop an integrative view of the relationship between the main resources (Sangwan et al., 2018).
3. Methodology

In order to develop a framework, we followed a narrative literature review approach (Secundo et al., 2019). This methodology’s main characteristic is the wide approach to the information sources available and the research question (Christenson et al., 2017). Traditionally, the narrative review of the literature can be used to develop conceptual frameworks and propositions and to consolidate the literature background (Neumann, 2017). Recently, the narrative review of the literature has been used in several fields with different purposes (Apostolakis et al., 2015; Neumann, 2017; Ogbeiwi, 2018; van der Meij et al., 2017). A detailed description of the steps adopted to develop the framework is provided in the following sub-sections.

3.1 Proposing an integrative framework for DSCC

We performed a search on leading databases (i.e. Emerald Insight, ScienceDirect, Taylor & Francis Online and Wiley Online Library), employing the terms “DSC” and “Industry 4.0”. Since our search was “open”, hundreds of articles appeared, and we filtered initially considering the title and, in sequence, the abstract in which the context had an adherence with DSC, Industry 4.0 technologies, or logistics. We considered article papers, proceedings, and book chapters published in English. Because these topics are recent, we did not restrict the search to any specific years.

In order to develop the framework, the following assumptions were considered:

1. Industry 4.0-related technologies are not consolidated yet. Due to the Industry 4.0 technologies recent emergence (Liao et al., 2017), the main technologies are evolving daily. In this regard, there are several challenges. For instance, the ICT infrastructure still not ready to support the companies digital transformation (Xu et al., 2018). Thus, the proposed framework can bring insights about the ICT impact on an organisation’s digital transformation planning.

2. The DSC is in the early stages. Following the disruptive phenomenon of Industry 4.0, DSC is in its first steps of development. Thus, according to Büyüközkön and Göçer (2018), the main challenges associated with the DSC implementation are lack of planning, collaboration, information sharing and integration and wrong demand forecast. Hence, more DSC literature development is urgently needed.
The awareness of digitalisation and digitisation are limited in the SCM. Due to the DSC being a recent approach in SCM, both, scholars and practitioners are in the stage of gaining in-depth concepts to understand and support strategies related to DSC (Büyüközkan and Göçer, 2018).

Figure 3 highlights the approach that supported the emergence of the proposed framework. First, anchored by the Industry 4.0-related literature, we drafted the idea of the DSCC. After that, by employing the DSCC emerging literature, we modelled the final framework containing a set of capabilities and enablers.

Table I shows the capabilities, and the main literature used to derive them. In the same line of thought, Table II points out the literature to support the enablers. Additionally, following Bartnik and Park (2018), this study offers some research propositions that can bring valuable insights both for both academia and practitioners. DSCCs identified in the literature analysis are highlighted in Figure 4.

The basic capabilities of the DSCC framework can be classified as ICT policies, worker policies, supplier integration, customer integration, warehouse capabilities, transportation and smart production. Besides capabilities, our analysis also identified some enablers which support the basic capabilities: BDA; blockchain; AI; CC; CPSs and IoT. The framework provides an overview concerning the importance of the development of the basic capabilities required to survive in a digital era; it also indicates that these basic capabilities require six fundamental enablers that allow high levels of integration with others supply chain members.
3.2 DSCC: basic capabilities

3.2.1 ICT policies. ICT is an essential resource for any DSC strategy. From this perspective, in the digital age, ICTs are fundamental not only to digitising current business models; ICTs’ true impact lies in their contribution to developing new operations models. Consequently, ICTs enable new relationship models (Scuotto et al., 2017) in which all supply chain members can interact with each other faster, improving solving-problem processes and bringing more certain information to support the decision-making process. In the DSCC framework, all basic capabilities interact with each other, and with all enablers. Thus, ICT policies are one of the most important drivers in organisations’ digitalisation. Therefore, this study suggests the following proposition:

P1. Organisations’ ICT policies have a positive influence on their DSCCs and consequently improve supply chain performance.

3.2.2 Worker policies. The human factor is also key to supply chain performance (Gunasekaran et al., 2017), and needs to be managed as a strategic resource (Das and Kodwani, 2018). From a DSC perspective, although a large number of activities may be digitised, talented professionals remain a strategic resource, and the requirement for new human capabilities poses a challenge to organisations’ development. For example, how can companies support data scientists’ development? What is the role of the organisation following job losses resulting from the digitalisation process? As reported in Figure 2, human capabilities (Sivathanu and Pillai, 2018) are an essential resource in supporting DSC integration.

Table I. Capabilities analytical support

<table>
<thead>
<tr>
<th>Capabilities</th>
<th>Derived from</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT policies</td>
<td>Scuotto et al. (2017), Giotopoulos et al. (2017), Bibri and Krogstie (2017),</td>
</tr>
<tr>
<td></td>
<td>Trentesaux et al. (2016)</td>
</tr>
<tr>
<td>Worker policies</td>
<td>Gunasekaran et al. (2017), Sivathanu and Pillai (2018), Waibel et al. (2017),</td>
</tr>
<tr>
<td></td>
<td>Erol et al. (2016)</td>
</tr>
<tr>
<td>Customer integration</td>
<td>Li et al. (2016), Zhong et al. (2017), Kunz et al. (2017), Bhattachariya et al.</td>
</tr>
<tr>
<td>Warehouse capabilities</td>
<td>World Economic Forum (2016b), Lee et al. (2018), Herzog et al. (2018)</td>
</tr>
<tr>
<td>Smart production</td>
<td>Waibel et al. (2017), Davis et al. (2015), Kibira et al. (2016), Hozdić (2015)</td>
</tr>
</tbody>
</table>

Table II. Enablers analytical support

<table>
<thead>
<tr>
<th>Enablers</th>
<th>Derived from</th>
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<tbody>
<tr>
<td>Cloud computing (CC)</td>
<td>Vazquez-Martinez et al. (2018), Wu et al. (2015), Suciu et al. (2016), Caggiano (2018), Hsu et al. (2014)</td>
</tr>
<tr>
<td>Cyber-physical systems (CPS)</td>
<td>Yu et al. (2015), Lee et al. (2015), Zamfirescu et al. (2013), Zhou et al. (2016), Lu and Xu (2018)</td>
</tr>
</tbody>
</table>
Consequently, IT skills is a fundamental capability in DSCs (Waibel et al., 2017). Hence, this study suggests the following proposition:

**P2.** Organisations’ digital policies concerning workers have a positive influence on their DSCCs and consequently improve supply chain performance.

### 3.2.3 Supplier integration

The advent of DSCs has led to new models for organisations’ integration with all their stakeholders in a supply network. According to Korpela et al. (2017), DSCs enable a multi-stakeholder perspective, in which the competition paradigm shifts towards collaboration. In this sense, DSCs enable effective relationships (Scuotto et al., 2017) and increased transparency and security in transactions (Korpela et al., 2017). Also, organisations’ integration with suppliers is fundamental to value co-creation (Jääskeläinen and Thitz, 2018). Therefore, this study suggests the following proposition:

**P3.** Organisations’ digital integration with suppliers has a positive influence on their DSCCs and consequently improves supply chain performance.

### 3.2.4 Customer integration

Similar to the supplier integration (Yu, 2015), DSCs enable new forms of customer integration and relationships. DSCs promote not only more information about the customers; the most important thing is the increased accuracy of this information (Büyüközkan and Göçer, 2018) thanks to smart-technology adoption. Consequently, DSCs entail smart connections between organisations and their customers (Li et al., 2016). Furthermore, customer integration remains a vital subject related to organisations’ performance (Afshan and Motwani, 2018). Hence, the current production paradigms are already being disrupted. Thus, this study proposes:

**P4.** Organisations’ digital integration with customers has a positive influence on their DSCCs and consequently improves supply chain performance.

### 3.2.5 Warehouse capabilities

Warehouse capabilities is a significant resource in any DSC strategy. Shared warehouses (World Economic Forum, 2016b) used in a smart-asset perspective will be increasingly available thanks to the digitalisation paradigm. With the intense use of augmented reality (Masoni et al., 2017) and virtual reality, DSCs are enabling a new generation of smart warehouses. The virtual picking activity is already a reality, utilising, for example, QR codes and smart glasses. With virtual reality, workers’ training can be more efficient.
Also, virtual reality enables the simulation of warehouse operations and enables interaction in real-time with the supply network. Therefore, this study proposes:

\[ P_5 \] Digitisation of the warehouse has a positive influence on organisations’ DSCCs and consequently improves supply chain performance.

3.2.6 Transportation. Transportation is one of the most traditional fields of logistics and SCM. From a DSCC perspective, transportation is now reshaping business models (Van Brummelen et al., 2018). For instance, with shared capabilities (World Economic Forum, 2016b), network transportation will utilise resources more efficiently. Regarding internal transportation, autonomous guided vehicles (AGVs) (Stock and Seliger, 2016) has shifting the transportation activities from manual to smart. Moreover, autonomous vehicles such as trucks and drones (World Economic Forum, 2016b) are enabling new capabilities for transportation. Hence, this study suggests the following proposition:

\[ P_6 \] The digitisation of transportation activities has a positive influence on organisations’ DSCCs and consequently improves supply chain performance.

3.2.7 Smart production. In a DSCC framework, smart production systems (SPS) can control and monitor the entire products lifecycle (Davis et al., 2015; Kibira et al., 2016). These capabilities can transform traditional products into smart products (Savarino et al., 2018), for which the entire lifecycle can be managed (Erol et al., 2016; Stock and Seliger, 2016). In this sense, the production systems will be more responsive, implying real-time decisions, according to demand patterns. Supported mainly by IoT (Bibri, 2018) and CPSs (Zhong et al., 2017), machines and various smart connected objects can make their own decisions (Lee, 2015). However, with the increase in decentralised manufacturing (Kohtala, 2015), traditional production systems are now challenged to meet smaller manufacturing demands at various locations (Srai et al., 2016). Therefore, this study suggests the following proposition:

\[ P_7 \] The digitisation of production system activities has a positive influence on organisations’ DSCCs and consequently improves supply chain performance.

3.3 Enabler technologies

This study also identified six main enabler technologies of the basic capabilities to support a traditional supply chain becoming a DSC. Although we have identified several DSC enablers in the literature, we have only selected those enabler technologies identified as having relationship with DSCCs, namely BDA, blockchain, AI, CC, CPSs and IoT (Büyüközkan and Göçer, 2018; Ivanov et al., 2019).

These technologies can be considered as enablers of DSCCs due to their influence in the digitalisation process. For instance, BDA has been shown to improve firms’ performance and competitive advantage (Akter et al., 2016; Wamba et al., 2017); Blockchain in supply chains (Queiroz and Fosso Wamba, 2019; Queiroz et al., 2019) has been provoking disruptive change given in intra- and inter-organisational contexts; regarding interaction between AI and workers, several organisations believe in its potential and are investing large amounts of money. However, we believe that there is a critical and unexplored issue regarding this relationship, namely that CC services is a critical enabler due to its ability to integrate resources in the digitalisation context, enabling a more accurate monitoring of companies’ internal activities and their SCM network (Porter and Heppelmann, 2014). In the Industry 4.0 era, CPS have an essential function of integrating the systems and the physical infrastructure (Wang et al., 2016).

In the DSC context, we consider these systems as a fundamental enabler because of the various interactions between smart objects. The final enabler identified in this study was IoT, which is of great importance, especially in providing feedback (Büyüközkan and Göçer, 2018).
terms of the (smart) product’s information and, consequently, contributing to continuous improvement in organisations. In the following sub-sections, we provide a detailed description of these technologies.

3.3.1 Big data analytics (BDA) policies. In a DSC age, data are one of the most critical assets. Because of this, techniques for data storage, management and analysis represent a fundamental DSCC. Recent literature regarding big data (Phillips-Wren and Hoskisson, 2015) and BDA capabilities (BDAC) has achieved a significant maturity level (Akter et al., 2016; Gupta and George, 2016; Jeble et al., 2018; Wamba et al., 2017). In this context, previous studies have demonstrated the positive impact of BDAC on firm performance (Akter et al., 2016; Wamba et al., 2017). BDA is conceptualised viewed in a 5V’s perspective (volume, velocity, variety, veracity and value) (Queiroz and Telles, 2018; Verma and Singh, 2017; Wamba et al., 2017). Therefore, for an organisation to create value, DSCCs must collect and analyse data in as short a time as possible, although, for the most organisations, analysing all data generated by their supply network in real-time may seem like a Utopian dream. Thus, this study proposes the following:

P8. Organisations’ BDA policies have a positive influence on their DSCCs and consequently improve supply chain performance.

3.3.2 Blockchain-related policies. The blockchain is disrupting all traditional business models (Scott et al., 2017). Based on the disintermediation process, costs minimisation and process efficiency are transforming organisations and their traditional business models (Wang et al., 2019; Queiroz et al., 2019). Blockchain technology refers to a distributed digital ledger (Al-Saqaf and Seidler, 2017) in which all transactions are shared within a tamper-proof network, i.e. the transactions cannot be modified. The blockchain is transforming the traceability of goods (Wu et al., 2017) and improving anti-counterfeiting measures (Toyoda et al., 2017). Another blockchain application is smart contracts. With smart contracts, supply networks can be more agile, responsive and more economical, due to disintermediation. Because of this, several industries have been incorporating blockchain in their DSC strategies. Hence, this study proposes the following:

P9. Organisations’ blockchain-related policies have a positive influence on their DSCCs and consequently improve supply chain performance.

3.3.3 Artificial intelligence (AI) and interaction with workers. According to the Oxford English Dictionary, AI refers to “The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages”. In the context of this paper, this means machines learning autonomously and behaving similarly to humans. However, in terms of DSCCs, skilled workers continue to be a critical and scarce resource. Recently, Barreto et al. (2017) highlighted the societal transformation caused by Industry 4.0 and the necessity of organisations rethinking their processes, considering human–machine integration and interaction. In this context, Oyekan et al. (2017) proposed a method of real-time manufacturing collaboration involving various teams at various locations. The method can enable organisations to digitise human activities. Consequently, world-class, real-time manufacturing will be a reality in the coming years (Oyekan et al., 2017). It is a significant disruption associated with production systems environment, reflecting how organisations must rethink and optimise collaboration between workers and machines. Thus, a worker in a DSC is continuously challenged to develop new skills, as IT capabilities (Waibel et al., 2017). Thus, this study suggests the following proposition:

P10. The degree of the interaction between workers and AI can bring positive outcomes on organisations’ DSCCs and consequently improve supply chain performance.
### 3.3.4 Cloud computing (CC)

CC refers to outsourcing services associated with information data management, including a large amount of data transactions generated by products and services (Vazquez-Martinez et al., 2018). From this perspective, it can be seen that CC is a critical resource for any organisation, since, in a DSC environment, all process and products have to be smart. Additionally, previous capabilities as BDA, IoT and CPSs require much integration with CC services, including exchanging data over the supply network. Because of this, CC has to offer high levels of integration throughout the entire product lifecycle. From the production systems’ perspective, CC enables manufacturing-on-demand production in the value chain (Li et al., 2018; Yu et al., 2015). Furthermore, CC can support more control, both internally and throughout the network (Porter and Heppelmann, 2014) via remote monitoring. Thus, safety levels can be enhanced by smart and decentralised maintenance (Waibel et al., 2017); it is also expected that cloud integration will improve cost optimisation in DSCs (Korpela et al., 2017). Therefore, this study proposes the following:

**P11.** Organisations’ CC policies have a positive influence on their DSCCs and consequently improve supply chain performance.

### 3.3.5 Cyber-physical system (CPS) policies

A CPS refers to the infrastructure that integrates both physical and cyber components. Thus, CPSs provide a network infrastructure with embedded devices (sensors) that can self-manage their operations process and feedback with the physical world (Wang et al., 2016). Due to smart objects and machines, CPSs can exchange information. Consequently, CPSs and IoT applications have great synergy. In a DSCC context, CPSs represent a crucial capability for organisations to enhance control and monitoring operations. For instance, AGVs in various production systems is a standard CPS application, in which it performs a set of jobs in a particular network, interacting with the physical environment and with the cyber world. Therefore, a SPS, also known as smart factory, with CPS capabilities can connect different objects, machines, and conveyors (Erol et al., 2016; Lee, 2015) with the IoT. In addition, for CPSs to achieve high levels of production, incorporating improvements to safety and information sharing over the supply network, a CC capability is mandatory for support the processes and operations. Hence, this study proposes the following:

**P12.** Organisations’ CPS policies have a positive influence on their DSCCs and consequently improve supply chain performance.

### 3.3.6 Internet of Things (IoT) policies

Literature regarding IoT in the capabilities context is scarce. The IoT enables a set of objects to communicate with each other, without human interaction. Consequently, traditional production systems can shift to a SPS. In this context, SPS capabilities can optimise a set of resources because the products that are manufactured are also smart. Consequently, products and services have information (Büyüközkan and Göçer, 2018), not only to optimise their production, planning and control from an internal perspective, but also including feedback throughout the supply network covering the entire product lifecycle. IoT capabilities also enhance production safety because of the reduction in human interactions (Suciu et al., 2016). According to the DSCC framework, as many tasks as possible should be performed using IoT or a combination of human–IoT interaction to improve DSCC performance. Thus, this study proposes the following:

**P13.** Organisations’ IoT policies have a positive influence on their DSCCs and consequently improve supply chain performance.

### 4. Managerial and practical implications

From a practical perspective, the proposed DSCC framework can bring essential managerial insights for practitioners and decision-makers, as well as anyone involved in the process or
interested in gaining a more in-depth understanding of the digitalisation phenomena. The DSCC framework highlights seven basic DSC capabilities and six enabler technologies that interact and support these capabilities. Thus, it offers impactful, practical implications to practitioners and decision-makers. For instance, managers need to recognise which are their DSCCs required to operate in order to achieve improved performance and how these capabilities integrate with their network. Thus, the framework provides a valuable managerial contribution, in which organisations need to understanding in-depth their internal resources and how it could be integrated with external partners. Thus, the framework provides a valuable managerial contribution, as may help managers and organisations to develop an in-depth understanding of their internal resources and how it could be integrated with their external partners.

Moreover, the DSCC framework points out that in the digital age era, managers are challenged constantly to improve their awareness of these cutting-edge technologies, in order to facilitate the adoption, implementation, and diffusion of the main technologies that support our DSC in the SCM. In addition, since we highlighted the seven capabilities as “basic capabilities”, managers need to understand the needs to incorporate other cutting-edge technologies harmoniously.

Thus, managers and practitioners should concern the need to understand the dynamics and complexities (e.g. barriers and facilitators) involved in supply chain digitalisation adoption. That is, a critical aspect is regarding the lack of decision-makers’ awareness at the digital disruption age, related to resources, capabilities, technologies and its integration. In this context, the DSCC framework contributes to shedding light on the business digitalisation phenomena for all practitioners and highlights the necessity to remodel traditional business models.

Also, supply chain digitalisation needs a high-level integration of organisations’ internal capabilities and those of their supply chain members. Consequently, decision-makers are challenged to develop these capabilities in an optimised way. Although the framework depicts the main capabilities that interact in a DSC, decision-makers have to consider the organisation’s culture complexities when shifting their traditional business model to a digitalised model. For example, workers’ resistance to adoption can arise at various stages of the process. Besides, the proposed framework represents a valuable tool that can help organisations generate insights and develop their supply chain digitalisation plan; however, for the project to be successful, the organisation’s framework needs to integrate with their network. Additionally, managers have to consider the costs and risks associated with a digitalisation project.

Besides, from an Industry 4.0 perspective (Hecklau et al., 2016; Qin et al., 2016), the framework emphasises that production systems are shifting towards a small production scale in different nodes of the network. Consequently, digital capabilities in production systems are essential for monitoring production in different locations. Ultimately, the final implication is derived from the fact that the workers’ capabilities gap can negatively impact a DSC project in term so of making it more expensive and, consequently, not achieving the expected performance. In order to avoid this, it is suggested that organisations, prior to initiating a DSC project, must develop a deeper understanding of the role of the “digital” workers and their required capabilities.

In summary, from a practical perspective, the proposed framework can provide insights for the supply chain digitalisation process. DSCCs, with their enablers identified, have important practical implications for supply chain digitalisation and digital transformation projects. We believe that the proposed framework can be a good starting point for managers, consultants, and practitioners involved in supply chain digitalisation projects. Moreover, the DSCC framework can be improved in the interaction between supply chain members and adapted to the reality of a specific organisation’s needs and capabilities.
5. Theoretical implications
This study has important theoretical implications for scholars interested in the digitalisation phenomena in organisations and supply networks (Büyüközkan and Göçer, 2018). The first significant implication concerns the opportunity to shed light on the discussion regarding DSCC practices. Considering the recent influential literature in digitalisation (Büyüközkan and Göçer, 2018; Legner et al., 2017), our study provides significant a contribution by proposing a rational vision of the digital transformation process and capabilities in the SCM field. Furthermore, supported by previous studies (Büyüközkan and Göçer, 2018; Kayikci, 2018; Legner et al., 2017), we have developed the concept and framework of DSCCs and their respective enablers. To the best of our knowledge, this is the first attempt to formalise the DSCC concept. In this view, it represents an important contribution to theory.

Second, this study argues that, to better understand DSCCs, an in-depth understanding of organisations’ internal capabilities and their relationships with supply chain members is mandatory. In this regard, previous literature has highlighted only the buyer–supplier relationships, with ICTs aiding and supporting improvements in these transactions (Scuotto et al., 2017). Therefore, our study significantly expands on the importance of ICTs within the SCM field.

Third, the CDSCI (see Figure 2) introduces to the DSC literature the necessity of organisations considering CDSCI as a success factor. Fourth, this paper introduces to the literature a robust framework that integrates cutting-edge technologies to gain an in-depth understanding of DSC complexities and, more specifically, to generate insights for scholars in terms of rethinking the necessity of organisations developing new business models and, consequently, the necessity to understand, develop, monitor and control these new capabilities. In this context, the DSCC framework represents a starting point for scholars and academics in the general advancement of the DSCC literature.

The fifth and final implication is related to the 13 propositions related to the framework. The DSCC framework, anchored in the emerging DSC and Industry 4.0 literature, presents several opportunities for scholars and practitioners to empirically test it in various scenarios (e.g. emerging and developed countries, small, medium and large organisations, etc.). Table III presents a summary of the propositions.

6. Final remarks and future research
This study has proposed a framework to shed light on DSCCs in response to rethinking supply chain complexities in the age of digitalisation. This study contributes to the literature and is also of benefit to practitioners, generating insights into the decision-making process by developing a robust framework (DSCC) to improve the awareness of all involved in the business digitalisation phenomena. Additionally, the DSCC framework emphasises that, in the digital age, organisations must make significant efforts to integrate their capabilities with their supply chain members. This implies that, if organisations focus only on internal capabilities development, this will likely result in an unbalanced DSC that, consequently, will not achieve the desired performance. Although DSCs involve significant digitalisation of physical activities, ICTs can be viewed as a critical (resource) enabler technologies (Scuotto et al., 2017), implying that organisations need to develop policies to ensure and provide the necessary (key) resources. In this regard, the framework highlights that, for a DSC project be successful; the human factor (Gunasekaran et al., 2017) remains as the leading resource. Because of this, the study suggests that organisations begin DSC projects by fist considering the human capabilities requirements. Moreover, the propositions of this study bring a relevant contribution to the theory and practice, as also have the potential to unlock the DSCC research stream.

Whilst this study makes significant academic and practical contributions, there are some limitations that future studies can address. The first is related to the fact that the DSCC
framework has not yet been tested. Future studies have the opportunity to develop and implement a conceptual model to test this framework empirically. Second, the proposed framework does not consider the particular characteristics of the organisations that operate in emerging and developed countries. Thereafter, scholars can expand the framework by considering supply network differences in these countries. Third, the study does not discuss the barriers to adoption related to the capabilities that comprise the DSCC framework. Also, our work deals only technological enablers approach.

Researchers can, therefore, aim to identify these barriers to support the framework’s adoption. Finally, it would be a valuable contribution to the literature if the critical success factors (Kumar and Singh, 2018) in DSC projects and their relationship with the DSCC framework could be identified.

<table>
<thead>
<tr>
<th>Proposition</th>
<th>Description</th>
<th>Adapted from</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Organisations’ ICT policies have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Scuotto et al. (2017)</td>
</tr>
<tr>
<td>P2</td>
<td>Organisations’ digital policies concerning workers have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Gunasekaran et al. (2017), Waibel et al. (2017)</td>
</tr>
<tr>
<td>P3</td>
<td>Organisations’ digital integration with suppliers has a positive influence on their DSCCs and consequently improves supply chain performance</td>
<td>Korpela et al., (2017), Scuotto et al. (2017)</td>
</tr>
<tr>
<td>P4</td>
<td>Organisations’ digital integration with customers has a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Li et al. (2016)</td>
</tr>
<tr>
<td>P5</td>
<td>Digitisation of the warehouse has a positive influence on organisations’ DSCCs and consequently improves supply chain performance</td>
<td>World Economic Forum (2016b)</td>
</tr>
<tr>
<td>P6</td>
<td>The digitisation of transportation activities has a positive influence on organisations’ DSCCs and consequently improves supply chain performance</td>
<td>Stock and Seliger (2016), World Economic Forum (2016b)</td>
</tr>
<tr>
<td>P7</td>
<td>The digitisation of production system activities has a positive influence on organisations’ DSCCs and consequently improves supply chain performance</td>
<td>Davis et al. (2015), Kibira et al. (2016), Lee (2015), Srai et al. (2016)</td>
</tr>
<tr>
<td>P8</td>
<td>Organisations’ BDA policies have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Queiroz and Telles (2018), Wamba et al. (2017)</td>
</tr>
<tr>
<td>P9</td>
<td>Organisations’ blockchain-related policies have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Akter et al. (2016), Al-Saqaf and Seidler (2017), Scott et al. (2017), Wu et al. (2017)</td>
</tr>
<tr>
<td>P10</td>
<td>The degree of the interaction between workers and robots can bring positive outcomes on organisations’ DSCCs and consequently improve supply chain performance</td>
<td>Barreto et al. (2017), Oyekan et al. (2017)</td>
</tr>
<tr>
<td>P11</td>
<td>Organisations’ cloud computing (CC) policies have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Li et al. (2018), Vazquez-Martinez et al. (2018), Yu et al. (2015)</td>
</tr>
<tr>
<td>P12</td>
<td>Organisations’ cyber-physical system (CPS) policies have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Erol et al. (2016), Lee (2015), Wang et al. (2016)</td>
</tr>
<tr>
<td>P13</td>
<td>Organisations’ Internet of Things (IoT) policies have a positive influence on their DSCCs and consequently improve supply chain performance</td>
<td>Suciu et al. (2016)</td>
</tr>
</tbody>
</table>

**Note:** DSCCs, digital supply chain capabilities

Table III. Summary of the propositions

Industry 4.0 and DSCCs
References


Industry 4.0 and DSCCs


Further reading


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