Examining the Effects of Digital Supply Chain Practices on Supply Chain Viability and Operational Performance: A Practice-Based View

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# Examining the effects of digital supply chain practices on supply chain viability and operational performance: A practice-based view


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## Abstract

Despite the increasing attention to the adoption of digital supply chain (SC) practices to support operational performance improvement in an ever increasingly volatile marketplace, many firms are still not achieving the desired outcomes. In this study, we argue that the development of SC viability within a digital SC practices framework is a key enabler to achieving superior operational performance. To date, SC viability is largely ignored and under-researched in the digital SC practices domain. To address this gap, this study draws upon and extends the practice-based view (PBV) to develop and empirically test a digital SC practices model, which explores the effects of digital SC practices on SC viability and operational performance during the COVID-19 crisis. Survey data returned by manufacturers in China was analysed to test the digital SC practices model. The findings reveal that both digital technology orientation (DTO) and digital SC platform have a significant positive effect on digital SC practices, which leads to SC viability and operational performance. More specifically, the results suggest that SC viability plays a partial mediating role in the digital SC practices–operational performance relationship, and DTO and digital SC platform play a moderating role in the SC viability–operational performance relationship. The findings provide managers with guidance and a framework to develop and implement Industry 4.0-ready digital SC practices to ensure a viable SC for long-term firm survival and operational success.



**Keywords**: Digital supply chain platform; Digital technology orientation; Digital supply chain practices; Supply chain viability; COVID-19; Practice-based view.

## 1. Introduction

Supply chains (SCs) worldwide are under increasing pressures. Recent disruptive events such as COVID-19 and Ukraine war have resulted in unprecedented volatility and uncertainty throughout global SCs (Ivanov, 2020; 2021a). To withstand these increasingly unpredictable shocks, the SC viability concept has emerged as a potential area of interest (Ivanov and Dolgui, 2020). The nascent literature on SC viability is promising and suggests that firms that have the capabilities to absorb, adapt, and respond to disruptions over an extended period, through timely (re)design of their SC structures and processes, will experience performance advantage (Faruquee et al., 2021). With the advent of Industry 4.0 and digitisation, the adoption of digital technologies in SCs (e.g., big data analytics (BDA), artificial intelligence (AI), internet of things (IoT), and blockchain) are being recognised as enablers to manage and respond to increasingly volatile global markets (Faruquee et al., 2021; Ho et al., 2022; Khan et al., 2021).

The recent literature on digital transformation in SCs suggests that firms who implement digital SC practices, referring to the execution of a set of SC activities that are facilitated by the effective adoption of digital technologies, may outperform others; especially in today's volatile marketplace (Ageron et al., 2020; Khan et al., 2021). Despite the increasing attention and potential of digital technologies, firms are still not achieving the desired performance outcomes (Cadden et al, 2022; Yu et al., 2023). It is argued in this study that the role and value of SC viability has been largely overlooked in the context of a digital SC practices model; and further research into this construct may be the key to unlocking the performance potential of digital transformation in SCs (Ivanov, 2021a; Ivanov and Dolgui, 2020).

In order to fully leverage digital SC practices in support of SC viability and operational performance, two key antecedents are proposed in this study: namely digital technology orientation (DTO) and digital SC platform. Firms need to have an appropriate digital architecture, encompassing both hardware and software, in place to initiate the digital transformation process and support performance improvements (Büyüközkan and Göçer, 2018; Li et al., 2020). DTO is also vital in tandem with a digital SC platform to create the environment and behaviours in the organisation for digital transformation to occur (Cadden et al, 2022). Having these two vital antecedents in place will then enable digital SC practices to be implemented more successfully. Less work, however, has been conducted in building a digital SC practices model from the SC disruption perspective during the COVID-19 crisis and other disruptive events.

To strengthen the understanding of a digital SC practices model, the practice-based view (PBV) proposed by Bromiley and Rau (2014) was employed as a theoretical foundation in this study. The PBV explains how firm performance variations are attributable to the implementation of imitable and transferable practices that are facilitated by explanatory variables (Bromiley and Rau, 2014, 2016). For example, a productivity increase of 11% was found where standard production practices such as regular preventative machine maintenance, documenting any machine breakdown issues, keeping the shop floor clean and tidy, and regular inventory counting, were implemented (Bloom et al., 2013). Thus, rooted in the PBV, this study develops a digital SC practices model that empirically tests the explanatory variables (digital technology orientation and digital SC platform) – practices (digital SC practices) – intermediate outcomes (SC viability) – performance (operational performance) relationship during a recent disruptive event (COVID-19). Recent work (e.g., Faruquee et al., 2021; Khan et al., 2021) and reports by IBM, Capgemini, and McKinsey (e.g., Garg et al., 2020; Patwardhan et al., 2018) have highlighted the importance of SC digitization in managing supply and demand disruptions during the COVID-19 crisis. Despite this, digital SC practices as a concept is still embryonic in the literature (Ageron et al., 2020; Büyüközkan and Göçer 2018) and its potential value for supporting the development of SC viability to deliver business benefits is still under-researched. Therefore, this study aims to address the following research questions: (1) *do DTO and digital SC platform influence digital SC practices?* (2) *do digital SC practices influence SC viability and operational performance?* (3) *does SC variability mediate the relationship between digital SC practices and operational performance?* and (4) *do DTO and digital SC platform moderate the relationship between SC viability and operational performance*? By answering these questions, our digital SC practices framework contributes to the literature and practice in several dimensions.

Firstly, this study builds upon and extends the PBV by identifying explanatory variables (i.e., digital technology orientation and digital SC platform) that facilitate the implementation of digital SC practices in uncertain times. According to the PBV, the execution of digital SC practices might deliver business benefits to firms, but the influence depends on explanatory variables (Bromiley and Rau, 2014). To successfully implement digital SC practices, firms are required to adopt innovative and contemporary digital technologies and establish digital SC platforms (Li et al., 2020). Specifically, innovative ideas, products, and processes require a digital technology orientation (DTO) (Masa'deh et al., 2018; Tsou et al., 2014), which demands a firm to be committed to the implementation of digital technologies through its values, structures, and processes to successfully deliver innovative products/services to customers (Khin and Ho, 2019; Yu et al., 2021). Furthermore, Industry 4.0 firms are required to consider how to digitally reshape and reimagine their SC practices and processes to build a digital SC platform (Büyüközkan and Göçer, 2018) to ensure digital connectivity, integration, and real-time open, accurate and timely information along its SCs (Li et al., 2020; Rai et al., 2006; Sedera et al., 2016). Therefore, compatible with the PBV, DTO and digital SC platform act in this study as explanatory and enabling variables to effectively execute digital SC practices.

Secondly, to further explore the proposed digital SC practices model, this study also explores the moderating effects of DTO and digital SC platform and the mediating effect of SC viability. This follows from PBV that practices influence performance but through a process of moderation and mediation effects (Bromiley and Rau, 2014). The degree of benefit derived to a firm is directly related to the way other practices have been implemented by the company (Bromiley and Rau, 2016). Ignoring the important moderation and mediation effects in the digital SC practices framework may result in a biased, unreliable or incomplete set of findings and conclusions. Previous studies that adopted the PBV theory and did not include mediating and moderating variables in their models acknowledged this limitation and signalled the inclusion of moderation and mediation effects in future studies (e.g., Shaw et al., 2020; Silva et al., 2019). We argue that digital SC practices might indirectly influence operational performance through an intermediary construct (SC viability in this case). Furthermore, according to the PBV, the effect of a specific digital practice on operational outcomes might be contingent upon the interaction of the practice with others (Bromiley and Rau, 2014, 2016). We therefore explore if DTO and digital SC platform moderate SC viability and operational performance.

Overall, this study significantly extends the PBV proposed by Bromiley and Rau (2014) and contributes to the literature on SC digitalization and viability. Since the PBV provides a novel and comprehensive perspective for exploring digital transformation and viability in SCs (Carter et al., 2017; Shaw et al., 2020), our digital SC practices model offers a deeper understanding of how DTO and digital SC platforms facilitate digital SC practices, leading to potential viability benefits and improved performance outcomes amid the COVID-19 crisis. Specifically, by examining both moderating and mediating analyses, which have been ignored in previous PBV research, this study significantly extends the PBV and provides more meaningful empirical findings for both researchers and practitioners during the COVID-19 pandemic. By empirically testing the digital SC practices model during a significant SC disruption event (i.e., COVID-19), this study provides managers with new insights, guidance, and a practical framework to develop and implement Industry 4.0-ready digital SC practices. This ensures a viable SC for long-term firm survival and success. More specifically, the empirical findings provide potential explanations for performance variation during the COVID-19 crisis and answer the question of how to successfully implement and execute digital SC practices to gain a competitive advantage.

## 2. Theoretical background and literature review

### 2.1. PBV and digital SC practices model

We use the PBV as a theoretical underpinning to develop the conceptual framework of digital SC practices. According to the PBV proposed by Bromiley and Rau (2014), imitable practices can explain the variations in firm performance. The PBV focuses on transferable and imitable practices, which are the activities that firms can adopt to improve their performance (Bromiley and Rau, 2014, 2016). The PBV has been proposed to better understand variations in the performance of a firm influenced by explanatory variables such as enablers or antecedents of the practice. It includes four components: explanatory variables, practices, intermediary constructs, and performance (Bromiley and Rau, 2014). However, Bromiley and Rau (2014) did not offer explicit definition for explanatory variables which can be considered as enablers or antecedents of the practice (Wang et al., 2018).

In the SC context, researchers have recently adopted the PBV to investigate how firms can enhance business performance by implementing SC management practices (Bromiley and Rau, 2016; Carter et al., 2017; Hitt et al., 2016). For instance, recent studies have used the PBV to examine the impact of sustainable SC management practices on performance (e.g., Shaw et al., 2020; Silva et al., 2019). Some studies have also investigated how the critical elements of practice interact with big data analytics capabilities using the PBV (e.g., Wang et al., 2018). However, the PBV has yet to be empirically tested in the digital SC context within the current COVID-19 pandemic.

Considering the aforementioned gaps, our aim is to develop a theoretical model of digital SC practices based on the PBV proposed by Bromiley and Rau (2014). The research model is presented in Figure 1. We use this digital SC practice model to identify explanatory variables (i.e., DTO and digital SC platform) that facilitate the implementation of digital SC practices during the COVID-19 crisis. Adopting and extending the PBV not only enables investigation of how companies implement digital SC practices through the proposed explanatory variables, but also helps obtain a deeper understanding of how the implementation of SC practices enhances business performance in the current uncertain times. As illustrated in Figure 1, by significantly extending the framework proposed by Bromiley and Rau (2014), our digital SC practices model follows a linear progression path: the explanatory variables (DTO and digital SC platform in this case)–SC management practices (digital SC practices)–intermediate outcomes (SC viability)–firm performance (operational performance) relationship.

Although Bromiley and Rau (2014) explicitly suggested that any theoretical model developed based on the PBV should examine mediator and moderator variables that depend on the specific practice and context, previous empirical PBV research (e.g., Shaw et al., 2020; Silva et al., 2019; Wang et al., 2018) has ignored the examination of moderation and mediation effects. Thus, to obtain a deeper and comprehensive understanding of the relationship between the four components of the digital SC practices model, we follow Bromiley and Rau's (2014, 2016) theoretical suggestions and propose that explanatory variables (DTO and digital SC platform in our model) moderate the impact of practices on performance (Kosmol et al., 2019) and that practices indirectly influence performance through an intermediary construct (SC viability in our model).

------------------------------ Insert Figure 1 -------------------------------

## 2.2. Explanatory variables

The first step in constructing the digital SC practices model (see Figure 1) from the PBV perspective involves defining the explanatory variables (Bromiley and Rau, 2014). In this study, the explanatory variables refer to DTO and digital SC platform, which are critical for companies to implement digital SC practices, especially during the COVID-19 pandemic (Li et al., 2020; Yu et al., 2023).

### 2.2.1. DTO

DTO guides firms to integrate advanced digital technology into the strategic decision making of the organisation (Yu et al., 2021). A firm that possesses a DTO is committed to the application and constant updating of new digital technologies (Gatignon and Xuereb, 1997; Khin and Ho, 2019). Firms driven by DTO employ advanced technologies to ensure new product development and innovation (Chen et al., 2014; Li et al., 2020). Digital technology-oriented firms can be better positioned to the introduction and application of new technologies, products/services, and innovations (Khin and Ho, 2019; Zhou et al., 2005). DTO not only focuses on a technological perspective but also encourages human elements such as proactiveness to acquire new technologies and leverage technological advancements to innovate and apply new processes, products, and ideas (Masa'deh et al., 2018; Tsou et al., 2014). This is achieved through integrating technology into the organisational values, structure, processes and resources as well as digital technology being a leveraged competency (Yu et al., 2021; Kateb et al., 2015). Therefore, firms that have a strong set of embedded digital orientation practices will seek out and implement new technologies in support of innovative SC practices and services (Yu et al., 2021).

#### 2.2.2. Digital SC platform

In this study, we defined a digital SC platform as a digitally driven infrastructure designed "for the consistent and high-velocity transfer of SC-related information within and across its boundaries" (Rai et al., 2006, p.229). Digital SC platform is the digital architecture and infrastructure of the firm. For example, it includes the servers, data centres, and networks used by the firm, as well as the enterprise portals, platforms, systems, and software. Additionally, it encompasses cloud services and software, operational security, and user identity and data encryption. Therefore, IoT, broadband, blockchain, and AI are all integral parts of the digital SC platform. The digital SC platform is the backbone that provides the digital hardware and software capabilities for secure, traceable, consistent, and high-velocity transfer of SC related information within and across its boundaries (Ivanov et al., 2022; Li et al., 2020). For example, IBM's Hyperledger is a bought in blockchain cloud computing service (Choi and Shi, 2022; Ivanov et al., 2022). Digital SC platform enables firms to use collaborative digital platforms to support real-time information transfer among SC partners (Büyüközkan and Göçer, 2018; Li et al., 2020; Rai et al., 2006). Digital SC platform has reshaped traditional SC operations by providing the environment to build an integrated and compatible end to end SC management information system; allowing key stakeholder to share information and business intelligence in support of increased outcomes for all participants(de Reuver et al., 2018; Li et al., 2020; Sedera et al., 2016). In addition to its technological focus, digital SC platform allows focal firms to build technical aspects and common workflows and rules to govern relationship management across inter-firm boundaries (Rai et al., 2006; Sedera et al., 2016), which entails centralizing and formalizing information flows (Cenamor et al., 2019), promoting real-time communication (Li et al., 2020), and supporting the coordinated processes of activities, resources, and goals (Han et al., 2017).

### 2.3. Digital SC practices

As shown in Figure 1, digital SC practices play a pivotal role by transforming explanatory variables (i.e., DTO and digital SC platform) into intermediate outcomes (Bromiley and Rau, 2014). The emergence and impact of digital technologies such as BDA, IoT, and AI have radically changed the way SC practices are executed (Büyüközkan and Göçer, 2018; Faruquee et al., 2021). Digital SC practices constitute the practical layer that operates on the digital SC platform developed by digitally oriented firms. For example, this includes how digitally oriented firms translate their digital assets and infrastructure into practices, such as using data collected on the platform for decision-making, holding internal meetings to share knowledge and communicate with suppliers and customers, utilizing digital metrics to shape supplier performance, and using information on changes in customer demand to affect production planning and control (Ageron et al., 2020; Faruquee et al., 2021). In this study, we therefore define digital SC practices as the adoption of a wide variety of sophisticated digital technologies to facilitate planning, control, and process coordination, with the goal of strengthening integration, responsiveness, and agility of the entire SC. The implementation of digital SC practices allows firms to access and process large-scale data, enabling communication and collaboration, and enhancing trust, agility, and effectiveness. This enables firms to effectively use digital technology to enhance visibility and gather useful intelligence that informs strategic SC decision-making, such as customer buying patterns, sourcing decisions, and inventory management (Ageron et al., 2020; Faruquee et al., 2021; Patwardhan et al., 2018).

### 2.4. Intermediate outcomes: SC viability

The third part of our digital SC practices model demonstrates that implementing digital SC practices generates intermediate outcomes (Bromiley and Rau, 2014). In our study, these outcomes are represented by SC viability, which allows companies to achieve superior operational performance (Ivanov, 2021a, 2021b). SC viability is a newly developed concept in the SCM literature. Ivanov (2020, p.4) defined SC viability as "the ability [of a firm] to maintain itself and survive in a changing environment over a long period of time through a redesign of the structures and replanning of economic performance with long-term impacts". Given the recent disruptive event in SC (the COVID-19 pandemic), this definition views SC viability as a specific type of dynamic capability that enables firms to enhance their effectiveness, speed, and efficiency in responding to unforeseen environmental changes (Ivanov, 2021a, 2021b; Ruel et al., 2021). SC viability reflects on a firm's "ability to meet the demands of surviving in a changing environment" (Ivanov and Dolgui, 2020, p.2905). While both SC resilience and viability are relevant for firms to adapt to environmental changes, the narrow perspective of SC resilience, limited to a closed system setting, is insufficient to explain how firms can survive and thrive during the COVID-19 crisis, as noted by Ivanov and Dolgui (2020). SC viability differs from resilience in that it takes into account the evolution of a system in response to disruptions in an open system context, which involves redesigning structures and replanning of performance with long-term impacts (Ivanov, 2021a, 2021b). To survive and prosper during and post long-term SC turbulence, such as COVID-19 crisis, a viable SC might be built through production changeovers, standardising product offerings product mixes, both upstream and downstream innovations, revised (re)sourcing strategies, and enhancing capacity utilization (Simchi-Levi, 2020; Ivanov, 2020).

## 3. Hypothesis development

### 3.1. Effect of DTO on digital SC practices

From the PBV perspective, DTO can be considered as an explanatory variable that could underpin the implementation of digital activities in the SC. DTO guides the way a firm interacts with its technological entities, and thus influence the relative priority the firm places on technologies, products, and processes (Gatignon and Xuereb, 1997; Yu et al., 2021). Digital technology and IT literature have concentrated on a technocentric perceptive; however, managerial and human views are also necessary to adopt technologies and embrace digital transformation (Khin and Ho, 2019). It is not only technology but also an orientation that drives digital transformation (Kindermann et al., 2020). DTO provides these human elements such as strong dedication and commitment to technology, R&D and enrich digitally technological base (Khin and Ho, 2019; Zhou and Li, 2010), which are recognised as a fundamental basis for incorporating digital technology into firms' organisational practices and SC operations. Firms with a DTO seek to excel in technological knowledge accumulation and application, such as quick acquisition and application of digital technology and collection of latest technology information (Adams et al., 2019). It appears that the most proactive firms in digital technology practice implementation are those which have a high technology orientation. Such firms, leverage technology improvements and advancements as a vehicle to introduce new ideas, products, processes and innovation (Gatignon and Xuereb, 1997; Hortinha et al., 2011). These technology orientation and technological drive encourage and enable the implementation of digital SC practices. Specifically, DTO not only allows firms to identify latest technological trends and transform the internal resource base to unearth those opportunities (Zhou et al., 2005), but also entails firms facilitating the external capturing, planning, analysing and interpreting, and coordination processes of SCs and digital SC practices (Ivanov, 2021a). Thus, we posit the following hypothesis.

*H1: DTO has a significant positive effect on digital SC practices.*

### 3.2. Effect of digital SC platform on digital SC practices

Rooted in the PBV, a digital SC platform is viewed as an explanatory variable to enable SC practice implementation (Bromiley and Rau, 2016; Li et al., 2020). The effective implementation of digital SC practices involves the collection, processing and application of a huge volume and variety of data in a timely manner to support SC planning, coordination, and process control practices (Ivanov, 2021a). SC platform can facilitate digital connectivity, system integration, and real-time communication across SC members (Han et al., 2017; Li et al., 2020; Sedera et al., 2016). An effective SC platform allows firms to consistently transfer real-time information between digital technology applications and SC-based functions across SC partners (Rai and Tang, 2010; Büyüközkan and Göçer, 2018), and results in the effective adoption of digital SC practices. Digital SC platform is the underlying architecture and infrastructure that is the background foundation for the implementation of SC practices. On the contrary, a lack of an effective digital SC platform may hinder the benefits of integrating digital technology into SC operations, due to the absence of digital SC platform-associated timely information exchange and quality communication, which otherwise provides a structure that supports cooperation and connection for digital hardware, software, and networks to facilitate the SC digitalisation (Li et al., 2020; Rai et al., 2006). Thus, we propose the following hypothesis.

*H2: Digital SC platform has a significant positive effect on digital SC practices.*

### 3.3. Effect of digital SC practices on SC viability and operational performance

As suggested by the PBV, by leveraging digitized data and digital technologies, digital SC practices could influence SC-based activities, functions, and processes, which results in operational enhancements and improved SC capabilities and flexibility through instant information exchange and intelligent data systems (Reddy et al., 2016; Yu et al., 2023). Specifically, by implementing digital SC practices, firms can increase their ability to deal with disruptive changes and uncertainties caused by the COVID-19 pandemic in a more responsive and efficient manner, particularly through network visibility. This enables the development of SC viability during uncertain times (Ageron et al., 2020; Büyüközkan and Göçer, 2018; Ivanov, 2021a). SC viability requires flexible and adaptable supply networks (Ruel et al., 2021), which are underpinned by effective implementation of digital SC practices. This enables quick and frequent transformations in response to global SC disruptions during the COVID-19 pandemic (Ivanov, 2021b; Ivanov and Dolgui, 2021). Thus, we hypothesize a positive relationship between digital SC practices and SC viability.

*H3: Digital SC practices has a significant positive effect on SC viability.*

Underpinned by the PBV, digital SC practices have a significant and direct effect on operational performance (Bromiley and Rau, 2014, 2016). The effective implementation of digital SC practices may directly produce an improvement on firm performance (i.e., operational performance). Digital SC practices not only enable firms to deliver their products in a speedy manner but also generate innovative ways to get product delivery efficiently and effectively (Büyüközkan and Göçer, 2018). Digital SC practices is of vital importance to enhance the efficiency, effectiveness, and speed of shaping responses to environmental changes by using the information collected and modelled (Ivanov, 2021a), which is likely to lead to operational benefits with respect to improving volume flexibility, producing high quality products, and creating cost-efficiency. Although previous research has examined the association between digital SC practices and firm performance (e.g., Yu et al., 2021, 2023), retesting this relationship can help replicate the theory and increase the certainty of results in other contexts, which is an important part of the theory development process in operations and SC management (Melnyk and Handfield, 1998). Thus, we offer the following hypothesis.

*H4: Digital SC practices has a significant positive effect on operational performance.*

### 3.4. Effect of SC viability on operational performance

Disruptive changes, such as the COVID-19 pandemic, resulted in firms experiencing sudden and major impacts in their SC operations, requiring firms to conduct a thorough and immediate assessment of all aspects their SCs, especially sourcing, resilience, sustainability and inventory management (Singh et al., 2021). SC viability emerges as a set of key SC capabilities to assist firms in adapting, responding and thriving in disruptive environments, (Ivanov and Dolgui, 2020). SC viability is a set of capabilities that permeate through a firms' organisational structures, resources, and operational aspects, enabling firms to adapt their SC structures in a timely manner (Ruel et al., 2021). In doing so, SC viability reduces the cost of inventory, production, and transportation as well as improving the flexibility to produce and deliver better quality products. Further, under changing conditions, the possession of SC viability is significant and imperative for a firm to safeguard quality levels and ensure delivery performance through quickly reconfiguring the resource base within the chain (Ivanov, 2021b). Thus, we posit the following hypothesis.

*H5: SC viability has a significant positive effect on operational performance.*

While the above hypotheses (H1-5) can clarify various individual interlinks, it may be more beneficial and practical to take an integrated perspective on how operational performance can be achieved through the interplay between DTO, digital SC platforms, digital SC practices, and SC viability. Supported by the PBV, our digital SC practices model provides this comprehensive coverage and explanation. Furthermore, the following sections introduce a mediation and moderation perspective to our research model, which provide a more holistic understanding of how digital SC practices and SC viability could influence operational performance more effectively.

### 3.5. Mediating effect of SC viability

As we argued earlier, digital SC practices can have a positive direct impact on operational performance (H4). However, the PBV also recommends the integration of an intermediary construct to clarify performance deviations (Bromiley and Rau, 2014, 2016). Bromiley and Rau (2014) suggested that mediating variables should be considered when investigating the influence of a practice on performance from the PBV perspective. According to the PBV, explanatory variables can be utilized to produce an intermediary construct that can explain variations in operational performance (Bromiley and Rau, 2016). In our theoretical framework (see Figure 1), SC viability acts as a mediator in the relationship between digital SC practices and operational performance in the context of the COVID-19 pandemic.

During the COVID-19 crisis, digital SC practices are crucial for improving operational performance (Yu et al., 2023). However, these effects may be indirect and mediated by intermediary constructs such as SC viability, which can help to address the significant SC disruptions and uncertainties caused by the crisis (Ivanov, 2021a, 2021b). The implementation of digital technologies is crucial for enhancing the effectiveness, speed, and efficiency of responses to environmental changes (Ivanov and Dolgui, 2021), which in turn can support the development of SC viability. However, firms may not experience direct improvements in operational performance from implementing digital SC practices, particularly in volatile and disruptive environments, if they lack the capabilities to respond adequately and efficiently to these disruptions (Ivanov, 2021b). Thus, we anticipate that the possession of digital SC practices indirectly affects operational performance through SC viability, particularly in the context of the COVID-19 crisis. Formally, we propose:

*H6: SC viability mediates the relationship between digital SC practices and operational performance.*

### 3.6. Moderating effects of DTO and digital SC platform

Bromiley and Rau (2014) argued that when applying the PBV, moderation variables that depend on specific practices and contexts should be considered. However, the moderation effect has been ignored in previous empirical PBV research (e.g., Shaw et al., 2020; Wang et al., 2018). To obtain a unique interpretation and application of the PBV in the digital transformation context, we examine the moderating effects of DTO and digital SC platforms (Kosmol et al., 2019). In other words, we argue that within the digital SC practices model, the influence of SC viability on operational performance may depend on explanatory variables (Bromiley and Rau, 2014). The linear progression path of our theoretical model (see Figure 1) suggests that explanatory variables (i.e., DTO and digital SC platform in our model) can be leveraged to not only develop the intermediary construct (i.e., SC viability) and enhance firm performance through the effective adoption of digital SC practices, but also to generate moderating effects between SC viability and operational performance (Bromiley and Rau, 2014, 2016).

Building SC viability in response to environmental changes during the COVID-19 crisis requires the utilization of digital technology resources that can be quickly and easily reconfigured (Ivanov and Dolgui, 2021). However, integrating digital technologies into SC operations may not be sufficient on its own (Yu et al., 2023); DTO is also required to develop SC viability and achieve superior operational performance. In other words, without a strong digital technology foundation, the development of SC viability may be hindered. According to the PBV, firms that are not digital technology-oriented, do not adopt the most advanced digital technologies, and do not constantly scan the environment to remain a digital leader will not be able to leverage SC viability to improve operational performance (Zhou and Li, 2010; Yu et al., 2023). Likewise, effective digital SC platform provides a seamless connection between firms and SC partners (Büyüközkan and Göçer, 2018; Li et al., 2020), which supports firms to better manage their SC processes to respond to sudden market changes and deliver high quality products, timely, and within cost constraints. Consistent with the PBV, while other firms may be able to imitate digital SC platforms, superior firm performance will not be achieved unless they have established a digital SC platform to support real-time information exchange between SC-based applications and functions (Rai and Tang, 2010; Sedera et al., 2016).

The argument above, based on the PBV, suggests that DTO and SC platform can potentially act as moderators, strengthening or weakening the relationship between SC viability and operational performance. Testing the effects of moderation is an important step in the proposed digital SC practice model based on the PBV, as highlighted by Bromiley and Rau (2014). Therefore, we posit:

*H7: DTO moderates the relationship between SC viability and operational performance.*

*H8: Digital SC platform moderates the relationship between SC viability and operational performance.*

## 4. Research methodology

### 4.1. Sampling and data collection

Due to the COVID-19 pandemic, we used an online questionnaire survey to collect primary data from manufacturers in China to test our digital SC practices model. With the assistance of the Provincial Economic and Information Technology Commission in different provinces and regions, we obtained a sampling pool of 1000 randomly chosen manufacturing firms. With the support of the commission, we sent the survey invitations via WeChat to the manufacturing firms. A low response rate has been considered a major problem for online surveys (Yan and Fan, 2010), and the COVID-19 pandemic adversely influenced the survey data collection; however, after several reminders, the resulting dataset has 113 usable responses, yielding a response rate of 11.3%.

There is a lack of consensus on determining the minimum sampling design required for structural equation modelling (SEM) (Westland, 2010). Researchers have recommended various rules-of-thumb for calculating sample size, including a minimum sample size of 100 (Boomsma, 1985) and the ratio of observations to estimated parameters (such as 5:1, 10:1, or 20:1) (Bollen, 1989; Kline, 2005). Instead of relying on those rules of thumb, we conducted two statistical tests to determine the required SEM sample size. We carried out the first test using Westland's (2010) formula, i.e., $n \geq 50r^2 - 450r + 1100$, where r is the ratio of indicators to latent variables, and the result suggests that the minimum SEM sample size of 112 observations is required for this study. In addition, we conducted another test by using an online calculator (Soper, 2021), and the results indicate a minimum sample size of 113 observations is required in light of the structural complexity of the model and the minimum sampling size of 87 observations to uncover the specified effect. Based on those results, it can be concluded that sample size used in this study (n = 113) meets the minimum requirements for performing SEM (Westland, 2010).

Table 1 presents the profiles of our respondents. Most respondents hold senior management positions including director, manager, president, CEO, who have been in their current position for over five years. This suggests the informants to be knowledgeable to answer the survey questions. Table 1 also shows that the firms in our sample are located in different major geographical regions, which depict different phases of industrial development in China. Thus, the survey data gathered from all these regions are representative of China.

------------------------------ Insert Table 1 -------------------------------

### 4.2. Bias assessment

We tested for non-response bias and common method bias (CMB). To examine the non-response bias, we compared the differences between early and late responses across number of employees and annual sales by performing a t-test (Hair et al., 2018), and the results indicated no significant differences. It can thus be suggested that non-response bias is not a serious concern in this study.

To examine CMB, we employed two methods that are commonly used in the SCM literature. First, confirmatory factor analysis (CFA) was applied to Harman's single-factor model. The CFA results reveal unacceptable model fit indices ($\chi^2$/df = 4.563, CFI = 0.622, IFI = 0.625, and RMSEA = 0.178) (Hu and Bentler, 1999). Second, we adopted the marker variable technique by using the respondents' years of employment as a method variance marker, which has no theoretical relationship with one or more variables in the study (Lindell and Whitney, 2001). The lowest positive correlation (r = 0.017) between the method variance marker and other variables (see Table 3) was chosen to adjust the construct correlations and statistical significance (Lindell and Whitney, 2001). As shown in Table 3, all the significant correlations remain significant after the adjustment. Therefore, we conclude that CMB does not represent a significant problem in this study.

### 4.3. Measures and control variables

#### 4.3.1. Measures

We conducted a comprehensive literature review in the fields of SCM and information systems to develop the survey instrument. Because the measures adapted from the literature were in English and were translated into Chinese, a back-translation process was used to ensure conceptual equivalence (Yu et al., 2019). Several questions were rephrased to enhance translation accuracy and relevance to Chinese practices. Table 2 presents the measurement items utilized in this study. As the scales are reflective constructs, they do not need to comprehensively capture the construct but instead, only represent certain aspects of it (Kerlinger and Lee, 2000). To improve the content validity and reliability of the instrument, a pilot test was conducted by inviting academic researchers and senior executives to review and provide feedback on the questionnaire.

------------------------------ Insert Table 2 ------------------------------

The measures for DTO were adapted and modified from previous research (Khin and Ho, 2019; Zhou et al., 2005), which included five items that focus on examining the extent to which the firm is proactive in the adoption of sophisticated digital technologies (e.g., IoT, AI, BDA, and blockchain) for smart SCs and manufacturing operations. The measures for digital SC platform were adapted from Rai and Tang (2010), using five items that focus on examining the extent to which the firm builds digital platforms to access suppliers' system, connect with suppliers' systems across multiple functions, exchange real-time information with suppliers, and aggregates relevant information from the suppliers' databases.

We adapted and modified the measurement items for digital SC practices based on our comprehensive literature review (e.g., Büyüközkan and Göçer, 2018; Nasiri et al., 2020; Sedera et al., 2016). The items for digital SC practices measured the firm's ability to implement a bundle of SC activities through the adaptation of digital technologies, such as using advanced digital technologies to reshape new product development that meet market needs, identify additional needs of customers, build internal and external organisational capabilities, and gain information regarding new technologies, products, and markets. All items for DTO, digital SC platform, and digital SC practices were measured using a 7-point Likert scale that ranges from 1 = strongly disagree to 7 = strongly agree.

Because no existing reliable and validated instrument measures existed for SC viability, we developed new measures based on the pioneer work of Ivanov and Dolgui (2020) and Ivanov (2020), and our observations during firm visits and interviews with senior executives at manufacturing firms in China. A total of six items were developed to measure the firm's SC viability during the COVID-19 pandemic, including respond to changing business requirements effectively, absorb and mitigate the effects of the COVID-19 crisis, adapt supply-demand allocations by production localisation, redesign supply base, redesign our logistics network, and maintain sustainable operations by adjusting capacity utilization. All items are also rated on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Furthermore, the reliability and validity of these newly developed SC viability scales were assessed and confirmed by performing a series of analyses, and the results are reported in Table 2.

The operational performance scale was adapted from Flynn et al. (2010), which focused on flexibility, delivery performance, quality, and cost. We asked the respondents to evaluate their operational performance compared to their major industrial competitors since the COVID-19 outbreak on a 7-point Likert scale anchored by 1 (much worse than your major competitors) and 7 (much better than your major competitors).

### 4.3.2. Controls

In the research model, we controlled for firm size, age, location, and industry type since firms with different age (young vs. old), size (small vs. large), location (geographical regions), and industry type might implement different digital SC practices to develop viable SCs for performance improvement during the COVID-19 pandemic. The mean of the latent variables (number of employees and annual sales) was used to measure firm size (Yu et al., 2019, 2023), and the year of incorporation was used to measure firm age (Yu et al., 2019, 2023). A dummy variable was used for firm location and industry type (Yu et al., 2019).

## 4.4. Measure assessment

As shown in Table 2, all five theoretical constructs had satisfactory reliability. Cronbach's alpha and CR were all above the minimal acceptable threshold of 0.70 (Hair et al., 2018). CFA results reported in Table 2 also indicate that the model fit indices are acceptable ($\chi^2$ / df = 1.931, CFI = 0.904, IFI = 0.906, and RMSEA = 0.091) and all item loadings are larger than 0.70 (except one item with the factor loading of 0.662), which provide evidence of unidimensionality and convergent validity (Hair et al., 2018). Additionally, as shown in Table 2, the average variance extracted (AVE) values for all constructs satisfied the minimum required level of 0.50, which indicates convergent validity (Fornell and Larcker, 1981). Table 3 reports the means, standard deviations, and intercorrelations among variables, which also provide evidence of discriminant validity that the square root of AVE on the diagonal is greater than inter-construct correlations (Fornell and Larcker, 1981).

------------------------------ Insert Table 3 ------------------------------

# 5. Hypothesis testing and results

Multivariate statistical methods, including SEM, bootstrapping approach, and moderated regression analysis, were used to test the hypothesized direct, mediation and moderation effects. The results are reported in Tables 4, 5 and 6.

## 5.1. Test of direct effect

SEM with AMOS 26 was carried out to test the explanatory variables–practices–intermediate outcomes–performance relationship. Table 4 presents the results of the structural model estimation, suggesting that the structural model has an acceptable fit (Hu and Bentler, 1999). Although firm age, size, location, and industry type were controlled in the theoretical model, no significant positive effect was found on operational performance. The results summarised in Table 4 reveal that explanatory variables, namely DTO ($\beta = 0.459$, $p \leq 0.01$) and digital SC platform ($\beta = 0.330$, $p \leq 0.05$), have a significant positive effect on digital SC practices, which lends support to H1 and H2, respectively. The results also reveal that digital SC practices has a significant positive effect on SC viability ($\beta = 0.636$, $p \leq 0.001$) and operational performance ($\beta = 0.247$, $p \leq 0.05$), which provides strong support for H3 and H4, respectively. H5 postulates that SC viability is significantly and positively related to operational performance. Table 4 shows the significant positive effect of SC viability on operational performance ($\beta = 0.373$, $p \leq 0.001$). Thus, H5 is supported.

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### 5.2. Test of mediation effect

To investigate whether SC viability acts as a mediator of the influence of digital SC practices on operational performance (H6), the bootstrap approach was used in this study. Bias-corrected bootstrapping approach (based on 2,000 bootstrap samples) was conducted to test the significance of the indirect effect (Zhao et al., 2010). The results of the bootstrapping test are reported in Table 5. The results reveal that the direct effect of digital SC practices on operational performance is significant ($\beta = 0.247$, $p < 0.05$), and that its indirect effect on operational performance via SC viability is also positive and significant ($\beta = 0.237$, $p < 0.10$; 90% confidence interval [0.026, 0.411]). In addition, Sobel test ($z = 2.871$, $p < 0.01$) was further conducted to provide additional support for the mediated relationship. In summary, both the Sobel test and the bootstrapping reveal that the impact of digital SC practices on operational performance is partially mediated by SC viability. Thus, H6 is supported.

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### 5.3. Test of moderation effect

Due to the relatively small sample size (n=113), SEM could not be applied in this study to test the moderating role of DTO and digital SC platform. Previous survey-based studies (e.g., Yu et al., 2021; Zhao et al., 2011) have used the multiple methods (SEM and regressions analysis).

Therefore, moderated regression analysis was used to investigate the moderation. Because there might be multicollinearity issues, mean-cantered scores were used, and each interaction term was entered the moderated regression model separately as suggested by the extant SCM literature (Williams et al., 2013). The results of the moderated regression analysis are reported in Table 6. The variance inflation factor (VIF) values in all models are well below the critical threshold of 10.0, confirming multicollinearity is not a serious concern (Mason and Perreault, 1991). As shown in Table 6, the coefficients of the cross-product terms (i.e., SC viability × DTO and SC viability × digital SC platform) are significant, indicating that DTO and digital SC platform moderate the SC viability–operational performance relationship. Thus, H7 and H8 are supported.

------------------------------ Insert Table 6 ------------------------------

We extended the interpretation through plotting the graphical view of the relationship between SC viability and operational performance (see Figures 2 and 3) to illustrate how DTO and digital SC platform moderate the relationship (Aiken and West, 1991). Figures 2 and 3 shows that the influence of SC viability on operational performance is more pronounced when DTO and digital SC platform are high, indicating the higher the level of DTO and digital SC platform the stronger the positive effect of SC viability on operational performance.

------------------------------ Insert Figures 2 and 3 ---------------------

# 6. Discussion

## 6.1. Theoretical contributions

This study significantly extends the PBV by identifying two explanatory variables (i.e., DTO and digital SC platform) that are not specified by Bromiley and Rau (2014), and by investigating the moderating role of DTO and digital SC platform and the mediating role of SC viability, which was explicitly noted by Bromiley and Rau (2014) but ignored by previous work. Thus, this study is one of the first attempts to systematically investigate the explanatory variables–practices–intermediate outcomes–performance relationship through the expanded PBV in the contexts of Industry 4.0 and the COVID-19 pandemic.

First, this study extends the PBV by identifying potential explanatory variables. In their work, Bromiley and Rau (2014) did not offer explanatory variables which can be considered as enablers or antecedents of practices. In this study, we identified two explanatory variables (i.e., DTO and digital SC platform), which will help to clarify how firms successfully implement digital SC practices during the COVID-19 pandemic or other similar disruptive events. We found that both DTO and digital SC platform have a significant positive impact on digital SC practices, and that also significantly moderate the relationship between SC viability and operational performance. With the advent of digitisation and Industry 4.0, while digital technologies appear to enable firms to increase the quality, quantity and timeliness of information dissemination along the entire SC, firms need to establish and leverage digital SC platform to increase sources of high-quality information and enhance interconnectedness (Li et al., 2020). Only those firms that invest heavily in advanced digital technologies and establish digitally enabled platforms across the SCs can successfully implement relevant digital SC practices. High technology-oriented firms, who pay more attention to the effective adoption of digital technologies, will in turn create a set of digital SC practices and a culture that will result in innovative products/services to customers (Gatignon and Xuereb, 1997; Yu et al., 2021). Likewise, firms that effectively develop digital SC platform could improve inter-firm process coupling, data transmission, and integration, so firms can access and combine external resources and knowledge from SC partners to improve digital SC operations (Li et al., 2020; Sedera et al., 2016). This finding reinforces Li et al.'s (2020) conclusion regarding the crucial role of digital SC platforms and extends it by considering the platform's significance from both PBV and pandemic perspectives.

Second, the study makes another important contribution to the literature on SC digitalization and viability by providing initial evidence of the importance of digital SC practices in developing viable SCs during the COVID-19 pandemic. To the best of our knowledge, this is the first attempt to empirically explore the effect of digital SC practices on developing viable SCs. As noted above, both practitioners (as indicated in the industrial reports and white papers) and academics (previous research focused more on conducting a systematic literature review) alike have acknowledged the importance of SC digitization in managing global SC disruptions during the COVID-19 pandemic (Garg et al., 2020; Ivanov and Dolgui, 2021). However, research on the SC digitalization is still in its infancy (Yu et al., 2023), and the potential benefits of the adoption of digital SC practices in developing viability in SCs is still unknown (Ageron et al., 2020; Büyüközkan and Göçer 2018). This study demonstrated that implementing digital SC practices has a significant positive effect on SC viability. Digital SC practices enabled by innovative digital technologies and digital SC platforms promise to enable firms respond to extraordinary events and deal with disruptive changes through enhanced data availability, timely, and accurate information sharing, and systems interoperability (Ageron et al., 2020; Büyüközkan and Göçer, 2018; Ivanov, 2021a).

Third, our study provides initial evidence that developing viable SCs can deliver operational benefits to firms during the COVID-19 pandemic. Recently, Ivanov and his colleagues (e.g., Ivanov, 2020, 2021a, 2021b; Ivanov and Dolgui, 2020, 2021) have defined SC viability and its importance in enabling firms to sense the sudden and unexpected supply and demand changes and quickly respond to global SC disruptions. However, existing research on SC viability is still at its nascent stage, particularly since the onset of the COVID-19 crisis (Ivanov and Dolgui, 2020). This study demonstrated that SC viability is significant and positively related to operational performance. Developing a viable SC allows firms to systematically solve problems in the expectation of surviving in the changing environment and deliver operational benefits, such as reduce lead time, quickly respond to market demands, organise on-time delivery, and create high quality products that meet customer needs (Ivanov and Dolgui, 2020, 2021). In this view, it represents a significant contribution to the SC management literature by confirming the importance of SC viability in improving business performance.

Fourth, this study offers another significant theoretical implication by exploring both moderator and mediator effects in the digital SC practices model. Although Bromiley and Rau (2014) has suggested moderating and mediating variables and context should be considered when testing relationships from the PBV perspective, previous research has ignored this suggestion (e.g., Shaw et al., 2020; Silva et al., 2019). For instance, Shaw et al. (2020) examined various enablers, inhibitors, and benefits that influence the implementation of environmental SC performance measurement practices, but they did not investigate either the moderation or mediation effects in their theoretical framework. Leaving out moderating or mediating effects in the digital SC practices model might hide potentially significant contributions and draw potentially misleading conclusions. This study therefore investigates the mediating role of SC viability and the moderating role of DTO and digital SC platform, and the data analysis also provides evidence on both mediation and moderation. Regarding the mediation effect, this study reveals that the execution of digital SC practices can yield superior operations performance (such as quick response to dynamic market demand, fast and on-time delivery, and shorten lead times) during the COVID-19 pandemic through the development of SC viability. During the COVID-19 crisis, manufacturing firms are facing unprecedented challenges due to workforce and operational restrictions and severe uncertainty caused by global SC disruptions (Ivanov and Dolgui, 2020). In this situation, SC viability emerged as a special SC property that allows firms to adapt and survive in critically disruptive changes (Ivanov and Dolgui, 2020; Ruel et al., 2021).

Regarding the moderation effect, this study also demonstrated the two explanatory variables, namely DTO and digital SC platform, significantly moderate the relationship between SC viability and operations performance. In other words, the positive influence of SC viability on operational performance depends on the establishment of digital SC platforms and the adoption of advanced digital technologies. This finding is consistent with that of Kosmol et al. (2019), who suggested that explanatory variables (such as digital procurement readiness) act as a moderator on the effect of digital procurement practices on performance. In the era of Industry 4.0, developing a viable SC requires firms to deploy quickly and reconfigure frequently digital technological resources (such as the adoption of digital technologies and the establishment of digital platforms) in response to environmental changes and significant disruptions especially caused by the COVID-19 pandemic (Ivanov and Dolgui, 2021).

### 6.2. Managerial implications

The empirical findings in this study offer practical insights and guidance for managers seeking to implement digital SC practices to develop SC viability and enhance operational performance. While the study was conducted during the COVID-19 pandemic, many of the findings are relevant to everyday situations within SCs. As SCs are increasingly facing volatility and unpredictability, where uncertainty and disruptions are now considered the norm, the findings presented in this study hold relevance for all SCs.

First, the findings provide empirical evidence that strongly supports the digital SC practice model proposed in this study. Our results provide evidence-based confidence to managers to better understand how the adoption of digital SC practices influences business performance during a key SC disruptive event (i.e., the COVID-19 pandemic). The digital SC practices model offers managers a new and different perspective to investigate the potential explanations for performance variation from the implementation of digital SC practices that are facilitated by explanatory factors, i.e., adopting digital technologies and establishing digital SC platform.

Second, the industrial reports by IBM and McKinsey reveal that business leaders have begun to recognize the importance of SC digitization, especially in dealing with the global SC disruptions during the COVID-19 pandemic. Shifting from a traditional SC to an intelligent digital SC requires firms to execute a complete digital transformation. Nevertheless, the question remains whether and how firms can successfully implement digital SC practices in the contexts of change and disruptions, such as Industry 4.0 and the COVID-19 pandemic. Our study identified two explanatory variables, namely, DTO and digital SC platform, which can be considered as antecedents or enablers of digital SC practices. This finding provides a useful guidance for managers by answering the question of how firms successfully implement digital SC practices. Additionally, our findings suggest that the impact of SC viability on operational performance is also dependent on the adoption of digital technologies and the establishment of digitally enabled platforms across the SC. Thus, this study suggests that firms should not only adopt digital technologies (e.g., IoT, big data analytics, and blockchain) but also establish a digital SC platform. By doing so, firms can successfully implement digital SC practices and help firms developing a viable SC for operational performance improvement during the COVID-19 pandemic.

Third, our study provides early empirical evidence of the important roles of digital practice-based SC viability: delivering operational benefits and mediating the effect of digital SC practices on operational performance during the COVID-19 outbreak. To survive and thrive during the COVID-19 crisis, firms should build a dynamically adaptable and structurally changeable value-adding network that enables them to react agilely to positive changes, be resilient to absorb negative events and recover after the disruptions. When firms are positioned in threatening situations caused by critical environmental changes, they are required to commensurately alter their SC viability in congruence with the changing environment. Developing SC viability has become more crucial than ever in enabling firms to tackle super disruption and uncertainties in SCs during the COVID-19 crisis. A viable SC might be built through production changeovers, reducing the product variety, radical changes in supplier base and logistics, production localization, and adjusting capacity utilizations.

## 7. Future research

Notwithstanding the main theoretical and managerial implications, our study is subject to limitations. First, in this study we identified two explanatory variables: DTO and digital SC platform that facilitate the implementation of digital SC practices. The explanatory variables are not specified in the PBV proposed by Bromiley and Rau (2014), which allows for idiosyncratic interpretation and applications (Wang et al., 2018). Thus, future research may define other potential explanatory variables that depend on the specific practice and context. Second, future research may consider conducting multiple case studies and/or longitudinal studies to explain how and why the execution of digital SC practices drives long-term firm survival and success during and post the COVID-19 pandemic. Such case study method would generate more meaningful and interesting results for researchers and practitioners. Third, to empirically test the digital SC practices model, we collected survey data from 113 manufacturers in China. We conducted two statistical tests and confirmed that the sample size is reasonable. Future researchers are encouraged to survey a large sample size and test the model in different industries (such as service industry) and research settings (such as developed countries) to confirm the findings generated from this study and compare the potential differences. Thus, these would be useful avenues to extend our work. Finally, in this study, we developed new measures for SC viability, and the analyses confirmed the reliability and validity of these newly developed scales. Future research could use psychometric tests such as classical test theory, item response theory, or multidimensional scaling to calibrate the newly developed scales used in this study.

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**Table 1: Profile of responding companies**

| | Percent (%) | | Percent (%) |
|---|---|---|---|
| **Industries** | | **Firm locations** | |
| Textiles and apparel | 4.4 | Bohai Sea Economic Area | 8.8 |
| Rubber and plastics | 3.5 | Central China | 51.3 |
| Food, beverage and alcohol | 28.3 | Northwest China | 1.8 |
| Fabricated metal product | 11.5 | Pearl River Delta | 15.9 |
| Electronics and electrical | 6.2 | Southwest China | 3.5 |
| Chemicals and petrochemicals | 3.5 | Yangtze River Delta | 18.6 |
| Automobile | 25.7 | **Job titles** | |
| Others | 16.8 | Director | 8.8 |
| **Number of employees** | | Manager | 51.3 |
| 1 – 100 | 35.4 | President / Chief executive officer (CEO) | 7.1 |
| 101 – 200 | 9.7 | Vice President | 0.9 |
| 201 – 500 | 13.3 | Other senior executive | 31.9 |
| 501 – 1000 | 11.5 | **Years in current position** | |
| 1001 – 3000 | 4.4 | ≤ 5 | 44.2 |
| > 3000 | 25.7 | 6-10 | 27.4 |
| **Annual sales (in million RMB)** | | > 10 | 28.3 |
| Below 10 | 10.6 | **Firm age (years)** | |
| 10 – 50 | 22.1 | ≤ 10 | 27.4 |
| 50 – 100 | 18.6 | 11-20 | 34.5 |
| 100 – 500 | 15.9 | 21-30 | 23.0 |
| 500 – 1000 | 6.2 | > 30 | 15.0 |
| Above 1000 | 26.5 | | |

**Table 2: Measurement model assessment**

| Measurement items | Factor loadings | α | CR | AVE |
| --- | --- | --- | --- | --- |
| **1. DTO** | | 0.941 | 0.942 | 0.767 |
| We use the most advanced digital technologies (e.g., IoT, artificial intelligence, advanced robotics) for smart manufacturing | 0.743 | | | |
| Compared to our industrial competitors, our digital technologies adopted for supply chain and manufacturing operations are more advanced | 0.854 | | | |
| We are always the first to use sophisticated digital technologies in our industry | 0.964 | | | |
| We are regarded as a digital technology leader in our industry | 0.931 | | | |
| We respond to market and customer needs swiftly and effectively by orchestrating multiple digital technologies | 0.871 | | | |
| **2. Digital SC platform** | | 0.906 | 0.908 | 0.665 |
| Our digital platform easily accesses data from our suppliers' systems | 0.824 | | | |
| Our digital platform provides seamless connection between our suppliers' systems and our systems (e.g., forecasting, production, shipment, etc.) | 0.837 | | | |
| Our digital platform has the capability to exchange real time information with our suppliers | 0.853 | | | |
| Our digital platform easily aggregates relevant information from our suppliers' databases (e.g., operating information and cost information) | 0.780 | | | |
| Our platform is easily adapted to include new suppliers | 0.780 | | | |
| **3. Digital SC practices** | | 0.930 | 0.933 | 0.735 |
| Where possible, we experiment and trial digital technologies in new ways to develop new products that can help attract and serve new markets | 0.869 | | | |
| Using digital technologies, we integrate and build internal and external capabilities in our organization | 0.888 | | | |
| Using digital technologies, we seek out information about new markets, products, and technologies from sources outside the organization | 0.877 | | | |
| Using digital technologies, we continuously try to discover additional needs of our customers (and potential customers) of which they are unaware | 0.877 | | | |
| Using digital technologies, we manage political and economic risks by promptly responding proactively to them | 0.770 | | | |
| **4. SC viability** | | 0.930 | 0.932 | 0.695 |
| Our company's supply chain is able to respond to changing business requirements caused by the COVID-19 pandemic | 0.868 | | | |
| Our company's supply chain is able to absorb and mitigate the effects of an unexpected event or disaster (the COVID-19 pandemic) | 0.798 | | | |
| We are able to adapt our supply-demand allocations by production localisation during the COVID-19 pandemic | 0.832 | | | |
| We are able to redesign our supply base during the COVID-19 pandemic | 0.868 | | | |
| We are able to redesign our logistics network during the COVID-19 pandemic | 0.777 | | | |
| We are able to maintain sustainable operations by adjusting our capacity utilization during the COVID-19 pandemic | 0.854 | | | |
| **5. Operational performance** | | 0.913 | 0.918 | 0.696 |
| Quickly respond to changes in market demand | 0.857 | | | |
| An outstanding on-time delivery record to our major customer | 0.943 | | | |
| The lead time for fulfilling customers' orders is short | 0.919 | | | |
| Produce high quality products that meet our customer needs | 0.755 | | | |
| Offer price as low or lower than our competitors | 0.662 | | | |
| Model fit statistics: $\chi^2 = 558.038$; df = 289; $\chi^2$ / df = 1.931; CFI = 0.904; IFI = 0.906; RMSEA = 0.091 | | | | |

**Table 3: Descriptive statistics**

| | Mean | S.D. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| **1. DTO** | 5.104 | 1.266 | **0.876** | 0.803** | 0.711** | 0.614** | 0.560** |
| **2. Digital SC platform** | 5.398 | 1.086 | 0.806** | **0.815** | 0.659** | 0.604** | 0.491** |
| **3. Digital SC practices** | 5.536 | 1.037 | 0.716** | 0.665** | **0.857** | 0.567** | 0.464** |
| **4. SC viability** | 5.500 | 1.009 | 0.621** | 0.611** | 0.574** | **0.834** | 0.534** |
| **5. Operational performance** | 5.605 | 1.022 | 0.567** | 0.500** | 0.473** | 0.542** | **0.834** |
| **6. Years of employment (marker variable)** | n/a | n/a | -0.088 | 0.017 | -0.108 | -0.123 | -0.101 |

Note: Square root of AVE is on the diagonal; unadjusted correlations appear below the diagonal; adjusted correlations for potential common method variance appear above the diagonal; ** $p \le 0.01$.

**Table 4: Structural model assessment: direct effect**

| **Direct effect** | **Path coefficient** | **t-value** | **Standard errors** |
|---|---|---|---|
| DTO → Digital SC practices | 0.459** | 2.793 | 0.175 |
| Digital SC platform → Digital SC practices | 0.330* | 2.019 | 0.164 |
| Digital SC practices → SC viability | 0.636*** | 6.837 | 0.083 |
| SC viability → Operational performance | 0.373*** | 3.179 | 0.121 |
| Digital SC practices → Operational performance | 0.247* | 2.107 | 0.107 |
| **Control variables** | | | |
| Firm age → Operational performance | -0.078 | -0.785 | 0.095 |
| Firm size → Operational performance | 0.045 | 0.430 | 0.057 |
| Industry1 (food, beverage and alcohol) → Operational performance | 0.019 | 0.203 | 0.205 |
| Industry2 (automobile) → Operational performance | -0.134 | -1.360 | 0.219 |
| Industry3 (fabricated metal product) → Operational performance | -0.051 | -0.559 | 0.277 |
| Region1 (Central China) → Operational performance | -0.008 | -0.063 | 0.242 |
| Region2 (Yangtze River Delta) → Operational performance | 0.030 | 0.264 | 0.286 |
| Region3 (Pearl River Delta) → Operational performance | 0.002 | 0.022 | 0.298 |
| **Variance explained ($R^2$)** | | | |
| Digital SC practices | 0.581 | | |
| SC viability | 0.404 | | |
| Operational performance | 0.324 | | |
| Fit indices: $\chi^2$ = 776.239; df = 477; $\chi^2$ / df = 1.627; CFI = 0.901; IFI = 0.903; RMSEA = 0.075 | | | |

*** $p \le 0.001$; ** $p \le 0.01$; * $p \le 0.05$.

**Table 5: Test of mediation effect**

| Structural paths | Direct effect | Indirect effect | SE of indirect effect | 90% CI for indirect effect | Sobel test | Mediation test outcome |
|---|---|---|---|---|---|---|
| DSCP→SCV→OP | 0.247* | 0.237† | 0.117 | 0.026–0.411 | z = 2.871** | Partial mediation |

Note: DSCP: digital supply chain practices; SCV: supply chain viability; OP: operational performance; SE: bootstrap standard error; CI: bootstrap confidence interval; Standardized effects; 2,000 bootstrap samples; ** $p \le 0.01$; * $p \le 0.05$; † $p \le 0.10$.

**Table 6: Test of moderation effect**

| | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| **Control variables** | | | | |
| Firm age | 0.042 (0.367) | -0.099 (-1.059) | -0.127 (-1.445) | -0.105 (-1.192) |
| Firm size | -0.033 (-0.269) | 0.065 (0.662) | 0.062 (0.669) | 0.058 (0.620) |
| Industry1 (food, beverage and alcohol) | 0.032 (0.291) | 0.067 (0.744) | 0.063 (0.751) | 0.084 (0.985) |
| Industry2 (automobile) | -0.005 (-0.042) | -0.117 (-1.277) | -0.135 (-1.575) | -0.103 (-1.187) |
| Industry3 (fabricated metal product) | -0.046 (-0.435) | -0.054 (-0.630) | -0.054 (-0.684) | -0.052 (-0.641) |
| Region1 (Central China) | -0.124 (-0.860) | 0.083 (0.695) | 0.066 (0.589) | 0.077 (0.678) |
| Region2 (Yangtze River Delta) | 0.110 (0.824) | 0.124 (1.148) | 0.142 (1.408) | 0.155 (1.520) |
| Region3 (Pearl River Delta) | 0.024 (0.180) | 0.109 (1.023) | 0.101 (1.012) | 0.117 (1.155) |
| **Independent variables** | | | | |
| SC viability (SCV) | | 0.284 (2.745)** | 0.271 (2.803)** | 0.285 (2.914)** |
| Digital technology orientation (DTO) | | 0.422 (2.961)** | 0.377 (2.825)** | 0.364 (2.690)** |
| Digital SC platform (DSCP) | | 0.012 (0.087) | 0.077 (0.595) | 0.057 (0.434) |
| **Interaction effects** | | | | |
| SCV × DTO | | | 0.288 (3.981)*** | |
| SCV × DSCP | | | | 0.267 (3.659)*** |
| $R^2$ | 0.053 | 0.420 | 0.499 | 0.488 |
| *F-value* | 0.731 | 6.640*** | 8.302*** | 7.948*** |
| *Max VIF* | 2.284 | 3.531 | 3.556 | 3.580 |

Note: t-values are shown in parentheses; dependent variable is operational performance; *** $p \leq 0.001$; ** $p \leq 0.01$.

**Figure 1: Digital supply chain practices model**

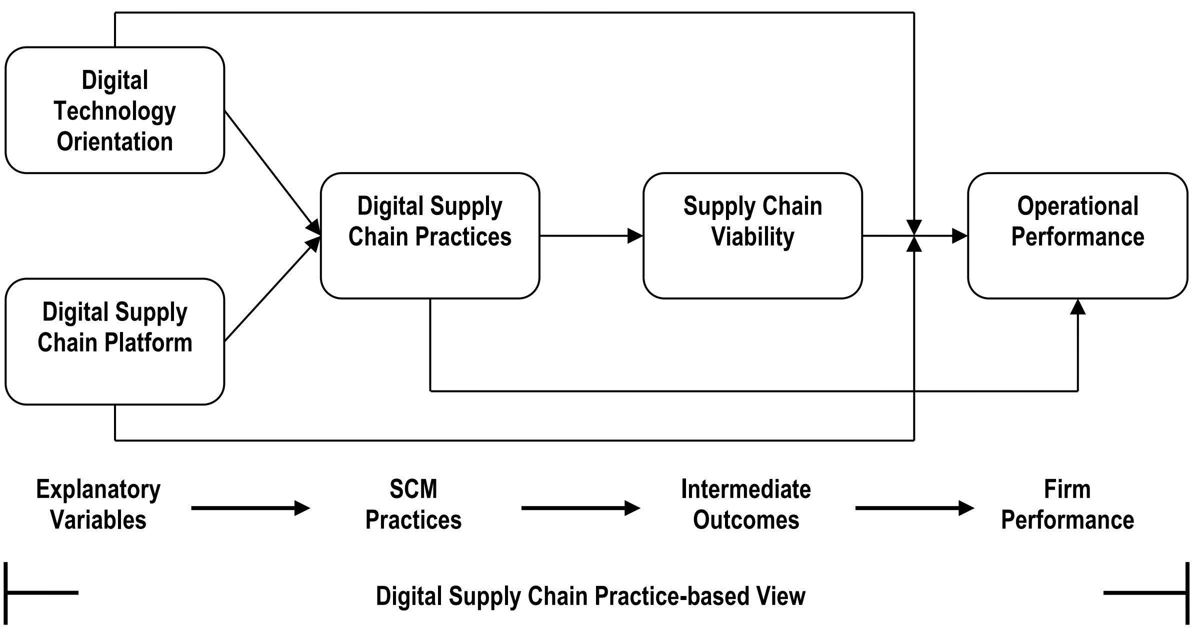

**Figure 2: Moderation effect of DTO**

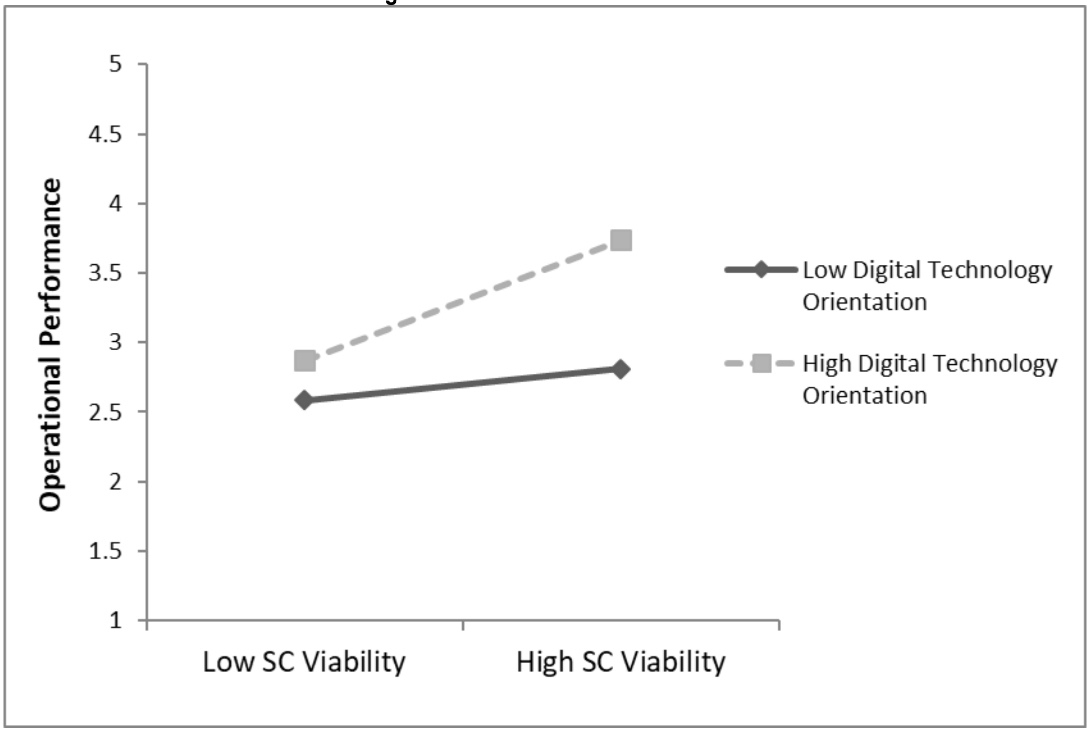


**Figure 3: Moderation effect of digital SC platform**