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## Article

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# Exploring supply chain managers' complex perceptions of dynamic capabilities for digital transformation

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## ABSTRACT

Although the use of new digital technologies is an increasingly important topic for supply chain managers, existing literature is limited on what specific capabilities are perceived to be important for a successful transition to digital supply chains, in particular from a managerial perspective. In response, this study examines how supply chain managers perceive the importance and interconnections of specific digital capabilities for digital transformation. Based on a digital capability framework, we surveyed supply chain managers in Austria and Germany. The sample consisted of two groups, comprising senior managers from logistics service providers and from manufacturing companies. Decision-Making Trail and Evaluation (DEMATEL) was used to evaluate the managers' perceptions of the importance of the enablers and their relationships between capabilities. Our findings show that senior managers in the supply chain domain perceive interactions between dynamic capabilities as a complex and highly interconnected system, rather than discrete and linear. Digital mindset crafting, digital scenario planning and improving digital maturity were identified as the most relevant capabilities in both subsamples, while digital sensing was considered to be the most relevant capability at the construct level, followed by digital seizing and digital transforming. Furthermore, supply chain managers in manufacturing perceived that digital capabilities were more developed in their industry. We anticipate that our findings will inform and guide capability-building in dynamic corporate settings. This study is one of the first to empirically assess how supply chain managers perceive the importance of specific digital capabilities and their interdependencies for digital transformation.

## 1. Introduction

Across a variety of industries, digital transformation is recognized as a necessity by leaders and strategists (Hasson et al., 2013; Warner & Wäger, 2019). Managers are increasingly under pressure to adopt and implement new technologies that may transform the very principles of doing business (Sergei et al., 2023) and gain a competitive advantage over existing competitors (Fitzgerald et al., 2014) or new market entrants (Mikl, Herold, Ćwiklicki, & Kummer, 2021).

Successfully navigating technological shifts and integrating innovative and novel ideas into business environments requires strong organizational commitment (Steelman et al., 2019). However, incumbents can face significant challenges even if senior management supports the digital transformation of existing structures, business processes and legacy business models (Hess et al., 2016). Often, the general understanding is that established firms do not have the relevant capabilities to

digitally reinvent themselves or will fail to do so due to organizational inertia (Kelly & Amburgey, 1991; Margiono, 2021; Mikalef et al., 2021). Scholars point out that traditional enterprises usually excel at executing proven business models in known and stable environments and seem to focus on activities that contributed to their past success even during substantial changes in their competitive environment (Mastio et al., 2021; Sull, 1999). While organizational ambidexterity, i.e., a firm's ability to simultaneously pursue exploitation and exploration as two distinct modes of learning, can be imperative to protect incumbents against discontinuities in their environment (Ossenbrink et al., 2019), legacy enterprises often struggle to balance the exploitation of existing capabilities while identifying and developing new digital capabilities (Svahn et al., 2017).

It is, therefore, important that managers are able to identify and understand digital opportunities and challenges to build the capabilities necessary for navigating technology transitions (Gurbaxani & Dunkle,

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2019; Singh et al., 2020; Wrede et al., 2020). In this respect, they are in charge of strategically planning the long-term transformation of organizations and of addressing and coordinating multiple organizational and operational changes resulting from the adoption of new digital technologies (Bresciani et al., 2021; Fernandez-Vidal et al., 2022; Kunisch et al., 2022; Singh & Hess, 2017). We argue that managers need to recognize the relevance and importance of dynamic capabilities for digital transformation as a prerequisite to deliberately developing them.

However, research shows that many managers are not able to formulate the digital strategies needed to achieve readiness for industrial digitalization (Chanias et al., 2019). Wrede et al. (2020) even point out that, despite the decisive role of top managers in strategic decision-making regarding digital transformation in practice, our empirical understanding of their role is still limited. A knowledge gap exists with respect to which specific capabilities are essential from a managerial perspective, when confronted with digital transformation (Carlsson et al., 2021; Lavie, 2006). Although substantial progress in understanding dynamic capabilities has been made in recent years, there is significant potential for further development, especially in terms of operationalizing and empirically validating key propositions (Ruiz-Ortega et al., 2023; Teece, 2023). In this respect, Warner and Wäger (2019) note that there is insufficient conceptual and empirical research on how organizations undergo transformative processes, particularly from a managerial perspective.

In response, this study contributes to the field's empirical knowledge base by examining managers' perceptions of the relevance and interdependencies of individual dynamic capabilities for digital transformation. To advance our understanding, we raised three research questions:

**RQ1.** Which capabilities for digital transformation do managers perceive as important?

**RQ2.** Which interdependencies do managers perceive between these capabilities?

**RQ3.** Which manifestations of capabilities for digital transformation are perceived by managers?

To systematically address and answer these research questions, we conducted a survey among senior supply chain managers in Austria and Germany between November 2023 and February 2024. We based the survey on capabilities explicated by Warner and Wäger (2019). We used the Decision-Making Trail and Evaluation (DEMATEL) method to analyse and evaluate the perceived prominence of each capability as well as their underlying cause-and-effect relationships. We contextualized our study by embedding it in a supply chain context, because navigating digital technology transitions in this domain is particularly important (Dobrovnik et al., 2018; Groschopf et al., 2021; Herold et al., 2021; Mikl, Herold, Pilch, et al., 2021). Recent studies indicate that digitally transforming an incumbent's business while also considering boundary-spanning aspects is a challenging task because supply chains are increasingly complex, highly collaborative and interorganizational in nature (Falcone et al., 2021; Gerschberger et al., 2023; Pant et al., 2021; Weisz et al., 2024).

The contribution of this work is threefold: First, this study is one of the first to empirically assess how supply chain managers perceive dynamic capabilities for digital transformation as well as their interdependencies, thereby providing insights to scholars, practitioners, managers and organizations to better navigate technology-induced shifts. Second, by using a managerial cognition perspective, we expand the body of knowledge about the role of managers in building capabilities for digital transformation. Third, this study expands supply chain literature by comparing perceptions between leaders of logistics service providers and manufacturing companies, thereby identifying key differences in cognition as a basis for forming digital transformation strategies.

The remainder of this study is structured as follows. In the next

section, we present and discuss current literature to provide a background on the role of digital transformation in organizations and supply chains. In Section 3, we outline our overall research approach. In Section 4, we present the results of the empirical study and the implications for the use of digital capabilities for a successful digital transformation. We conclude with a summary of the contributions and limitations of the study.

## 2. Digital capabilities in supply chains

Digital transformation is an increasingly important topic among supply chain managers and academics. Research has shown that the use of novel digital technologies can lead to profound changes on an industry level (Bonnet & Westerman, 2021; Majchrzak et al., 2016) as well as on an organizational level (Agi & Jha, 2022). This showcases that companies need to identify and implement 'strategies that embrace the implications of digital transformation and drive better operational performance' (Hess et al., 2016; Kraus et al., 2022). By introducing new practices and processes, digital transformation can be a driver to solve challenges concerning efficiency and effectiveness (Heavin & Power, 2018). In a supply chain context, the strategic use of digital technologies can enable members along the supply chain to increase performance, minimize risks and predict disruptions by using cloud computing, big data analytics and AI-supported forecasting (Choi et al., 2022; Geske et al., 2024; Gupta et al., 2022; Herold, Fahminnia, & Breitbarth, 2023; Weisz et al., 2023).

Digital transformation can be defined as 'a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication and connectivity technologies' (Vial, 2019). Scholars link its success to whether and how organizations can build relevant dynamic capabilities. Dynamic capabilities are rooted in the resource-based view and can be defined as 'the firm's ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments' (Teece et al., 1997). Eisenhardt and Martin (2000) expanded that view and saw dynamic capabilities as an antecedent of organizational strategy, where management integrates, acquires and recombines resources, including and emphasizing the role of organizational processes. Others see dynamic capabilities as the result of experience accumulation, knowledge articulation, knowledge codification and knowledge sharing (Sabahi & Parast, 2020) as means to achieve strategic change in a patterned, repeatable and reliable way (Helfat & Peteraf, 2003; Helfat & Raubitschek, 2018; Magliocca et al., 2023; Teece, 2007; Winter, 2003). Overall, scholars agree that dynamic capabilities consist of well-defined strategic and organizational processes that can quickly adapt or reorchestrate resources for value-creating strategies (Martelo et al., 2013).

Recent research streams have examined how dynamic capabilities can be built that enable *major business improvements* through the use of new digital technologies (Liu et al., 2011; Núñez-Merino et al., 2020; Yang, Xie, et al., 2021). While early research on dynamic capabilities was primarily conceptual, dynamic capabilities are now one of the most active streams of research in the field (Dovbischuk, 2022; Herold et al., 2024; Sandberg, 2021; Sjödin et al., 2021; Soluk & Kammerlander, 2021; Yang, Fu, & Zhang, 2021). For example, Dubey et al. (2024) examined how digital capabilities can help to build alliances across supply chains to better respond to crises. Investigating procurement practices, Herold, Heller, et al. (2023) identified nine micro-foundations for the digital procurement transformation in and for supply chains, thereby highlighting the capabilities required for a better performance. Konopik et al. (2022) clustered organizational capabilities into seven critical themes and how these capabilities at different time points change to support and enable organizations during their digital transformation journey.

There is extensive scholarly consensus that dynamic capabilities can be broadly categorized into three clusters (Teece, 2007; Teece et al.,

1997): (1) sensing opportunities (and threats); (2) seizing opportunities; and (3) transforming the organization's business model and wider resource base. From a digital transformation perspective, Warner and Wäger (2019) extended this view and proposed a model consisting of *digital sensing*, *digital seizing*, *digital transforming* along with nine associated capabilities that trigger, enable and hinder building dynamic capabilities. For the purpose of this study, we use their model to examine the perceived relevance and causal relationships between digital capabilities.

Managers play an important role in the implementation or use of digital capabilities. In other words, managers are a key factor in how digital transformation can help an organization purposefully create, extend, or modify its supply chains in a practiced and patterned manner. Existing research has found that a manager's leadership and the associated decision-making power can significantly influence strategies and performance (Acciarini et al., 2021; Cantor & Macdonald, 2009; Clifford Defee et al., 2010; Mantel et al., 2006). For example, Heubeck (2023) identifies managerial human capital as a critical facilitator of digital business model transformation to drive and increase performance. More specifically, scholars often point out that the manager's ability and extent to exert influence are related to the 'managerial discretion' embedded in the company's hierarchy (Chin et al., 2021; Duan et al., 2023; Wangrow et al., 2015). Studies also show that managerial discretion has increased, putting additional pressure on managers' behaviour and choices and also creating an enhanced responsibility to develop, implement and execute digital capabilities that increase the competitiveness of their companies (Finkelstein & Peteraf, 2007; Hess et al., 2016; Wrede et al., 2020).

However, current research shows that the role of managers and how they perceive capabilities for navigating digital transformation remains unexplored. More specifically, although studies report that management support is vital for building capabilities due to its access to resources, less attention has been paid to how managers understand the role and importance of digital capabilities for the competitiveness of their companies. Rather, existing literature suggests that managers struggle to develop corporate strategies for digital transformation and lack the ability to build relevant digital capabilities. As such, a better understanding of the role of managers in the digital transformation process, regarding the specific capabilities for digital transformation, is warranted.

### 3. Methodology

#### 3.1. Research method

To examine the degrees of influence of the digital capabilities as well as their interdependencies, we developed a questionnaire based on the digital capability framework proposed by Warner and Wäger (2019). Their framework measures a company's overall digital transformation capability along three categories, namely *digital sensing*, *digital seizing* and *digital transforming* (see Fig. 1). They link each of the capabilities to three specific items that describe capability-based practices. For the analysis, we applied the DEMATEL method (Gabus & Fontela, 1972). Based on the gathered experts' perceptions, this approach allows for the development of a structural model as well as the visualization of the direct and indirect interaction effects by means of a causal diagram (Wu & Lee, 2007). It is considered to be an effective method for the explanation of cause-and-effect chain relationships within complex systems (Si et al., 2018). In recent years, DEMATEL has been increasingly used to study phenomena relating to digital transformation in supply chain management, such as blockchain adoption (Agi & Jha, 2022; Yontar, 2023), identifying challenges (Tripathi & Gupta, 2021) and enablers (Gupta et al., 2021) for supply chain digitization, and understanding the interplay of digitization and sustainability (Singh & Maheswaran, 2024; Tseng et al., 2021).

In addition, we captured and assessed managerial evaluations about the current level of development for each capability in their industry and applied parametric and non-parametric tests to infer statistically significant differences.

#### 3.2. Selection of experts and data collection procedure

Because DEMATEL uses expert evaluations as the primary data source, identifying suitable experts was a critical activity. With reference to Meuser and Nagel (2009) we understood experts to be persons who (i) are responsible for the development, implementation or control of solutions/strategies/policies (power dimension); and (ii) have privileged access to information about groups of persons or decision processes (knowledge dimension). This understanding is recommended and implemented in multiple DEMATEL-based studies, using (1) the number of years of experience in the relevant field and (2) the position in the company as important criteria to select potential respondents (Agi & Jha, 2022; Gandhi et al., 2016).

Our goal was to identify experts who had more than 10 years of

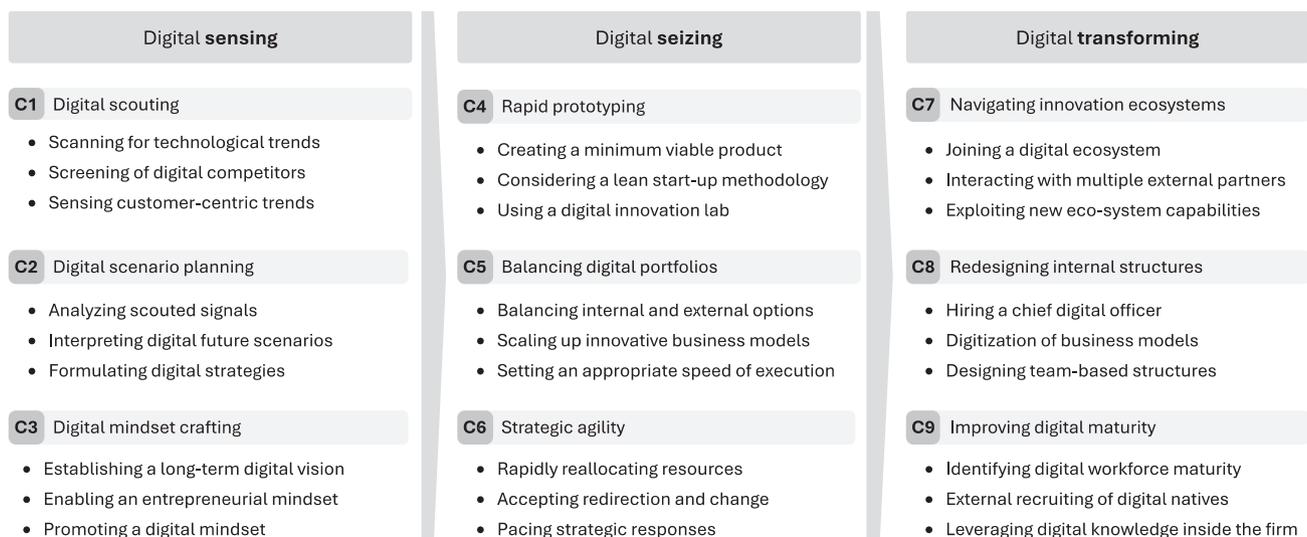


Fig. 1. Capabilities for digital transformation (Source: Warner & Wäger, 2019).

experience in supply chain management and/or digital transformation in the supply chain context and who were responsible for digital transformation in their organizations. All experts selected for this study were actively working for German or Austrian legacy businesses with a minimum of 500 employees to maintain a similar cultural background and market environment. In addition, we chose to ex-ante differentiate between two sampling groups, because it allowed for another dimension of analysis. Group 1 comprised senior managers and executives from logistics service providers and group 2 consisted of senior supply chain managers and executives from manufacturing companies.

We combined purposive and chain-referral sampling to target experts for each group and defined a relaxed quota with 15 complete responses for each subsample. This is in line with existing work suggesting that 4 to 15 experts are appropriate for DEMATEL if their selection is criteria-based and they all have relevant domain knowledge (Jafari-Sadeghi et al., 2022; Quayson et al., 2023; Raj & Sah, 2019).

An online survey was conducted to collect data. We divided the survey into three parts. In the first part, each respondent was tasked with assessing the influence of each capability on all other capabilities was perceived using a five-point Likert scale (0–no influence, 1–low, 2–moderate, 3–high, 4–very high), resulting in 72 assessments.

In the second part, respondents were asked to assess the perceived manifestations of each capability in their industry using a five-point Likert scale (0–capability does not exist, 1–low, 2–moderate, 3–high and 4–very high). No data was collected concerning the respondent’s own organizations. The last section of the questionnaire gathered information about industry experience and the expert’s current role within their company. Online as well as pen-and-paper pretests confirmed the first part of the study to be cognitively challenging. To actively reduce potential survey fatigue and insufficient effort responding (Huang et al., 2012; Schoenherr et al., 2015) we probed different approaches to brief the experts and tested multiple survey designs. Eventually, we opted for a written briefing including generic examples for each capability as well as adding pictograms as visual aids helping to navigate the survey. It is this respect, it was not only important to achieve a unified understanding of the examined capabilities but also to ensure a consistent interpretation of the studied relationships between these factors. To facilitate a more unified understanding, the surveyed managers were, explicitly informed before and during the survey that it is not relevant whether the potential

influence is positive or negative, but only whether and to what extent the (non-)existence of one capability affects another capability. The nature of the studied relationships was also graphically visualized in the survey.

We contacted 45 experts in total and obtained 31 complete and evaluable responses between November 2023 and February 2024. This represented a response rate of 68.89 %. Table 1 depicts a breakdown of the respondents’ profiles.

### 3.3. Stepwise DEMATEL analysis

In our study, we implemented the DEMATEL method following a 7-step procedure as proposed by Agi and Jha (2022) as described below (see also Fig. 2).

#### 3.3.1. Step 1: Gather expert perceptions

$n$  was defined as the number of capabilities studied. A matrix  $n \times n$  was generated with all capabilities arranged in rows and columns. This matrix was then populated based on surveyed evaluations from  $E$  experts (cf. Section 3.2). The evaluations of each expert  $e$  (with  $e \in [1, E]$ ) were used to compile an expert-specific matrix  $A_e = [a_{ij}^e]$  representing their evaluation ( $a_{ij}^e$ ) concerning the influence of each capability ( $i$ ) in the rows on each capability ( $j$ ) in the columns. An evaluation  $a_{ij}^e$  represented a numerical value  $v$  (with  $v \in [0, 1, 2, 3, 4]$ ) on a five-point Likert scale. The diagonal of each matrix  $A_e$  was zero (i.e.  $a_{ij}^e = 0$ , where  $i = j$ ) because it was assumed that a capability did not exert direct influence on itself. All expert responses included in our analysis were checked for completeness and plausibility. However, since we apply DEMATEL to capture differentiated perceptions, we consciously chose not to apply methods aimed at removing responses from non-consensus experts or generating higher degrees of consensus.

#### 3.3.2. Step 2: Compute the direct relation matrix A

In the next step, a single direct relation matrix  $A = a_{ij}$  was generated by synthesizing  $E$  expert matrices  $A_e$  using Eq. (1).

$$A = \frac{1}{E} \sum_{e=1}^E A_e \tag{1}$$

**Table 1**  
Overview of respondents.

	Total sample		Subsample (Logistics)		Subsample (Manufacturing)	
		Count		Count		Count
Gender	male	29	male	16	male	13
	female	2	female	0	female	2
Years of expertise	> 0 and < 10	0	> 0 and < 10	0	> 0 and < 10	0
	≥ 10 and < 20	9	≥ 10 and < 20	5	≥ 10 and < 20	4
	≥ 20 and < 30	5	≥ 20 and < 30	2	≥ 20 and < 30	3
	≥ 30 and < 40	16	≥ 30 and < 40	9	≥ 30 and < 40	7
	≥ 40 and < 50	1	≥ 40 and < 50	0	≥ 40 and < 50	1
Formal education	Professional Training	7	Professional Training	6	Professional Training	1
	Highschool Diploma	2	Highschool Diploma	0	Highschool Diploma	2
	University	22	University	10	University	12
Function/role	Logistics Manager	1	Head of Digitization	2	Logistics Manager	1
	Supply Chain Manager	2	Head of Innovation	1	Supply Chain Manager	2
	Head of Logistics	2	Managing Director	8	Head of Logistics	2
	Head of Operations	2	Board Member	5	Head of Operations	2
	Head of Procurement	1			Head of Procurement	1
	Head of Supplier Management	1			Head of Supplier Management	1
	Head of Supply Chain Management	1			Head of Supply Chain Management	1
	Head of Digitization	2			Director Logistics	1
	Head of Innovation	1			Senior Director Global Procurement	1
	Director Logistics	1			Vice President Procurement	1
	Senior Director Global Procurement	1			Chief Operating Officer	1
	Vice President Procurement	1			Managing Director	1
	Managing Director	9				
Chief Operating Officer	1					
Board Member	5					

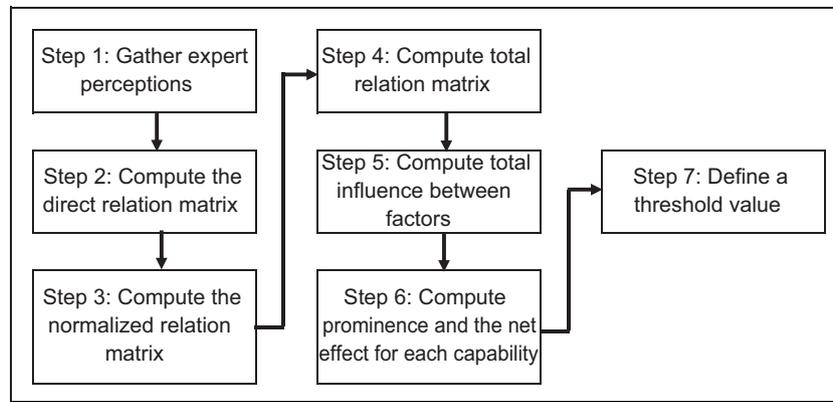


Fig. 2. DEMTAL-Steps.

### 3.3.3. Step 3: Compute the normalized relation matrix $N$

Then, the Eq. (2) was applied to compute the row sums for the direct relation matrix  $A$  and are thereby able to identify the corresponding maximum value.

$$S = \frac{\max}{1 \leq i \leq n} \sum_{j=1}^n a_{ij} \quad (2)$$

Afterwards, the normalized direct relation matrix  $N$  was calculated using Eq. (3).

$$N = \frac{1}{S}A \quad (3)$$

### 3.3.4. Step 4: Compute total relation matrix $T$

The total relation matrix ( $T = [t_{ij}]$ ) was computed by applying Eq. (4)

$$T = N + N^2 + N^3 + N^4 \dots = N(I - N)^{-1} \quad (4)$$

### 3.3.5. Step 5: Compute total influence between factors

The influence of a capability ( $i$ ) on all other capabilities was computed by calculating the sum of the elements in the corresponding row  $R_i$  of the total relation matrix ( $T$ ), as depicted in Eq. (5)

$$R_i = \sum_{j=1}^n t_{ij}; i, j \in [1, n] \quad (5)$$

The influence that a capability ( $j$ ) received from other capabilities was represented by the sum of the elements in the corresponding column ( $C_j$ ) of the total relation matrix (Eq. (6)).

$$C_j = \sum_{i=1}^n t_{ij}; i, j \in [1, n] \quad (6)$$

### 3.3.6. Step 6: Compute prominence ( $PR_i$ ) and the net effect ( $NE_i$ ) for each capability

For each capability, ( $i$ ) the overall prominence (relevance) ( $PR_i$ ) and net effect ( $NE_i$ ) were computed using Eqs. (7) and (8).

$$PR_i = R_i + C_j | i = j \quad (7)$$

$$NE_i = R_i - C_j | i = j \quad (8)$$

The prominence  $PR_i$  of a factor ( $i$ ) represented the sum of the influence that this capability exerted on and received from the other capabilities studied. The net effect  $NE_i$  of a factor ( $i$ ) represented the difference between the influence that this capability exerted on the other capabilities and the influence of the other capabilities on it.

### 3.3.7. Step 7: Define a threshold value $\theta$

If there are many relationships (81 in our study), it is recommended to derive a more comprehensible and manageable set of in-

terconnections to be further investigated and to allow for an informed analysis and decision-making process (Li & Tzeng, 2009). Therefore, significant interdependencies between the capabilities were discerned by identifying all the values in the total relation matrix  $T$  that exceeded a threshold value  $\theta$ . There is no general rule for setting  $\theta$ . Agi and Jha (2022) point out that opting for a small value for  $\theta$  results in dismissing few relationships and thereby fails to appropriately reduce complexity, while choosing a high value might lead to ignoring relations worthwhile to be investigated.

We defined and computed  $\theta$  as the average of the elements in the total relation matrix  $T$  using

$$\theta = \text{Mean}(t_{ij}); i, j \in [1, n] \quad (9)$$

This definition represents a deviation from Agi and Jha (2022) who calculated the threshold as the sum of the mean and one standard deviation. However, they directly attribute their choice for a higher threshold value to the high number of factors examined in their work. In their research, 20 factors (resulting in  $20 \times 20 - 20 = 380$  interconnections) are examined, whereas in our paper only 9 factors (resulting in  $9 \times 9 - 9 = 72$  interconnections) are studied. By applying their reasoning to link the threshold value to the complexity induced by the problem size, we opted for a mean-based approach.

## 4. Results and interpretation

By applying the steps outlined in Section 3.3 for each subsample as well as for the total sample we were able to obtain the corresponding prominence and net effects (Table 2) as well as the total relation matrices (Table 4). In this section, we analyse and draw conclusions from DEMATEL and identify similarities and key differences in managerial perceptions between the studied groups to answer RQ1 and RQ2. Furthermore, we statistically test and interpret the observed industry-specific manifestations of these capabilities to address RQ3.

### 4.1. Analysis of prominence and net effect of capabilities and capability categories

Table 2 presents the prominence ( $R_i + C_i$ ) of each capability, which can be interpreted as a measure of its overall importance. A higher prominence value translates to a higher perceived importance. This allowed us to address and answer RQ1.

The study identified digital mindset crafting (C3) as the most important capability, followed by improving digital maturity (C9), digital scenario planning (C2), digital scouting (C1), strategic agility (C6), navigating innovation ecosystems (C7), balancing digital portfolios (C5), redesigning internal structures (C9) and rapid prototyping. By comparing the subsamples, we found that digital mindset crafting (C3), digital scenario planning (C2) and improving digital maturity (C9) were

**Table 2**  
Prominence and net effects of capabilities.

	Total sample				Subsample (logistics)				Subsample (manufacturing)			
	$R_i + C_i$	$R_i - C_i$	Identity	Rank	$R_i + C_i$	$R_i - C_i$	Identity	Rank	$R_i + C_i$	$R_i - C_i$	Identity	Rank
<b>Capability</b>												
C1 Digital scouting	14,8936	0,1900	<b>Cause</b>	4	12,3831	0,0809	<b>Cause</b>	5	11,3506	0,2126	<b>Cause</b>	5
C2 Digital scenario planning	15,9564	0,2606	<b>Cause</b>	3	13,2590	-0,3514	Effect	3	12,1582	0,7269	<b>Cause</b>	3
C3 Digital mindset crafting	16,5807	-0,0715	Effect	1	14,0033	-0,2519	Effect	1	12,4328	0,1184	<b>Cause</b>	2
C4 Rapid prototyping	13,1700	-0,0201	Effect	9	11,0037	-0,2653	Effect	8	9,9617	0,2170	<b>Cause</b>	9
C5 Balancing digital portfolios	14,4833	0,7475	<b>Cause</b>	7	11,5363	1,0143	<b>Cause</b>	7	11,4780	0,2189	<b>Cause</b>	4
C6 Strategic agility	14,8372	-0,7876	Effect	5	12,6930	-0,3914	Effect	4	10,9619	-0,8542	Effect	7
C7 Navigating innovation ecosystems	14,5182	0,1126	<b>Cause</b>	6	12,0797	0,3281	<b>Cause</b>	6	11,0210	-0,1346	Effect	6
C8 Redesigning internal structures	13,1881	-0,2560	Effect	8	10,9153	-0,2465	Effect	9	10,0716	-0,1640	Effect	8
C9 Improving digital maturity	16,5243	-0,1753	Effect	2	13,4956	0,0833	<b>Cause</b>	2	12,8078	-0,3410	Effect	1

identified as the most relevant capabilities in both subsamples, while redesigning internal structures (C8) and rapid prototyping (C9) represented the lowest ranking capabilities in both sections. The biggest differences were detected for strategic agility (C6), ranked at position 4 (7) for logistics (manufacturing) and balancing digital portfolios (C5), ranked at position 7 (4) for logistics (manufacturing). We then computed the prominence of each capability category and found that digital sensing was considered to be the most relevant capability at the construct level, followed by digital seizing and digital transforming.

The net effect ( $R_i - C_i$ ) of each capability told us whether it could be classified as a cause (positive value) or as an effect (negative value). Capabilities identified as causes exerted more influence on other enablers than they were affected by all other enablers. However, effect capabilities can be affected more by other enablers than they themselves exert in influence on other capabilities. While our subsamples were found to be relatively similar with respect to prominence, our analysis of net effects called for a more nuanced interpretation. Logistics managers identified digital scouting (C1), balancing digital portfolios (C5), navigating innovation ecosystems (C7) and improving digital maturity (C9) as causing capabilities and all other factors as effects. By contrast, supply chain managers perceived a net enabling effect of digital scouting (C1), digital scenario planning (C2), digital mindset crafting (C3), rapid prototyping (C4) and balancing digital portfolios (C5). An analysis at the construct level (Table 3) confirmed this conjecture.

Managers in the logistics service industry recognized digital seizing and transforming as causes and understood digital sensing to be an affected variable. By contrast, supply chain managers in manufacturing expressed a diametrically opposing perspective. They also perceived stronger effects and differences between the enabling categories.

The prominence and net effect for both subsamples are visualized in Fig. 3. A capability's position on the horizontal axis denotes its prominence and the vertical axis expresses the net effect. We matched the scales of the axes to the sample-specific data to enable a meaningful interpretation of each sample. Each diagram was subdivided into four sections: (i) capabilities located in the upper right part are important enablers; (ii) those in the upper left are represents less important enablers; (iii) the lower right quadrant depicts important affected variables; and (iv) the lower left area represents less important affected capabilities. It must be acknowledged that, based on our analysis, it is not possible to draw conclusions concerning the absolute importance of any capability, because only relative differences could be computed

**Table 3**  
Prominence and net effects of capability categories.

	Total sample				Subsample (logistics)				Subsample (manufacturing)			
	$R_i + C_i$	$R_i - C_i$	Identity	Rank	$R_i + C_i$	$R_i - C_i$	Identity	Rank	$R_i + C_i$	$R_i - C_i$	Identity	Rank
<b>Capability category</b>												
Digital sensing	15,8102	0,1263	<b>Cause</b>	1	13,2151	-0,1741	Effect	1	11,9805	0,3526	<b>Cause</b>	1
Digital seizing	14,1635	-0,0201	Effect	3	11,7443	0,1192	<b>Cause</b>	3	10,8005	-0,1394	Effect	3
Digital transforming	14,7435	-0,1062	Effect	2	12,1635	0,0550	<b>Cause</b>	2	11,3001	-0,2132	Effect	2

from the underlying data.

4.2. Analysis of relationships between capabilities and capability categories

By looking at the total relation matrix  $T$  (Table 4) we were able to interpret the interaction effects between the capabilities. Bold values indicate that the observed effect exceeded the sample-specific threshold value  $\theta$ . Shaded areas are a visual aid to differentiate data belonging to the same capability category, according to the literature.

First, we validated the data for plausibility. The strongest interaction effects were observed for digital scenario planning (C2) and digital mindset crafting (C3), which were both identified as capabilities strongly affected by other variables in our prior analysis. However, digital mindset crafting (C3) also exerted a significantly high influence on all other variables except on balancing digital portfolios (C5). All capabilities, except for rapid prototyping (C4), which was slightly below the threshold value, strongly influenced the improvement of digital maturity (C9). In addition, improving digital maturity (C9) had a significant influence over all capabilities, apart from balancing digital portfolios (C5). Redesigning internal structure (C8) was not perceived to have any significant effect on other capabilities and balancing digital portfolios (C5) was not significantly affected by any other capability. Strong interaction effects were seen within the category of digital sensing. The strongest influence was detected between digital mindset crafting (C3) and digital scenario planning (C2). By contrast, limited interaction effects were detected between the capabilities of digital seizing and only moderate within-category-effects for digital transforming.

Supply chain managers in manufacturing perceived the effects exerted on the capability of improving digital maturity (C9) as the strongest overall, with all capabilities significantly influencing C9. We detected an equally significant impact in the opposite direction. The observed pattern for C9 was, therefore, comparable with the logistics reference group. More similarities between the samples were identified in rapid prototyping (C4) and redesigning internal structures (C8), neither of which seemed to be highly influenced, nor were they perceived to exert substantial influence over other capabilities. By studying the capabilities from a cause perspective, the manufacturing sample was subdivided into two segments. In group A (C1, C2, C3, C5, C9), each capability influenced at least six other variables, whereas any

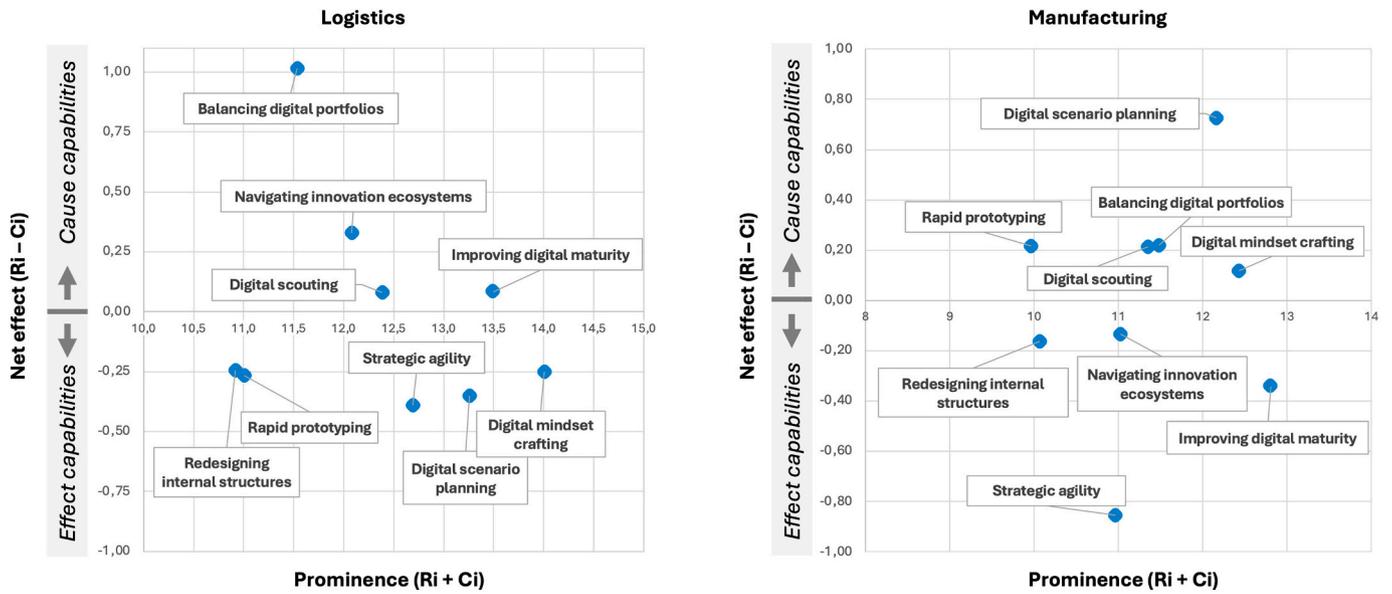


Fig. 3. Prominence and net effect diagram.

Table 4

Total relation matrix T for each sample and for individual capabilities.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	R <sub>i</sub>
	Digital scouting	Digital scenario planning	Digital mindset crafting	Rapid prototyping	Balancing digital portfolios	Strategic agility	Navigating innovation ecosystems	Redesigning internal structures	Improving digital maturity	
<b>Subsample logistics (θ = 0,69)</b>										
C1 Digital scouting	0,6035	<b>0,7962</b>	<b>0,8213</b>	0,6310	0,5837	<b>0,7616</b>	0,6753	0,6173	<b>0,7419</b>	6,2320
C2 Digital scenario planning	<b>0,7321</b>	<b>0,6906</b>	<b>0,8444</b>	0,6556	0,6370	<b>0,7868</b>	0,6700	0,6677	<b>0,7696</b>	6,4538
C3 Digital mindset crafting	<b>0,7873</b>	<b>0,8575</b>	<b>0,7710</b>	<b>0,7118</b>	0,6534	<b>0,8164</b>	<b>0,7418</b>	<b>0,6910</b>	<b>0,8455</b>	6,8757
C4 Rapid prototyping	0,6164	0,6552	<b>0,7005</b>	0,4765	0,4972	0,6305	0,5818	0,5387	0,6724	5,3692
C5 Balancing digital portfolios	<b>0,6921</b>	<b>0,7939</b>	<b>0,8088</b>	0,6256	0,5202	<b>0,7555</b>	0,6688	0,6314	<b>0,7789</b>	6,2753
C6 Strategic agility	0,6622	<b>0,7658</b>	<b>0,8058</b>	0,6233	0,6019	0,6326	0,6466	0,6532	<b>0,7594</b>	6,1508
C7 Navigating innovation ecosystems	<b>0,7161</b>	<b>0,7782</b>	<b>0,8143</b>	0,6580	0,5860	<b>0,7129</b>	0,5734	0,5961	<b>0,7690</b>	6,2039
C8 Redesigning internal structures	0,5867	0,6422	0,6758	0,5485	0,5330	0,6438	0,5820	0,4680	0,6542	5,3344
C9 Improving digital maturity	<b>0,7547</b>	<b>0,8256</b>	<b>0,8855</b>	<b>0,7042</b>	0,6486	<b>0,8021</b>	<b>0,7362</b>	<b>0,7175</b>	<b>0,7151</b>	6,7895
C <sub>i</sub> Sum	6,1511	6,8052	7,1276	5,6345	5,2610	6,5422	5,8758	5,5809	6,7061	
<b>Subsample manufacturing (θ = 0,63)</b>										
C1 Digital scouting	0,5470	<b>0,6897</b>	<b>0,7087</b>	0,5473	<b>0,6411</b>	<b>0,6820</b>	<b>0,6441</b>	0,5656	<b>0,7562</b>	5,7816
C2 Digital scenario planning	<b>0,7109</b>	0,6232	<b>0,7820</b>	0,6287	<b>0,7334</b>	<b>0,7684</b>	<b>0,7053</b>	<b>0,6696</b>	<b>0,8210</b>	6,4426
C3 Digital mindset crafting	<b>0,7185</b>	<b>0,7173</b>	<b>0,6544</b>	0,6089	<b>0,6982</b>	<b>0,7305</b>	<b>0,6929</b>	<b>0,6374</b>	<b>0,8175</b>	6,2756
C4 Rapid prototyping	0,5509	0,5663	0,6206	0,4201	0,5758	0,5821	0,5881	0,5101	<b>0,6754</b>	5,0894
C5 Balancing digital portfolios	<b>0,6417</b>	<b>0,6842</b>	<b>0,7169</b>	0,5545	0,5578	<b>0,6952</b>	<b>0,6389</b>	0,5957	<b>0,7634</b>	5,8484
C6 Strategic agility	0,5377	0,5822	0,6291	0,4889	0,5696	0,5062	0,5443	0,5315	<b>0,6643</b>	5,0539
C7 Navigating innovation ecosystems	0,6272	0,6137	<b>0,6817</b>	0,5368	0,5926	0,6205	0,5151	0,5300	<b>0,7256</b>	5,4432
C8 Redesigning internal structures	0,5359	0,5376	0,5949	0,4818	0,5694	0,5953	0,5519	0,4293	<b>0,6577</b>	4,9538
C9 Improving digital maturity	<b>0,6992</b>	<b>0,7013</b>	<b>0,7689</b>	0,6054	<b>0,6917</b>	<b>0,7278</b>	<b>0,6971</b>	<b>0,6486</b>	<b>0,6934</b>	6,2334
C <sub>i</sub> Sum	5,5690	5,7156	6,1572	4,8723	5,6295	5,9080	5,5778	5,1178	6,5744	

Note: Shaded areas visualize relationships within the same capability category (light = digital sensing; medium = digital seizing; dark = digital transforming).

capability in group B (C4, C6, C7, C8) influenced at most two other factors. The logistics sample was less clearly separable.

Computing the average relational values for each capability category

allowed us to interpret the interaction effects at the construct level. Table 5 shows that digital sensing exhibited interesting characteristics, because it exerted significant influence on both other categories. This

Table 5

Total relation matrix T for each sample and capability categories.

	Subsample logistics (θ = 0,69)			Subsample manufacturing (θ = 0,63)		
	Digital sensing	Digital seizing	Digital transforming	Digital sensing	Digital seizing	Digital transforming
Digital sensing	<b>0,7671</b>	<b>0,6930</b>	<b>0,7133</b>	<b>0,6835</b>	<b>0,6710</b>	<b>0,7011</b>
Digital seizing	<b>0,7223</b>	0,5959	0,6590	0,6144	0,5500	0,6124
Digital transforming	<b>0,7421</b>	0,6486	0,6457	<b>0,6401</b>	0,6024	0,6054

was the case for both samples. However, it was also significantly affected itself—by both other categories within the logistics group and by digital transforming in the manufacturing sample. In addition, due to the above-mentioned within-category-interactions, digital sensing also had substantial self-enhancing properties.

However, if we also factored in prominence and net effect, we identified additional differences, because digital sensing was an important enabler in the manufacturing sample, while it had an important effect capability in logistics. This is visualized in Fig. 4. Comparing Fig. 3 and Fig. 4 also shows that net effect averaged out across the board. This meant that all categories were positioned closer to 0 along the vertical axis.

4.3. Analysis of perceived capability manifestations

All respondents were also asked to evaluate the manifestations of each capability in their industry on a five-point Likert scale (0—capability does not exist, 1—low, 2—moderate, 3—high, 4—very high). First, the data were validated for plausibility. Then, scores for each capability category as well as a total score were computed at the respondent-level by calculating mean values with average weights for each capability. The calculated mean values in the manufacturing sample were higher for each case, except for strategic agility (C5) and redesigning internal structures (C8). The medians also appeared to be higher for the second sample for each capability examined. This allowed us formulate the hypothesis that managers in this group perceived these capabilities to be more developed in their industry.

In the next step, we statistically evaluated our conjecture. We first conducted a normal distribution test using the Shapiro-Wilk normality test. Only the redesigning internal structures (C8) in the manufacturing sample, at the level of individual capabilities, confirmed a normal distribution. By contrast, at the construct level, as well as for the total digital capability score, a normal distribution was assumed. Therefore, for individual capabilities, we applied the non-parametric Wilcoxon rank sum test with continuity correction for unpaired data to identify differences between logistics and manufacturing. This test was computed as a 2-sided test as well as a 1-sided test corresponding to the above-defined hypothesis. For the aggregated data, a parametric Welch 2-sample *t*-test was used as well. Table 6 summarizes the results of the analysis. For all capabilities, apart from balancing digital portfolios (C5) and strategic agility (C6) as well as for digital seizing, the alternative hypothesis ( $M > L$ ) is accepted.

5. Conclusion, practical implications and call to action

The purpose of this study was to investigate digital transformation in logistics and supply chain management through a perceptual lens. We were able to explain the perceived importance of capabilities and understand the underlying cause-and-effect relationships and interaction effects in the studied domain. Based on our analysis and results, we identify two distinct contributions advancing understanding in this field.

First, our research demonstrates that senior managers view dynamic capabilities for navigating technology transitions as a complex and highly interconnected system. The work thereby complements and extends the existing body of literature on dynamic capabilities. Previous studies often assumed discrete and linear interactions between sensing, seizing and transforming (Leemann et al., 2021). While this is perfectly understandable from a standpoint of reducing complexity, it might lead to oversimplification. Our results indicate that even between relatively homogeneous subsamples embedded in a supply chain context, significant differences in cognition were identified. We argue that these nuanced differences cannot be neglected, considering how leadership and decision-making power influence strategic action among incumbents (Acciarini et al., 2021; Cantor & Macdonald, 2009; Clifford Defee et al., 2010; Mantel et al., 2006).

Our study allows for extending existing models to include non-linear and complex relationship effects as well as cognitive influencing factors. This has important practical implications. Managers’ perceptions, beliefs and biases strongly affect decision-making processes (Barrero, 2022; Gfrerer et al., 2021; Malmendier et al., 2022). Insufficient knowledge and distorted perceptions can have a major impact on companies, industries and economies. Owing to the complex nature of comprehensive transitions in a boundary-spanning supply chain context and the convergence of multiple technologies such as blockchain and AI, managers face multifaceted challenges. We, therefore, recommend that managers actively and reflectively acquire skills and build knowledge to enable the knowledge-based and targeted development of dynamic capabilities for digital transformation.

We must point out that certain limitations may affect the interpretation and generalizability of our findings. They predominantly stem from the characteristics and inherent boundaries of the applied methods as well as our sample. While our work meets generally accepted sample size requirements for the application of DEMATEL, we invite future researcher to test our findings with a larger number of respondents which would enhance the robustness of the findings and would also

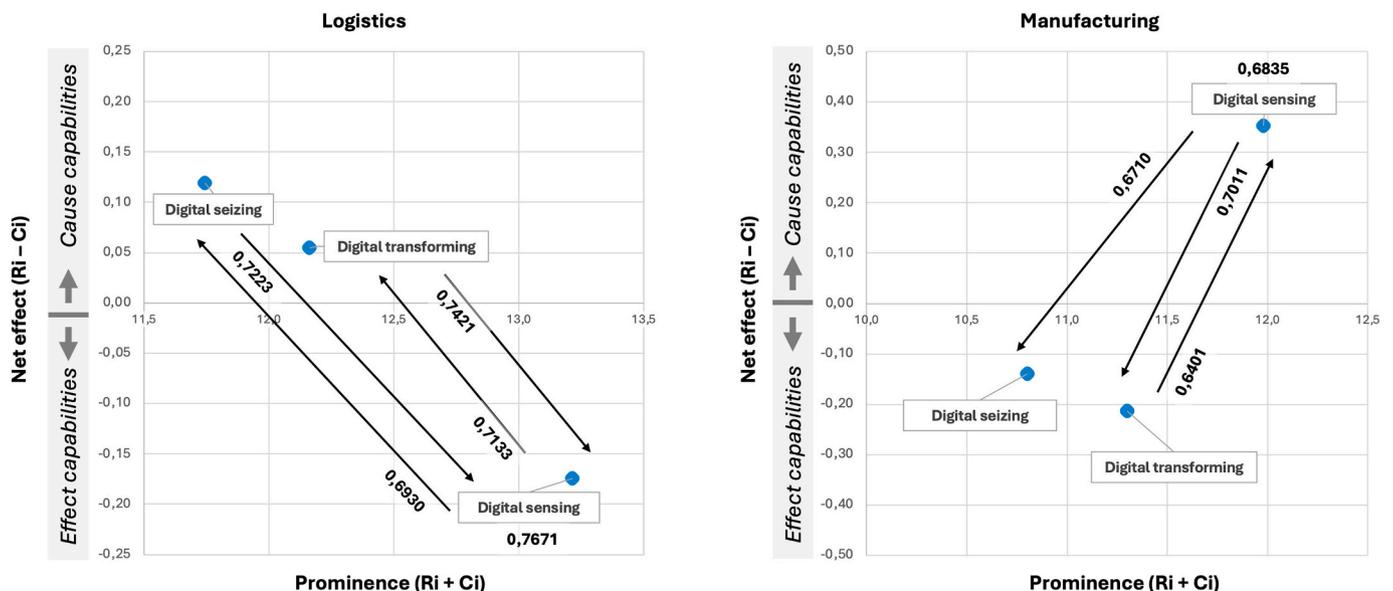


Fig. 4. Prominence and net effect diagram for capability categories.

**Table 6**  
Test statistics for industry assessment.

	Logistics (n = 16)					Manufacturing (n = 15)					Wilcoxon RS test		Welch 2-sample t-test	
	Shapiro-Wilk					Shapiro-Wilk					2S-M ≠ L	1S-M > L	2S-M ≠ L	1S-M > L
	median	mean	SD	W	p-value	median	mean	SD	W	p-value	p-value	p-value	p-value	p-value
<b>Capability</b>														
C1 Digital scouting	2,000	1,813	0,750	0,809	0,004	3,000	2,667	0,488	0,603	0,000	<b>0,002</b>	<b>0,001</b>	not applicable	
C2 Digital scenario planning	1,500	1,625	0,719	0,768	0,001	2,000	2,467	0,834	0,845	0,015	<b>0,007</b>	<b>0,004</b>	not applicable	
C3 Digital mindset crafting	2,000	1,813	0,834	0,787	0,002	2,000	2,533	0,834	0,870	0,034	<b>0,032</b>	<b>0,016</b>	not applicable	
C4 Rapid prototyping	1,000	1,375	0,500	0,621	0,000	2,000	2,000	0,845	0,805	0,004	<b>0,033</b>	<b>0,016</b>	not applicable	
C5 Balancing digital portfolios	2,500	2,188	0,911	0,738	0,000	3,000	2,467	0,915	0,828	0,009	0,425	0,212	not applicable	
C6 Strategic agility	2,000	2,188	0,750	0,809	0,004	2,000	2,000	0,926	0,862	0,026	0,642	0,694	not applicable	
C7 Navigating innovation ecosystems	1,000	1,500	0,632	0,729	0,000	2,000	2,600	1,056	0,867	0,031	<b>0,003</b>	<b>0,001</b>	not applicable	
C8 Redesigning internal structures	1,500	1,813	0,981	0,796	0,002	2,000	1,733	0,961	0,884	<b>0,055</b>	0,983	0,525	not applicable	
C9 Improving digital maturity	2,000	2,063	0,772	0,819	0,005	3,000	2,667	1,113	0,870	0,034	0,104	0,051	not applicable	
<b>Capability category</b>														
Digital sensing	1,667	1,750	0,430	0,917	<b>0,149</b>	2,333	2,556	0,530	0,953	<b>0,575</b>	<b>0,000</b>	<b>0,000</b>	<b>0,000</b>	<b>0,000</b>
Digital seizing	2,000	1,917	0,447	0,888	<b>0,052</b>	2,000	2,156	0,434	0,886	<b>0,059</b>	0,203	0,905	0,142	0,071
Digital transforming	1,833	1,792	0,515	0,920	<b>0,167</b>	2,333	2,333	0,807	0,922	<b>0,210</b>	<b>0,026</b>	<b>0,013</b>	<b>0,037</b>	<b>0,018</b>
<b>Total capability</b>	1,778	1,819	0,317	0,924	<b>0,194</b>	2,333	2,348	0,434	0,936	<b>0,340</b>	<b>0,001</b>	<b>0,001</b>	<b>0,001</b>	<b>0,000</b>

allow the use of parametric statistical tests. Moreover, our study focused on only two industries within the supply chain, thus results for other supply chain members may differ. Future research may investigate other industries along the supply chain or even go beyond the supply chain to examine similarities or differences in other industries such as retail or finance which undergo significant digital transformation. We also did not differentiate between different types of technologies (e.g., AI, blockchain), which might also influence the answers of the respondents, thus we restricted our questionnaire to the items of the digital capability framework. Future research may look at technologies in more detail or extend or expand the digital capability framework to include other components such digital culture and resistance that influence the success of digital transformation. It also needs to be highlighted that our DEMATEL study comprises a large number of items and we have mostly relied on non-parametric tests, which limits the degree of statistical inference that can be drawn. We would also like highlight that our study deals with managers perceptions, thus the responses could be biased. We deliberately embedded our study in the supply chain domain to limit industry-related distortion effects. For similar reasons, we restricted our analyses to a defined geographical region and only included companies that met our firm-size and legacy status criteria. As the study was conducted in Austria and Germany, results may differ in other regions due to other cultural and regulatory factors. Overall, we acknowledge that generalizability across industries, geographical regions, business scales and stages of maturity might be limited.

Hence, this paper should primarily be considered as an initial step towards a more extensive research agenda. It shows that there is a need for further research to explain the interplay of dynamic capabilities for digital transformation across different industrial landscapes, geographical regions and specific supply chain functions. Building on this research will provide a more comprehensive understanding of managerial perceptions and allow for effective digital transformation initiatives to be strategized and implemented in the supply chain domain.

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**CRedit authorship contribution statement**

**Mario Dobrovnik:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **David M. Herold:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Sebastian Kummer:** Writing – review & editing, Supervision.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data availability**

Data will be made available on request.

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