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The adoption of digital technologies in supply chains: Drivers, process and impact

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ABSTRACT

Digital technologies have been extensively studied in academic research and industry. However, little is known about the adoption of digital technologies in manufacturing firms at a supply chain level. This paper aims to understand *why* and *how* manufacturing firms adopt digital technologies, and the *impact* of the adoption on supply chains. The study uses literature review method, identifies the main drivers of manufacturing firms adopting digital technologies (*why*), develops a new model of the adoption process (*how*), and synthesizes the impact of the adoption on supply chains into four aspects (*what*): supply chain efficiency, supply chain structure, sustainability and innovation. The paper then proposes a conceptual framework consisting of *driver, process* and *impact*, and discusses their inter-relationships. The study identifies that the technological intelligence and supply chain cooperation are two important factors and proposes a two-dimentional levels of adopting digital technologies according to their low-to-high degrees. The proposed framework, in particular the levels of digital technology adoption, are novel to the existing literature. Each of the three parts of the framework and their inter-relationships lays a foundation for further empirical studies in this field. This study also provides guidance for practitioners adopting digital technologies for supply chain management and developing appropriate business strategies at different digitalization levels.

1. Introduction

The adoption of digital technologies in manufacturing becomes increasingly important in the current global business environment. In the last decade, manufacturing firms have been exploring how to use emerging digital technologies, e.g., Internet of Things (IoT), big data analytics (BDA), and artificial intelligence (AI), in their production and supply chain management (SCM) (Addo-Tenkorang and Helo, 2016; Caputo et al., 2016). SCM includes the control, management and improvement of the flows of materials and information between the initial suppliers and end users through a network of connected organisations (Christopher 2016). These technologies are seen as promising means to improve supply chain functions, such as procurement, logistics, scheduling and planning (Arunachalam et al., 2018). IoT has been extensively applied in factories and transportations to monitor the production process, and track and trace the logistics and warehouse operations (Hopkins and Hawking, 2018; Caro and Sadr, 2019). The real-time data collected from the IoT devices, combined with the data from other supply chain processes, has the potential to generate significant business value through the application of BDA and AI (Kache and Seuring, 2015). It could help firms better forecast customer demands, reveal the inventory problems, optimise resource allocation, and manage suppliers' relationships. These emerging digital technologies are not only changing the products and process, but also modifying value chains, renovating business models, and affecting the industrial structures (Ceipek et al., 2020).

There is a growing research interest in the adoption of digital technologies in manufacturing firms at a supply chain level (Hazen et al., 2016). In general, existing studies have shown that digital technologies can help firms improve their supply chain performance by enhancing efficiency (Govindan et al., 2018; Yu et al., 2018), visibility (Arya et al., 2017; Gunasekaran et al., 2017; Kache and Seuring, 2017), resilience (da Silva et al., 2018) and robustness (Brandon-Jones et al., 2014), as well as reduce supply chain risks (Büyüközkan and Göçer, 2018; Khan et al., 2019) and supply uncertainties (Bag, 2017). The digitalisation of supply chains produces large volumes of data, which is regarded as a new kind of resource and has the potential to create value and enhance competitiveness. This could affect firms' business models and change

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the ways how firms create and capture value (D'lppolito et al., 2019; Chan et al., 2018; Hänninen et al., 2018). Research has also shown that digital technologies have transformed the traditional ways of managing supply chains towards more data-driven approaches (Singh and El-Kassar, 2019; Waller and Fawcett, 2013). Manufacturing firms are putting more focus on how to use supply chain data to predict market demand, provide predictive maintenance and optimise production and logistics (Arunachalam et al., 2018). This requires a much higher level of data analytic skills and capabilities compared to the traditional SCM.

However, the adoption of digital technologies does not always succeed (Correani et al., 2020). Many manufacturing firms put large investments into digital transformation, but failed to deliver the expected business value (Rai, 2000). The failure is often caused by the disconnection between the strategy formulation and implementation (Correani et al., 2020). Inappropriate adoption of digital technologies may result in disruptive change that leads to high risk and uncertainty during the transformation. Some researchers pointed out that digital manufacturing could change the structure of supply chains from centralised production model to distributed model (Holmström and Partanen, 2014). This usually greatly shortens the supply chain, resulting in the potential risks to other players within the supply chain as they also need to quickly adapt to this disruptive change.

The adoption of digital technology is significantly affected by the technological, organisational and environmental factors (Yadegaridehkordi et al., 2018). Therefore, before adopting any technologies, it is essential for firms to understand its purposes and the assess these factors, analyse what might happen in the process and how each process might affect the supply chain. In other words, firms need to start with analysing "why" (representing the drivers, purposes and motives), followed by "how" (representing the processes or methods) and "what" (representing the impacts, outcomes or results). Despite the growing research interests in the area, the current understanding of these three layers (i.e., why, how and what) of adopting digital technologies in supply chain is still limited. Managers are still facing challenges of aligning their implementation processes with their drivers in order to achieve the expected outcomes of adopting the digital technologies. Therefore, this paper aims to investigate this phenomenon by answering the following three research questions (RQ).

RQ1: *Why* do manufacturers adopt digital technologies in supply chains?
RQ2: *How* do manufacturers adopt digital technologies in supply chains?
RQ3: *What* is the impact of digital technology adoption on supply chains?

We use a systematic literature review method to investigate these questions. This paper is structured as follows. First, the process of the method used in this research is introduced. Second, a descriptive analysis of the literature in this field is provided. Third, the findings and answers to the three research questions are presented, followed by the development of a conceptual framework of the adoption of digital technologies in supply chains. Each part of the framework is discussed. The theoretical and practical implications, limitations and the areas for future research are addressed.

2. Methodology

This study uses a systematic literature review on the academic papers related to digital technology adoption in supply chains. The reason for using this method is that the existing studies on the research questions have separately developed from specific cases or survey studies, and a systematic literature review of these studies can offer an overview on this topic, identify the patterns of drivers, adoption process, and provide scientific insights into the impact of the adoption.

2.1. Systematic literature review approach

This research follows four steps to conduct the systematic literature review method: *identification of research scope, selection of studies, literature analysis*, and *synthesis* (Tranfield et al., 2003). Each step was recorded to ensure a transparent and replicable process.

The first step is the *identification of research scope* (Tranfield et al., 2003). Considering that "digital technologies" is a broad term and could include all technologies with digital elements, we decided that this paper only focuses on three emerging digital technologies in the context of manufacturing: IoT, big data and AI. This means that the scope of the literature review neither include some other emerging digital technologies (e.g., blockchain and virtual reality), nor the traditional information technologies (e.g., ERP, CAD, CAPP). The reasons are that IoT, big data and AI are regarded as one of the most important sets of digital technologies in manufacturing sector (The McKinsey Global Institute, 2013). The main function of IoT is to generate, connect and store real-time data. Big data analytics is used to analyse the large volume of data generated from IoT devices and other sources. AI is used to provide predictive and preventive functions of data analysis through learning algorithms. amongst the three, IoT and AI are most often associated with Industry 4.0 (Florian and Abubaker, 2018; Bag et al., 2018), and big data analytics is highly connected to them because the collected data from IoT devices need to be analysed. Wherever IoT is applied, there is the potential for massive amounts of data to be generated (Büyüközkan and Göçer, 2018). The data should be analysed with efficient data analytic methods in order to be useful for business, and the application of AI can contribute to the predictive and prescriptive purposes.

The second step is the *selection of studies* (Tranfield et al., 2003). Following the common practice of most review studies (Addo-Tenkorang and Helo, 2016; Manavalan and Jayakrishna, 2019), our search was limited to peer-reviewed English journal papers. In order to identify all possible articles related to digital technologies in supply chains, our search strings include any combinations of "digit*" OR "Internet of Things" OR "IoT" OR "Big data" OR "artificial intelligence" OR "AI" OR "industry 4.0″ and "supply chain" or ""SCM" or "supply network". We used the keyword "digit*" to fetch all possible results including the keywords of "digit", "digital" and "digitalization".

We applied the search strings to the titles and abstracts in the following databases: EBSCOhost, Scopus, Emerald, ScienceDirect, and Web of Science. These databases were chosen because they are widely used in academic review studies and have a multi-disciplinary scope (Graham et al., 2015). We did not apply restrictions on time and journals in this step, in order to include all possible studies into our list. The latest search was done in March 2019. The paper selection process is shown in Fig. 1. We aggregated all results into a list of 3085 papers. After deleting duplicated results, the number of papers was reduced to 1639.

We then developed the inclusion and exclusion criteria to narrow down the selection of studies. In order to reduce bias, more than one reviewer decided the inclusion and exclusion criteria (Tranfield et al., 2003). First of all, we only considered articles with a management focus, and excluded the pure technical papers on technical problems, such as optimization and algorithm development. Second, the studies need to address both digital technologies and supply chain management. Papers only focusing on one single stage of the supply chain were excluded. Furthermore, the studies need to address one or several specific digital technologies amongst IoT, big data and AI. We reviewed the titles and abstracts of the 1639 papers according to the criterion. After this procedure, 252 papers remained.

The next step is *literature analysis* (Tranfield et al., 2003). We read the 252 papers in detail, analysed the main ideas in each paper and further selected 128 papers within the research scope. We carefully evaluated the 128 papers and selected the ones which address at least one of the three research questions. All authors conducted this stage in order to reduce the bias of the paper selection. We also considered the quality of the papers to ensure the reliability of the review. According to the

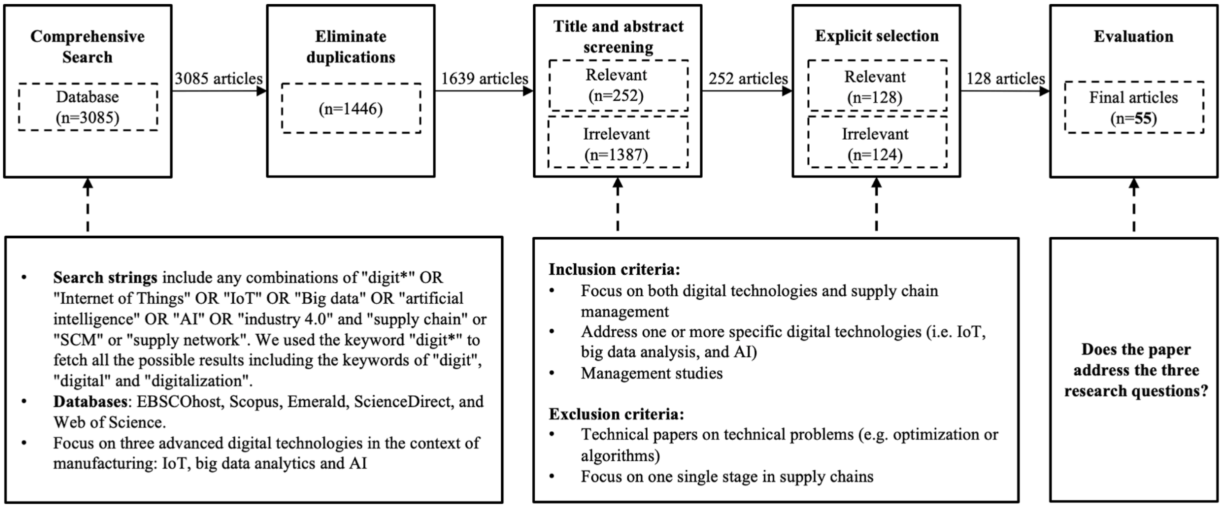

Fig. 1. Literature review paper selection process.

criterion and the relevance to the three research questions, we finally selected 55 selected papers to implement this study.

2.2. Descriptive analysis

The adoption of digital technologies in SCM is an emerging research topic. All the papers selected were published after 2005, and mostly between 2015 and 2019 (up to March 2019).

Fig. 2 shows the distribution of the selected papers by their year of publication. Before 2015, there was less than three papers published per year on this topic. The number of publications only increased since 2015, and a large number of papers were found between the period of 2017 and 2018, including twenty papers in 2017 and eleven in 2018. Since the final search was conducted in March 2019, only four paper published in 2019 were selected.

The 55 papers are distributed in 38 journals, shown in Table 1. It shows that there is not a dominating journal on this topic. The top 5 contributing journals are *Industrial Management & Data Systems* (5 papers), *Supply Chain Management: An International Journal* (5 papers), *Technological Forecasting and Social Change* (4 papers), *International Journal of Logistics: Research & Applications* (3 papers) and *Benchmarking: An International Journal* (3 papers). The top authors include Gunasekaran, Papadopoulos, Wamba, Childe and Dubey.

The research methods used in the selected papers were analysed (shown in Fig. 3). It shows that case study and survey are the most used methods, followed by literature review, conceptual study and other methods, such as Delphi, DEMATEL and ANFIS. There are three papers using mixed methods of literature review and case study. We found that papers before 2014 were mainly empirical studies, and the conceptual studies emerged and increased from 2014 to 2019.

We also analysed the theories addressed in the papers, shown in Table 2. The resource-based view is the most used theory, followed by dynamic capabilities, network theory, system theory, and transaction cost theory. It is worth noting that amongst the selected 55 papers, only 22 of them discussed their studies from theoretical perspective. It indicates that more theoretical studies are required in the field.

3. Thematic findings

We used content analysis on the selected papers to investigate the three research questions. This section presents our thematic findings.

3.1. Why do the manufacturers adopt digital technologies (RQ1)?

It is important to understand what drives manufacturers to adopt digital technologies, as the drivers could significantly influence the adoption behaviour and outcomes (de Vass et al., 2018; Fernando et al., 2018; Hänninen et al., 2018). It is also essential for firms to align the actual adoption activities with the drivers, so that the outcomes could better align with the initial business objectives (Correani et al., 2020).

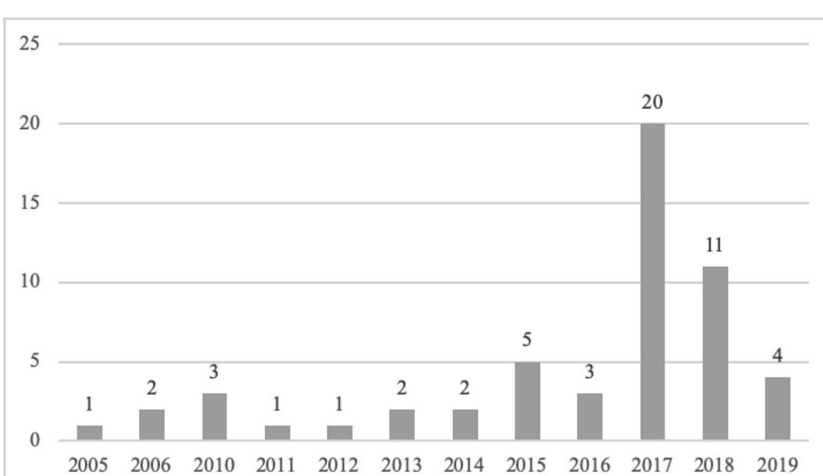

Fig. 2. Distribution of papers by publication year.

Table 1
Distribution of papers by journals.

Journal	No. of articles
Industrial Management & Data Systems	5
Supply Chain Management: An International Journal	5
Technological Forecasting and Social Change	4
Benchmarking: An International Journal	3
International Journal of Logistics: Research & Applications	3
The International Journal of Logistics Management	2
Transportation Research Part E: Logistics and Transportation Review	2
Baltic Journal of Management	1
Business Horizons	1
Business Process Management Journal	1
Computers and Electronics in Agriculture	1
Computers in Industry	1
Decision Support Systems	1
Electronic Market	1
Engineering	1
Food Control	1
Industrial Marketing Management	1
Information Technology & Management	1
International Journal of Advanced Manufacturing Technology	1
International Journal of Computer Integrated Manufacturing	1
International Journal of Information Systems and Supply Chain Management	1
International Journal of Operations & Production Management	1
International Journal of Production Economics	1
International Journal of RF Technologies	1
Journal of Business Logistics	1
Journal of Business Research	1
Journal of Cleaner Production	1
Journal of Management Information Systems	1
Journal of Marketing Management	1
Journal of Systems and Information Technology	1
LogForum	1
MIS Quarterly	1
Organization Science	1
Production Planning & Control	1
Production Planning and Control	1
Waste Management	1
International Journal of Information Management	1
Journal of Transport and Supply Chain Management	1
Industrial Management & Data Systems	5
Total	55

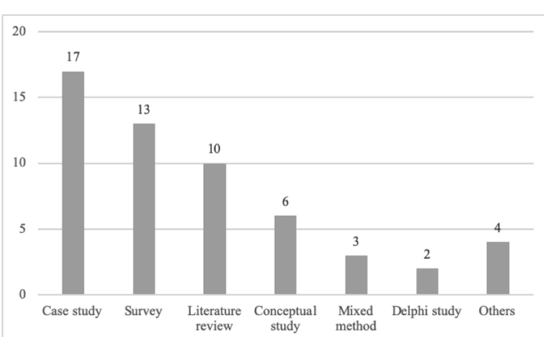

Fig. 3. Distribution of papers by research methods.

amongst the 55 papers, 14 papers mentioned about the factors driving manufacturers to adopt digital technologies. We analysed these drivers and categorised them into two types (i.e., internal and external) and five aspects (i.e., operational, strategic, customer, supplier or supply chain partner, and competition), as shown in Table 3.

3.1.1. Internal drivers

Operational. The adoption of digital technologies in manufacturing firms is largely driven by internal operational problems, or for the purpose of improving operational performance (Accorsi et al., 2018; Gunasekaran et al., 2018). In the highly globalised world, supply chains become more complex and new operational problems are arising. It is no longer efficient to rely on manual work due to the complexity of operations and the increasing cost of labour. There is a greater need for cutting down the cost and improving efficiency in procurement, production, warehousing and logistics than before (Bienhaus and Haddud, 2018). Many manufacturing firms have been exploring how to use faster, more accurate digital management systems to replace the traditional, inefficient management method (Baruffaldi et al., 2019); as well as how to use the IoT and biga data to facilitate lean and agile activities in operations and supply chains. The operational problems and objectives are usually clear. The adoption process is therefore a bottom-up, problem-solving approach, normally including problem identification, target setting, digital solution development, implementation, feedback, and adjustment.

Table 2
Distribution of papers by theories.

Theory	No. of articles
Resource based view	12
Dynamic capabilities	5
Network theory	4
System theory	4
transaction cost theory	3
behavioural decision theory	1
Contingency theory	1
Dual-process theory	1
Evolutionary-technological theory	1
Organizational information processing theory	1

Strategic. The adoption of digital technologies is also largely driven by strategic directions. Internet firms, e.g., Amazon, Alibaba and Google, are the pioneers in using digital technologies to innovate their business models (Hänninen et al., 2018). Influenced by this, many manufacturing firms are actively developing digital strategies as part of their core business directions. They believe that adopting digital technologies has the potential to trigger both incremental and disruptive innovation (Chavez et al., 2017; Moretto et al., 2017; Ranganathan et al., 2011; Reeves et al., 2011). Some firms adopt digital technologies for their future product development (Søgaard et al., 2019), or as part of their sustainability strategy (Garcia-Muiña et al., 2018).

The two drivers may have different influences on the digital technology adoption process and outcomes. The operational drivers are straightforward, usually resulting in a measurable problem-solving approach as adoption process. Compared to operational drivers, the strategic drivers tend to be more ambiguous and uncertain, leading to a more top-down, proactive process rather than a bottom-up, reactive process (Raisinghani and Meade, 2005). Moreover, the adoption process usually involves the changes in the workflow and business process, which might cause internal resistance (Büyüközkan and Göçer, 2018; Chong and Chan, 2012). The process of this kind of adoption will face more uncertainty and might result in failing to achieve the expected outcome. However, if the digital project is closely aligned with the firms' higher-level strategy, it can get more attention and higher priority from the top management team (Ranganathan et al., 2011). The commitment and support of the top management is essential to help overcome the internal resistance and ensure the allocation of sufficient resources into the implementation (Gunasekaran et al., 2017). It is important that the strategy-driven adoption needs to be pre-planned with complete design of digital transformation process and is aligned with firms' long-term interests (Chen et al., 2015; Moretto et al., 2017).

3.1.2. External drivers

Customer. Several papers indicated that customer needs is an important driver of manufacturing firms adopting digital technologies (Soliman and Meade, 2005; Chen et al., 2015; Seethamraju, 2014). There is increasing market demands for digitalized product, process or

Table 3
The drivers of digital technology adoption in manufacturing firms.

Drivers	Examples		Related papers
Internal drivers	Operational	Firms use digital technology to improve their operational performance in production and supply chain. For example, RFID-based technologies are widely used in warehousing to deal with increased complexity of products and customer orders; equipment manufacturers use digital technologies to facilitate postponement; service managers adopt big data analysis to improve the supply chain visibility and transparency, agility and integration.	(Soliman and Meade, 2005; Iskanius and Kilpala, 2006; Wang et al., 2010; Holmström and Partanen, 2014; Boone et al., 2017;)
	Strategic	Strategies aiming at economic, environmental and social improvement become a competitive advantage to companies. Driven by the strategic directions made by top management, firms adopt digital technologies to gain the first mover advantage. For example, the early adopters of IoT have benefited from the improved supply chain visibility, transparency and sustainability.	(Zhu et al., 2006; Boone et al., 2017; Moretto et al., 2017; Garcia-Muiña et al., 2018; Pishdar et al., 2018; Kamble et al., 2019)
External drivers	Customer	Driven by customer needs, firms provide digitalised products and services to better fulfil the market demands and manage customer relationships. Some firms also use it as a powerful marketing tool, as it creates a positive image of firms being digital and innovative.	(Soliman and Meade, 2005; Gunasekaran et al., 2016; Chen et al., 2015; Seethamraju, 2014)
	Supplier or supply chain partner	An example is related to an original equipment manufacturer who must adopt certain digital technologies in assembly lines due to customer demands. These technologies are integrated in a network system and work in distributed environments. By doing so, the analysis of the sensor data can determine the potential quality defects, alert the relevant stakeholders in the supply chain, and propose corrective measures. This drives other supply chain partners adopting related digital technologies.	(Holmström and Partanen, 2014; Caputo et al., 2016; Gunasekaran et al., 2016; Florian and Abubaker, 2018; Teucke et al., 2018)
	Competition	Digital solutions have the potential to help firms significantly reduce supply chain costs compared to those who rely on conventional approaches. Many incumbent firms try to adopt the latest digital technologies to match digital frontrunners. Those who chose not to follow the trend will have the risk of being left behind by their competitors.	(Chong and Chan, 2012; Lyly-Yrjänäinen et al., 2016; Adamson et al., 2017; Hänninen et al., 2018)

service in many industries. Driven by this, firms need to adopt digital technologies for better fulfilling their client needs and managing customer relationships (Chen et al., 2015). Many firms also use as a powerful marketing tool, as it creates a positive image of firms being digital and innovative.

Supplier or other supply chain partner. The digitalisation of one firm influences other players in the supply chain. When a core player decides to use a particular digital system, other within the supply chain usually face the pressure of adapting to that system (Holmström and Partanen, 2014). Firms in different power positions in a supply chain result in different levels of pressure to other firms. The digitalisation of a supply chain is usually initiated by the dominant firm due to its stronger bargain power. It gives pressure, and also examples, to other firms by changing their supplier selection criteria, cooperation strategy, and other routines. Driven by powerful supply chain partners, firms need to adapt and respond to their digital innovation, keep close cooperation with the dominant firm and upgrade the whole supply chain to avoid being weeded out (Gunasekaran et al., 2016; D'Ippolito et al., 2019). Remaining at the forefront of technological advances and keeping close cooperation with the supply chain partners are the main external drivers for many firms adopting digital technologies.

Competition. Another external driver comes from the competition (Chen et al., 2015; Adamson et al., 2017; Büyüközkan and Göçer, 2018). Adopting digital technologies is regarded as an approach to enhance manufacturing firms' competitiveness, especially if their competitors are doing so. Chong and Chan (2012) pointed out that most firms tend to adopt a digital technology if they see competitors adopting it, as they believe that it is the direction of the entire industry. This causes a fear that they may face the risk of being left behind by their competitors if they choose not to do it.

3.2. How do manufacturing firms adopt digital technologies in supply chains (RQ2)?

3.2.1. The activities of adopting digital technology in supply chains

Literature shows that digital technologies can be applied in various supply chain process (e.g., demand management, procurement, production, warehousing and logistics) to enhance different supply chain functions (e.g., supplier selection, demand prediction and logistic planning). Table 4 presents the examples of the activities of adopting digital technologies in supply chains.

Many firms deployed IoT devices to track and trace the real-time data

Table 4
The adoption of digital technologies in supply chains.

Supply chain processes	Supply chain functions	Example of digital technology adoption	Related papers
Product design	General product design	The real-time data collected through IoT devices in supply chain can improve product development.	(Yerpude and Singhal, 2018)
	User involved product design	The digital supply chain can enable the open innovation that includes user and supplier into the product development	(Reeves et al., 2011; Holmström et al., 2016; Chavez et al., 2017)
Demand management	Demand forecasting	Big data predictive analysis is used for demand forecasting in the pharmaceutical industry.	(Min, 2010; Waller and Fawcett, 2013; Seethamraju, 2014; Caro and Sadr, 2019;Shafique et al., 2019)
Procurement	Supplier selection	Big data analysis can forecast margins for different supplier and optimize the selection of supplier. After that, digital procurement system can inform the selected supplier promptly.	(Sanders et al., 2016; Boone et al., 2017; Moretto et al., 2017)
	Procurement decision making	Artificial intelligence is used in procurement decision making especially in the ambiguous tasks. The AI system can use different solutions according to different level of task ambiguity to increase the accuracy.	(Nissen and Sengupta, 2006; Min, 2010; Moretto et al., 2017)
	Sourcing cost reduction	Online digital procurement collaboration system can help to forecast the orders and reduce the cost of negotiation process.	(Yan et al., 2016)
	Production planning	With direct digital manufacturing, product-centric control and IoT can simplify production planning and material handling and recovery.	(Lyly-Yrjänäinen et al., 2016; Fang et al., 2016)
Manufacturing	Quality management	Sensor technologies combining with telematics and digital services can ensure the quality of manufacturing.	(Verdouw et al., 2013; Teucke et al., 2018)
	Equipment maintenance	Use digital technology to diagnostics and prognostics equipment. IoT technology can be used to track the location of every equipment.	(Arya et al., 2017)
	Digital manufacturing	The implementation of digital manufacturing in the complex product supply chain will change the relationship between firms, OEMs and logistic service providers.	(Holmström and Partanen, 2014; Arya et al., 2017)
Warehousing and logistics	Storage assignment Inventory control and planning	Visual control used in the warehouse can collect the data of real-time inventory. RFID label can automatically identify and track material information. Assignment can be completed after the calculation in the cloud platform	(Lyly-Yrjänäinen et al., 2016; Choy et al., 2017; Hopkins and Hawking, 2018; Yu et al., 2017; Min, 2010)
	Logistics planning	Big data analysis can support routing optimization, real-time traffic operation monitoring and proactive safety management.	(Lai et al., 2010; Graham et al., 2015; Hahn and Packowski, 2015; Badia-Melis et al., 2018; Hopkins and Hawking, 2018; Nguyen et al., 2018)
Other Supply chain processes	E-business process	The digital retailer platform can be regarded as a new business model that changes the supply chain structure amongst supplier and consumers.	(Ittmann, 2015; McIntyre and Srinivasan, 2017; Hänninen et al., 2018)
	Traceability of business process	Implementation of a traceability system in a product line can improve the overall quality of the product and minimize the impact of a product recall. The digital retailer platform can be regarded as a new business model that changes the supply chain structure amongst supplier and consumers.	(Campos and Míguez, 2006; Yan et al., 2016; Li et al., 2017; McIntyre and Srinivasan, 2017; Hänninen et al., 2018; Garcia-Torres et al., 2019)
	Customer relationship Management	Use data mining system to discover the knowledge from customer base. Implementation of a traceability system in a product line can improve the overall quality of the product and minimize the impact of a product recall.	(Min, 2010)

along the supply chain (Li et al., 2017), and adopt advanced data analytics for a faster and more accurate analysis for SCM. Caro and Sadr (2019)'s study presented that the use of IoT could bridge supply and demand and therefore enhance new value creation. The data enables a more accurate analysis which supports decision making and provides higher flexibility. For example, it can help firms make real-time decisions based on real-time orders and price of raw material (Radanliev et al., 2019; Yerpude and Singhal, 2018), and make better plans based on the prediction of the future price of raw materials and future demand. In addition, the sensors installed in production lines can be used to collect real-time data of production processes and to monitor the state of equipment and the quality of production (Teucke et al., 2018). The real-time data also helps firms react faster to changes occurred within the supply chain.

Chavez et al. (2017) claim that digital technologies can increase the connectivity and information sharing inside and outside firms and catalyse user involvement in product innovation. The information sharing can greatly reduce the information asymmetry and therefore the transaction cost for firms. For example, the traditional procurement is usually slow and costly due to massive time spent in communication inside and outside firms. The digital procurement system with greater information sharing mechanism could largely avoid unnecessary communications and accelerate the procurement activities, such as ordering, resource planning, sourcing and auctioning (Davila et al., 2003). It can also trigger product innovation through user involvement. For instance, digital devices could involve the equipment users and help the equipment developer to improve and innovate the design of their products (Reeves et al., 2011).

Some authors believe that the predictive function of digital technologies could trigger disruptive innovation on supply chains. There are a few cases in which firms use the improved computing power and analytical algorithms to support business decision making in a faster and more accurate manner (Radanliev et al., 2019a). For instance, some firms installed IoT devices to collect the real-time data of storage and transportation, and the data analysis can help arrange the warehouse location and optimise the transportation routines automatically (Nguyen et al., 2018). Some firms use big data analysis to optimise their supplier selection, sourcing strategy and logistic plan (Boone et al., 2017).

3.2.2. The levels of adopting digital technologies in supply chain

We analysed the cases in the selected literature and found that manufacturing firms go through different levels when adopting digital technologies. We further analysed the patterns and identified that the degrees of *technological intelligence* (Addo-Tenkorang and Helo, 2016; Nguyen et al., 2018; Tiwari et al., 2018) and *supply chain cooperation* (Adamson et al., 2017; Bogers et al., 2016; Papert and Pflaum, 2017) are the two most important factors determining which levels of the adoption firms go through. We therefore developed a two-dimensional adoption levels of digital technologies according to the low-to-high degrees of *technological intelligence* and *supply chain cooperation*, shown in Fig. 4.

The *technological intelligence level* represents the degree of intelligence of the digital technologies adopted in operations and supply chains (Schoenherr and Swink, 2015). The low level refers to the digital technologies with little intelligence, such as the traditional information management systems (e.g., ERP, MRP), data collection, visualisation and data processing techniques for descriptive purposes. The high level refers to the digital technologies with highly intelligent functions, such as real-time data collection through smart sensors, predictive and prescriptive analysis. These functions can be used to support the forecast of market needs, prediction of maintenance and real-time logistic planning. Advanced intelligent technologies could help firms better identify the underlying business value from large volume of data and make data-driven decisions. For example, the real-time data from online channels can be used to predict the future needs of the consumers and optimize the procurement, manufacturing and shipping plan for firms

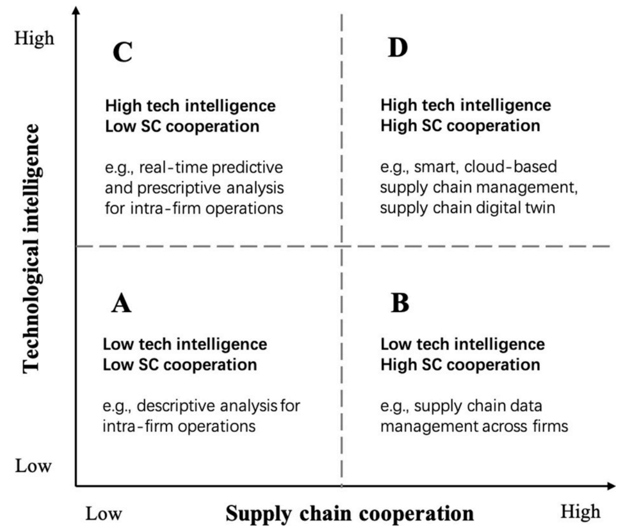

Fig. 4. The levels of adopting digital technologies in supply chains Note: there is no empirical evidence of the level D in the selected papers.

(Lee, 2017). Compared to the basic level of technological intelligence, the advanced level can enhance the decision making capabilities in a dynamic environment with high-level complexity and turbulences (Radanliev et al., 2019; Schoenherr and Speier-Pero, 2015).

The *supply chain cooperation level* represents the level of collaborations of firms within the supply chain (Ding et al., 2011; Xu and Beamon, 2006; Yu et al., 2001). The low level of supply chain cooperation refers to the situation where the digital technologies are applied within the firm without being connected to other partners in the supply chain. The process of data collection and analysis is accomplished within a single firm and served mainly for this firm. The high level means that technologies are applied in different firms across the supply chain and data is shared amongst partners.

Combining the levels of supply chain cooperation with the technological intelligence, we developed a matrix with four different levels of digital technology adoption (Fig. 4).

3.2.3. Level A: low technological intelligence with low supply chain cooperation

In this category, both the technological intelligence and supply chain cooperation are at a low level. Most manufacturing firms regard this level as the starting point of their digitalisation journey. The digital technologies with low intelligence are applied internally in the firm, including the traditional information management systems (e.g., ERP, MRP and PLM), the basic data collection and transmission devices (such as sensors, visual control system), and data visualisation and processing for descriptive purposes (Nguyen et al., 2018; Tiwari et al., 2018). For instance, ERP has been widely used in manufacturing firms to collect, store, manage, and interpret data from intra-firm business activities. Such software has provided an integrated, efficient management system to support the core business processes in manufacturing firms, such as strategic sourcing and supplier relationship management (Huang and Handfield, 2015). In recent years, the radio frequency technologies and visualisation systems have also been applied in manufacturing firms to collect and visualise real-time data from equipment, inventory and transportation. These devices usually comprise hardware and modular software applications and connect to a central database which stores and delivers business data internally.

3.2.4. Level B: low technological intelligence with high supply chain cooperation

At this level, the technologies with low intelligence are applied for data collection and sharing amongst different firms within the supply chain. This level of adoption requires strong cooperation of firms in the supply chain. The ERP and MRP systems in individual firms, at the supply chain level, should be partly connected amongst different departments or stakeholders across the supply chain. This would achieve a certain degree of real-time data sharing along the supply chain, from design, to production, logistic and services. By providing the right data at the right place at the right time, it enables quicker accessibility and more accurate data to stakeholders within a supply chain, thereby enhancing efficiency and decision-making process. The traditional data sharing between suppliers, producers and customers is commonly achieved through E-business platforms, such as E-procurement system. The e-procurement system can connect the demands and supplies and make the purchase, sale and payment activities through the Internet. It improves the visibility and control of procurement, production and supplies across the supply chain. This level requires high-level trust amongst the supply chain partners (Dubey et al., 2017).

3.2.5. Level C: advanced technological intelligence with low supply chain cooperation

At level C, advanced intelligent digital technologies are internally applied within individual firms. The main function of this category is the use of predictive and prescriptive analysis for business decision making, such as marketing forecasting, predictive maintenance, and intelligent production planning. Many manufacturing firms start to use data mining and predictive modelling to analyse the future trends based on the current and historical data. This is crucial for firms to gain a competitive advantage, because an accurate prediction of market demands and production could massively reduce time and cost, and improve supply chain operational efficiency (Min, 2010; Tiwari et al., 2018). The historical production data, such as defects and quality issues in production process, can be used to predict and prevent similar problems that might happen in the future. The historical data of supply and demand can help managers forecast the price of raw material, customer needs and optimise the production and logistic planning.

3.2.6. Level D: advanced technological intelligence with high supply chain cooperation

Level D is the most advanced level in which advanced intelligent digital technologies are applied amongst different firms with high level of supply chain cooperation. There are a few empirical cases of level A, B and C, however, there is no case of the level D in the selected literature. Some scholars provided the projections about the future digital technology adoption which relates to this level. For instance, Roßmann et al. (2018) predicted the future big data analytics in the supply chain through a Delphi study, and suggested that firms need to cooperate and improve the availability of data across the supply chains. Adamson et al. (2017) proposed the future trend of cloud manufacturing, which provides a platform that manufacturing resources and capabilities could be shared in the supply network. It is believed that the supply chain in cloud manufacturing context will be highly flexible and can be realised through the dynamic composition of cloud services. Cloud computing will gradually replace the centric system and the big data analysis will become an online service in the future (Cozmiuc and Petrisor, 2018). In this scenario, cloud computing and other technologies would be merged in product design and manufacturing processes, forming the cloud-based design and manufacturing platform. The platform can be accessible from mobile devices and help users to manage complex information. The direct benefit to production is that production lines can be more effective, efficient, real-time reconfigurable, and more responsive to market and customer needs. The cloud-based platform can serve not only a single supply chain but also multiple supply chains (Adamson et al., 2015). This level has the potential to lead to supply chain disruption and produce large impact. It will also significantly improve the availability of supply chain related data. With a cloud-based application, firms can use advanced analysis without the investment in building their own computing system. This will help reduce the entry cost of adoption. The relationship amongst the firms connecting to the cloud would be changed from traditional supply chain. With cloud-based platform, firms can achieve high level of cooperation and integration through real-time information sharing and flexible value network (Cozmiuc and Petrisor, 2018).

3.3. What is the impact of digital technology adoption on supply chains (RQ3)?

We found in the literature that the adoption of digital technologies mainly affects the supply chain in four aspects: *supply chain efficiency* (e.g., Akhtar et al., 2018), *supply chain structure (*e.g.*, Holmström and Partanen., 2014), sustainability (*e.g.*, Dubey et al., 2017)*, and *innovation (*e.g.*, Roßmann et al., 2018)*.

3.3.1. Supply chain efficiency

The most immediate effect of adopting digital technologies on supply chain seems to be the improvement of supply chain operational efficiency, including the operating speed, cost, quality, flexibility, agility and reliability (Calatayud et al., 2019; Chavez et al., 2017; Dubey et al., 2019; Singh and El-Kassar, 2019). Most of the papers provided empirical evidence to illustrate a positive relationship between the adoption of digital technologies and supply chain efficiency (Akhtar et al., 2018; Kache and Seuring, 2017). There are a few case studies indicating that the adoption of digital technologies could improve the product quality, supply chain resilience, responding speed, production and planning efficiency and accuracy (Calatayud et al., 2019; Dweekat et al., 2017; Verdouw et al., 2013). Some studies have used survey method to empirically test the relationships by measuring the supply chain efficiency related indicators (Chavez et al., 2017; Chen et al., 2015; Gunasekaran et al., 2017; Ranganathan et al., 2011).

3.3.2. Supply chain structure

Supply chain structure changes over time in order to maximise supply chain performance (Hagelaar and Van der Vorst, 2001). The change of supply chain structure includes the supply chain integration, merging, separation or reconfiguration (Zolait et al., 2010). The most common effect is the integration of the supply chain across organizational boundaries through communications, partnerships, alliances, and cooperation (Power, 2005). The adoption of digital technologies can improve the information flows between supply chain partners and increase the integration level of the supply chain (Ardito et al., 2019), therefore affects the supply chain structure. Some scholars regard the integration as an intermediate variable between digital technology adoption and firm performance (Büyüközkan and Göçer, 2018; Demartini et al., 2019; Xue et al., 2013; Zolait et al., 2010). We believe that it is an independent consequence of digital technology adoption in the perspective of supply chain structure. The supply chain integration emphasizes the coordination and cooperation between different firms in supply chains. D'Ignazio and Giovannetti's (2014) provide evidence that the global supply chain networks enabled by digital technologies increase the integration level in the industrial clusters. Digital technologies can also influence the relationship between supply chain partners and customers, for instance, involving users and suppliers in product design through digital platform (Holmström et al., 2017).

3.3.3. Sustainability

A number of studies have suggested that digital technologies could be used to improve supply chain sustainability (Bag et al., 2018; Birkel et al., 2019; Melo et al., 2019; Dubey et al., 2016). Both Jeble et al. (2018) and Dubey et al. (2017)'s research have shown the positive effects of the big data analytics capability on firms' economic, social and environmental performance. Some studies have shown that big data could be effectively used to increase energy efficiency, reduce carbon emission and prolong product longevity (Holmström et al., 2017; Ji and Sun, 2017; Tao et al., 2014; Dubey et al., 2017). Hopkins and Hawking

(2018)'s study found that the IoT and big data analytics could largely reduce the environmental impact of vehicles required for logistics. Some scholars investigated how to use IoT and big data for waste management (Gu et al., 2017) and provided the potential applications of digital technologies in sustainable product life cycle management (He et al., 2015; Qian et al., 2017; Li et al., 2015). IoT technologies enable firms to collect data related to the energy consumption and carbon emission timely across the product life cycle (Tao et al., 2014), which provides an evaluation of the real-time environmental performance of the product life cycle. The analysis of the real-time data can help firms identify the most polluted stages in the supply chains so that firms can focus on solving these problems (Garcia-Torres et al., 2019). IoT can also be used to track the wastes and by-products produced across the supply chains to help design a more sustainable industrial system (Gu and Tong, 2004). In the e-commerce context, digital technologies can be used in the design of delivery model for online retailers. Applying a unified digital delivery system with low-carbon constraints, the retailers can not only improve the relationship between supply and demand sides, but also achieve the purpose of energy saving and emission reduction (Ji and Sun, 2017).

3.3.4. *Innovation*

There are also a few papers showing that the adoption of digital technologies has the potential to contribute to manufacturers and their suppliers' innovation capabilities on products (Lee and Berente, 2012), business models (Ehret and Wirtz, 2017; Rodriguez and Da Cunha, 2018; Wamba et al., 2015; Kache and Seuring, 2015) and ecosystem (Papert and Pflaum, 2017). Most of them are developed from case studies. Literature has discussed that the adoption at high intelligent technology level (the level C in Fig. 3) can help firms respond faster to the changing environment and facilitate the risk management (Büyüközkan and Göçer, 2018; Schoenherr and Speier-Pero, 2015; Wood et al., 2017). This is a type of dynamic capabilities for adapting to the fast environment changes and also an essential factor to trigger innovation (Teece et al., 1997).

As for the digital technology adoption with a high level of supply chain cooperation (the level D in Fig. 4), it is believed that a more open, but secured, data sharing system across firms could lead to open innovation (Bär et al., 2018). It was found that when firms have access to new data sources or collaborate with new partners, innovation would occur more frequently. Hänninen et al. (2018) investigated digital retailing platforms and found that business model innovation emerged most often when firms try to satisfy consumers' needs through digital solutions. The retailer platforms change the value creation logic by altering the structure of the supply network (McIntyre and Srinivasan, 2017).

4. Discussion

4.1. *A conceptual framework of digital technology adoption in supply chains*

This section discusses the thematic findings and further develops a conceptual framework of digital technology adoption in supply chains, as shown in Fig. 5.

This conceptual framework contains two main messages. First, the framework is composed of three layers, and illustrates the drivers (*why)* and process (*how)* of manufacturing firms adopting digital technologies in supply chains, and the impact *(what)* of the adoption. The first layer presents the drivers. The internal drivers mainly derive from the operational problems and strategic directions, and the external drivers come from customers, supplier or other supply chain partner, and competition. The second layer depicts the adoption process, including the adoption activities and levels. The adoption activities refer to the actions of applying digital technologies (e.g., descriptive, prescriptive and prescriptive functions) in different stages of supply chain processes (e.g.,

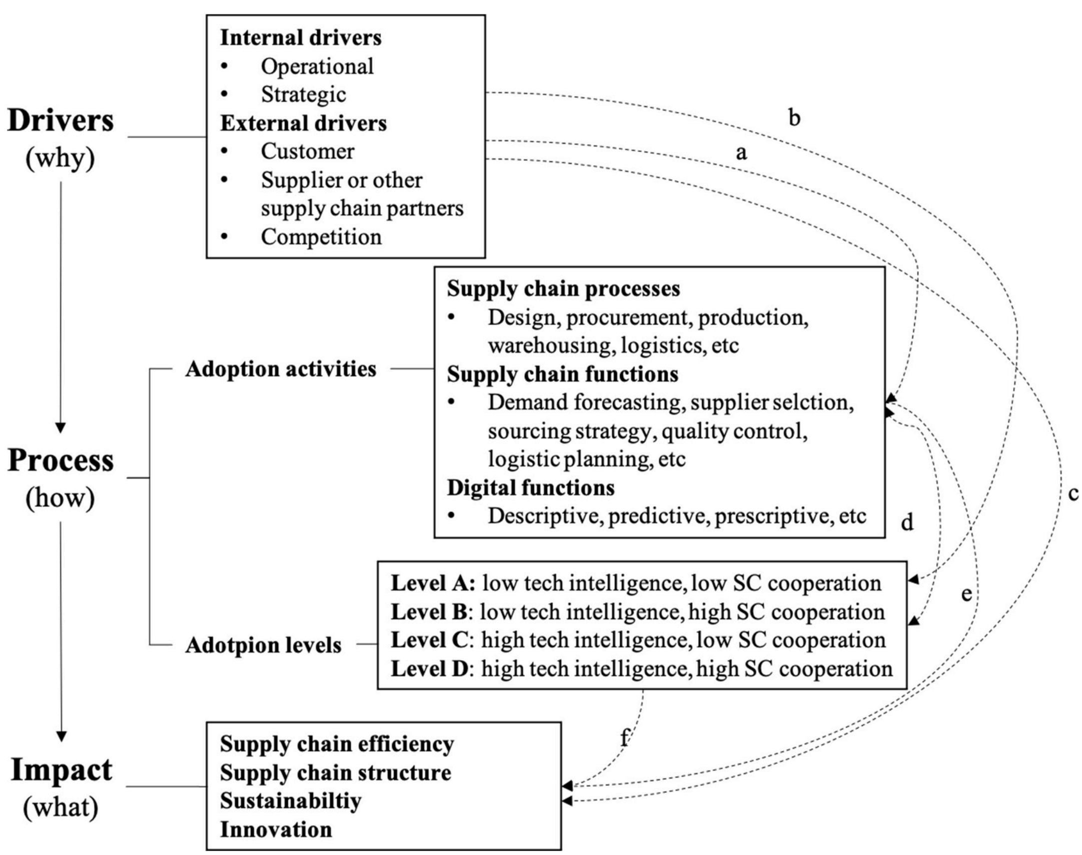

Fig. 5. Conceptual framework of digital technology adoption in supply chains.

procurement, production, logistics) to support various supply chain functions (e.g., supplier section, demand forecasting). These activities result in different levels of adopting digital technologies. We proposed a two-dimensional model based on the degrees of technological intelligence (from low to high) and the supply chain cooperation (from low to high). This model represents four different levels of adopting digital technologies in manufacturing firms (Level A to D shown in Fig. 5). The third layer illustrates the impact of the adoption on supply chains, including supply chain efficiency, supply chain structure, sustainability and innovation.

Second, the framework illustrates that the drivers, process, and impact are inter-related to each other. In particular, the literature analysis indicates that different drivers have distinct influence on the adoption activities, and then on adoption levels, and that the adoption levels could affect the impact on supply chain efficiency, supply chain structure, sustainability and innovation. We further analysed the patterns and their potential relationships and proposed two propositions as below.

Proposition 1. *Different drivers have different influences on the adoption activities (a), adoption levels (b), and therefore the impact on supply chains (c). The adoption activities and levels affect each other (d). The adoption activities and levels both have great influences on the impact (e) (f).*

There are many potential interesting patterns behind the relationships between the adoption drivers, process (activities and level) and impact. For example, the external drivers from supply chain partners are more likely to affect the adoption activities which move the adoption level towards a higher supply chain cooperation degree, and this is more likely to affect the supply chain structure. It needs to be noted that there is a lack of empirical evidence in the literature regarding the proposition, which implies that further empirical studies can be carried out to investigate the inter-relationships of the drivers, processes and impact in the framework.

Proposition 2. *There is no fixed, best pathway for adopting digital technologies in manufacturing firms. Firms need to start from why, link the drivers and process, and develop adoption strategies according to their current supply chain situation and make appropriate decision for different digitalisation levels.*

The four adoption levels also indicate different levels of digital transformation in manufacturing firms. Although there is no fixed, best pathway for adopting digital technologies, literature has shown some patterns of possible pathways (e.g., from Level A to B, or A to C) and the conceptual design of future pathways (e.g., from B to D, or C to D, or A to D). The four levels and the potential pathways could help firms strategically design pathways to transform from one level to another. Many digital transformation projects failed in practice due to the disconnection between strategy formulation and implementation (Correani et al., 2020). It is therefore important to analyse the drivers, the process and the potential impact before transiting to another level. It also requires firms to revise the process and constantly analyse firms' current conditions, as well as the enablers and barriers of the transformation.

The digitisation of the entire supply chains cannot be achieved by any firm alone. It requires strong collaboration amongst multiple stakeholders along the supply chain. Multi-stakeholder initiatives play an essential role in this transformation, especially in the transit from a low level of supply chain cooperation to a higher level (e.g., from Level A to B, or C to D). The dominant firms who have stronger bargain power could take the initiative and help other supply chain partners develop digitalisation pathways by providing learning platforms and training mechanisms. Driven by these powerful firms, other stakeholders need to adapt and respond to their digital innovation, keep close cooperation with them and upgrade the whole supply chain to avoid being weeded out.

4.2. Theoretical implication

In general, there is a lack of management studies on digital technology adoption in supply chains (Hamdi et al., 2018; Manavalan and Jayakrishna, 2019; Viet et al., 2018). This paper contributes to this field in four significant ways.

First, we propose a conceptual framework of digital technology adoption in supply chains (Fig. 5), answering the three research questions. This framework advances the current understanding of why and how manufacturing firms adopt digital technologies in supply chains, as well as the impact of the adoption. This framework is composed of three parts, and each part paves a foundation for the future empirical testing studies in the area. The framework also provides a basic structure of the adoption of digital technologies in supply chains. Scholars can follow this framework to extend and explore relevant points and their inter-relationships to develop future research.

Second, the paper proposes four-level model of adopting digital technologies and offers valuable insights into the studies of digital transformation. We investigate the adoption activities in each stage of supply chain processes and how they affect the supply chain functions, and develop a two-dimensional, four-level model adoption levels of digital technologies. We initially combined the levels of technological intelligence and the supply chain cooperation to exploit comprehensive perception on the digitalisation level of firm. This model is a novel contribution to the existing literature and provides a structure for the future studies on digitalisation.

Third, the paper identifies four main impacts of the adoption of digital technologies in supply chain, including supply chain efficiency, supply chain structure sustainability and innovation. The positive relationship between the adoption of digital technologies and the four dimensions of impact was synthesised from literature. From this point of view, we indicate that digital technology adoption in manufacturing firms can generally improve the various functions of supply chains and facilitate and consolidate the cooperation amongst upstream and downstream stakeholders.

4.3. Practical implication

In practice, most manufacturing firms are still at an early stage of adopting advanced digital technologies. It is challenging for managers to make decisions on what digital technologies they should adopt, how to adopt them; and to understand how it might affect supply chain structure and performance. This study provides a guidance of digital technology adoption in practice. It can help managers understand the potential impact of digital technologies on supply chains, and support managers to develop appropriate business strategies at different digitalisation levels.

Furthermore, managers can follow the two-dimensional, four-level adoption model to develop step-by-step strategies of adopting digital technologies at different levels, from individual firms towards supply chain cooperation. The model can help managers understand which digitalisation level the firms are at the present, and which level the firms plan to transform toward to. There are no fixed, best paths of digitalisation which guarantee success, but the model could help firms strategically design possible pathways to transform from one level to another. It is important for managers to analyse their current situation and make appropriate business decisions for different levels and develop a pathway of transformation for their business.

4.4. Limitation

There are mainly two limitations in this study. The main limitation of the study is that this paper mainly investigates three digital technologies, i.e., IoT, big data and AI. Other emerging digital technologies, such as blockchain, virtual reality, additive manufacturing, are not included in this study. The reason is that IoT, big data and AI have highly connected functions and are regarded as one of the most important sets of the digital technologies in manufacturing sector. Other technologies (e.g., blockchain, additive manufacturing) also have huge impact on supply chain, especially in terms of supply chain structure, transparency and security. However, these technologies are less connected to IoT, big data and AI, and there is very little existing literature on these technologies within management scope. Therefore, we decided not to include other technologies in our literature review.

Second, the literature reviewed mostly concentrated in the manufacturing sector. Service providers, or other firms with unique supply chains were not included in literature. However, in a digitalized supply chain, firms are highly connected to each other and the division of industrial sectors become blurred. This means, our study does include the service providers, who may play important roles and their digitalisation have great impact on supply chains.

4.5. Future research

In general, there is a need for studies on digital technologies in the field of supply chain management. Based on the research findings and conceptual development, future research directions are presented as below.

First, the framework provides a basic structure for the future research on the empirical studies of each part of the framework, as well as their inter-relationships (the a, b, c, d, e, f in Fig. 5). Further research can investigate each of the relationships and identify the success factors of the adoption process. Scholars can follow this framework to extend and explore the drivers, process and impact of adopting digital technologies in manufacturing firms, and study how specifically the internal and external drivers would influence the process and impact.

Second, more studies are needed to investigate how manufacturing firms can develop digital technology adoption strategies which align with their drivers, and how the process of adoption can result in a positive impact on supply chain efficiency, sustainability, innovation and supply chain structure. For example, we think that future research can use resource-based view and dynamic capabilities theories to study the use of data as resources to improve the capabilities of adopting digital technologies.

We therefore proposed the following research questions for future research based on the findings of this paper: *How do the drivers of adopting digital technologies influence the adoption process? How do the drivers and adoption process of adopting digital technologies affect the impact on supply chain structure and performance? How do manufacturing firms transit from one level to another according to the proposed four-level model of adopting digital technologies? What are the enablers, barriers and conditions of the different pathways of digital transformation? How to simulate the potential pathways of the digital transformation according to the four-level model?*

5. Conclusion

This paper investigated *why* manufacturing firms adopt digital technologies, *how* they adopt, and *what* is the impact of the adoption on the supply chains. We used a systematic literature review on 55 peer-reviewed journal publications and developed a conceptual framework for digital technology adoption in supply chains, consisting of three parts: *drivers (why), adoption processes (how)*, and *impact (what)*. We identified that the internal drivers mainly derive from the operational problems and strategic directions, and the external drivers come from customers, suppliers, other supply chain partners, and competitions. We then investigated the adoption process, which includes the adoption activities and levels. The adoption activities refer to the actions of applying digital technologies (e.g., descriptive, prescriptive and prescriptive functions) in different stages of supply chain processes (e.g., procurement, production, logistics) to support various supply chain functions (e.g., supplier section, demand forecasting). These activities result in different levels of adopting digital technologies. We then developed a two-dimensional model based on the degrees of technological intelligence and the supply chain cooperation. Finally, we analysed the main impact of the adoption of digital technologies on supply chains, and synthesised them into four dimensions: supply chain efficiency, supply chain structure, sustainability and innovation.

This research contributes to the fields of the digital technology and supply chain management. The proposed framework, in particular the two-dimensional adoption levels of digital technologies, are novel to the existing literature. Each of the tree parts of the framework and their inter-relationships pave the way for further empirical testing. This study also provides a guidance of digital technology adoption in practice. It can help managers understand the potential impact of digital technologies on supply chains, and support managers to develop appropriate business strategies at different digitalisation levels. Therefore, this paper lays a foundation for future research in the emerging field of digital technologies in supply chain management.

CRediT authorship contribution statement

Miying Yang: Conceptualization, Data curtion, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Mingtao Fu:** Data curtion, Formal analysis, Methodology, Writing – original draft. **Zihan Zhang:** Conceptualization, Data curtion, Formal analysis, Methodology, Writing – original draft.

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