Aug 10th, 12:00 AM

Exploring the Relevance and Maturity of Digital Supply Chain Transformations in Academia and Practice

Frauke Hellweg
University of Münster, frauke.hellweg@wi.uni-muenster.de

Kevin Wesendrup
University of Münster, kevin.wesendrup@ercis.uni-muenster.de

Bernd Hellingrath
Westfälische Wilhelms-Universität Münster, bernd.hellingrath@uni-muenster.de

Exploring the Relevance and Maturity of Digital Supply Chain Transformations in Academia and Practice

Completed Research

Frauke Hellweg
University of Münster, Germany
frauke.hellweg@wi.uni-muenster.de

Kevin Wesendrup
University of Münster, Germany
kevin.wesendrup@wi.uni-muenster.de

Bernd Hellingrath
University of Münster, Germany
bernd.hellingrath@wi.uni-muenster.de

Abstract

Nowadays, the management of supply chains has become an indispensable success factor, and the digital transformation changes supply chains fundamentally, increasing competitive advantage. Even though the importance of "going digital" is undisputed, previous research lacks clear insights into the fundamental capabilities to facilitate a successful transformation and how far they are realized in practice.

Therefore, this paper presents nine capabilities crucial for the digital transformation of supply chains. We explore the coverage of these capabilities with an extensive multivocal literature review where we juxtapose theoretical white and practical grey literature. Additionally, the maturity of the capabilities is assessed in a survey and discussed with experts. Furthermore, we discuss fits and gaps between the findings and provide explanations and avenues for future research.

Keywords

Digital transformation, supply chain management, maturity models, survey.

Introduction

Nowadays, the management of companies' supply chains (SCs) is closely connected to the companies' success, and they have become an indispensable part of the companies' most valuable building blocks. During the COVID-19 crisis, the SCs' importance and vulnerability became alarmingly evident, and digital transformation (DT) was a crucial countermeasure to inhibit the crisis' negative impacts (Tortora et al. 2021). Experts, therefore, expect recent disruptions to "spur a leap to the supply chain digitalization" (Cai and Luo 2020), increasing the awareness and importance of the topic (Schuh et al. 2020). The DT promises many advantages, including increased visibility, higher flexibility due to real-time information, ensuring customer responsiveness, and improved risk mitigation (Büyüközkan and Göçer 2018; Cai and Luo 2020). Yet, what capabilities are relevant for the DT and the maturity of these capabilities in practice remains unclear (Tortora et al. 2021).

The topic of DT of SCs attracts attention not only from organizations but also from researchers. Due to the complexity of the topic, its scope is not yet well defined, and clear definitions and terms are absent (Büyüközkan and Göçer 2018). In this paper, we follow the definition by Büyüközkan and Göçer, defining the digital SC to be "a smart, value-driven, efficient process to generate new forms of revenue and business value for organizations and to leverage new approaches with novel technological and analytical methods" (2018). Literature related to the topic is dispersed, spanning different research streams from information systems (IS) over supply chain management to business administration literature, making exhaustive overviews of state of the art difficult (Queiroz et al. 2019; Verhoef et al. 2021). Often, current literature only considers one single technology and its application in specific scenarios and functions of supply chains, e.g., focusing on big data analytics (Barlette and Baillette 2020) or procurement (Pereira et al. 2020). This

restricts the view and neglects other important dimensions such as strategic or human aspects. Furthermore, empirical studies about SC capabilities and the current state and maturity are scarce; if all, they are confined to different parts of SCs, e.g., measuring smart manufacturing readiness (Lin et al. 2020).

We draw a set of nine capabilities necessary for the DT of SCs from previous research. The nine capabilities circumvent the above-described limitations as they consider many SC areas and functions and do not focus on specific technologies. In this paper, the coverage and confirmation level of the nine capabilities in academic and grey literature is the target of our examination. Furthermore, the maturity of the capabilities in practice is unknown, and we set out to explore this. This is the first step towards a capability maturity model able to measure the degree of the DT of SCs from different sectors. This research is guided by the following goal with subsequent research questions.

Research Goal: Identify and assess the prevalence, relevance, and maturity of capabilities crucial for the digital transformation of supply chains.

- **Research Question 1:** Which capabilities for the digital transformation of supply chains are most prevalent in literature?
- **Research Question 2:** How relevant and mature are these capabilities for the digital transformation of supply chains in practice?

The paper is structured as follows. The second section provides background information on the nine capabilities considered in our analysis. The methodology chapter presents the multivocal literature review process and the applied survey. Fourth, the findings from literature (academic and practice) and survey are shown separately. Literature and survey are juxtaposed in the penultimate section, and the capabilities' prevalence, relevance, and maturity are discussed. The last section concludes the paper with the work's limitations and avenues for future research.

Theoretical Background for Capabilities and Dimensions of Digital Supply Chains

Büyüközkan and Göçer's definition (cf. introduction) is one of the first definitions of digital supply chains (DSC) in academic literature and highlights three main aspects: First, the transformation is a process that is (constantly) happening; second; the transformation has a clear goal (e.g., new forms of revenue); and third, it is based on new technologies and digital methods (Büyüközkan and Göçer 2018). "Updating" from traditional to DSC is inevitable, yet, the capabilities necessary for it remain unclear (Queiroz et al. 2019). We apply the definition of Teece et al. for defining (dynamic) capabilities as follows: "the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments" (Teece et al. 1997).

Identifying the capabilities necessary for the DT of SCs is the focus of a separate study, where they are retrieved from two structured literature reviews with qualitative content analysis and discussed in semi-structured expert interviews. However, this study is not published yet and is still under review. Therefore, we briefly present the nine capabilities in the following and study their literary prevalence, practical relevance, and adoption in the remainder of the paper.

The first capability (C1) is the capability of companies to formulate, adapt, and (re-)design a digital SC along with their SC partners. Many authors emphasize the importance of SCs for continuous redefinition (Warner and Wäger 2019). SC strategies are applicable at different levels, ranging from strategic to operational levels, where they are supported by action plans (Sahu et al. 2018).

The second capability (C2) is the capability of companies to initiate and drive innovations in and along their SCs continuously. Market-sensing activities can lead to new ideas for joining digital and physical features creating new products or processes (Tortora et al. 2021), initiated through decentral SC collaboration. However, the different innovations need to be continuously evaluated and brought together (Rueckel et al. 2019), for which centralized mechanisms, such as short design cycles or incorporation of creative sessions, are pivotal (Li et al. 2019).

The third capability is the company's digital cultural mindset (C3) and that of its SC partners. According to researchers, it needs to span all levels and departments of a company (González-Varona et al. 2021), and SC partners need to be "on board", e.g., committing to share data (Sanchez and Zuntini 2018). Corner pillars

of the mindset include, e.g., learning willingness (Fischer et al. 2020) and more risk-tolerant attitudes (Barlette and Baillette 2020), which can be built through change management (Warner and Wäger 2019).

The fourth capability (C4) is the capability of a company to structure and reorganize its SC design in a digital manner. Current research predicts a change toward a more "organic" design with decentral authorities, decision-making, and cross-functional teams (Chirumalla 2021). Structures, roles, practices, and processes must be adapted; however, the specifications remain vague (Soluk and Kammerlander 2021). Most research focuses on firm-internal changes, while SC-wide research is neglected (Warner and Wäger 2019).

The fifth capability (C5) is the capability of a company to apply knowledge management and learning skills throughout the SC to leverage the benefits of the DT. Knowledge needs to be shared to build skills between business units and SC actors (Mishra et al. 2013). Here, it can be distinguished between technical and management skills (van de Wetering et al. 2019), for which SC-wide education and development programs are essential (Fischer et al. 2020).

The sixth capability (C6) is a company's capability to control and steer (their) digital SCs. Recent literature discusses new forms of governance, favoring lean and bottom-up approaches for added flexibility (Barlette and Baillette 2020). The focus shifts from controlling company-internal artifacts to cross-functional SC tasks and data (Fischer et al. 2020) while prioritizing growth over profitability (Verhoef et al. 2021).

The seventh capability (C7) is the capability of a company to gather, manage, and work with SC data to create value. In literature, data collection, integration, and utilization are presented as preconditions for the DT, and difficulty and importance increase when crossing company borders (Rai et al. 2006). Data acquisition focuses on collecting data from different sources, e.g., sensing market trends (Matarazzo et al. 2021). After processing the data, data analysis is pivotal and especially valuable beyond descriptive analyses (Soluk and Kammerlander 2021).

The eighth capability (C8) is the capability of a company to provide, manage, and work with a suitable SC information systems architecture and infrastructure, which is a technological enabler for the DT of SCs (Chirumalla 2021). Vital is the interconnection of systems and applications to share SC-related information with partners (Sahu et al. 2018), such as a shared repository (Fischer et al. 2020). Despite its importance, this capability is challenging as networks expand (Verhoef et al. 2021).

The ninth capability (C9) is the capability of a company to orchestrate its digital SC and integrate the necessary actors to the optimal degree. To deliver value, companies need a digitally connected network, which needs to be steered to reduce counteracting efforts (Fischer et al. 2020; Warner and Wäger 2019). Here, SC partners' internal and external integration is imperative to mastering the DT (Wielgos et al. 2021).

This research also targets the maturity for the above-described capabilities and therefore overlaps with maturity models, as these are described as appropriate tools to identify and build the necessary capabilities (Asdecker and Felch 2018). Especially models in novel and immature topic areas like the DT arouse interest from academia and practice. First models that (partially) target the DT of SCs have started to emerge (e.g., Klötzer and Pflaum 2017), and we take them into account in our research. However, a model spanning the whole SC and considering all relevant capabilities and dimensions for the DT is not yet available. As a result, empirical research from applying maturity models is also still scarce. Due to the scope of this research, we cannot provide a full maturity model, yet, we present first insights into how mature the different capabilities are currently. This could be the first step towards a capability maturity model to measure the degree of the DT of SCs.

Methodology

Multivocal Literature Review

The first research question is answered by examining scientific works, e.g., through a structured literature review. However, looking at scientific literature does not suffice to analyze which capabilities are prevalent in practice. Therefore, a multivocal literature review (MLR) is conducted following Garousi et al. (2019). Beyond scientific sources, an MLR allows to include grey literature (e.g., company reports) to capture the capabilities of the DT of SCs in practice. In the MLR, no additional capabilities besides the nine capabilities are identified. MLRs are generally separated into three phases: Planning, conducting, and reporting the review, as depicted in Figure 1.

Planning the review. Here, the need for an MLR is determined, and its goal and research questions are formulated (Garousi et al. 2019), as described in section 1.

Conducting the review. For the scientific sources, the literature review of Hellweg et al. (2021) is updated and refined. Here, the titles, abstracts, and keywords of the databases Scopus and Web of Science were queried with combinations of the keywords digit*, smart, intellig*, 4.0, supply chain*, value chain*, logistic*, and maturity. The Google search engine was queried with "digital transformation" "supply chain" "maturity model" filetype:pdf to retrieve grey literature.

The queries returned an initial pool of 393 white literature (WL) and 150 grey literature (GL) sources after a theoretical saturation had been reached (cf. Garousi et al. 2019). This pool was reduced to 125 publications (84 WL, 41 GL) after applying exclusion criteria via a title, abstract, and keywords review. For example, some papers target a different research stream but appeared in the sample because the keywords were similar, e.g., agricultural research regarding different maturity stages of fruit and their transportation (logistics), e-commerce in the publishing industry, or sustainable urban freight solutions. A full-text review followed this first exclusion round. Further papers were excluded that only in the full-text read revealed their focus, e.g., on the technical details about the computer systems and coding necessary for implementing a specific technology (e.g., digital twin) in a certain sector (e.g., manufacturing). The full-text review led to 46 publications in total. Papers were excluded when one of the following criteria applied: No SCM focus (38% WL, 6% GL), no relation to maturity (20% WL, 17% GL), no digitalization focus (1% WL, 3% GL), other reasons, e.g., technical or mathematical level of discussion (12% WL, 15% GL), not available (2% WL, 2% GL), duplicates (27% WL, 7% GL), or scientific literature (only applicable in GL: 50%). This pool was extended via forward and backward searching (i.e., snowballing), leading to the final data pools (29 WL, 26 GL). All review steps were conducted by at least two reviewers from the research team.

The final publication pool was analyzed with content analysis, an often applied qualitative research method to derive meaning from textual data (Hsieh and Shannon 2005). We combine a directed approach and a summative approach in our research, following the differentiation of Hsieh and Shannon (2005). First, this allows us to use the defined capabilities to guide the initial codes (directed). A data extraction form was composed using the capabilities described in section 2.2 and applied to the literature. Second, we examine the number of appearances of the capabilities in the literature to infer their importance (summative). Whenever a publication addressed one or multiple capabilities, they were flagged. For all of these steps, two reviewers were assigned to each publication. A preliminary meeting was held between all researchers to establish a common understanding of exclusion criteria and the data extraction form. After reviewing the initial literature, an intermediate meeting was held to discuss mismatches of exclusion and mapping and reinforce the common understanding. After extracting the data, the results were synthesized, and the prevalence of the different capabilities was analyzed.

Reporting the review. Lastly, the MLR results are intended to be published for this AMCIS conference.

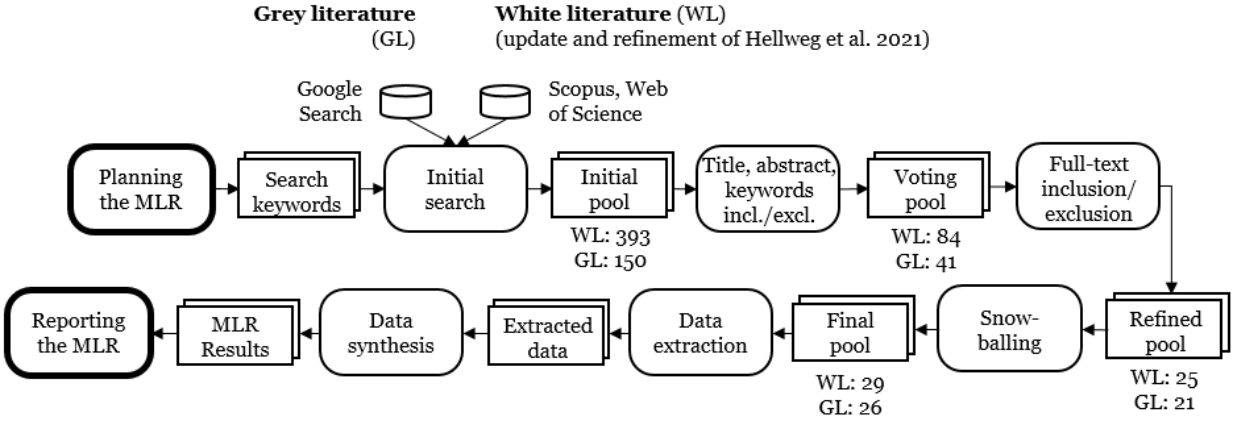

Figure 1. Multivocal Literature Review Process of Research Paper

Survey and Plenary Discussion

After the prevalence of different capabilities was analyzed in scientific and practical publications, it was still open to assess their relevance and maturity in practice, which was not reported in the literature. We, therefore, followed a mixed-method research approach (Venkatesh et al. 2013) to answer the second research question and complement our MLR results with practical insights. Therefore, a survey and plenary discussion was carried out with two researchers as moderators and 23 SC experts during a hybrid conference (in-person and digital). All experts are consultants from one company but with various foci (e.g., strategic or project management, data analytics) working in various industries (e.g., aerospace, automotive). If a respondent did not feel knowledgeable enough to rank a capability, they omitted it.

First, the nine capabilities, definitions, and survey instructions were introduced in a presentation by the researchers to the study participants. The presentation was followed by a short discussion about any understanding problems to establish a common terminology. The participants then had time to rate the relevance and maturity they perceive in practice (i.e., average assessment of their customers) by placing a dot on nine two-dimensional coordinate systems (i.e., one for each capability). The x-axis contained the maturity, and the y-axis the relevance score. Both axes were subdivided into a uniform 5x5 grid with values *not existing, low, moderate, high, and very high*. These values were later translated into a Likert scale from one to five with a minimum possible step size of .25.

Afterward, the completed coordinate systems were presented step-by-step and discussed between the experts to identify causes of different relevance and maturity.

Findings of the Literature Review and Survey

Results of the Multivocal Literature Review

The 29 WL and 26 GL papers were published across similar periods (WL: 2014-2021; GL: 2013-2022), and the number of publications per year is increasing. This shows the growing importance and attention of the topic in both areas. On average, each paper discusses between four and five of the nine capabilities presented earlier, while the average is slightly higher in the GL. No paper discusses all nine capabilities. While some WL papers try to give a complete overview of the SC and therefore include nearly all capabilities (Klötzer and Pflaum 2017), many have a technological focus and thus miss to examine other capability areas (Frank et al. 2019). Compared to the WL, the GL is more concerned with covering the whole topic area, which results in a less granular level of detail. The capabilities' frequencies reveal a significant gap between the most often and least often discussed capability in both sets (see Table 1).

	Frequency (in %)	
Capability	White Literature	Grey Literature
C1 DSC Strategy	20 (69%)	23 (88%)
C2 DSC Innovation	5 (17%)	8 (31%)
C3 Digital Cultural Mindset	10 (34%)	12 (46%)
C4 SC Design & Reorganization	14 (48%)	10 (38%)
C5 Knowledge & Learning	15 (52%)	15 (58%)
C6 DSC Governance	10 (34%)	9 (35%)
C7 SC Data Management	16 (55%)	23 (88%)
C8 IS SC Architecture & Infrastructure	24 (83%)	16 (62%)
C9 DSC Orchestration & Integration	14 (48%)	18 (69%)

Table 1. Prevalence of the Capabilities in the MLR

In the WL, the most often discussed capability is mentioned nearly five times more often; in the GL, nearly three times. In both literature sets, the capability of digital SC innovation (C2) is least often discussed,

namely in 17% (WL) and 31% of the papers (GL). Wiesböck et al. state that it is often assumed that traditional product innovation can be transferred to digital product and service innovation without any alterations reducing the research activities (Wiesböck et al. 2020). Yet, they disagree and present the results of their research focusing on IT capabilities for developing digital products and services. It is one of few papers addressing this topic and research gap. Examining the peculiarities of digital SC innovation could lead to insights not yet addressed by literature. Furthermore, differences between WL and GL appear, analyzing the most often discussed capabilities. While in the WL, the SC IS architecture and infrastructure development (C8) is discussed most often (83%), it is only addressed by 62% of GL. The reason for this strong representation in the WL could be a bias in the literature search with a viewpoint of an information systems researcher. This results in being closer to topics like IS architecture and infrastructure. The GL, however, also addresses the capability, yet not as excessively. In the GL, the capabilities DSC strategy formulation and adaption (C1) and SC data management (C7) share the top spot (88% each). While the first is well addressed in WL (69%), the latter is neglected (55%). Besides these differences, the remaining capabilities align well between WL and GL.

In the WL, the DSC strategy capability (C1) and SC IS architecture and infrastructure development capability (C8) are the capabilities most frequently paired with each other (17 times). This seems reasonable as DT often starts with a strategy or roadmap formulation, and most papers consider this. Maturity models are tools from the information systems domain to structure and initiate transformation processes and are therefore strongly represented (as discussed above). A different picture emerges when looking at the GL. Here, the most often mentioned capabilities, namely strategy (C1) and data management (C7), are most frequently paired. As consultancies often operate on strategic levels and use maturity models, also here, the strategic focus is not surprising. Yet, the combination with SC data management (C7) is interesting. It mirrors the current focus of companies in practice: data is the new gold. In the last years, companies have turned their focus to collecting data and using it. This is also supported by the discrepancy between WL addressing the seventh capability less often (55%) than GL (88%).

Results of the Survey

The survey was conducted to gather insights into how relevant and mature SCs are regarding the nine capabilities, which was not feasible with the multivocal literature review. Table 2 shows the number of respondents, the different capabilities, their mean rating of relevance and maturity (out of 1 minimum, 5 maximum), and the corresponding standard deviations.

		Relevance		Maturity	
Capability	Number of Respondents	μ	σ	μ	σ
C1 DSC Strategy	23	3.75	0.85	2.53	0.88
C2 DSC Innovation	15	3.02	0.83	2.20	0.63
C3 Digital Cultural Mindset	19	3.55	0.69	2.63	0.88
C4 SC Design & Reorganization	17	3.26	0.77	2.49	0.74
C5 Knowledge & Learning	19	3.82	0.52	2.33	0.77
C6 DSC Governance	19	3.22	0.66	2.37	0.77
C7 SC Data Management	19	4.00	0.51	2.80	0.66
C8 IS SC Architecture & Infrastructure	18	3.88	0.64	2.80	0.85
C9 DSC Orchestration & Integration	18	3.29	0.83	2.17	0.88

Table 2. Results of the Survey

It can be seen that the average relevance of all capabilities is between three and four, whereas the maturity fares much lower between two and three. The highest relevance and maturity score are achieved for the two IT- and digital technology support capabilities (SC data management (C7) and IS architecture and infrastructure (C8)) with low standard deviations. During the discussion, one expert highlighted an

automotive SC with a pervasive IT infrastructure and only minor data inconsistencies as a representative example of the high relevance. The data management capability (C7) received a mean relevance rating of 4 and a mean maturity rating of 2.80. IS architecture and infrastructure (C8) received a mean relevance of 3.88 and a mean maturity of 2.80.

On the lower end, continuous SC innovation (C2) received the lowest relevancy rating of 3.02 and the second-lowest maturity rating of 2.20. It seems that SCs face difficulties in exploiting the DT, whereas exploration is not deemed highly relevant. One expert states that their customers focus on short-term successes and "putting out fires" rather than investing in innovations with a long-term payoff. DSC governance and control (C6) is the second-least relevant capability with a mean score of 3.22, but with a significant gap of .2 points in contrast to its predecessor. While more flexible bottom-up approaches are used (Barlette and Baillette 2020), one expert criticizes that it led to a conflict of powers and isolated SC actors that do not cooperate. The acceptance of this heterarchy through upper management inhibits changes and digitalization. Finally, the least mature capability is orchestration and integration (C9), with a maturity of only 2.17, which is also the third least relevant capability. An expert notes that production and logistics are often integrated while their SCs have an independent procurement that is not orchestrated efficiently.

All in all, while generally lower, it can be seen that maturity is proportional to relevance (i.e., the higher the relevance, the higher the maturity). However, this is not the case for all capabilities, and thus, we calculated the Pearson correlation coefficient to see where the survey participants saw significant discrepancies between relevance and maturity. Here, two conspicuities are apparent. First, continuous SC innovation (C2) has a low positive correlation of .15. This means that a higher relevance amplifies a better adoption and higher maturity. It could be interesting to see why this effect is more prominent for this capability. On the contrary, knowledge management and learning (C5) is moderately negatively correlated with a correlation coefficient of -.55. It scored third place in relevance and third-last place in maturity. Respondents that rated the capability as more relevant rated it as less mature. Here, more research is necessary to analyze why this peculiar effect exists for this capability.

Discussion

Next, the literature and survey results are compared and discussed, as depicted in Figure 2. Here, the x-axis represents the number of publications (WL and GL combined) addressing the different capabilities (i.e., the prevalence), the y-axis the mean relevance, and the bubble colors the mean maturity assigned by the survey participants.

Surprisingly, the two lower quadrants are empty, implying that the respondents perceive all the capabilities to be at least moderately relevant. On the contrary, the prevalence of the capabilities in the literature is more widely spread. For example, the innovation capability (C2) is least frequently discussed in the literature, and its relevance is rated lowest, showing a lack of attention. This is further supported by the maturity value of 2.20, which is the second-lowest. Thus, the innovation capability is currently not perceived as essential and lags in practical adoption. It could be valuable to gain insights into the reasons for the low score. Researchers have already started to investigate (Tortora et al. 2021; Wiesböck et al. 2020).

All in all, prevalence, relevance, and maturity seem to align very well (i.e., higher prevalence equals higher relevance equals higher maturity), but some counterexamples are discussed in the following. The orchestration and integration capability (C9) received the lowest maturity scores overall, while this is not mirrored by the relevance and prevalence (both ranked in the midfield). This misalignment hints at a fruitful area for companies to improve, as literature describes the internal and external collaboration and integration as important enablers for the DT (Rueckel et al. 2019; Soluk and Kammerlander 2021; Verhoef et al. 2021). Reasons for the low maturity score can be manifold, e.g., missing trust and fear of losing negotiation power or the necessity of expensive IT investments, and should be examined in more detail in further research. Splitting the capability and measuring the maturity more granularly (e.g., internal and external integration and further into supplier or customer integration) might be insightful.

Another misalignment appears in the knowledge management capability (C5), which has a high relevance but is only midrange to low in prevalence and maturity. This distribution hints at research opportunities also identified by literature: the balance between knowledge that is owned by individuals and the necessity to spread it across departments and companies to increase its value is delicate (Matarazzo et al. 2021).

Furthermore, the digital cultural mindset capability (C3) is situated in the quadrant of mid to low prevalence and mid relevance but high maturity. It seems as if this capability is easy to attain. However, this is not generalizable and is not usually the case. The source of the distortion could lie in having consultancies from digitalization projects as survey practitioners. This group is often in touch with people from higher positions who initiate the projects and are interested in the topic. This might bias the answers to the mindset capability. In the discussion, one expert stated that while digitalization is ubiquitous in all companies' and employees' minds, many people (especially lower positions) do not understand their role in digital transformation and the "future" SC. Often, technological progress is taken for granted without questioning the effects on individuals and their mindsets. The expert stated that the increasing integration and consolidation through digitalization causes fear of job loss. If not appropriately addressed, this can be daunting and negatively influence the employees' digital cultural mindset. This suggests that the maturity of the capability is not at high as thought at first.

Another aspect to discuss is the high relevance, prevalence, and maturity of the data management (C7) and architecture and infrastructure (C8) capabilities. Academics and practitioners agree on the high importance and confirm a high maturity in practice. However, companies might have the latest technologies and cloud-based solutions for their planning systems while neglecting other factors like the connection to their business goals (Sahu et al. 2018). This "technology first" mindset (also represented in our sample) often hinders the successful transformation in the long run. Researchers suggest taking into account not only technology applications but also management strategies or organizational structure (Li et al. 2019), but the corresponding capabilities (C1 and C4) are only moderately mature. Here, one participant stated that you should "not digitalize because of the sake of digitalization". If companies realize this and adapt their way of working, connecting the data and technologies to business cases, and generating value, this can be a valuable lesson learned. However, it is difficult to directly assess how much value a new technology offers the SC. This can be addressed in the future by examining how companies currently prioritize technology implementation and evaluating the costs associated with it.

Finally, a closer look at the maturity scores shows the overall low level of maturity according to the experts. Three exceptions are noticeable (marked with green bubbles in Figure 2), namely C3, C7, and C8. We observe that those three (architecture & infrastructure, data management, and digital culture capability) can be grouped to be the "current" capabilities, which companies have recently focussed on and are already advanced. Contrasted to that are the "future" capabilities that have not yet been sufficiently developed.

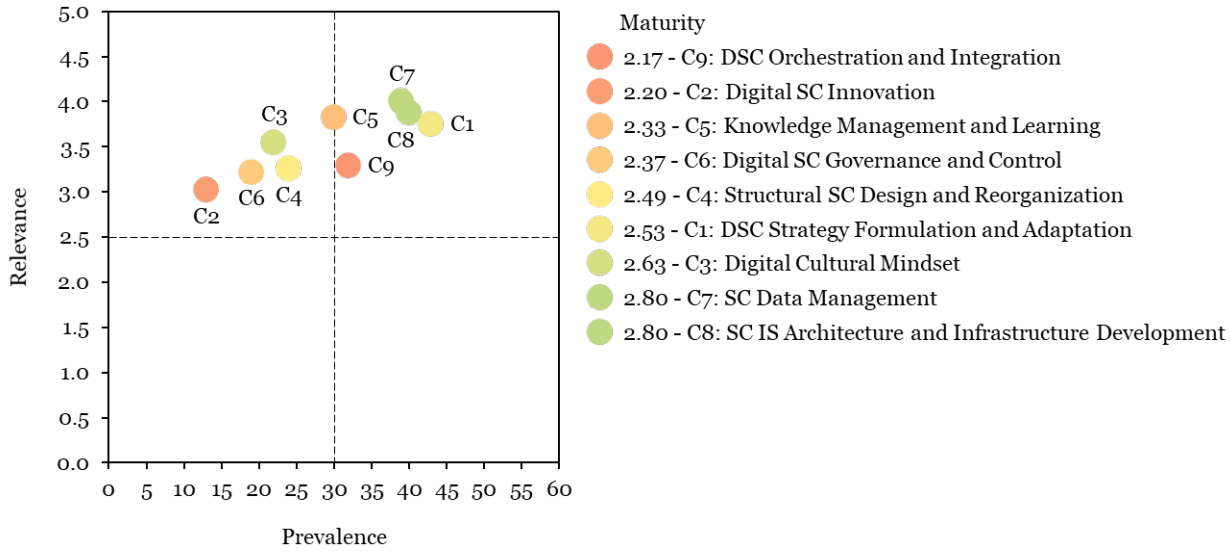

Figure 2. Prevalence, Relevance, and Maturity of Capabilities

Conclusion

To conclude, this research paper aims to identify and assess the relevance and maturity of capabilities for the DT of SCs. Therefore, we first present the set of nine capabilities identified in previous studies. In this

paper, we examined their prevalence using an MLR. Generally, WL and GL match well and give a coherent picture of the capabilities. Only the focus and degree of detail vary. Second, we conducted a survey to capture the perceived relevance and maturity of the capabilities. Interestingly, relevance and maturity are mostly proportional, though the latter lags, which makes sense. However, enormous differences between the capabilities regarding maturity or relevance were not identified. Lastly, we compared the MLR and the survey findings discussing alignments and anomalies and presenting future research ideas.

The conducted research has some limitations that are addressed in the following and open up possibilities to expand. First, the survey is limited because only consultants from one company participated in it. One can argue that consultants have a broad range of customers and get insights into different industries. Additionally, the number of respondents is relatively small. Enlarging it and diversifying the professional backgrounds can be beneficial for more reliable and generalizable results. Fourth, the survey format leads to the limitation that the results cannot be traced back to individual persons, preventing further analyses (e.g., clustering). Future research could change the technical setup to retrieve even more information about the participants, enabling a more detailed analysis. Lastly, while our analyses show which capabilities are crucial for DTs of SCs, they do not indicate whether strengthening them improves SC performance, which could be another variable to examine.

Overall, the presented research offers a valuable contribution to researchers in the field of digital SCs. It does not only provide an overview of the different capabilities but also examines their importance and maturity from different perspectives. For practitioners, the main benefit is the structured overview of different capabilities and their relevance, which can be helpful when initiating or redefining transformation projects. This research offers decision support to develop an order for capability development. The field of research is highly relevant and is currently evolving and will continue to do so in the future. We hope that our research can contribute to understanding the phenomenon of the digital transformation of SCs.

Acknowledgments

We would like to thank the industry experts of the consultancy company who took their time participating in the survey and plenary discussion, providing valuable information.

REFERENCES

Asdecker, B., and Felch, V. 2018. "Development of an Industry 4.0 maturity model for the delivery process in supply chains," *Journal of Modelling in Management* (13:4), pp. 840-883.

Barlette, Y., and Baillette, P. 2020. "Big data analytics in turbulent contexts: towards organizational change for enhanced agility," *Production Planning & Control* (33:2-3), pp. 105-122.

Büyüközkan, G., and Göçer, F. 2018. "Digital Supply Chain: Literature review and a proposed framework for future research," *Computers in Industry* (97), pp. 157-177.

Cai, M., and Luo, J. 2020. "Influence of COVID-19 on Manufacturing Industry and Corresponding Countermeasures from Supply Chain Perspective," *Journal of Shanghai Jiaotong University (science)* (25:4), pp. 409-416.

Chirumalla, K. 2021. "Building digitally-enabled process innovation in the process industries: A dynamic capabilities approach," *Technovation* (105), Article 102256.

Fischer, M., Imgrund, F., Janiesch, C., and Winkelmann, A. 2020. "Strategy archetypes for digital transformation: Defining meta objectives using business process management," *Information & Management* (57:5), Article 103262.

Frank, A. G., Dalenogare, L. S., and Ayala, F. 2019. "Industry 4.0 technologies: Implementation patterns in manufacturing companies," *International Journal of Production Economics* (210), pp. 15-26.

Garousi, V., Felderer, M., and Mäntylä, M. V. 2019. "Guidelines for including grey literature and conducting multivocal literature reviews in software engineering," *Information and Software Technology* (106), pp. 101-121.

González-Varona, J. M., López-Paredes, A., Poza, D., and Acebes, F. 2021. "Building and development of an organizational competence for digital transformation in SMEs," *Journal of Industrial Engineering and Management* (14:1), pp. 15-24.

Hellweg, F., Lechtenberg, S., Hellingrath, B., and Thomé, A. M. T. 2021. "Literature review on maturity models for digital supply chains," *Brazilian Journal of Operations & Production Management* (18:3).

Hsieh, H.-F., and Shannon, S. E. 2005. "Three approaches to qualitative content analysis," *Qualitative health research* (15:9), pp. 1277-1288.
Klötzer, C., and Pflaum, A. 2017. "Toward the Development of a Maturity Model for Digitalization within the Manufacturing Industry's Supply Chain," in *Proceedings of the 50th Hawaii International Conference on System Sciences (2017)*, T. X. Bui and R. Sprague (eds.), Hawaii, USA, pp. 4210-4219.
Li, J., Zhou, J., and Cheng, Y. 2019. "Conceptual Method and Empirical Practice of Building Digital Capability of Industrial Enterprises in the Digital Age," *IEEE Transactions on Engineering Management*, pp. 1-15.
Lin, T.-C., Wang, K. J., and Sheng, M. L. 2020. "To assess smart manufacturing readiness by maturity model: a case study on Taiwan enterprises," *International Journal of Computer Integrated Manufacturing* (33:1), pp. 102-115.
Matarazzo, M., Penco, L., Profumo, G., and Quaglia, R. 2021. "Digital transformation and customer value creation in Made in Italy SMEs: A dynamic capabilities perspective," *Journal of Business Research* (123), pp. 642-656.
Mishra, A. N., Devaraj, S., and Vaidyanathan, G. 2013. "Capability hierarchy in electronic procurement and procurement process performance: An empirical analysis," *Journal of Operations Management* (31:6), pp. 376-390.
Pereira, C. R., Da Lago Silva, A., Tate, W. L., and Christopher, M. 2020. "Purchasing and supply management (PSM) contribution to supply-side resilience," *International Journal of Production Economics* (228), Article 107740.
Queiroz, M. M., Pereira, S. C. F., Telles, R., and Machado, M. C. 2019. "Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities," *Benchmarking: An International Journal* (28:5), pp. 1761-1782.
Rai, A., Patnayakuni, R., and Seth, N. 2006. "Firm Performance Impacts of Digitally Enabled Supply Chain Integration Capabilities," *MIS Quarterly* (30:2), pp. 225-246.
Rueckel, D., Muehlburger, M., and Koch, S. 2019. "An Updated Framework of Factors Enabling Digital Transformation," in *AMCIS 2019 Proceedings,* Cancun, Mexico, (12:4), pp. 1-26.
Sahu, N., Deng, H., and Molla, A. 2018. "A capability based framework for customer experience focused digital transformation," in *Australasian Conference on Information Systems 2018*, R. Stockdale, K. T. Win, and V. Sugumaran (eds.), Sydney, Australia.
Sanchez, M. A., and Zuntini, J. I. 2018. "Organizational readiness for the digital transformation: a case study research," *Revista Gestão & Tecnologia* (18:2), pp. 70-99.
Schuh, G., Anderl, R., Dumitrescu, R., Krüger, A., and Hompel, M. ten. 2020. "Industrie 4.0 Maturity Index Update: Managing the Digital Transformation of Companies," acatech study. https://en.acatech.de/publication/industrie-4-0-maturity-index-update-2020/.
Soluk, J., and Kammerlander, N. 2021. "Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective," *European Journal of Information Systems* (30), pp. 676-711.
Teece, D. J., Pisano, G., and Shuen, A. 1997. "Dynamic capabilities and strategic management," *Strategic Management Journal* (18:7), pp. 509-533.
Tortora, D., Chierici, R., Farina Briamonte, M., and Tiscini, R. 2021. "'I digitize so I exist'. Searching for critical capabilities affecting firms' digital innovation," *Journal of Business Research* (129), pp. 193-204.
van de Wetering, R., Mikalef, P., and Krogstie, J. 2019. "Big Data is Power: Business Value from a Process Oriented Analytics Capability," in *Business Information Systems Workshops*, W. Abramowicz and A. Paschke (eds.), Cham: Springer International Publishing, pp. 468-480.
Venkatesh, V., Brown, S. A., and Bala, H. 2013. "Bridging the Qualitative-Quantitative Divide: Guidelines for Conducting Mixed Methods Research in Information Systems," *MIS Quarterly* (37:1), pp. 21-54.
Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., and Haenlein, M. 2021. "Digital transformation: A multidisciplinary reflection and research agenda," *Journal of Business Research* (122), pp. 889-901.
Warner, K. S., and Wäger, M. 2019. "Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal," *Long Range Planning* (52:3), pp. 326-349.
Wielgos, D. M., Homburg, C., and Kuehnl, C. 2021. "Digital business capability: its impact on firm and customer performance," *Journal of the Academy of Marketing Science* (49:4), pp. 762-789.
Wiesböck, F., Hess, T., and Spanjol, J. 2020. "The dual role of IT capabilities in the development of digital products and services," *Information & Management* (57:8), Article 103389.